International Symposium on Coastal Zones and Climate Change:

Assessing the Impacts and Developing Adaptation Strategies

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Monash University Gippsland, Churchill, Victoria, Australia

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Dr Dushmanta Dutta & Dr Wendy Wright
Monash University

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PREFACE

The symposium addresses issues related to coastal zone management at a time of rapid change and increased pressure resulting from population growth, infrastructure development and climatic change. It is designed to provide a forum for decision makers, practicing professionals, academics, researchers and students to share their knowledge and expertise in the main themes of:

- the assessment of impacts of climate change in coastal zones,
- existing and new adaptation strategies and policies, and
- the engagement of relevant stakeholders in planning for the consequences of climate change impacts in coastal areas

The symposium program features two keynote speakers, approximately 40 presentations from international and Australian presenters. The international participants include decision makers, practitioners, academics, researchers and students from more than 15 nations. The two-day program includes 11 sessions comprising 2 plenary sessions, 8 technical sessions and one special project session, as well as several social events, to promote discussion and sharing of knowledge, information and ideas.

The proceedings of the symposium include keynote papers and technical papers presented in the symposium. The technical papers have been peer-reviewed for the contents and their suitability for presentation at the symposium.

The symposium is generously sponsored by the Asia Pacific Network for Global Change Research (APN), Monash University, the West Gippsland Catchment Management Authority, the Department of Sustainability and Environment, Victoria and the Latrobe City Council, Victoria. We express our sincere gratitude to the sponsors for their generous support and contribution.

We would like to take this opportunity to thank the members of the Steering, Review and Organizing Committees for their time and effort in putting this symposium together. Special thanks are due to the authors of keynote and technical papers, participants and all other who took time out of their schedules to contribute to the success of the symposium.

We extend our warm welcome to all participants and we hope the Symposium provides you the opportunity to share your knowledge and learn from others in this important area of coastal zone management.

Dr. Dushmanta Dutta
Chair, Organizing Committee

Dr. Wendy Wright
Co-Chair, Organizing Committee

REVIEW PROCESS

All technical papers presented at the International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies have been peer reviewed through a formal process, outlined below.

In response to the Call for Papers inviting abstracts, the organising committee received 65 abstracts of proposed papers.

Members of the organising committee evaluated all of the abstracts with regard to their suitability for the symposium. The authors of accepted abstracts were then invited to prepare a full paper for peer review.

The Reviewer Committee consisted of experts in fields relevant to the symposium themes. All papers were peer reviewed by two independent reviewers according to a set of criteria. Reviewers were asked to assess the paper against these criteria and provide comments on the paper for both the author and the organising committee. The reviewers' comments were sent to the authors. For papers accepted subject to revision, authors were then requested to revise their manuscript in accordance with reviewers' comments for inclusion in the proceedings. A total of 45 papers have been accepted for publication in the conference proceedings.

The final proceedings were edited by Dr. Dushmanta Dutta and Dr. Wendy Wright.

TABLE OF CONTENTS

GLOBAL WARMING, SEA LEVEL RISE AND IMPACTS ON COASTAL ZONES IN AUSTRALIA

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ABSTRACT

Sea levels have been rising since the 19th Century and the rate of rise has increased from 1.8 ± 0.5 mm y^{-1} from 1961 to 2006 to 3.4 ± 0.4 mm y^{-1} from 1961 to 2003. Projections of future sea level rise are for even higher rates of rise over the course of this Century. Extreme sea levels evaluated for different return periods for Victoria exhibit considerable variation along the coast due to the large spatial variation in tides as well as storm surge. Under future scenarios of sea level rise, the potential inundation from such events may increase non-linearly for many locations, particularly urban areas. Information on changes in other variables and processes that influence the coast such as wave climate and coastal erosion are currently limited for reasons which include: uncertainties in projected future climate change; constraints at the process understanding level; lack of observations; the need for significant computational resources to simulate processes at the localized scales over which these variables and processes occur.. Further research is needed to refine future estimates of climate change and address such knowledge gaps. However, recent studies indicate that significant progress on identifying and prioritizing adaptation options for future climate change can progress despite these limitations and uncertainties.

1. INTRODUCTION

For the 2000 years up to the start of the 19th Century, sea levels remained reasonably constant. However, since the early 1800s, sea levels have been rising and this is now beginning to impact coastal regions and low lying islands that have been occupied and developed during the period of relatively stable sea levels of the previous two millennia. Due to the long response times of the climate and oceans to greenhouse conditions that have occurred and uncertainties around future emissions, adaptation will be increasingly adopted as a complimentary strategy to dealing with future climate change.

Sea levels are projected to continue rising in the future although there are large uncertainties around the amount of projected future sea level rise. Contributions to these uncertainties are the future trajectories of greenhouse gas emissions, incomplete scientific understanding of some of the processes that contribute to climate change and also limitations of the global climate models that are used to simulate future climate and oceanic conditions.

The most significant impacts associated with sea level rise will be felt during storm surges and high wave events, the meteorological drivers of which may also be affected by changing climate. Physical impacts of extreme sea levels at the coast include coastal inundation and erosion. However, quantifying these impacts also poses challenges. These are due to, constraints at the process understanding level, lack of observations, the need for significant computational resources to simulate processes at the localized scales on which physical coastal impacts play out and uncertainties in projected future climate change.

Integrated impact assessments have increased in number over recent years due to the increasing recognition that adaptation is necessary to address the risks posed by climate change and it compliments mitigation as a strategy for dealing with climate change risks (Preston and Westaway, 2009). Adaptation aims to enhance resilience to climate change that has and will continue to occur due to the long response times of the climate and oceans to greenhouse gas emissions that have already occurred and that will continue to occur to unmitigated climate change. Integrated impact assessments evaluate the current and projected climate impacts on both biophysical and social systems.

This paper describes recent developments in climate science relevant to the coastal zone. Section 2 reviews the climate change science from the global to the coastal scale with particular focus on studies undertaken for the Victorian coast while section 3 describes and discusses the impacts for parts of Victoria's coast from recent studies. Conclusions are presented in section 4.

2. CLIMATE CHANGE AND THE COASTAL ZONE

Two physical hazards that pose risks for the coastal zone are coastal inundation and coastal erosion. Erosion and inundation events are affected by oceanic extreme events such as storm surges and waves which in turn are related to atmospheric storm events. Climate change will affect the frequency and severity of these hazards in the future through rising sea levels, changes to the distribution and intensity of climate and weather systems that influence wave climates and extreme wave and storm surge events. The interactions between these various elements are illustrated in Figure 1.

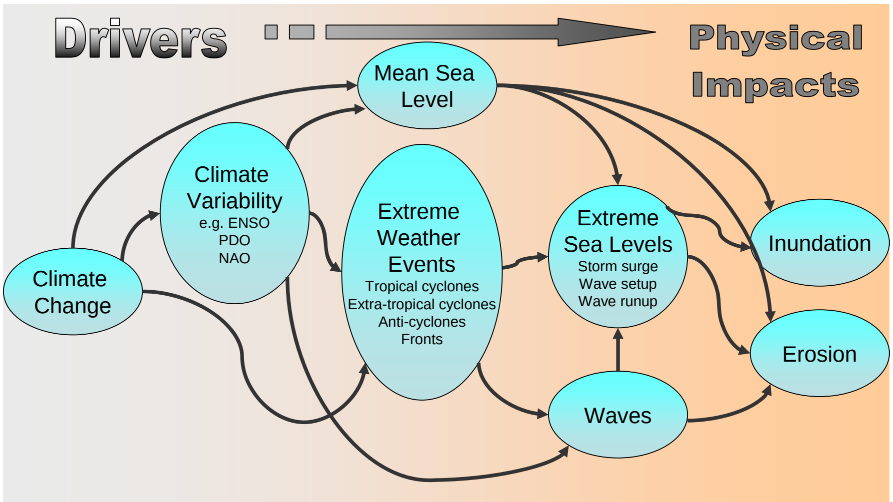

Figure 1: the relationship between climate and weather phenomena and physical impacts in the coastal zone.

2.1 Mean Sea Level Rise

Sea levels have been rising at an increasing rate since the early 1800s. Over the period 1961-2003 the average rate of rise was 1.8 ± 0.5 mm y^{-1} (IPCC, 2007) and over the period 1993–2006 globally averaged sea level trends based on both reconstructed sea level (Church and White, 2006a) and satellite altimetry have risen to 3.3 ± 0.4 mm y^{-1}.

Projected sea level rise for 2090-2099 relative to 1990-1999 due to ocean thermal expansion, melting of glaciers and ice caps, and modelled ice sheet contributions is 18–59 cm with an additional allowance of 10–20 cm of sea-level rise for a possible rapid dynamic response of the Greenland and West Antarctic ice sheets. Because of insufficient understanding of the dynamic response of ice sheets, it was noted that an even larger contribution to sea level rise could not be ruled out (IPCC, 2007; Meehl et al., 2007).

Recent rates of sea level rise are consistent with the high end IPCC estimates (Rahmstorf et al, 2007) and although the degree to which the recent observations are caused by global warming or natural variability is uncertain, there is increasing evidence that the contribution to sea level due to mass loss from Greenland and Antarctica is accelerating (Velicogna, 2009). These observed and projected changes in sea level pose threats for coastal settlements that have developed during the period of relatively stable sea levels of the previous two millennia (Jansen et al. 2007).

2.2 Extreme Sea Levels

The AR4 reported that the rise in mean sea level and variations in regional climate led to a likely increase in trend of extreme high water worldwide related to storm surges in the late 20th century (Bindoff et al. 2007). In Australia, Church et al (2006b) examined changes in extreme sea levels before and after 1950 in two tide gauge records of approximately 100 years at Fort Denison and Fremantle on the east and west coasts of Australia respectively. At both locations a greater positive trend is found in the 0.01 percentile sea level compared to the median sea level suggesting that shorter term variability is also contributing to the extremes.

On the Victorian coast, the impact of future climate change on storm surges has been assessed as part of the Victorian Government's Future Coasts Program (McInnes et al. 2009b, c). The assessment used a 'perturbed baseline approach' (e.g. McInnes et al, 2009a) in which hydrodynamic modeling and statistical techniques were used to quantify the hazard posed by storm surges and tides under current climate conditions. The impacts of future climate conditions were then explored through the application of sea level rise scenarios and wind speed change. Figure 2a illustrates the elevations associated with the 1 in 100 year storm tide (i.e. the sea level that is estimated to be exceeded only once on average every 100 years due to the combined elevation from storm surge and astronomical tide).

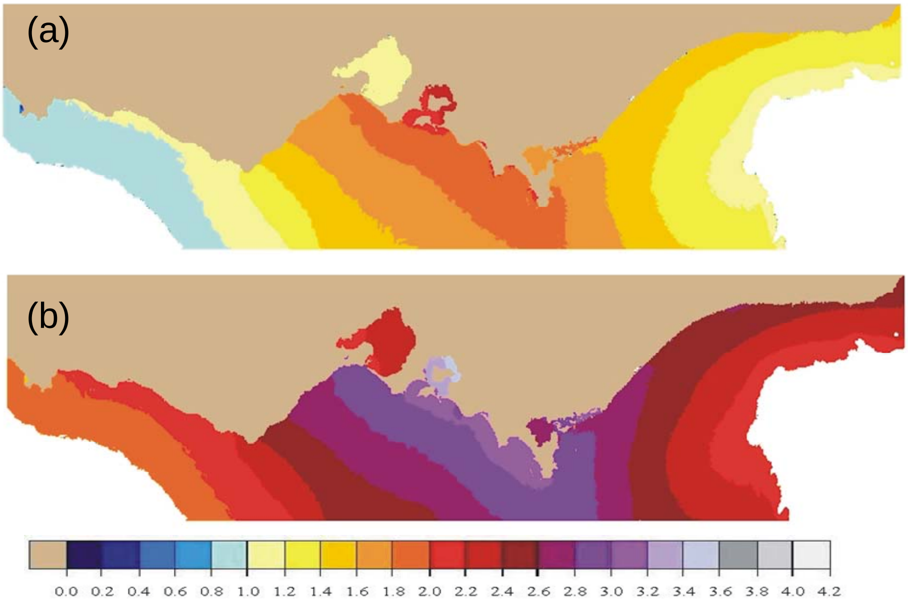

Figure 2: The spatial pattern of 1 in 100 year storm tide heights for the Victorian coast under (a) late 20th Century climate conditions, (b) 2100 based on Table 1 scenario 2 which includes a 19% increase in wind speed and a sea level rise of 0.82 m. Values are in metres relative to late 20th Century mean sea level.

The highest coastal values, in excess of 2 m, occur in and around Western Port Bay and values of 1.8 to 2.0 m extend from just west of Port Phillip Bay to Wilson's Promontory. These high values are the result of a large contribution from both storm surges and astronomical tides. In Port Phillip Bay, the lower storm tide heights of 1.0 to 1.2 m are due to the strong attenuation of the tides across the entrance to the bay. Figure 2b shows the results for the year 2100 assuming high end projections of sea level and wind speed changes that have been estimated for a high greenhouse emission scenario (the so-called A1FI scenario).

2.3 Waves

The breaking of waves at the coast during storm events can further contribute to extreme sea levels at the coast through wave set-up and wave run-up. Continental shelf width and coastline geometry in relation to meteorological drivers contribute to the relative contributions of waves and storm surges to sea level extremes. Although the studies reported in McInnes et al (2009b, c) did not consider the contribution of wave setup, recent modeling work indicates that wave setup may further contribute to extreme sea levels on the open coast, and this contribution is maximized for onshore winds and waves and is negligible when the prevailing wind is directed along shore (McInnes et al. 2009d; O'Grady and McInnes 2010).

Storm waves also drive significant coastal erosion events and this will be exacerbated by rising sea level. However, wave height is not the only attribute that influences coastal erosion. Other wave properties such as wave direction and length are important determinants in processes such as coastal sediment supply. However, despite the importance of waves on coastal processes, to date relatively little attention has been given to how wave climates will evolve under future climate conditions (Hemer et al, 2010).

3. IMPACTS AND INTEGRATED ASSESSMENTS ALONG THE VICTORIAN COAST

An increase in the frequency and severity of coastal flooding and erosion is likely to emerge along many stretches of coastline as a consequence of rising sea levels, changes in the frequency and severity of extreme sea level events and changes in wave climate that arise from changes in global circulation patterns. Understanding the socio-economic implications of climate change at the regional level requires combining information from a variety of sources which include; the physical environment, present and projected future climate conditions, and relevant socio-economic information (Preston et al. 2007). Information drawn from recent assessments is presented to illustrate the process by which adaptation options can be developed and prioritized.

3.1 Potential Inundation

The potential inundation arising from extreme sea levels along the Victorian coast was recently investigated by McInnes et al, (2009b,c) as part of the Future Coasts Program using the evaluated 1 in 100 year storm tide levels combined with scenarios of future climate change. The study used a high resolution Digital Elevation Model (DEM) developed from a LiDAR survey of the Victorian coast that was also undertaken as part of the Future Coasts Program.

The impact of associated increases in coastal inundation depends on the location of coastal assets and the topography of coastal terrain. Inundation over northern Port Philip Bay, illustrated in Figure 3 was investigated for several climate change scenarios described in Table 1. Scenario 1 is consistent with the sea level rise adopted by the Victorian Coastal Strategy (2008). Scenario 2 also considers a wind speed increase associated with the A1FI emission scenario based on CSIRO and Bureau of Meteorology (2007). Scenarios 3 and 4 are exploratory scenarios adopted from alternative estimates of future sea level rise.

The sea level heights, area of land inundated and number of land parcels affected are presented in Table 3 along with the percentage increases over current climate estimates. These results highlight the non-linear impact that increasing sea levels in particular can have on inundation and exposure. For example, increases of mean sea level 0.47 and 0.82 m respectively increase sea level heights by 42%

and 73% respectively, increase the area inundated by 45% and 125% respectively and increase the number of land parcels affected by 290% and 1010% respectively. If sea levels were to rise by 1.4 m, the increase in sea level, area inundated and the number of land parcels affected would be 125%, 365% and 5040% respectively. Such figures indicate the non-linear impact and by implication cost that will be required to adapt to such increases if the high scenarios of future sea level rise are to eventuate.

Table 1: Climate change scenarios considered in inundation modeling of McInnes et al. (2009a, b).

Future climate scenario			2030	2070	2100
1	IPCC 2007 A1FI scenario (Hunter, 2009)	Sea level rise (m)	0.15	0.47	0.82
2	IPCC 2007 A1FI scenario in combination with 'high' wind speed scenario from CSIRO and Australian Bureau of Meteorology (2007) averaged over Bass Strait.	Sea level rise (m)	0.15	0.47	0.82
		Wind speed increase (%)	4	13	19
3	Sea level rise based on Netherlands Delta Committee Vellinga (2008)	Sea level rise (m)			1.10
4	Rahmstorf (2007) upper estimate	Sea level rise (m)			1.40

Table 2: Sea level height associated with the 1 in 100 year storm tide, area of land inundated and number of land parcels affected for the region shown in Figure 3 under the various climate change simulations described in Table 1. The changes relative to current climate values expressed as a percent are also given.

Year		2030		2070		2100			
Scenario	Current	1	2	1	2	1	2	3	4
Sea level (m)	1.12	1.27	1.36	1.59	1.81	1.94	2.26	2.22	2.52
change (%)	1	13	21	42	62	73	102	98	125
Area (km^2)	6.9	7.8	8.3	10.0	13.1	15.5	23.5	23.2	32.0
change (%)	1	13	20	45	90	125	240	235	365
# Parcels	303	415	491	1,187	2,240	3,373	10,409	9,531	15,568
change (%)	1	37	62	290	640	1,010	3,340	3,050	5,040

3.2 Western Port Integrated Impact Assessment

While inundation from increasing sea levels poses a threat to coastal communities, the appropriate responses must be assessed and prioritized against other risks facing communities. One such study was recently completed for Western Port (Kinrade and Preston, 2008; Kinrade and Justus, 2008). The aims of this two year study were to develop projections of key climate drivers for the region, evaluate the impacts, prioritise the risks to local governments and investigate possible adaptation options. The study evaluated the impacts of changes in extreme sea levels, temperatures, rainfall and weather conditions conducive for bushfires and found that climate change could pose significant risks to settlements and communities in the Western Port region. The assessment of those risks was accomplished through workshops involving stakeholders from each of the five local Councils. Over 200 climate change risks were identified and prioritized in terms of importance in the workshops. While most risks were rated as manageable over the short term, the majority of the risks over the medium (2030) to long term (2070), that were ranked as either high or extreme were those related to coastal inundation. Of the risks related to coastal inundation, the most significant of those identified were associated with;

(1) inadequacy of planning controls for areas affected by coastal inundation or flooding
(2) loss or degradation of beaches and foreshore
(3) flooding of essential public infrastructure in low-lying areas
(4) loss of road access during inundation events
(5) increased flash flooding due to inadequate drainage systems

The majority of adaptation responses identified for future inundation risk were associated with planning and legislation including planning policies and associated legislation and decision-making processes. The other set of measures proposed by stakeholders centered around the need for further research and also the education of community and stakeholders.

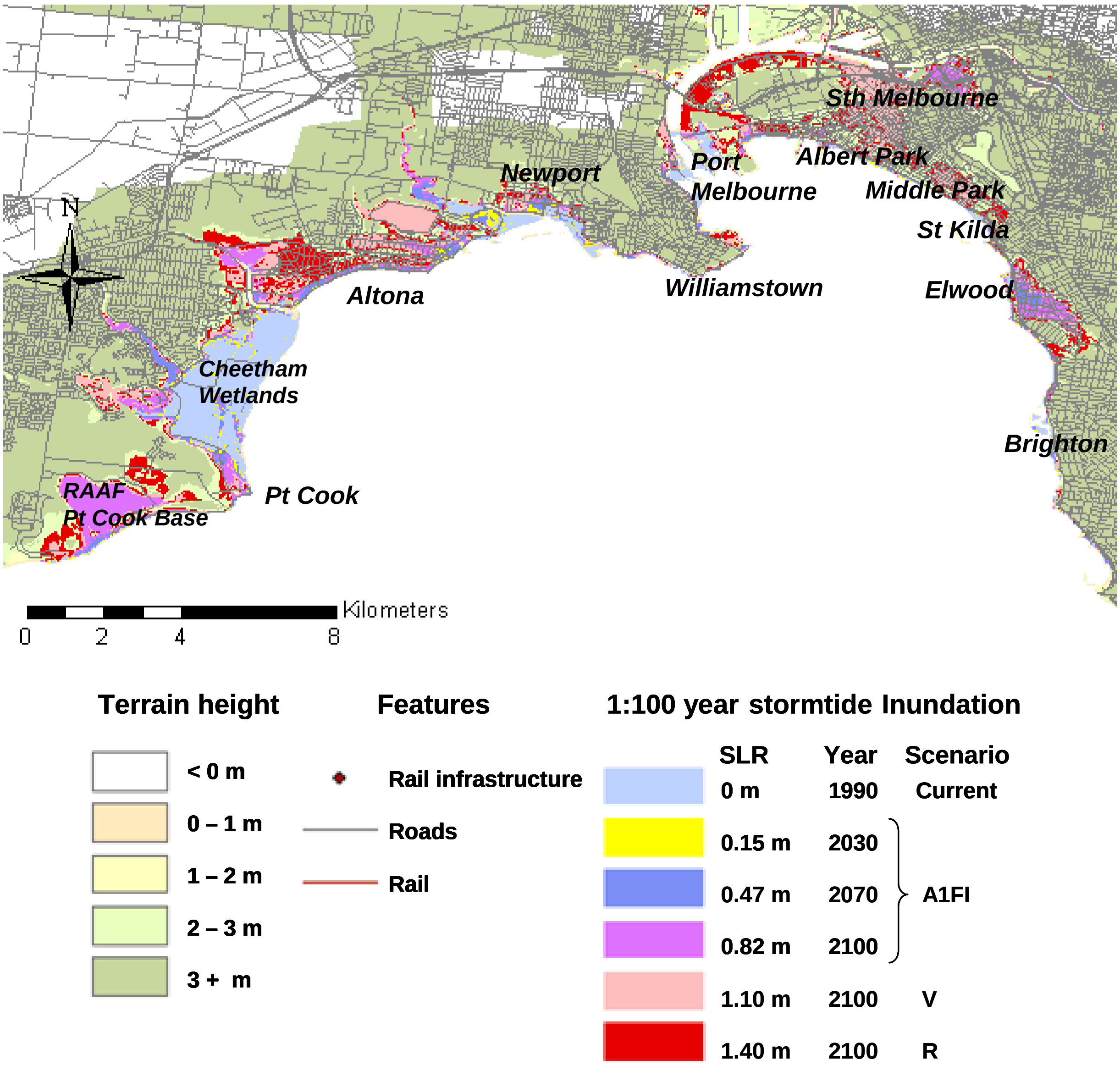

Figure 3: The spatial pattern of 1 in 100 year storm tide heights for the Victorian coast under (a) late 20th Century climate conditions, (b) including a 19% increase in wind speed and a sea level rise of 0.82 m for 2100 Values are in metres relative to late 20th Century mean sea level.

4. CONCLUSIONS

The IPCC, in its most recent assessment concluded that 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level' and that 'Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century' (IPCC, 2007). Studies that have emerged since the IPCC assessment continue to support these conclusions.

Recent studies highlight the potential for significant impacts from inundation during extreme sea level events in the future due to climate change particularly in relation to rising sea levels although large uncertainties about the extent of the impacts occur due to uncertainties in both future emissions and the response of the global climate system to those emissions. There are also significant gaps in understanding how climate change will impact on some aspects of the climate system and the natural environment, including for example, the wave climate and coastal erosion. Although further research is needed to refine future estimates of climate change and to obtain more extensive knowledge on impacts on the coastal zone, these present limitations do not and should not preclude the evaluation of adaptation strategies for dealing with climate change in the future. In order to adapt to climate change, communities need to not only understand the likely risks and impacts but engage in a planning process to consider what can and should be done about them. The Western Port Integrated Impact Assessment provides an example of this process and the Western Port Greenhouse alliance has used information generated on risks to trigger the development of adaptation plans and enter into an ongoing process of engagement with local communities.

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CLIMATE CHANGE – THE NEED FOR ADAPTATION ON THE GIPPSLAND COAST

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ABSTRACT

The world is facing massive readjustment due to the forecast impacts from climate change and global warming. As ocean temperatures continue to rise the level of the Earth's seas will also rise due to a combination of thermal expansion and ice caps melting. Weather patterns will change altering rainfall distribution, storm frequency and severity. The combination of higher acidification of the world's oceans due to greater carbon sequestration, plus potential changes to some ocean currents, will put greater pressures on marine life including commercial fisheries. It is highly likely that more terrestrial and marine species will become extinct. In those parts of the world where the concentrations of population are situated in low lying, flood prone areas, risk and vulnerability will increase and some areas will no longer be viable to support stable, safe communities.

The Gippsland coast has many valuable natural, cultural and built, assets. During the past 6 years regional and state initiated research and modeling has identified those areas and settlements that are most vulnerable to the predicted changes. The research has identified that on some parts of the coast risks and vulnerabilities will be further magnified due to its geomorphic characteristics and the potential for coastal subsidence.

At present any planning for adaptation is in its infancy and state and national protocols have yet to address some of the broader issues such as threats to cultural heritage, natural heritage and emerging social equity problems. The combination of research, modeling, risk evaluation and the development of interactive and static visual tools have helped many people and agencies to better understand the local and regional issues.

For some Gippsland coastal settlements the future looks bleak and they may have to be abandoned and relocated during this century. For others, a combination of an adjustment in community expectation, some limited coastal fortification and partial retreat to available higher ground may enable the retention of location, form and character.

Although there is much political and community debate surrounding the voracity of climate change and global warming predictions, there seems to be a reasonably high level of awareness and belief. However, there are also high levels of skepticism and denial within the community, making political consensus difficult. Discussions currently tend to focus on the issue of mitigation rather than adaptation and therefore the scale of the challenges facing the community may be under appreciated. Because climate change has been portrayed as a phenomenon that will play out during the remainder of this century (and beyond) there is a reduced sense of urgency for the need to evaluate, plan, prepare and act.

1. INTRODUCTION

Climate change accelerated by global warming is happening, the impacts are increasing and despite the arguments of the skeptics, deniers and lobbyists, it will affect our lives and our wellbeing. Whether the people of the world and their leaders act quickly enough to mitigate the most severe global warming and climate change predictions remains to be seen. What seems clear is that even if we do act quickly enough and governments agree to arrest the growth in greenhouse gases and reduce their levels to a point that will halt or reduce global warming, we will still see further impacts on our lives and our society in the interim.

At a global scale, higher temperatures of 4-7 degrees on land and 2 degrees in our oceans will lead to further ice-cap melting and thermal expansion of the world's oceans. Conservative science predictions are increasingly suggesting at least a meter of sea level rise by the end of this century. Not only will our oceans be warmer, but it is predicted that increased carbon uptake will raise acidity levels bringing further stresses to marine flora and fauna. Further predictions indicate that as the polar ice caps melt, some of the ocean currents on which many parts of the world rely, could slow or cease, bringing fish famines, a localized mini ice age in parts of the northern hemisphere and physical dislocation and food shortages globally. There are fears that the combinations of these conditions will also bring about extinctions of some species on the land and in our oceans.

In Australia, we are already experiencing extreme weather events in the form of higher average annual temperatures, markedly lower rainfall in some areas and higher falls in others. The past decade in Victoria has been characterized by drier conditions, low catchment runoff, and high fire risks. The 2006/07 fire and flood episodes in Gippsland are examples of how one severe event (fire), closely followed by another (flood) can lead to increased runoff and soil erosion. The events in the Macalister river catchment led to a mobilization of sediment not previously recorded and a reduction of an estimated 6-7% in the storage volume of Lake Glenmaggie due to silt deposition in the bed of the lake. Nearer to the coast the flood resulted in high turbidity levels in the Gippsland Lakes, which persisted for 4-5 months (June to October 2007) and a Synechoccocus algal bloom that commenced in November 2007 and persisted until May 2008. These two events resulted in almost 12 months of severe light attenuation in the lakes and there was a loss of sea grass ranging from 50-75%. The sea grass beds are slowly recovering, but the impacts on fish recruitment and growth will evidence itself through the system for some time. There will be more of the same, as the forecast weather pattern for this area is one likely to be characterized by dry spells punctuated by frequent more severe storm events. We will have to learn to live with these dynamics and adjust our lifestyle expectations to suit the changing climate.

Even though the science of climate change and global warming has been canvassed for at least two decades, governments have generally been slow to react and even slower to plan for the social and physical challenges that we face. There has also been a reluctance to openly discuss the more serious impacts including threats to low-lying coastal infrastructure. Some of this reluctance is driven by a perhaps justifiable concern that open discussions of some scenarios will bring about fear and panic within vulnerable communities, slashing property values and raising unrealistic expectations of timely, equitable, government responses. Some of the reluctance is also because governments are simply ill prepared to have the discussion, to formulate policies and to take tough and potentially unpopular, planning decisions.

2. THE GIPPSLAND COAST

How will climate change impact on the Gippsland Coast and what forms of adaptation should we be planning? To answer these questions we first need to look at some of the characteristics of our coast. From San Remo in the west, to the NSW border in the East – it stretches for approximately 850 kilometres. It boasts some wonderful features including Corner Inlet, bordered by Wilson's Promontory, the Ninety Mile beach, the Gippsland Lakes, Croajingalong National Park and in common with the rest of the South facing Australian coastline, many marine species not found in other parts of the world.

Located along our coastline are 30 communities ranging from a few dwellings housing less than 100 permanent residents to larger centres such as Lakes Entrance with 6000 permanent residents. Most coastal settlements experience spikes in numbers during holiday seasons with two, three and sometimes fourfold increases in numbers, as visitors travel to the beaches, inlets and lakes to enjoy the natural and built features. Many of our settlements are situated adjacent to estuaries and can be subject to periodic catchment derived floods as well as on-shore storm events. From time to time these events inundate parts of settlements and bring about severe disruption. Each settlement can expect some increased risk of disruption and dislocation from climate change impacts, although the level of risk will vary.

The Gippsland coastline is characterized by its long, sandy, beaches and 85% of the coastline is classed as “erodible”, or “highly erodible”. Much of our coast sits on mud flats laid down between 8,000 and 12,000 yeas ago and behind the predominantly low, single dune barriers, can be found low lying areas that were previously inundated. Some of these areas have elevations close to current sea level. During the last century it is calculated that the sea rose 17cm along our coastline and current estimates suggest rises of 3mm per annum over the past decade for a total of approximately 20 cm during the past 110 years.

2.1 Climate change and coastal subsidence – Gippsland predictions

Studies commissioned by the Gippsland Coastal Board during the past 6 years and featured in the Victorian Coastal Strategy 2008, plus recent global forecasts, indicate the following likely changes in our situation.

- A further 80 cm (at least), of sea level rise by the end of this century
- More frequent storm events, with the 100-year return interval events occurring every 5-10 years.
- More severe storms – up to 19% more severe, this equates to approx 40 cm on top of a typical large 200cm event
- Higher levels of erosion and coastal retreat in low lying erodible areas (the Bruun Rule 1962, indicates coastal retreat of 50-100 times unit height increase of sea level on an erodible coastline, that is, 50-100 m of retreat for each meter of rise.
- Larger catchment derived floods exacerbated by more severely damaged catchments due to drought and increased bushfire frequency and severity.
- The potential for coastal subsidence along parts of the 90 Mile Beach ranging from 50 to 210 centimeters in less than a century, due to the draw down of fluid levels in the Latrobe group of aquifers.

3. ADAPTATION

It is estimated that at 1 meter of sea level rise, there are over 700,000 properties around the Australian coast that will be compromised. We have some of those properties. Assuming the predictions are correct, we will have to adapt to our altered circumstance.

In a coastal context, adaptation can be characterized in several ways:

- Stay –adjust and adapt to more frequent storm and flood events and ever higher “King” tides
- Defend – build higher sea walls and other protective infrastructures
- Retreat – progressively move parts of settlements to adjoining higher, safer, terrain
- Abandon and relocate - move to safer coastal communities or develop new low risk sites and abandon some existing settlements

3.1 Stay

In many parts of the world, people experience flood and storm events that inundate homes, properties, businesses and infrastructure. They cope as best they can with these fairly frequent events, clean up afterwards and get on with their lives. For poorer people in these situations, relocation is often not an option. On parts of the coast of Australia it is not unusual to experience cyclones that bring damaging winds and flooding rains, communities and governments generally accept this situation. In December1974 the Northern Territory capital city Darwin, was razed by cyclone “Tracey”. Despite the massive scale of the destruction, Darwin was subsequently rebuilt and has experienced substantial growth in its infrastructure and population numbers in the years since.

Under some climate change scenarios, events such as these will increase in both frequency and severity making this option ever more difficult. As sea levels rise, the constant inconvenience and costs of storms and floods including high insurance costs (where insurance is obtainable) and decreasing property values, will stymie further development. This in turn will lead to the decline and a partial or total abandonment of some settlements. Long before the above-mentioned factors drive people to make these choices, they may be hastened in their decisions by the inability of utilities and government agencies to continue to provide reliable power, water, sewerage, access, communications and other infrastructure and services. There will also be issues relating to the provision of reliable and adequate emergency services.

3.2 Defend

There is a natural tendency in the face of predicted sea level rise and more frequent flood events, to assume that we can defend what we have built using measures such as levees and sea walls. Levees work reasonably well on some large rivers where flood events are more predictable and not subject to the ferocity of a coastal storm. Where there are concentrations of valuable assets, there may be an option to build fortifications to hold back the sea eg: Melbourne’s Southbank, fringing the Yarra River. However, such fortifications are usually very expensive to build and maintain, with no guarantee that they will withstand the forces of nature they can be subjected to. Many areas, such as the erodible dunes along the Gippland coast will not be suitable for fortification and it is difficult to imagine that the value of the assets behind them will justify protective measures. The Netherlands is often quoted as an example of a country that successfully holds back the sea. It is worth noting however, that this is a country with a coastline of 451 kilometers, a population of 16,500,000 and per capita income similar to that of Australia. Compare this to Australia’s mainland coastal length (including Tasmania) of 35,877 kilometers, plus the combined coastal length of its many islands (23,859 kilometers), a population of around 22,000,000 and the problems become apparent.

The Victorian Government via its “Future Coasts” program is currently assembling data to evaluate and assess climate change risks to the coastline under various assumptions and scenarios. The future coasts project has two initiatives. The first part of the project has provided detailed digital elevation mapping (DEM) for the Victorian coast, to greater levels of accuracy than was previously available (500cm horizontally, 10-20cm vertically, up to 15 meters AHD). The second phase of the project involves analysis and modeling of the data to assess scale and range of risk and vulnerability across the state’s various coastal settlements. This information may provide a basis on which to assess whether it is practicable and affordable to fortify some assets. Such fortification may buy time for other adaptation measures to come into play, but it is questionable whether they can provide either long, or short-term comfort for many parts of our coastline. Further, it is extremely doubtful if there will be the political will or cash, to fortify or defend all coastal settlements, especially those that are smaller and of less value (political and financial). There are at least a dozen small communities and settlements along the Gippsland coast that could fall into this category.

3.3 Retreat

Some coastal communities have topographic features, which would enable a staged retreat to higher ground whilst potentially retaining the essence and character of the settlements. Examples are; Lakes Entrance, Mallacoota, and Sea spray and these are either partially located on higher terrain or, in the case of Seaspray, have higher ground close by Lakes Entrance is a particularly interesting example. The most vulnerable section of the town is the area known as Cunningham Arm and this area has been partially flooded most recently in 1998 and 2007. Both floods were classified as 1 in 20 year return interval events and were 130 cm in depth, or approximately 70 cm below the 1 in 100 year return interval event estimates. Under current climate change predictions Cunningham Arm is very vulnerable. At 80 cm of sea level rise, parts of the area would be inundated at high tide and given the porous sandy base on which it is constructed, it is doubtful if higher sea walls could keep out the water. At present, in even modest flood events, water finds its way up town drainage and sewerage lines to flood land and property, raising significant health and safety issues. Additionally, there is a further risk that rising sea levels and storms could breach the narrow dunes fringing the front lake on the Southern side of the area, thus exposing part of the township to the ocean.

Cunninghame Arm has approximately 1000 permanent residents, about one sixth of the Lakes Entrance population. However, it contains virtually all of the retail commercial premises, approximately 90% of the tourist accommodation, the bulk of the small industrial base, the State’s largest fishing fleet and the settlement’s three schools. During peak holiday times, this area of Lakes Entrance trebles or quadruples the town’s total population. Cunningham Arm is the commercial heart of Lakes Entrance and is arguably the major part of its character and attractiveness for those that visit and live there and yet, there is a very strong case for the planned, progressive, relocation of this area to available higher ground.

3.4 Relocation

Settlements form for various reasons. Some are recreation locations that have developed from small seasonal clusters of fishing huts or camps such as, Sea spray, Woodside and McLoughlin’s Beach. Others, such as San Remo, Inverloch, Port Welshpool, Port Albert, Lakes Entrance, and Marlo, provided ocean access for commercial fishing and trade before the development of rail and road transport. Port Albert was the acknowledged entry point for many early settlers wishing to further explore and open up the rich pastoral and gold mining potential of Gippsland, it has a rich history, is an attractive area but is also one of the potentially vulnerable settlements. For many in the wider community who are regular visitors to vulnerable coastal communities and for those who are permanent residents, it is unthinkable that they may have to close down. However, for some settlements the options of stay and adjust, defend, or retreat, won’t be viable. Settlements such as McLoughlin’s Beach, Mann’s Beach, Port Albert and Port Welshpool, are very low lying and there is not much immediately adjacent and sufficiently high ground to retreat to. In the case of McLoughlin’s Beach, it has the additional risk from periodic flooding from the nearby Bruthen Creek, which can severely compromises road access and escape options. During the past 60 years, with even modest sea level rise increases, there has been a significant change in the coastal form near this settlement and it is increasingly exposed to storm events. There is a strong case to plan for relocation of the settlement and its 100 (approx) permanent residents – but to where?

4. COASTAL SETTLEMENT POLICY

Victorian Government policy directs coastal growth and development towards existing settlements and it can be argued that this has sometimes blocked opportunities to examine options for new or “green-field” sites. It can also be argued that most current coastal development proposals are developer led and are driven by an opportunistic profit motive, rather than by public policy. Coastal settlement relocation imperatives will force a rethink of the current Victorian coastal policies. Those settlements that are seriously threatened by climate change and have few options that would provide for a long-term retreat strategy may have to be abandoned. The challenge is to find alternative sites that meet the same criteria that attract people to these existing settlements in the first instance primarily, near ocean dwelling, recreation, commercial and visitation opportunities. Some of the most vulnerable settlements are also those that are most poorly serviced by even basic amenities such as reticulated water and sewerage, health services and shops. Because infrastructure and amenity is basic, land and house prices are often correspondingly more affordable, providing an entrée for lower income earners, particularly retirees. It is unlikely that if new coastal settlements are planned and constructed using modern day planning conventions for the supply of water and sewerage, sealed roads, kerbing and drainage, that they will be affordable for low-income earners.

5. COASTAL CLIMATE CHANGE – SOCIAL EQUITY

As it becomes increasingly apparent that some vulnerable coastal settlements have a limited future, property prices will stagnate or fall, thereby reducing the wealth of property owners and residents and their relocation options. In some instances properties will become worthless. It is ironic, that some of the permanent residents in the most threatened coastal communities may be those with the least financial and emotional capacity to adapt or to relocate to another venue.

The demise of settlements is not a new phenomenon. During the comparatively short period of Australian non-indigenous settlement we have seen many instances where towns both large and small, establish, grow, peak, decline and disappear. Some of the smaller gold rush towns grew to accommodate numbers in the thousands only to fold when the commercial gold quantities fell below workable levels. Examples of such towns in East Gippsland include Grant and Sterling. As pastoral and grain product prices have fallen in real terms many small country towns in the Wimmera and Mallee regions of Victoria have either declined or in some instances, remain only as place names on the landscape. In other examples poor closer settlement policies or inadequate knowledge of climate and soil types led to the establishment and subsequent demise of quite large rural settlement areas. In most cases the residents and property owners have borne the decline in their circumstance with stoicism and acceptance, neither expecting, or receiving, government assistance. Community expectations have changed and not only do some people in our society look for someone to blame for their misfortune, they more often than not also expect some form of compensation.

There are few recent examples of forced relocations of substantial townships in Victoria, but Talangatta in the northeast during the 1950's expansion of Eildon reservoir and more recently, Yallourn, in the Latrobe Valley are two. When the area beneath the town of Yallourn was required for open cut coal mining, during the 1980s' and 1990s' it was progressively dismantled, its assets sold, and its residents compensated and provided with assistance to relocate to other areas within the Latrobe Valley. Whilst the closure of Yallourn may provide a good case study of planned and well managed community transition, the question still remains whether it can be seen a model for many small coastal settlements around Australia. The imperative for the closure of Yallourn and the relocation of its residents and commerce was driven by, and funded by, commercial and state interests and the need to continue to secure the Victorian power supply at affordable levels. Similar examples happen from time to time in other parts of the mining sector as construction camps or towns are built, serve their purpose and are either abandoned or dismantled. A bigger question is whether an economy the size of ours will be able to afford the relocation and reconstruction of very sizable chunks of its coastal infrastructure in an environment already stressed by other climate change initiatives and impacts.

6. CONVEYING MESSAGES – SEEING IS BELIEVING

In 2003 the Gippsland Coastal Board saw the need for more comprehensive region specific climate change information for the Gippsland coast. The Board commissioned research (CSIRO) on the characteristics of the weather patterns that impact our coast and how predicted changes to current patterns, plus sea level rise, might further impact the area. Additional work included assessment of the potential impacts to the coastal geomorphology, subsidence risks on the Ninety Mile Beach and a coarse risk and vulnerability assessment for each of the coastal settlements. This work was then consolidated into one compact readable report. (Final Report, Phase 2 of the Gippsland Climate Change study, 2008). There are very few similar studies available for other parts of the Australian coast although several are now in progress.

Research and reports, however well crafted, can only provide so much information and many people still lack ready access to authoritative sources, despite the convenience of web based reference material and the many opinion pieces published in newspapers, magazines and journals. Pictures and video footage of events similar to the magnitude of those predicted by the research can help bridge gaps in our understanding, but many people find it difficult to imagine the scale of a storm or a flood if they haven't seen or experienced it firsthand.

As part of its strategic plan to provide useful tools to assist individuals and agencies with climate change data, research and modeling material, the Board looked at options to source "virtual" representations of predicted events. Fortunately, at around the same time a Monash PhD student. Peter Wheeler and his colleagues were developing a visual tool using photogrametry, topographic data, cadastral information, road lines and utilities (water and sewerage). The product of their research has been of great assistance in getting the message across to people.

6.1 Cunninghame Arm – the "Oh my God!" model

The first model was of the afore mentioned Cunninghame Arm, Lakes Entrance and it enabled a detailed visualization of flooding over a range of levels including the actual 2007 event (130 cm) and a simulated 1 in 100 year return interval event (200 cm). Fortuitously, aerial photography of the 2007 event validates the model and gives it credence, even to the "doubters". The model, incorporates an interactive component allowing viewers to raise flood levels via a graduated scale up to a level of 200 cm. Almost without exception first time users of this visual aid are shocked by the implications of a 2007 flood event with an additional level of 7-800 cm of sea level rise. Subsequent models have been developed and purchased for Loch Sport (Gippsland Coastal Board funding) and Anderson Inlet (Gippsland Coastal Board and Central Coastal Board funding). The models not only provide a useful representative sample of the types of settlements along the Gippsland coast, but also provide examples in each of the four coastal shires; Lakes Entrance/Cunninghame Arm (East Gippsland Shire), Loch Sport (Wellington Shire), Anderson Inlet/Inverloch/Venus Bay (South Gippsland and Bass Coast Shires). During the next five years the Future Coasts program will supplement this work with additional risk and vulnerability studies for other areas along our coast.

Additional photographic material highlights current localized flood events, substantial beach and dune erosion during 2007 and evidence of coastal retreat and reconfiguration that has occurred during the past 60 years (McLoughlin's Beach and McGauran's Beach). The latter information is possible because of the detailed and accurate photography carried out from the RAAF base at East Sale, which enables us to impose like images taken at various times over that period thus tracking visible changes.

Underpinned by sound science and research, these "visuals" help people to "see", to understand, to worry and be concerned. Understanding, belief, worry and concern, generated amongst enough people, are the drivers of action, response and policy change.

7. LOCAL POLITICS AND TOUGH DECISIONS

When large transitions are planned, managed and executed within extended timeframes, societies and economies have a better chance of coping. Until we as a society believe that climate change is real, we won't ask ourselves honestly, how it will impact on our future and that of the generations that succeed us. Although many people do believe the predictions and forecasts, there is not as yet a strong societal clamor for action. Part of the problem is that there is insufficient discussion of the issues at a local level and therefore little of the robust "storming" required to bring about similarly robust policy reconsideration. Another part of the problem is the uncertainty in the minds of many people regarding the voracity or integrity of the science. Because we are also hampered by an inability to visualize, to picture, the likely scale and impact (temporal and spatial) of climate change on our landscape, coastline and society, we tend to retreat variously to denial, inactivity, or the comfort of leisurely paced consideration.

7.1 Wellington Shire – The Honeysuckles

In the few instances where authorities have attempted to impose planning and construction constraints based on climate change predictions, there has been substantial community resistance.

In 2008, Wellington Shire tried to shut down the option of further development in an area near Seaspray on the 90 Mile Beach, known as The Honeysuckles. Their decision was based on much of the work undertaken by the Gippsland Coastal Board, plus independent evaluation of their own. The shire had good reason to be concerned. The current small community is located and built on a sandy area with the ocean to its South and Lake Reeve to its North. Modeling carried out on behalf of the Gippsland Coastal Board has identified this area as having high erosive potential under current climate change predictions and the likelihood that parts of the area will be severely flooded by large ocean storm events and catchment sourced floods. It is also possible that when these types of events happen at the same time, that the sand dunes on which some house are built could breach, threatening occupants safety and property.

When the Wellington Shire attempted to implement a ban on further development, owners of vacant blocks rallied with a campaign that included emotional and angry public meetings. In the face of this opposition the shire retreated to a position where responsibility for any risks associated with the construction of new dwellings would be the responsibility of the owner of the property. People seeking permission to build on blocks at the Honeysuckles must now lodge a climate change risk assessment plan with the shire, which demonstrates that they are aware of the risks associated with building on their land. in this location. Plans must include a removal and abandonment contingency to be implemented should the assets come under future increased risk from erosion or more frequent flood and storm events that threaten the viability of the construction. Further, owners must attach the plan as a 173 Agreement component of their title so that any future owners, or potential purchasers, are also aware of the risks and compromises associated with the title and its built assets.

The Wellington Shire solution is one that smacks of local political pragmatism and is possibly an indication that some of its councilors and officers may not have had a total belief of the inherent risks associated with granting a building permit in such a potentially high-risk area. At least two councilors at the time voiced skepticism re climate change theory and modeling. It is also an example of how difficult it can be for popularly elected councilors to hold the line on such a difficult issues as this one. By seeking to lay off the risks on to the applicants and future owners, one has to ask whether they (the councilors) responsibly addressed the matter or whether they have simply parked the problem for a future council to deal with. It can hardly be said that they weren't aware of the climate change risks, as the requirement for the applicants to prepare a climate change risk analysis makes that clear. In fact it could be argued that in approving an application contingent on the approval of such a plan, that they are complicit and accountable. History will judge.

8. WHERE TO NOW?

In an ideal world, each of the four Gippsland coastal shires would have a strategic plan with a detailed analysis setting out risks and vulnerabilities. There would be actions to address those risks and vulnerabilities including the "stay", "defend", "retreat" and "relocate" options, for the next 30 –50 years. The analysis would assess costs both social and economic, of "do nothing" versus "planned adaptation" options. It would also include identification of sites for new coastal settlements, to allow for ongoing population growth and pressures and the continuance of the "sea change" phenomenon.

At state and national levels we would by now have explored and resolved some of the very important and emerging issues such as, protocols for dealing with the issues surrounding the likely exposure and destruction of ancient coastal indigenous burial sites and other sacred cultural sites, indigenous and non-indigenous. We would by now be formulating a policy on how best to adjust to the loss of public and private land frontage as some parts of our coastline erode and retreat, including whether there should be some acknowledgement of private loss. We would be establishing a legislative framework to allow continued public access to beaches where the Crown frontage has totally eroded. We would have nationally agreed sea level rise benchmarks. We would have indicators to assess, measure and cost, the social equity (or inequity) factors arising from a changing coastal dynamic. We would have a very comprehensive inventory of our marine and near coastal natural values and an appropriate monitoring regime to track changes to environmental health of the many species. And so on.

Unfortunately, we are a long way from dealing with most of these issues and we should not underestimate the scale of the task. It is likely that progress will be slow. The democratic political system that many of us value highly can be an impediment to speedy action on something as important and contentious, as climate change. At present the debate surrounding mitigation, both global and national, is overshadowing the debate surrounding adaptation. Government preoccupation with issues such as global financial crises, population growth and aging, public transport, health and education, peak oil, immigration and the economic growth imperative etc, seemingly leave little time for the more mundane planning required to prepare us for the changes ahead. Ultimately, the balance of public opinion and our community understanding of climate change impacts will provide the political "tipping point", urgency and impetus via our political process, for the necessary policy change and direction. It seems we are yet to reach that tipping point.

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ANALYZING IMPACTS OF CLIMATE CHANGE ON SEDIMENT DYNAMICS IN RIVER BASINS USING A PROCESS-BASED DISTRIBUTED MODELING APPROACH

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ABSTRACT

Sediment dynamics in a river basin e.g., soil erosion, sediment transport and deposition are accelerated in an alarming way due to the climate change conditions such as increasing rainfall intensity and frequency, changing land use pattern, etc. The impacts of sediment dynamics under climate change conditions are recognized as a global threat to sustainability of nature since soils are a major component of enormous environmental processes and on the other form, sediment controls lake and river pollution extensively and ultimately it would create an adverse effect on coastal region. Sediment dynamics under climate change conditions will provoke enormous social, environmental and economic issues. An improved adaptive technology would be one of the best approaches to address future worsening impacts. To adopt the appropriate adaptive measures into conservation policy and management, impact of climate change on sediment dynamics is needed to assess at local and regional scales since these changes are not uniform over the globe. Precise estimation of sediment dynamics under climate change conditions has now become one of the greatest challenges to engineers in devising environmental regulation and planning for sustainable natural resource management. Different hydrological processes govern sediment dynamics in a river basin which are highly variable in spatial and temporal scales. In addition, many hydrological components are expected to be changed adversely both spatially and temporally at local scale due to climate change which would trigger a high soil erosion and sedimentation. The study has undertaken several approaches and their integration strategies to estimate sediment dynamics under climate change conditions. This includes (1) integrating sediment processes (soil erosion, sediment transport and deposition) with an existing process-based distributed hydrological model; (2) modeling hillslope sediment micromechanics and channel sediment dynamics separately; and (3) simulating sediment dynamics with respect to climate change conditions. In this approach, water flow and suspended sediment concentration at different surface grids and river nodes are modeled using one dimensional kinematic wave approximation of Saint-Venant equations. The amount of soil erosion is estimated by adopting suitable physical equations after a comprehensive review. Sediment transport and deposition has been modeled both at hillslope and channel areas based on Govers transport capacity concept. The paper describes the model application on Latrobe River basin, Australia under climate change conditions.

1. INTRODUCTION

Soil erosion, sediment transport and deposition are considered as the major processes of catchment sediment dynamics. Hydrological events mainly govern sediment dynamics in a river basin which are highly variable in spatial and temporal scales. An accelerated rate of soil erosion and sedimentation would affect the sustainability of nature adversely to a great extent, since soils are a major component of enormous environmental processes (Johnson, 1995) and on the other form, sediment controls lake and river pollution extensively (Verstraeten *et al.* 2006). In fact, sediment dynamics in a river basin are natural processes and had been going through almost in a balanced way till the beginning of modern civilization. But, nowadays sediment dynamics in a river basin are accelerated in an alarming way due to climate change conditions such as increasing rainfall intensity and frequency, changing land use pattern, etc. As a result of anthropogenic activities like pollution of the atmosphere with greenhouse gases, aerosols and human modifications of the land surface, significant climate change is also expected in the next century. The impact of global climate change processes at local scale will be entirely uneven (Brauch, 2002). Many hydrological components are also expected to be changed adversely both spatially and temporally at local scale due to climate change conditions which would trigger a high soil erosion and sedimentation (IPCC, 2007). An improved adaptive technology would be one of the best approaches to address future impacts. Hence, quantitative estimation of a watershed sediment dynamics under climate change conditions is required to adopt an appropriate adaptation system into conservation policy and management.

Precise estimation of sediment dynamics under climate change conditions has become one of the greatest challenges to engineers in devising environmental regulation prior to initiating appropriate management practices for soil erosion and sediment control. Modeling tools can estimate sediment dynamics both quantitatively and consistently (Bhattarai and Dutta 2007). A number of sediment transport models and studies have been presented by researchers during the last four decades (Bhattacharya *et al.* 2007) such as, ANSWERS (Beasley *et al.* 1980), WEPP (Nearing *et al.* 1989), EUROSEM (Morgan *et al.* 1993), Jain *et al.* (2005), etc. The major drawback of most of the past studies is that the concept for simulation has been developed focusing on one or two elements in a river basin whereas the other elements were considered conceptually. However, research on sediment dynamics requires simulation of hydrologic and sediment processes with different climate parameters for evaluating climate change effect which is still not well investigated.

Basin scale distributed approach is often advantageous to model sediment delivery processes since eroded sediments are produced from different sources throughout a basin (Ferro and Porto 2000). The processes of rainfall-runoff and soil erosion-sediment transport are explicitly coupled (Jain *et al.* 2005). Sediment dynamics in hillslope areas and channel systems are different and need to be modeled separately (Ferro and Porto, 2000). Emphasizing all the above facts, the current study is an extension of the previous study on process-based sediment dynamic modeling as on Kabir *et al.* (2009) for investigating climate change effect on sediment dynamics. The distributed hydrological model presented by Dutta *et al.* (2000) has been adopted in this sediment modeling. In this approach, water flow and suspended sediment concentration at different surface girds and river nodes are modeled using one dimensional kinematic wave approximation of Saint-Venant equations. The amount of soil erosion is estimated by adopting suitable physical equations after a comprehensive review. Sediment transport and deposition are modeled using Gover's transport capacity equation.

The study aims to analyze sediment dynamics in Latrobe River basin under climate change conditions using a process-based distributed modeling approach. Flood events at Latrobe River basin, Australia in the year, 2007 have been selected for this study. The study has undertaken some simplified conditions such as, (i) water flow and sediment transport at different surface grids and river nodes have been modeled using one dimensional kinematic wave approximation of Saint-Venant equations, (ii) a simplified form of transport capacity equation presented by Govers (1990) has been used to quantify the amount of sediment transport or deposition both in land and river systems, (iii) a constant runoff coefficient has been used to estimate runoff volume instead of simulating sub-surface hydrology. Elevation data from Shuttle Radar Topographic Mission (SRTM) has been used with other spatial datasets such as, land use and soil classification data, etc. consistently using raster "Geographic Information System (GIS)" tools.

2. MODEL OVERVIEW

In this study, the sediment dynamic model described as on Kabir *et al.* (2009) has been applied which is an integration of a process-based distributed hydrological model with sediment modules. The adopted distributed hydrological model (DHM) is owned by University of Tokyo (Dutta *et al.* 2000) which considers the watershed as an array of homogeneous grid cells to capture the catchment spatial heterogeneity. The model represents all the components of hydrologic cycle mathematically based on their physical governing equations and then simulates the movement of water from cell to cell using the principles of conservation of mass and momentum. All the hydrologic components of this model can be described as five distinct modules: (i) Interception and evapotranspiration simulation module, (ii) Unsaturated zone flow simulation module, (iii) Saturated zone flow simulation module, (iv) Overland flow simulation module and (v) Channel network flow simulation module.

The sediment modules represent sediment processes such as, soil erosion, sediment transport and deposition, with the driving hydrological components. The modules are categorized as rainfall impact detachment simulation module and flow detachment or deposition simulation modules. The rainfall impact detachment simulation module estimates total eroded soil using the relationship between kinetic energy and the amount of detached soils, proposed by Torri *et al.* (1987). The module for soil detachment and deposition has been followed the equations as described on Morgan *et al.* (1998) which is based on generalized erosion-deposition theory proposed by Smith *et al.* (1995). In this study, Govers (1990) transport capacity equation has been used to estimate transport capacity concentration (*TC*) due to its simple structure and easily available input dataset. The flow detachment simulation module is considered soil cohesion since cohesion force encounters detachment processes in case of cohesive soil. Table 1 summarizes all the governing equations used in different sediment modules as described in this section.

Table 1: Governing equations used in sediment modules

Modules	Descriptions
Rainfall impact detachment simulation	Soil detachment (Torri *et al.* 1987), $D_R = \frac{k}{\rho_s}(KE)e^{-ZH}$ k is the soil detachability index, ρ_s is the soil density, e^{-ZH} is the correction factor for water ponding, where Z depends on soil texture, H is surface water depth. KE is the kinetic energy, For direct rainfall impact (Brandt, 1989), $KE(DT) = 8.95 + 8.44\log(I)$ For leaf drip impact (Brandt, 1990), $KE(LD) = 15.8(PH)^{0.5} - 5.87$ I is the rainfall intensity, PH is the canopy height
Flow detachment/ deposition simulation	Flow detachment or deposition (Morgan *et al.* 1998), (Positive sign for detachment and negative for deposition) $D_F = \beta w v_s (TC - C)$ C is sediment concentration, w is the width of the flow, v_s is the particle settling velocity, β is a correction factor in case of cohesive soil erosion. *TC* is the transport capacity concentration (Govers, 1990), $TC = c(\omega - \omega_{cr})^{\eta}$ Where, $\omega = 10\,u\,s$, $c = [(d_{50} + 5)/0.32]^{-0.6}$, $\eta = [(d_{50} + 5)/300]^{0.25}$ ω is the unit stream power, u is the mean flow velocity, s is the slope in percentage, ω_{cr} is the critical value of unit stream power, c and η are coefficients depending on median particle size, d_{50} of the soil. The transport capacity equation is suitable for particle size ranging from 50 to 250 μm with sediment concentrations maximum up to 0.32 m^3m^{-3}.

The sediment modules are linked as sub-components within the distributed hydrological model under the FORTRAN programming environment. The overall sediment dynamic model indicating different modules with their simulation sequence is shown in Figure 1. A one-dimensional kinematic wave approximation of the Saint-Venant equations for continuity and momentum is conveniently applied in this model application to simulate surface and river flow movement based on the direction of steepest descent. This is because, in Latrobe River basin, the flow is mostly unidirectional and back water effect is insignificant. Thus, it has efficiently been chosen to reduce computational time considerably and to make suitable for large scale river basin simulation incorporating sediment dynamic modules with driving hydrological components.

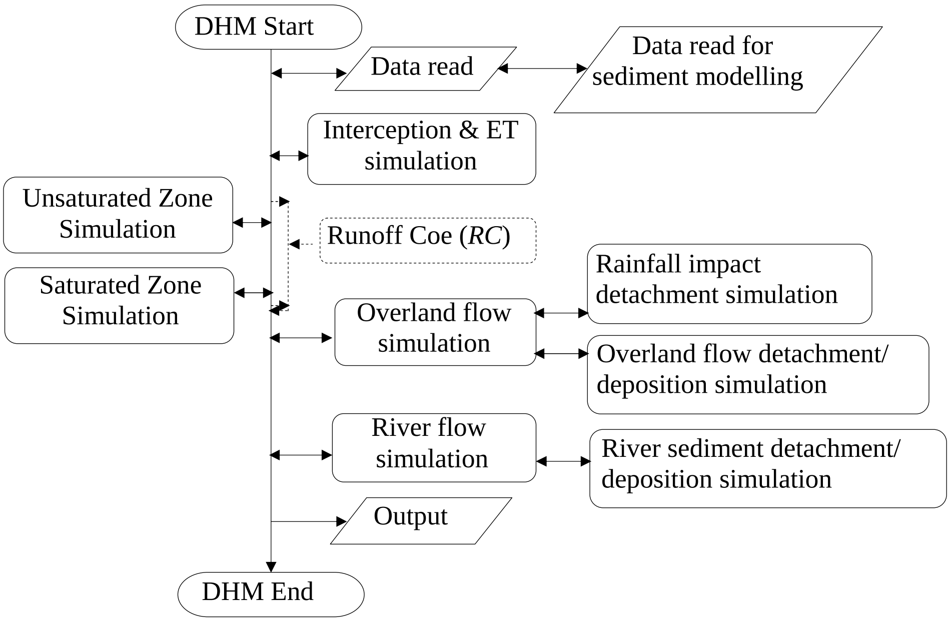


Figure 1: Structure of process-based sediment dynamic model

3. SOLUTION APPROACHES

In this modeling approach, the movement of sediments in each discretized cell is estimated in the same spatial and temporal steps as when the water discharges are calculated. The backward finite-difference scheme has been taken into consideration in solving kinematic wave equations numerically. In this method, the time and space derivatives of water flow (*Q*) and sediment concentration ($C_{s)}$ are approximated on the *x-t* grid as shown in Figure 2. The kinematic wave equations and their finite-difference interpretation used in this solution approach are shown in Table 2.

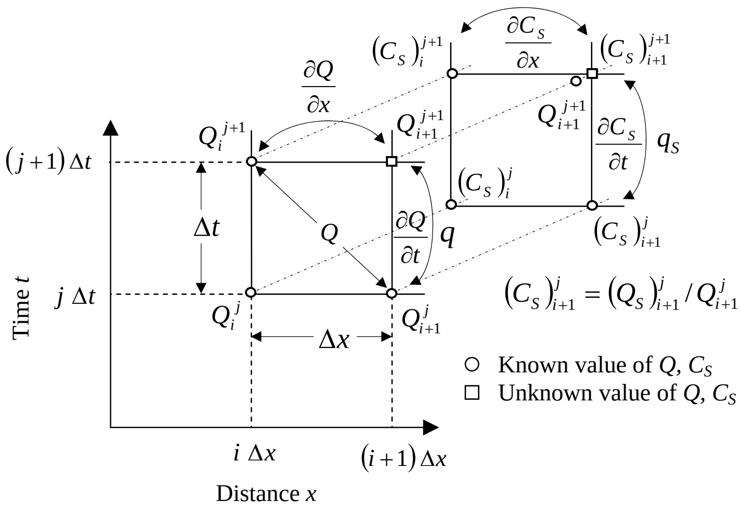


Figure 2: Time and space derivatives of both Q and Cs by finite-difference scheme in kinematic modelling (After Chow 1959)

Table 2: Kinematic wave equations and Finite difference interpretation

Equations for solution of '*Q*'	Equations for solution of 'C_S'
$\frac{\partial Q}{\partial x} + \alpha\beta Q^{\beta-1}\frac{\partial Q}{\partial t} = q$ Where, $A = \left(\frac{nP^{2/3}}{s^{1/2}}\right)^{3/5} Q^{3/5} = \alpha\, Q^{\beta}$ $\frac{Q_{i+1}^{j+1} - Q_i^{j+1}}{\Delta x} + \alpha\beta\left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2}\right)^{\beta-1}\frac{Q_{i+1}^{j+1} - Q_{i+1}^{j}}{\Delta t} = \frac{q_{i+1}^{j+1} - q_{i+1}^{j}}{2}$	$\frac{\partial Q_S}{\partial x} + \frac{\partial A_S}{\partial t} - e(x,t) = q_S$ Where, $Q_S = Q\,C_S; Q = AV; Q_S = A_S V$ $\frac{\partial (QC_S)}{\partial x} + \frac{\partial\left(\frac{QC_S}{V}\right)}{\partial t} - e(x,t) = q_S$, $e(x,t)$=DR+DF $\frac{(QC_S)_{i+1}^{j+1} - (QC_S)_i^{j+1}}{\Delta x} + \frac{\left(\frac{QC_S}{V}\right)_{i+1}^{j+1} - \left(\frac{QC_S}{V}\right)_{i+1}^{j}}{\Delta t} - [e(x,t)]_{i+1}^{j+1} = \frac{(q_S)_{i+1}^{j+1} - (q_S)_{i+1}^{j}}{2}$

The mass-balance equations (Table 2) have been applied on surface grids along the order of flow accumulation values and in river nodes from upstream to downstream. GIS software ArcGIS (version 9.3) has been used to delineate river network and flow accumulation map from digital elevation model. The lateral flow in surface grids is estimated from rainfall directly to route water whereas in sediment transport calculation, the amount of rainfall impact detachment and flow detachment are considered as lateral sediment supply. The lateral flows for solving mass-balance equations in river points are determined by estimating water discharges and sediment loads coming from surface grids to river grids in adjacent to the river nodes to route water discharge and sediment concentration respectively.

4. STUDY AREA (LATROBE RIVER BASIN)

Latrobe River basin is located in the south-eastern part of Victoria, Australia as shown in Figure. 3. The main stream of this watershed is Latrobe River, which flows eastwards throughout the whole basin and ultimately discharges into Lake Wellington. The central part of this basin is less elevated and covered with elongated flat farmland with unconsolidated soils, which are very much susceptible to bank erosion (DPI 2009). The other parts excluding central region consist of steep mountains with fairly dense forest. The basin includes the three major towns of Moe, Morwell and Traralgon along its central part. The total basin area is around 4,675 Km^2 and it sustains a population of 97,339 (BRS and BOM 2008).

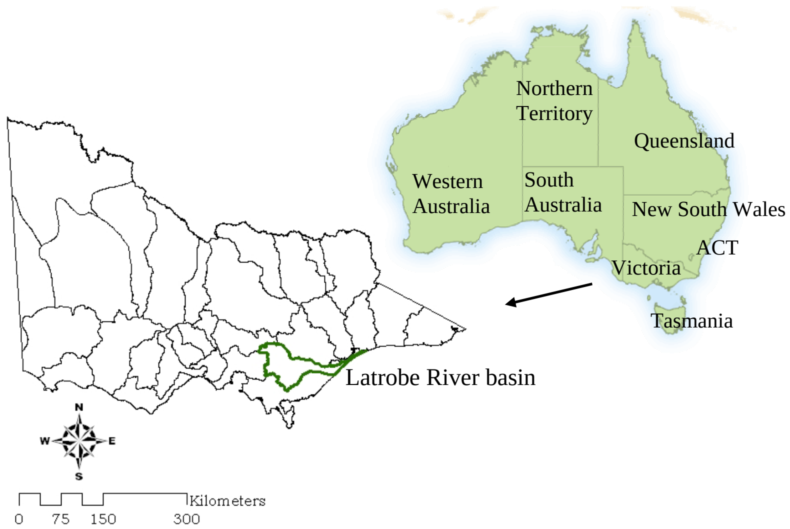
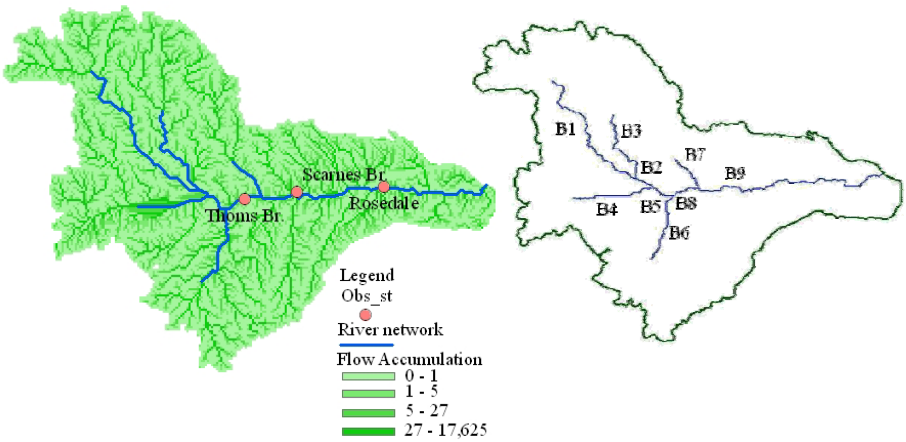


Figure 3: Latrobe river basin location in Victoria, Australia

5. HISTORICAL EVENT SIMULATIONS AND DISCUSSIONS

In this study, the Latrobe River basin has been simulated for different climate change conditions with respect to the base period of 2007 flood event. Prior to describing climate change effect in the next section, the model setup and simulations for 2007 flood case have been repeated here in this section. The digital elevation model (DEM) of *500-m* grid spacing has been used in simulation which was originally taken from SRTM data of *90-m* resolution. The flow accumulation map and the major river network which has been generated from SRTM DEM are shown in Figure 4a. Rosedale, Scarnes Bridge and Thoms Bridge are the three gauging stations along the river network, which have been selected for calibration and verification of the model application. The maximum temporal resolution has been set to *1-hr* during model simulation. The model stability checking and temporal resolution refining have also been carried out based on the satisfaction of courant condition. Roughness coefficient (n) values and an index of soil detachability (k) have been considered main calibrating parameter in this modeling. The major river network has been described by hydraulic parameters associated with each of river branches to capture river flow dynamics properly. The different branches of Latrobe River have been defined separately in this study as shown in Figure 4b.



(a) *(b)*

Figure 4: Flow Accumulation Map and river network for Latrobe River basin modeling

Figure 5 shows the total water budget allocation during 2007 flood periods based on simulation results of different hydrological modules. It implies that a higher interception and evapotranspiration rate in Latrobe River basin minimizes the amount of overland flow into the river systems.

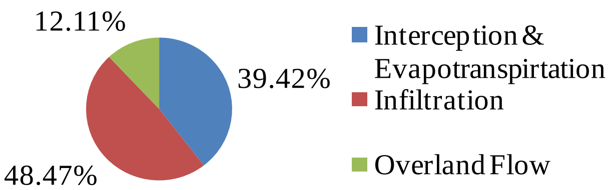


Figure 5: Water budget allocation in Latrobe River basin (Jun-Aug, 07)

In 2007, the flood hydrographs in different stations revealed multiple peaks during June to August. It has revealed that a runoff coefficient of 0. 2 allocates water distributions properly for hydrological simulations at Latrobe River basin when the basin antecedent soil moisture content is high. Since the basin has a high soil moisture capacity that triggers a high infiltration rate (Potter, 2005) and on the other hand, a constant runoff coefficient has been planned to use instead of sub-surface simulations, the flood events in August, 2007 have been chosen to analysis which occurred due to rainfall with wet soil moisture antecedent conditions.

August, 2007 flood events have been simulated well with using the constant runoff coefficient. Figure 6 shows water and suspended sediment discharges at Rosedale and Scarnes Br. respectively with basin average rainfall. The model well simulated daily water discharges and the correlation coefficients (R-squared values) 0.935 and 0.876 at Rosedale and Scarnes Br. respectively are found in between simulated and observed daily water discharges as shown in Figure 7. Table 3 presents the highest and lowest Nash-Sutcliffe's coefficient of 0.926 and 0.830 respectively between simulated and observed daily water discharges at different river gauging stations during the flood event August, 2007.

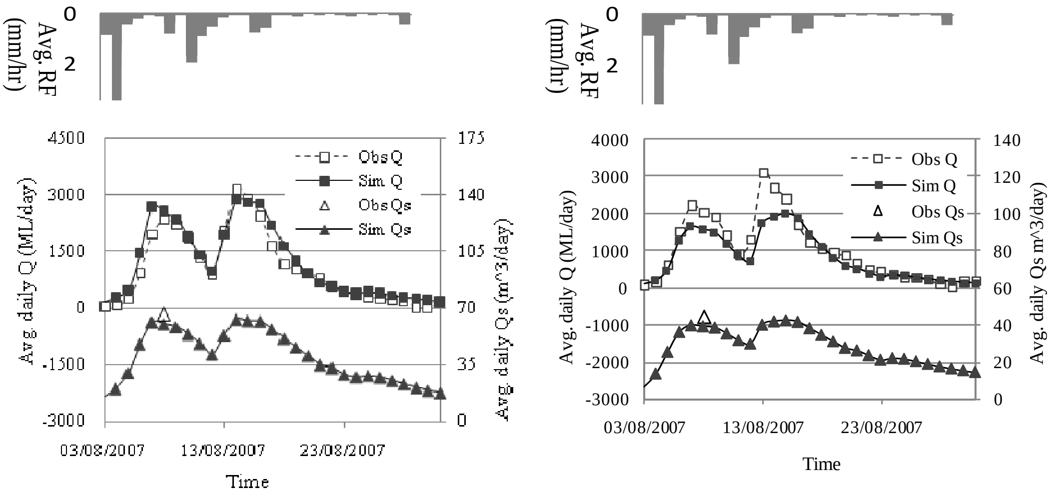
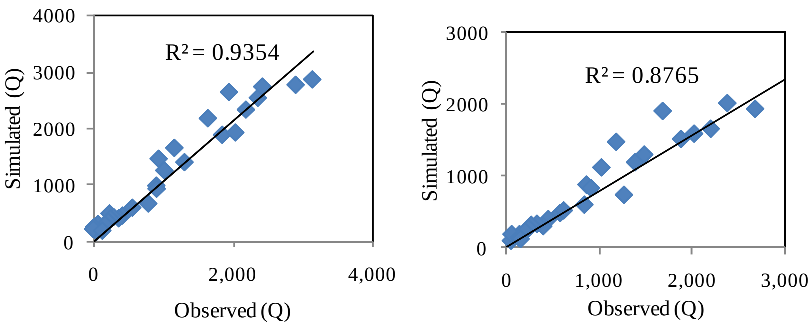


Figure 6: Water and suspended sediment discharges with basin avg. Rainfall



(a) At Rosedale *(b) At Scarnes Br.*

Figure 7: Comparison of simulated water discharges at Latrobe River

Table 3: Evaluation of hydrological simulation of Latrobe river basin modelling

Items	Stations	Nash-Sutcliffe COE
Avg. daily, Q	Rosedale	0.926
	Scarnes Br.	0.830

The suspended sediment discharges at Rosedale and Scarnes Br. are found to follow a similar trend as on the water discharges along the river ways. A relatively smaller portion from eroded soils from hillslope area reaches to the river systems due to less overland flow. On the other hand, many reservoirs along the river courses caused a decrease of flow velocity which promotes large particle sized sediment deposition. It is worth noting here, usually grains smaller than 0.125 mm always behave as suspended sediment while grains coarser than 8 mm travel as bed load (Wilcock, 2004). But, these limits are highly variable with flow strength. Analyses of observed data revealed that the water discharges at Latrobe River delivered a limited force to channel systems during the flood events

August, 2007 and in these circumstances, the suspended sediment concentration ranges were within the threshold limits of using the Govers transport capacity equation as mentioned in Table 1. Therefore, simulated suspended sediments are found to be similar by comparing with a single observed data as described in Table 4. Analyses of model results in this study area with more observation data are now underway.

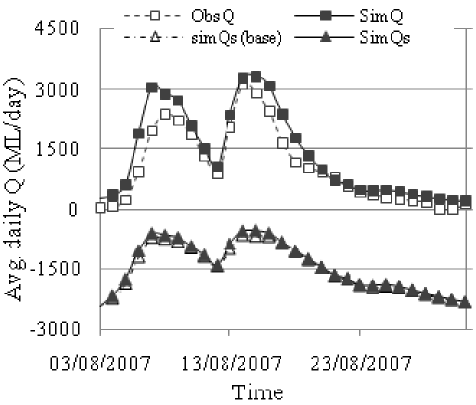
Table 4: Evaluation of simulated suspended sediment results

Items	Stations	% of deviation at single obs.
Avg. daily, Qs	Rosedale	+9.73
	Scarnes Br.	+12.3

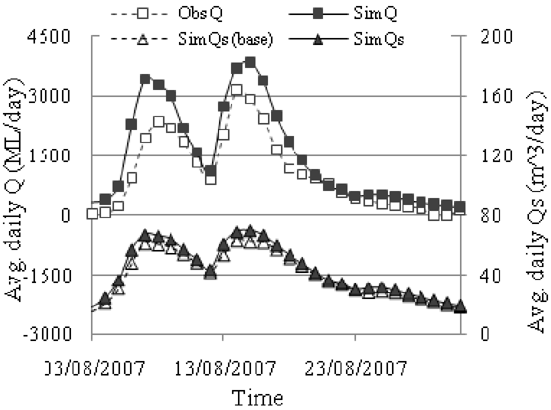
7. ASSESSMENT OF CLIMATE CHANGE CONDITIONS

Impacts of climate change on earth have already been observed and further changes are unavoidable. In Australian context, some of the issues for climate change conditions are identified as critical, e.g., severe droughts, extreme climatic events like heatwaves, floods and bushfires (Steffen, 2009). The intensity of precipitation events over the twenty-first century in southeast Australia are also predicted by Intergovernmental Panel on Climate Change (IPCC) to be increased (Niall and Walsh, 2005). Due to the significant change of precipitation patterns, the region is expected to be experienced more frequent droughts and flood events. Frequent bushfires and forest area reductions in the southeast region are also expected due to continuing dry and warm weather (Murphy and Timbal, 2008). On a contrary to this fact, intensification of rainfall intensity within a short duration will deliver critical force on earth sedimentology. As a part of this climate change, increasing rainfall intensity and frequency, changing land use pattern would trigger a higher rate of soil erosion and sedimentation (IPCC, 2007).

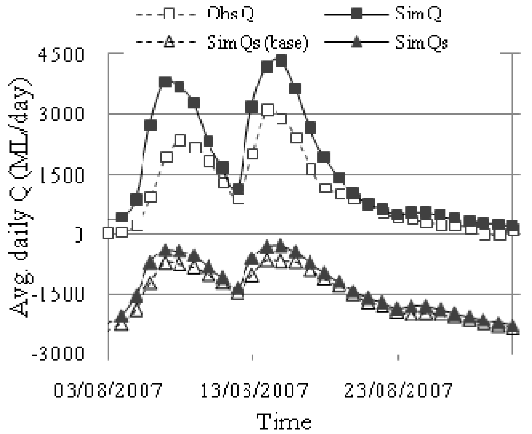
In this study, process-based sediment dynamic modelling on Latrobe River basin has been carried out under climate change conditions considering the base flood event in August, 2007. The climate change conditions have been represented through 1) increasing rainfall intensity; 2) reducing forest areas (exposing more bare lands); and increasing soil erodibility as per the case of presence of ashes after bushfires. Figure 8 shows water and suspended sediment simulations at Rosedale station, Latrobe River basin under different climate scenarios. Table 5 summarizes the outcomes of all the simulations in terms of numerical values. The results show that daily average sediment discharges will increase 4.14%, 8.14% and 11.74% for 10%, 20% and 30% increase of rainfall respectively with respect to the flood event August 2007. Sediment dynamics in this basin will also be significantly impacted due to the reduction of forest areas. As stated earlier, reduction of forest areas in this region is expected via bushfires which in other way, would increase soil erodibility due to presence of huge ashes. Simulation results for 10%, 20% and 30% reduction of forest areas and same percentile increase of soil erodibility show that sediment yield would be 0.65, 1.74 and 3.53 times higher than the yielding during August, 2007 respectively. It is worth noting here that reduction of forest areas has not been considered in flow simulations. The sediment dynamics would be much worsened in the above climate conditions since reduced forest areas decrease time of concentration which results a higher peak flow. However, a simultaneous effect of these two climate change conditions reveals high amount of sediment yielding.


ObsQ
SimQ
simQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
03/08/2007
13/08/2007
23/08/2007
Time

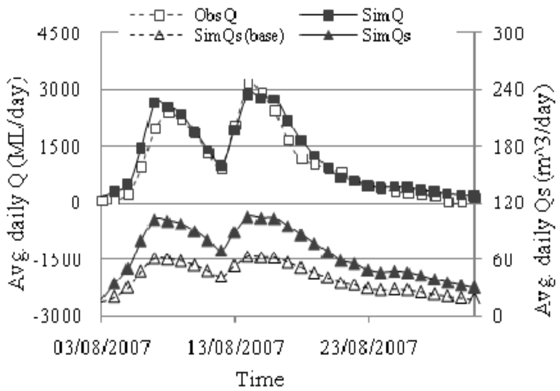
(a)


ObsQ
SimQ
SimQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
13/08/2007
23/08/2007
Time

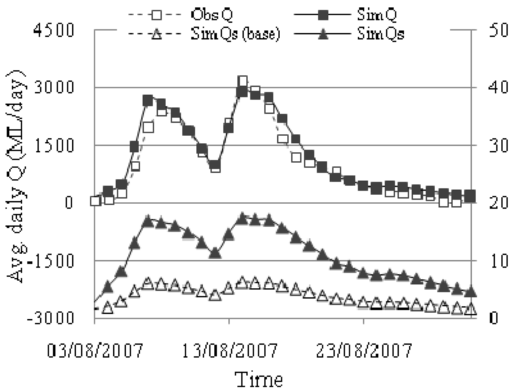
(b)


ObsQ
SimQ
SimQs (base)
SimQs
Time

(c)


ObsQ
SimQ
SimQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
03/08/2007
13/08/2007
23/08/2007
Time

(d)


ObsQ
SimQ
SimQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
03/08/2007
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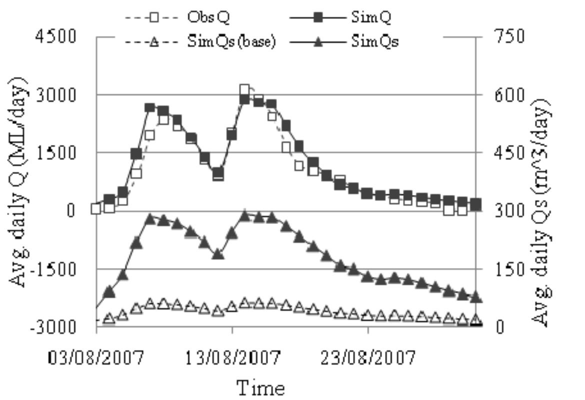
23/08/2007
Time

(e)


ObsQ
SimQ
SimQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
03/08/2007
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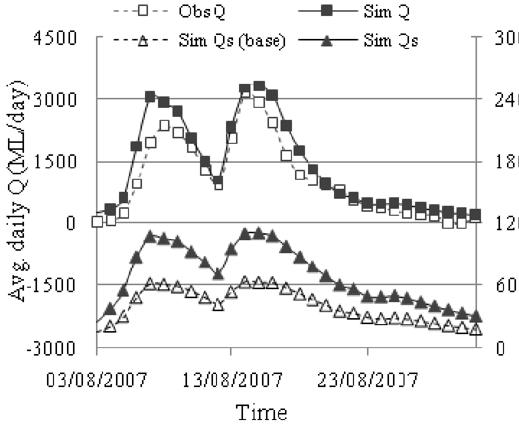
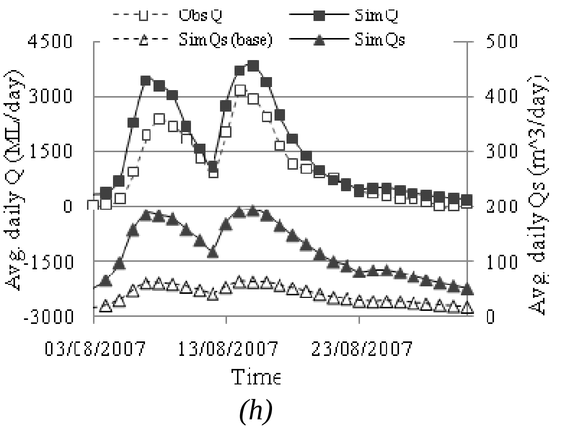
23/08/2007
Time

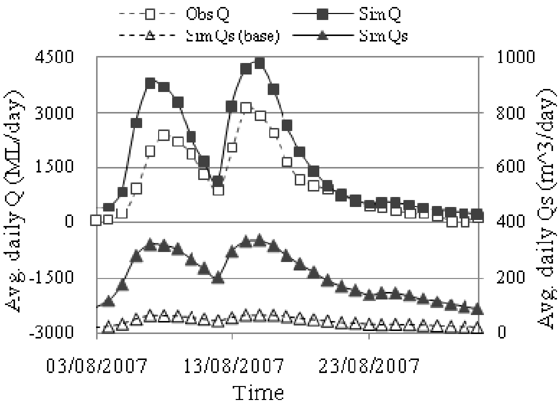
(f)


ObsQ
Sim Q
Sim Qs (base)
Sim Qs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
03/08/2007
13/08/2007
Time

(g)


ObsQ
SimQ
SimQs (base)
SimQs
Avg. daily Q (ML/day)
Avg. daily Qs (m^3/day)
13/08/2007
23/08/2007

(h)



(i)

Figure 8: Water and suspended sediment discharges (Q and Qs) at Rosedale station for (a) 10% (b)20% (c) 30% increase of rainfall,(d)10% reduction in forest areas & 10% increase in soil erodibility, (e) 20% reduction in forest areas & 20% increase in soil erodibility, (f) 30% reduction in forest areas & 30% increase in soil erodibility, (g) 10% increase of rainfall and soil erodibility, 10% reduction of forest areas, (h) 20% increase of rainfall and soil erodibility, 20% reduction of forest areas, (i) 30% increase of rainfall and soil erodibility, 30% reduction of forest areas, with respect to the flood event 2007.

Table 5: Change in water and sediment discharges (Q and Qs) at Rosedale station under in different climate conditions with respect to the flood event 2007

Scenarios	Avg. Q		Peak Q		Avg. Qs		Peak Qs	
	ML/day	% change	ML/day	% change	m^3/day	% change	m^3/day	% change
a) 10% increase of RF	1351.62	12.45	3324.74	15.51	41.75	4.14	66.35	5.21
b) 20% increase of RF	1498.60	24.68	3848.44	33.70	43.36	8.14	69.82	10.70
c) 30% increase of RF	1644.07	36.79	4348.87	51.09	44.80	11.74	72.77	15.39
d) 10% reduction of forest areas & 10% increase of soil erodibility	1201.93	-	2878.31	-	66.31	65.39	104.94	66.39
e) 20% reduction of forest areas & 20% increase of soil erodibility	1201.93	-	2878.31	-	109.96	174.25	174.50	176.68
f) 30% reduction of forest areas & 30% increase of soil erodibility	1201.93	-	2878.31	-	181.84	353.53	289.90	359.66
g) a+d	1351.62	12.45	3324.74	15.51	69.37	73.01	110.42	75.07
h) b+e	1498.60	24.68	3848.44	33.70	119.53	198.13	193.27	206.45
i) c+f	1644.07	36.79	4348.87	51.09	204.58	410.25	335.01	431.19

8. CONCLUSIONS

A sediment dynamic analysis in Latrobe River basin, Australia for flood events, 2007 under climate change conditions has been carried out in this study using a process-based distributed modeling approach. The model has used SRTM DEM and other spatial datasets with a spatial resolution of *500-*

m. The temporal resolution of *1-hr* has been used during model simulation. The model estimates soil erosion using physical equations for rainfall impact and flow associated soil detachment. The water and sediment discharges are calculated using one-dimensional kinematic wave approximation of the Saint-Venant equations. Sediment transport and deposition has been estimated using a simplified Govers (1990) transport capacity equation. A constant runoff coefficient has been used instead of simulating sub-surface flow conditions for the sake of simplified solutions in the current model application.

The study has been carried out considering the base period of August, 2007 flood event. The model has well simulated runoff at Latrobe River basin, Australia with highest and lowest Nash-Sutcliffe's coefficient of 0.926 and 0.830 respectively between simulated and observed discharges at different river gauging stations during the flood event August, 2007 with a constant runoff coefficient of 0.2. Based on available limited observed data, the model has also found consistent to estimate suspended sediment transport in river systems. Evaluation of model results with more observation data is highly recommended.

In climate change conditions, analyses reveal that sediment dynamics in this river basin would be much affected by reduction of forest areas mostly due to bush fires since in this case, soil erodibility will also be higher owing to the presence of huge ashes in the bare lands. In such a case e.g., for 30% reduction of forest areas and 30% increase of soil erodibility, sediment yield would be 3.6 times of yielding that of during August, 2007 flood period. With this, a synchronization of 30% increase of rainfall will raise 4.3 time sediment yielding with respect to the same base period. The preliminary analysis indicates that sediment dynamics in Latrobe River basin will be highly affected in climate change conditions since it get regulated by multiple climate parameters. Assessment of sediment dynamics using GCMs data is now underway.

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QUANTIFICATION OF CLIMATE CHANGE IMPACT ON NUTRIENT POLLUTION: APPLICATION OF A DYNAMIC MODEL FOR LATROBE RIVER BASIN IN AUSTRALIA

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ABSTRACT

The concern over diffuse nutrient pollution has increased due to rapid urbanization and population growth all over the world. In Australia this is one of the major issues in water resource management. Climate change has much escalated this issue further affecting the hydrology and nutrient process severely. This has drawn huge public attention and called for sustainable development plan for future growth of the society and protection of natural environment. However, tackling climate change issue for nutrient management is challenging and it depends on the ability to accurate estimation of pollution level and its prediction under changing hydro-climatic conditions, where modelling has the significant roles to play. As most of the existing modelling tools have limitations that unable to incorporate the climate variability and the required process descriptions in nutrient simulation a new generation modelling tool is necessary. With this focus this study has developed a robust modelling tool by adopting an integrated approach in nutrient modelling that has combined catchment generation process and dynamic modelling of in-stream process for prediction of nutrient level in river water. In this modelling soil moisture and climate driven transformation process of nutrient for different land uses have been considered in model formulation. Different pathways have been modeled to estimate different form of nutrient release to the waterways. Soil erosion and sediment yield model determines release of soil bound nutrient in river water. Inorganic form of nutrient is released with rainfall- runoff process. Model has introduced a dynamic approach for in-stream modelling by incorporating physical and biogeochemical process that solves unsteady flow and solute transport equations. In rainfall-runoff modelling runoff coefficient has been used ignoring sub-surface component of the hydrologic model. Hence all forms of nutrient release have been calculated with surface flow only. The model has been developed in the platform of an existing distributed hydrological modelling tool. In this study the model has been calibrated for small catchment in Latrobe River basin in Australia and applied for simulation of climate change scenarios. The study has successfully demonstrated how the climate change affects the nutrient process and quantified its pollution level for future changes. Due to climate change and projected future growth of the region the upstream catchments are likely to affect the Gippsland lakes and its coastal environment. Higher temperature enhances nitrogen release from soil and increase the stream nitrate level. This assessment provides a basis for quantification of climate change impact on nutrient pollution that can be useful in devising the strategy for future pollution management plan.

Keyword: Nutrient pollution, dynamic model, climate change impact, river basin

1. INTRODUCTION

Since release of the 4th Technical Report AR4 of the Intergovernmental Panel on Climate Change (IPCC) in 2007 scientific understanding has improved remarkably over the last 3-4 years and it appears overwhelmingly that climate system is likely to be changing faster than it was thought before- which means more serious risk (Steffen, 2009). This has drawn urgent attention on the need to adapt with the strategies that enhances resilience and develops capacity to cope with new climate condition

(Steffen, 2009). In context of nutrient pollution management this has to be developed based on risk based management plan. The water quality situation is already severe in many parts of the world due to human intervention that disturbs established natural processes. Exploitation of natural resources for human need such as food and energy supply and urbanization are altering nutrient cycle badly with consequence of excessive pollution in waterways. Use of chemical fertilizer, combustion of fossil fuel, dairying, and waste disposal are few human induced factors contributing this pollution. The climate change is likely to affect the process further. Warmer temperatures in some regions and the changes in hydrological cycle have implication of many forms of water pollution including nutrients (IPCC, 2008). Proper assessment and quantification of this impact on nutrient pollution could be useful for planning strategy in future management.

This study has developed a new modelling tool for nutrient pollution assessment in river basin (Alam and Dutta, 2009; Alam et al., 2008, 2009), which has been presented here. The Model has been applied in a small catchment in the Latrobe River Basin, Australia. The calibrated model has been used for climate change simulation. The paper demonstrates usefulness of this model for hydro-climate change based simulation.

2. MODELLING APPROACH

The modelling approach consists of three components as shown in Figure 1. Catchment generation process has been dealt with for accounting soil nutrient transformation process. The transfer mechanism of nutrients from surface to the waterways has been considered via pathways for soil erosion and surface runoff. The river component deals with dynamic transport and biogeochemical process in river water. The model has been developed in an existing platform of distributed hydrological modelling tool called IISDHM (Dutta et al., 2000).

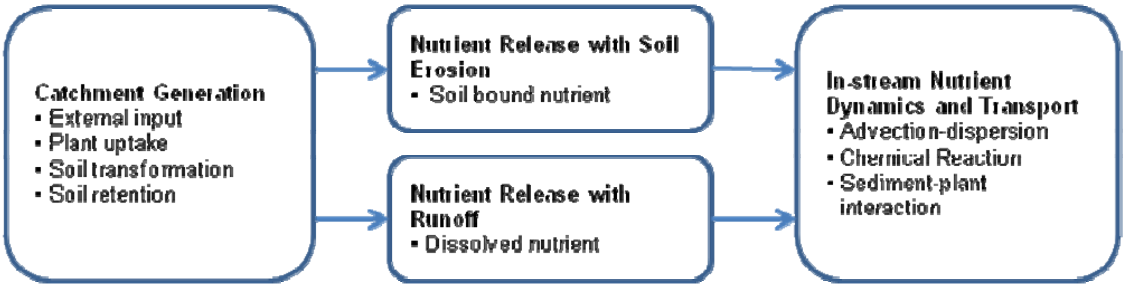

Figure 1: Integrated modelling approach

2.1 Catchment generation process

Sub-catchment based approach has been adopted for catchment process modelling. The model takes into account of transformations process of organic nitrogen and phosphorus in soil layer. Mineralization and immobilization has been considered to calculate net generation of ammonium *N* and phosphate *P*. Nitrification and de-nitrification determine the nitrate level and losses of nitrogen through atmosphere. Nutrient consumption for plant growth is determined based on uptake equation (Whitehead et al., 1998 a, b). The reaction processes depends on the soil moisture condition and temperature in soil layer. These equations (Equation 1-7) are shown in Table 1 and 2.

Table 1: Equations for nitrogen transformation process in soil layer (Whitehead et al., 1998 a,b)

Process	**Equations**
Plant Uptake	$Uptake = C_{up}u_i\left(x_{NO_3} + x_{NH_4}\right)$ (1) Where, C_{up}= plant uptake rate (day^{-1}), X_{NO3} = amount of nitrate, X_{NH4} = amount of nitrate,
Mineralization-immobilization	$Net\ Mineralization = C_{mina}S_i - C_{imm}X_{amm}$ (2) Where, C_{mina}= Mineralization rate (g day^{-1}), *SMI*=soil moisture index, C_{imm}= Immobilization rate (day^{-1}), X_{amm}= Ammonium *N* content
Nitrification	$Nitrification = C_{nitri}U_w X_{NH_4-N}$ (3) Where, C_{nitri}= Nitrification rate (day^{-1}), X_{NH_4-N} = Ammonium *N* content
Denitrification	$Denitrifcation = C_{deni}U_w X_{NO_3-N}$ (4) Where, C_{deni}= Denitrification rate (day^{-1}) , X_{NO_3-N} = Nitrate N content
Temperature correction	$C_n = 1.047^{(\theta_s - 20)}C$ (5) Where, C_n =rate coefficients (day^{-1}), *C*= rate coefficients (day^{-1}) at 20°C, θs= Soil temperature

Table 2: Equations for phosphorus transformation process in soil layer

Process	**Equations**
Plant Uptake	$Uptake = C_{up}u_i x_{PO_4}$ (6) Where, C_{up}= uptake rate (day^{-1}), u_i= plant growth index, x_{PO_4} = amount of Phosphate P
Mineralization-immobilization	$Net\ Mineralization = C_{mina}S_i - C_{imm}X_{DPO_4}$ (7) Where, C_{mina}= Mineralization rate (g day^{-1}), *SMI*=soil moisture index, C_{imm}= Immobilization rate (day^{-1}), X_{DPO_4} = amount of dissolved *PO4*.

The soil moisture index (SMI) has been determined based on the soil moisture deficit (SMD) in the soil layer. The index is zero when maximum moisture deficit and 1 in saturation. The *SMI* and *SMD* can be calculated as below (Equation 8-9).

$$SMI = \frac{SMD_{Max} - SMD}{SMD_{Max}} \qquad \text{(Whitehead et al. 1998a,b)} \tag{8}$$

$$\frac{dSMD}{dt} = -P_{eff} + ET \qquad \text{(Finkele et al. 2006)} \tag{9}$$

Where, P_{eff} (rain-interception-runoff) = effective rainfall and *ET*= Evapo-transpiration.

Ensuring mass balance of the different transformation process the release of nutrient has been estimated based on the following equations (Equation 10-15).

$$(NH_3 - N)_t = Ext_{input} + mineralization - immobilization - uptake \tag{10}$$

$$(NH_3 - N)_{release} = (NH_3 - N)_t * U_w \tag{11}$$

$$(NO_3 - N)_t = Ext_{input} + nitrification - uptake - denitrification \tag{12}$$

$$(NO_3 - N)_{release} = (NO_3 - N)_t * U_w \tag{13}$$

$$(DPO_4 - P)_t = Ext_{input} + mineralization - immobilization - uptake \tag{14}$$

$$(DPO_4 - P)_{release} = (DPO_4 - P)_t * U_w \tag{15}$$

Where, suffix t denotes computational time level; NH_4-N, NO_3-N and DPO_4-P are ammonium, nitrate and dissolved phosphate, respectively; Ext_{input}= all input associated with external sources on the surface, mineralization is net load of mineralized ammonium N and phosphate P, immobilization denotes amount immobilized, denitrification is loss of nitrate, *uptake* = consumption for plant growth. A pollutant load function U_W has been introduced (Equation 16) to account of storm and land surface type when determining dissolved nutrient release with runoff.

$$U_W = aQ^b \tag{16}$$

Where, a = coefficient for soil and land cover effects, b= power factor, Q = Flow (m3/s).

2.2 Sediment yield and estimation of organic or soil bound nutrients

MUSLE (Williams 1975; Williams & Berndt, 1977) has been used to generate sediment yield. Based on the sediment yield soil bound or organic nutrient has been calculated as below (Leon et al., 2001).

$$N_{SED} = N_{SCN} Y_{SED} ER \tag{17}$$

$$P_{SED} = P_{SCN} Y_{SED} ER \tag{18}$$

$$E_R = aY_{SED}^b T_f \tag{19}$$

Where N_{SED} = nitrogen transported by sediment (kg ha^{-1}), N_{SCN}= soil nitrogen concentration. Similarly, P_{SED} = phosphorous transported by sediment (kg ha^{-1}), P_{SCN}= soil phosphorous concentration. Y_{SED} = Sediment yield, ER = Nutrient enrichment ratio, a and b are enrichment coefficients, T_f = correction factor for soil texture.

2.3 In-stream process and river transport modelling

Using explicit solution scheme in finite difference method Advection-dispersion equation (Equation 20) has been solved to calculate nutrient concentration at each river grid. First order reaction has been considered in this equation for all chemical reaction and in-stream biogeochemical process (Chapra, 1997).

$$V \frac{\partial c}{\partial t} = \underbrace{\frac{\partial\left(A_c E \frac{\partial c}{\partial x}\right)}{\partial x} dx - \frac{\partial (A_c U c)}{\partial x} dx}_{Advection-dispersion} + \underbrace{V(rc + p)}_{Reaction} + \underbrace{S}_{source/sink} \tag{20}$$

Where, V = element volume, c= nutrient concentration, A_c= element cross-section area, E= Longitudinal dispersion coefficient, X= space unit, t= time, U= average velocity, r=reaction rate, p= internal source/sink through transformation, s= external loading (source/sinks).

The chemical reaction process and nutrient/plant components are shown in Figure 2 and the corresponding equations (21-27) have been tabulated in Table 3.

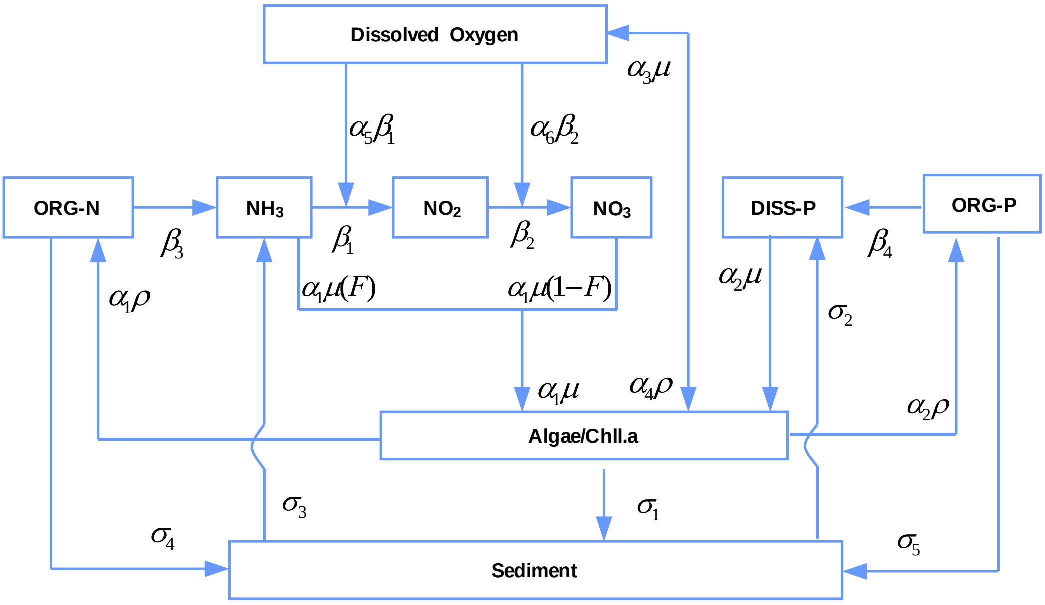

Figure 2: Nutrient interaction and chemical reactions process (modified from Chapra, 1997)

Table 3: Equations for chemical reaction (Chapra, 1997)

Algae (A):	$$\frac{dA}{dt} = \mu A - \rho A - \frac{\sigma_1}{H} A \qquad (21)$$
Organic Nitrogen (*ORG-N*)	$$\frac{dN_{ORG}}{dt} = \alpha_1 \rho A - \beta_3 N_{ORG} - \sigma_4 N_{ORG} \qquad (22)$$
Ammonia Nitrogen (*NH_4-N*)	$$\frac{dN_{NH4}}{dt} = \beta_3 N_{ORG} - \beta_1 N_{NH4} - \frac{\sigma_3}{H} - F_i \alpha_i \mu A \qquad (23)$$
Nitrite Nitrogen (*NO_2-N*)	$$\frac{dN_{NO2}}{dt} = \beta_1 N_{NH4} - \beta_2 N_{NO2} \qquad (24)$$
Nitrite Nitrogen (*NO_3-N*)	$$\frac{dN_{NO3}}{dt} = \beta_2 N_{NO2} - (1 - F)\alpha_1 \mu A \qquad (25)$$
Organic Phosphorous (*ORG-P*)	$$\frac{dP_{ORG}}{dt} = \alpha_2 \rho A - \beta_4 P_{ORG} - \sigma_5 P_{ORG} \qquad (26)$$
Dissolved Reactive Phosphorous (*DISS-P*)	$$\frac{dP_{DISS}}{dt} = \alpha_4 P_{ORG} + \frac{\sigma_2}{H} - \alpha_2 \mu A \qquad (27)$$
Where, *A*= Algae as *Chlorophyll a*, *ORG-N*= Nitrogen as organic matter, *NH_4-N* = Nitrogen as Ammonium, *NO_2-N*=Nitrogen as Nitrite, *NO_3-N*= Nitrogen as Nitrate, *ORG-P*= Phosphorous as organic matter, *DISS-P*= Soluble reactive phosphorous in dissolved form, $\sigma i,,\alpha i,,\beta i,,\mu,\rho$= Rate of reaction, *H*= Water depth, *F*= Attenuation factor	

2.4 Study area

The Latrobe River, one of the important river systems in Victoria State of Australia, drains a catchment area of 4500 sq-km in central Gippsland region (Figure 3). The climate of the region is temperate. Land use types are mainly forest, agriculture, urban and industrial area. Dairy and sheep grazing are the predominant agricultural land uses. Urban and industrial areas are relatively small. In this study upper part of the catchment has been considered for analysis. The information of few reservoirs below this area is not readily available that affects the calibration at the downstream gauges.

Figure 3: Location map and study area in Latrobe River Basin

2.5 Model set up

The model consists of digital elevation model (DEM) of the surface topography of the basin area. 1 km grid has been used to set up the surface component of the model. Using GIS technique flow direction and flow accumulation maps have been derived to determine the flow paths and used for generating river network system. A sub-catchment based analysis has been carried out for catchment process modelling.

2.6 Model calibration

The simulation has been carried out for 7 months period starting from June 2007 to January 2008. During this period river observed a major flood in June-July 07. The model results have been compared with daily observed discharge. However, very few data is available for nutrient and sediment calibration and it is not for all form of nutrients.

The comparison of observed and simulated discharge shows quite acceptable performance of the model in representing the overall shape of the hydrograph and matching the peak (Figure 4). Nash-Sutcliffe model efficiency coefficient is 0.34. The sediment yield comparison has also shows quite accurate prediction at gauge location (Figure 4).

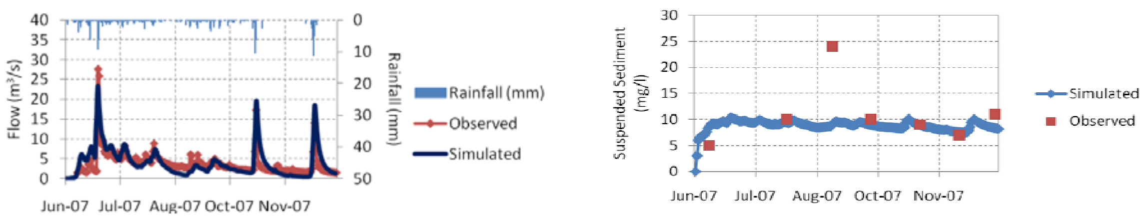

Figure 4: Comparison of discharge (left) and sediment yield (right) at Willow Grove Station

For catchment process modelling the soil moisture index (SMI) has been prepared for the entire simulation period using hydrologic input data. The nutrient generation rate for various land use type has been assumed and considering different transformation rate with SMI the nutrient transformation process has been modeled. The nutrient simulation results have been compared and presented below (Figure 5-7).

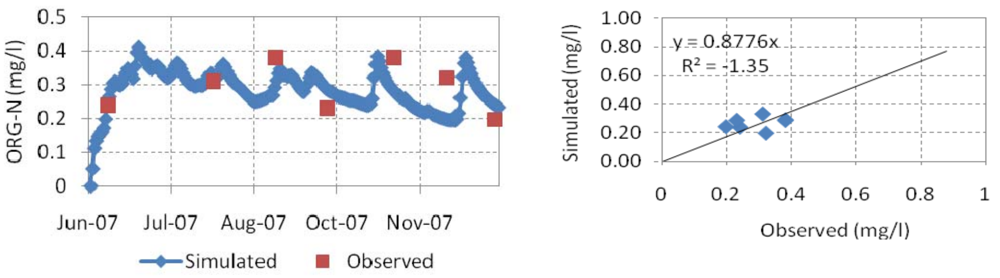

Figure 5: Observed and simulated ORG-N at Willow Grove

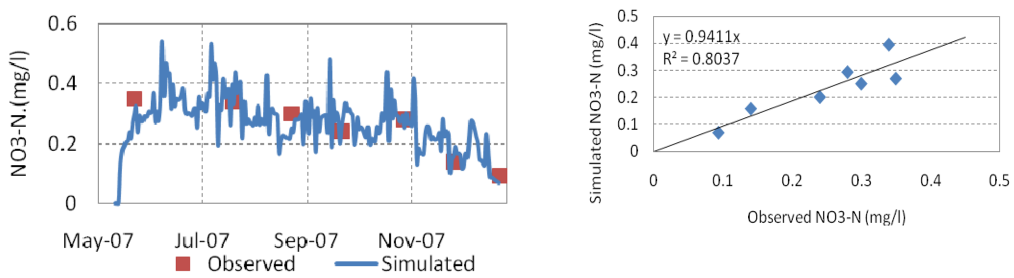

Figure 6: Observed and simulated NO_3-N at Willow Grove

The results shown above are considered to be quite satisfactory especially for *NO_3-N* (Figure 6). The root mean square error (RMSE) between observed and modeled result has been tabulated in Table 4.

Table 4: Calculated RMSE value

	ORG-N	***NO_3-N***	**Total *P***
RMSE value	0.07	0.05	0.01

2.7 Simulation of climate change scenarios

The climate in Gippsland has observed measureable changes over the last century. The average temperature has increased by 0.8 °C and annual average rainfall is likely to decrease (Brooke & Hennessy, 2005). In a number of studies assessment of climate change in Gippsland region has been found (Brooke & Hennessy, 2005; CSIRO and BoM, 2007; Jones & Webb, 2008). Table 5 shows the projection of changes in temperature and rainfall based on IPCC emission scenarios for 2030 and 2070.

Table 5: Projection of climate change (rise and fall) in Gippsland Region (Jones & Webb, 2008)

	For 2030 (AIB Scenario)	**For 2070 (Lower Emission Scenario B1)**	**For 2070 (Higher Emission Scenario A1F1)**
	Range (10-90%)	Range (10-90%)	Range (10-90%)
Annual rainfall	-8 to 0 %	-12 to 0 %	-22 to 0 %
Temperature	+0.5 to +1.1 °C	+0.9 to +1.9 °C	+1.7 to +3.6 °C

In this study the projections for annual average changes in temperature and rainfall have been applied. Using upper range of change for A1F1 emission scenario following scenarios have been developed for nutrient simulation. These changes have been applied on existing condition i.e. for the simulation period of the model for June 2007 to January 2008.

Scenario 1: Effect of 3.6 °C temperature rise on soil moisture condition and nutrient transformation process. Change in Potential evapotranspiration occurs 2-8% increase par degree global warming (Whetton et al., 2002).

Scenario 2: Reduction of rainfall plus the conditions in scenario 1.

Scenario 3: 9% Increase in rainfall (Brooke & Hennessy, 2005) plus the conditions in scenario 1.

The climate change effects influence the temperature dependant chemical reaction process in the model. The soil nutrient transformation process is related with soil moisture condition, which is dealt with the term soil moisture index *SMI* in the model.

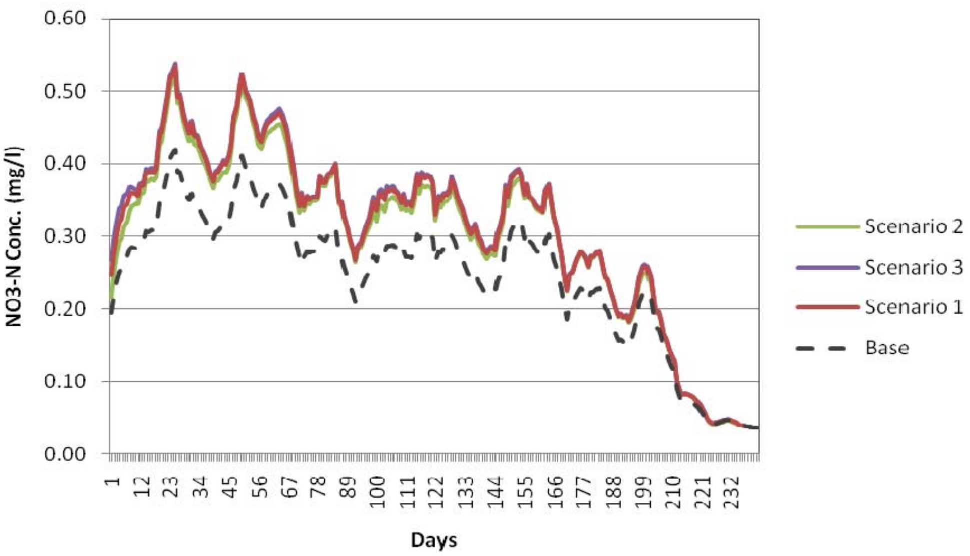

Figure 7: Climate change effects on NO_3-N concentration

The results have been shown in weekly period moving average plot (Figure 7) for all scenarios and compared with base condition. It is seen that 3.6°C temperature change has significant effects on *NO_3-N* level increasing (Scenarios 1). The peak difference is 0.16 mg/l, which is 30% increase in nitrate level. However, scenarios 2 and 3 did not influence the nutrient level compared to scenario 1. It appears that the change in rainfall did not affect much in hydrologic runoff probably because of using same runoff coefficient for changed hydrologic condition. Accurate representation of the soil moisture condition is crucial for this kind of simulation and more importantly for this type of catchment where the climate is very dry and temperate. It is also notable that the study has only been carried out in small area in upper part of the catchment, so effect could be minor in this area but may have significant impact at the basin downstream.

3. CONCLUSION

The overall performance of the model is quite satisfactory. Due to insufficient data proper calibration could not be shown for all nutrient parameters. Only the result for nitrate level has been presented. The result for prediction of climate change is quite significant. Further investigation is underway to verify the hydrologic response and the soil moisture condition that influence nutrient release from land surface. It appears that integration of sub-surface component would be useful in improving model performance. Using this model we can obtain a comprehensive analysis of climate change impact on nutrient pollution if downscaled GCM data for temperature, precipitation, evaporation and soil moisture condition, and projection of land use change are available for prediction.

ACKNOWLEDGEMENT

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DEVELOPMENT OF A FLOOD PREDICTION METHOD FOR THE NILWALA WATERSHED IN SRI LANKA

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ABSTRACT

Flooding is the major natural disaster in Sri Lanka and reliable forecasts with longer lead time reduces the damages. Same model can be used to quantify possible changes in flood paterns in the future due to climate change and in turn helps in policy development. In the study a weather model was coupled with a hydrologic model and a hydraulic model for predicting floods in Nilwala river basin in southern Sri Lanka. The basin is located mainly in the Matara district within the latitudes 5° 55' - 6° 13' and longitudes 80° 25' - 80° 38'.

WRF 3.0 (Weather Research and Forecasting) weather model was used to predict rainfall over the basin 24 h into future. The model was fine-tuned to suit its operating environment by investigating the impacts of its physics options on precipitation forecasting. In model fine-tuning, impacts of microphysics schemes, cumulus schemes, land surface schemes, long/shortwave schemes and boundary layer schemes on rainfall predictions were investigated. Model predictions were compared with observed point rainfall data for three rainfall events to find reasonably good physics combination. It was seen that model physics combination; Ferrier microphysics scheme, Kain-Fritsch cumulus scheme, Rapid Update Curve land surface scheme, Rapid Radiative Transfer Model longwave radiation scheme, Dudhia shortwave scheme and Yonsei boundary layer scheme yields better precipitation predictions over the basin.

After fine-tuning the weather model, hydrologic model HEC-HMS 3.3 (Hydrologic Engineering Center-Hydrologic Modeling System) was calibrated and verified with Clark's, Snyder's and SCS transformation methods for three rainfall-runoff events on its application to Nilwala basin upstream of Pitabeddara. In all model runs Green-Ampt loss model was executed with recession base flow method. It was found that Snyder's method performs better than other methods in calibration and verification. Snyder's method produced Nash-Sutcliff efficiencies greater than 70% and 50% in calibration and verification respectively. Ungauged portion of Nilwala basin was divided into 10 sub basins and Snyder's method was applied based on judgments and assumptions. Snyder's basin lag time was manually calculated for all the sub basins. Hydraulic conductivity for the whole basin was assumed to be same as for the upper basin. In order to couple weather model with hydrologic model a Microsoft Excel based program was developed. The program converts the distributed rainfall output of WRF into a lumped input for HEC-HMS sub basins.

As a demonstration May-2003 flood was simulated with the model combination. WRF predicted rainfall was introduced to HEC-HMS and the generated river discharges of sub basin were ingested to the HEC-RAS 4.0 hydraulic model for water profile computations along the Nilwala main river from Pitabeddara to Matara. Output of HEC-RAS was exported to Arc-GIS 9.2 where it was two dimensionally visualized as a flood map. Flood map generated was compared with observed flood inundation data obtained from literature. The model simulated map indicated a maximum of 2.25 m of flood depth which is a slightly under estimation. However, the model is capable of predicting the areas as inundated regions despite the underestimation of inundation depth. The underestimation was mainly due to the fact that model has underestimated river discharge as 664 m^3/s, which was about 1000 m^3/s on 18-May-2003 at Pitabeddara and elevation averaging of the DEM.

Once the models are calibrated they can be used with the available data on climate change scenarios from the Global Circulation Models to evaluate possible future conditions of the floods.

1. INTRODUCTION

Floods are the most common and widespread climate-related hazard on the earth. Flood forecasting can reduce the death toll associated with floods. (Guleid et al, 2007) Historically floods have been the most prevalent cause of death from natural disasters (Jonkman, 2005).

Most of the human losses due to floods occur in the tropical regions of Africa, Asia, and Central America. It has been established that flood early warning systems are the most effective means to reduce the death toll caused by floods. Operational flood forecasting has traditionally been driven by a dense network of rain gauges or ground-based rainfall measuring radars that report in real time (Guleid et al, 2007).

Flooding has been one of the most costly disasters in terms of both property damage and human casualties in Sri Lanka. Records show that major floods have occurred in Sri Lanka in the years of: 1913, 1940, 1947, 1957, 1967, 1968, 1978, 1989, 1992, and 2003 with severe loss of human lives, public and private property and the environment. Sri Lanka is blessed with 103 major river basins. Of these, 17 rivers are associated with flood problems. These 17 rivers have a catchments area of about 1,600 km2. Kalu, Kelani, Gin, Nilwala and Mahaweli are the major rivers causing floods in Sri Lanka (Jayasekera, 2009).

The basic intention of the study was to develop a computer based flood prediction tool for the Nilwala river basin. The study area was selected as the flood plain along the Nilwala River, downstream of Pitabeddara up to Matara, where the river meets the Indian Ocean. This area was selected for the study since the population density of this region is higher (particularly in the Matara town and its outskirts) and great degree of commercial plus social activities are taking place in the same zone, besides this the flood plain is largely used for various cultivations. So a severe flood could cause serious damages not only to human lives but also to the physical properties.

A model having following three basic components is used to introduce long lead flood forecasts to reduce damages.

1) Atmospheric model (To predict precipitation over the basin)
2) Hydrologic model (To predict the river flow at various location)
3) Hydraulic model (To predict the river water profile, inundation area and depth on the flood plains)

An atmospheric model was used initially to predict the precipitation over the river basin. The output of the atmospheric model was ingested to a hydrologic model to predict the river flow and using a hydraulic model and GIS (Geographic Information System) tools, the river flow levels as well as the inundation area were determined. The Fig. 1 describes the chain of models used in the study.

Once the models are calibrated they can be used with the available data on climate change scenarios from the Global Circulation Models to evaluate possible future conditions of the floods.

1.1 Nilwala River basin

River Nilwala is one of the longest rivers in southern Sri Lanka. It originates at Panilkanda near Deniyaya of Gin basin at an altitude of 1,050 m, after traversing about 72 km the river flow meets the Indian Ocean at Matara. Before falling into the sea it passes the Deniyaya town, Morawaka and Akuressa regions. Nearly 90 per cent of the area covered by the catchment of Nilwala River belongs to the Matara District. The area of the river basin is about 1,073 km^2. It lies mainly in the Matara district within the latitudes 5° 55' - 6° 13' and longitudes 80° 25' - 80° 38'. Figure 2 below shows the location of the Nilwala river basin and the network of rivers.

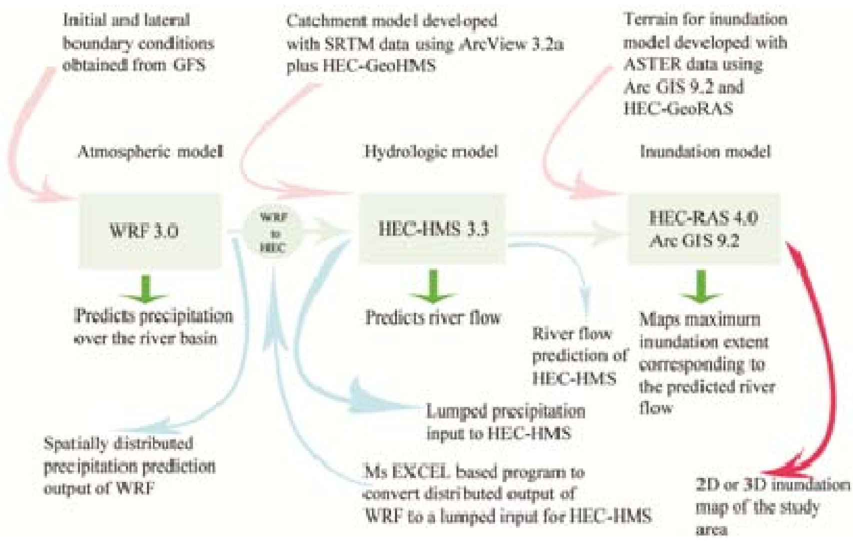


Fig. 1 Flow diagram depicting the chain of model components

Fig.2 Nilwala basin location and river network

The watershed is mainly located within the wet zone and the upper part of the catchment is covered by a rainforest. The mean annual rainfall of the upper basin is generally over 3000 mm, but the lowest point of Matara receives only about 1900 mm of annual rainfall. The monthly rainfall exceeds 200 mm during the March–June and August–December periods, but in other months it is about 150 mm (Elkaduwa et al, 1998).

2. METHODOLOGY

2.1 Weather modeling with WRF

A numerical weather model is a mathematical model constructed around a set of primitive dynamic equations which govern atmospheric motions, in today's world, it is a computer program that produces meteorological information for future times at given positions and altitudes.

The Weather Research and Forecasting (WRF 3.0) model used here is a numerical weather prediction and atmospheric simulation system designed for both research and operational applications. It falls into the category of regional weather models (Skamarock et al, 2008).

45 km/15 km/ 5 km domain configuration was used in the present study. Spatial extents of domains were maintained as 1800 x 1800 km/645 x 645 km/245 x 245 km, respectively for the 1st 2nd and 3rd domains. Initial and lateral boundary conditions for the model runs were obtained from the GFS (Global Forecast System) for three rainfall events on 10/12/2008, 20/03/2009 and 06/04/2009. All the domains shared the same center. Figure 3 depicts the arrangement of the three domains nested for the model runs. Initial and lateral boundary conditions for the WRF model were obtained from the GFS (Global Forecast System) global weather model.

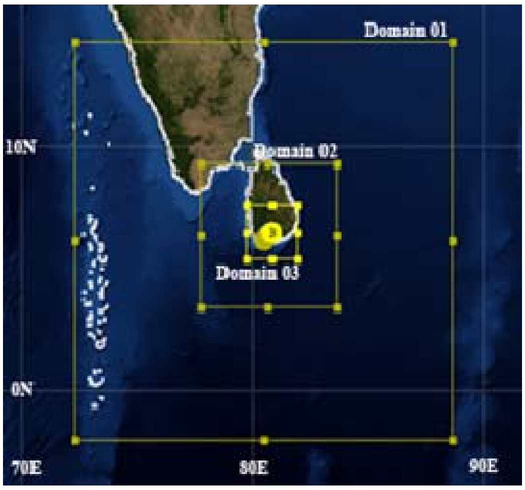


Fig. 3 Arrangement of three domains over the Nilwala river basin

According to a previous study done in China a grid configuration of horizontal resolutions 45/15/5 km with 30 vertical layers, had been used, covering the entire Shanxi province in China. It produced forecasts up to 48 - 72 h at 12 h intervals (Chen et al, 2007).

WRF model contains number of physics options. Under these physics options there are many physics schemes available for selection. This allows the modeler to use wide variety model physics combinations in predicting weather. These physics options could be varied to fine tune the model to suite its operating environment. In model fine tuning model physics schemes were varied to investigate their impacts on precipitation forecasting over the Nilwala basin as given below. This enabled to select a reasonably good model physics combination for the study. In the model fine-tuning process the impacts of microphysics schemes, cumulus schemes, land surface schemes, long/shortwave schemes and planetary boundary layer schemes on precipitation predictions were investigated as described below.

In all the above cases, model accuracy was monitored by comparing the model predictions with observed point rainfalls, obtained from the Department of Meteorology, Sri Lanka, for the rain gauging stations at Mapalana, Kekanadura tank, Thihagoda, Thelijjawila, Goluwatta, and Mawarella Estate. Since the output of WRF is spatially distributed and the field observed rainfall data are in the point format, these point rainfall data were spatially distributed on 5 km x 5 km horizontal grid for comparison purposes with the predictions (using inverse distance weighted method). For checking the accuracy of model predictions the difference between the WRF predictions and observed precipitation (spatially distributed) were plotted over the watershed. The 0 – 5 mm over/underpredictions were considered as acceptable forecasts. Area inside the basin in which the predictions were within the above specified +/- 5 mm range was expressed as a % of the total area of the basin (Correctly

Predicted Area %, CPA). This was taken as the measure of success of predictions. Once these investigations were done results enabled to select a set of model physics schemes which is capable of producing good precipitation predictions over the basin.

2.2 Hydrologic Modeling with HEC-HMS

For the hydrologic modeling of the Nilwala basin HEC-HMS 3.3 (Hydrologic Engineering Centre-Hydrologic Modeling System) hydrologic model was used. HEC-HMS is a numerical model (computer program) that includes a large set of methods to simulate watershed, channel, and water-control structure behavior, thus predicting flow, stage, and timing (USACE, 2008).

Data needed for the hydrologic component of the study basically comprised of precipitation records of the Nilwala basin, discharge data of the river, digital elevation map of the basin, location data of the rain gauges and river gauges etc… Kekanadura, Goluwawatta, Tawalama, Pannilkanda, Mapalana, and Mawarella estate were the rainfall stations selected for the hydrologic study. The consistency check of rainfall data is popularly done with the double-mass Analysis. Prior to the double mass analysis the missing daily precipitation data were filled up by applying the normal ratio method. According to the double-mass plots it was identified that the rainfall data are very consistent. River flow data were obtained for the Pitabeddara River gauging station. Initially hydrologic modeling was performed on the upper part of the Nilwala basin upstream of Pitabeddara.

For model calibration and verification phases, as transformation techniques Clark's method, Snyder's method and SCS (US Soil Conservation Services) method were applied in conjunction with the Green Ampt loss model. The recession base flow method was used for modeling base flow in all the cases. Losses due to evaporation were neglected Amit, (2007). The Green and Ampt infiltration equation has been used for the modeling of infiltration by Lincoln, (2009) in a hydrologic study.

For the model calibration three rainfall-runoff events were arbitrarily selected as given in the following table1. The rainfall-runoff events selected were of different magnitudes and independent of each other.

Table1 Rainfall-runoff events selected for the calibration of the HEC-HMS model

Start date of event	End date of event	Peak date of event	Peak discharge
14-Sep-74	20-Sep-74	16-Sep-74	125.6
5-May-75	13-May-75	07-May-75	171.8
9-May-78	20-May-78	15-May-78	279.3

For the evaluation of model performance there are various different criteria are used. In this investigation Nash–Sutcliffe efficiency index, Q Simulated /Q Observed ratio and Peak Q Simulated/Peak Q Observed ratio were used to evaluate the model performances. In flood simulations basically three factors have to be considered; the time of occurrence of simulated and observed flood peaks, simulated and observed flood volumes and the simulated and observed flood peaks. The above three factors were statistically evaluated with the aforementioned model evaluation criteria. For model verification another set of different flood events were selected as given in table 2.

Table 2 Rainfall-runoff events selected for the verification of the HEC-HMS model

Start date of event	End date of event	Peak date of event	Peak discharge
10-Jun-79	18-Jun-79	14-Jun-79	105.4
10-Jul-84	17-Jul-84	13-Jul-84	128.8
25-Sep-79	30-Sep-79	27-Sep-79	199.0

The model was verified with the sets of calibration parameters which yielded the best performances in the calibration phase. The set of calibration parameters which showed the best performance in calibration and verification was selected for the hydrologic modeling component of the chain of models.

At first under the hydrologic modeling part of the study only the upper Nilwala catchment (outlet at Pitabeddara) was calibrated and verified as mentioned above, this had to be done since no location other than the river gauge at Pitabeddara flow data were available. So the only solution was to calibrate and verify the HEC-HMS model by applying it to the Upper Nilwala catchment and for the rest of the basin the model had to be applied based on assumptions and judgments. The ungauged portion of the Nilwala river basin was subdivided into 10 sub basins. The subdivision of the watershed was done based on the existence of the tributaries. Always care was taken to confine large tributaries to separate sub catchments, since this enables to find the flow contributions of each major tributary separately and finally in HEC-RAS hydraulic analysis it is easier to input these discharges as lateral flows. Nilwala basin subdivision in to 11 sub basins is depicted in figure 4.

In modeling the ungauged sub-basins with the Snyder's method the lag time was manually calculated and it was assumed that the hydraulic conductivity of the entire basin is the same as that of the upper basin. The hydraulic conductivity depends not only on land use but also on the terrain since this determines the contact time. So obtaining hydraulic conductivities from literature, based on land use alone was not a smart option. This forced to assume a uniform hydraulic conductivity all over the basin which may be regarded as a course assumption.

Flows generated in the sub-basins had to be routed in order to convey them downstream. The Muskingum-Cunge routing technique was selected in the study as it contains a lot of parameters which could be derived from details of river cross-sections. As the parameters, reach length, reach slope, invert level, bottom width and side slope had to be input to the model for each reach. Trapezoid shape was selected as the cross-sectional shape. For all the reaches the manning's n was taken as 0.030 (Dyhouse et al, 1996).

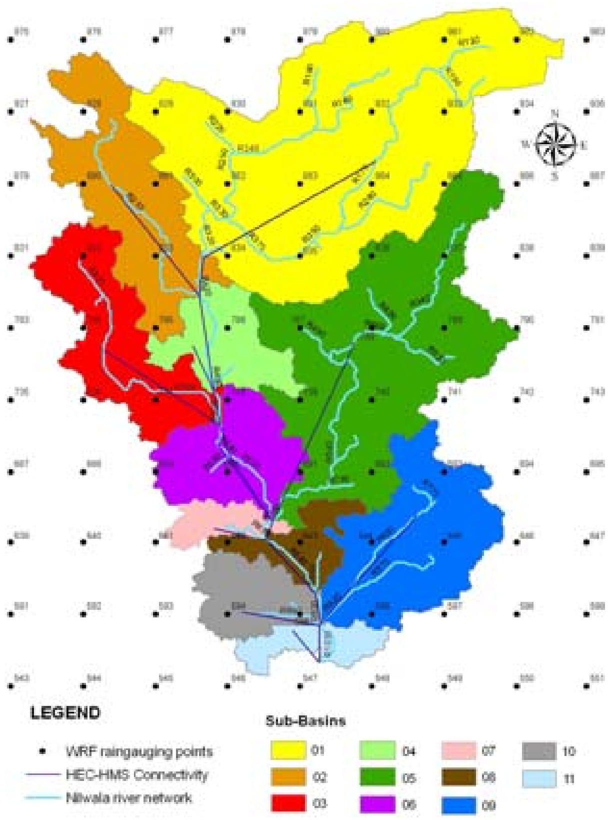


Fig.4 Nilwala Sub-basin division

2.3 Coupling WRF with HEC-HMS

The predicted rainfalls of the atmospheric model had to be ingested to the hydrologic model in order to predict the discharge of the river. There were several options available for coupling the two models. One option was to take the WRF predicted rainfalls as a spatially distributed input to HEC-HMS; the other option was to get the arithmetic average of WRF predictions pertaining to each sub basin and input to HEC-HMS as a lumped value. The first method sounds more sophisticated but it needs more time and effort and more importantly it was proven when the upper Nilwala basin was modeled taking the spatial variation of rainfall into consideration, it does not improve the predictions as expected. This forced the authors to develop a MS EXCEL based tool (WRF to HEC) to calculate the arithmetic averages of rainfalls over the 11 sub basins from the WRF output file.

2.4 Inundation Mapping

The flow prediction of the hydrologic model was used to map the inundation extent in 2D downstream of Pitabeddara up to Matara town, along the main river. To obtain the water levels along the main river HEC-RAS 4.0 hydraulic model was used. Two dimensional plotting capabilities of GIS package Arc-GIS 9.2 were used in preparing the inundation map in conjunction with HEC-GeoRAS which is an extension for Arc-GIS.

For inundation mapping initially the main river was digitized in Arc-GIS environment from Pitabeddara to Matara. Since only the flooding along the main river was expected to be mapped tributaries were not digitized. A DEM (Digital Elevation Model) derived from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) elevation data was used as the terrain since this set of data had a spatial resolution of 30 m X 30 m unlike the SRTM data used in hydrologic modeling which has a resolution of 90 m x 90 m. The ASTER elevation data set was the finest resolution data set available free of charge for the study area. Along the digitized segment of the main river cross-sections were defined. Then the GIS data were extracted and imported to HEC-RAS environment for hydraulic analysis. Here the river cross-sections were introduced to the package. The manning’s n value for river was selected as 0.030 and for the left and right river flood plains a value of 0.035 was assigned (Dyhouse et al, 1996). In HEC-RAS the lateral flows from tributaries were introduced to the main river at various locations as shown in figure 4. It was assumed that in tributaries no flooding occurs so that the total flow generated in a sub-basin contributes to flooding along the main river. As the boundary condition at upstream the river flow was introduced (predicted by HEC-HMS, driven by rainfall from WRF) and as the lower boundary condition river bed slope at Matara for normal depth computation was used in the model runs. By running HEC-RAS, river water profile was obtained for the flood event. Once this was done data from HEC-RAS were exported back to Arc-GIS for two dimensional visualizations. In flood inundation mapping what is actually plotted is the daily maximum flood inundation extent along the Nilwala main river which refers to a steady condition but in reality flooding is a much complicated dynamic process.

As a demonstration, inundation corresponding to the flood event occurred on the 18-May-2003 was mapped. There flood maps were prepared for 16th,17th,18th and 19th of May-2003 with the discharges obtained from the HEC-HMS hydrologic model driven by the precipitation predicted by WRF weather model.

3. RESULTS AND DISCUSSION

In the study it was observed that all the tested microphysics schemes (Lin et al, Kessler, Thompson, Morrison, WSM3, WSM6 and Ferrier) show similar spatial distribution of accuracy over the basin for each individual rain event. In the case of rain events on 10/12/2008 and 06/04/2009 higher prediction accuracies have been observed over the upper Nilwala catchment whereas for the rain event on 20/03/2009 prediction accuracies were relatively low over the entire basin except with the Ferrier microphysics scheme. Results of the investigation of impacts of microphysics schemes have been given in table 3

Table 3. CPA % for different Microphysics schemes

Rain event	10/12/2008	20/03/2009	06/04/2009
Microphysics scheme	CPA %	CPA %	CPA %
Lin et al	66	55	88
Kessler	68	19	86
Thompson	40	37	88
Morrison	46	16	88
WSM3*	80	37	90
WSM6	50	13	86
Ferrier	71	84	91

*WRF 3.0 default option

When it comes to the cumulus schemes a clear pattern of prediction accuracy over the basin was not observed. The prediction accuracy changed spatially from event to event as well as with different cumulus schemes used. The model default Kain-Fritsch cumulus scheme produced reasonably good CPA% for all the three events, considered. This scheme has been able to attain a good degree of accuracy over the upper basin in particular. In the case of land surface options executed in model runs Noah, RUC as well as the Thermal diffusion models have produced good predictions over the upper Nilwala basin in all the three rain events. Even the spatial distribution of the prediction accuracies varied across the basin in a very unique manner to each individual rain event. The RUC could be taken as the most consistent land surface model among the three models tested on the three rain events. The RRTM longwave radiation scheme with Dudhia shortwave scheme produced almost equally good rainfall predictions for the three events considered. More importantly these are the model default longwave and shortwave radiation options in WRF. Tested combinations of long/shortwave radiation schemes have shown spatial patterns of accuracies unique to rain events on 10/12/2008 and 06/04/2009. The rain event on 06/04/2009 has exhibited very little dependence on the combinations of long/shortwave radiation options considered. Mellor Yamada and YSU planetary boundary layer schemes have shown very little influence on the CPA% and the spatial distribution of the accuracy of the predictions.

According to the results of hydrologic modeling performances, the Snyder's transformation technique in HEC-HMS produced the best results for the Upper Nilwala basin in calibration and verification phases, and more importantly Snyder's transformation technique is applicable to ungauged catchments. This allowed the application of Snyder's method to the ungauged sub basins of the Nilwala watershed while the same method was applied to the upper Nilwala basin. In all these cases the Green Ampt loss model was executed with the recession base flow method. Results of model validation with Snyder's transformation technique have been given in table 4.

Table 4. Results of model validation with Snyder's transformation (14-May-78 calibration parameters used)

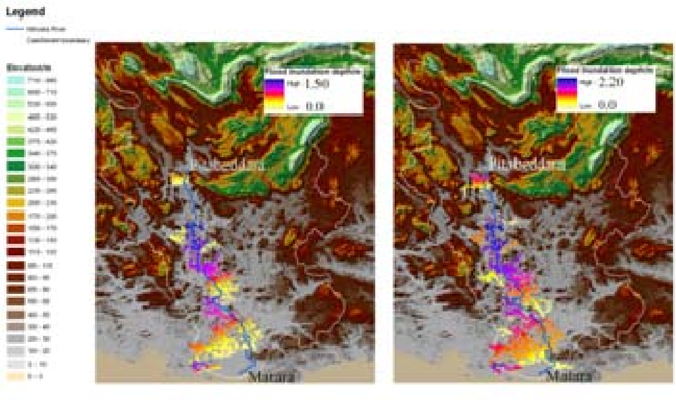
Model performance evaluation criterion	Rainfall-Runoff event (date of peak)		
	14-Jun-79	13-Jul-84	27-Sep-79
Nash–Sutcliffe efficiency %	76.14	51.31	57.75
Q Simulated /Q Observed	1.29	1.27	1.09
Peak Q Simulated/Peak Q	1.03	0.78	0.76

The inundation maps developed for the stretch of Nilwala River from Pitabeddara to Matara have been shown in figure 5. Depths of inundation and corresponding areas affected have been given in table 5.

Table 5 Depths of inundation and corresponding areas affected

Depth of inundation/ m	Inundated area km 2			
	16-May	17-May	18-May	19-May
0.0-0.5	28.3	16.9	16.2	16.6
0.5-1.0	15.7	30.1	30.1	31.1
1.0-1.5	12.2	14.7	15.3	14.4
1.5-2.0	0.0	13.1	13.8	10.5
2.0-2.5	0.0	0.5	1.2	0.4
Total inundated area km ^{2}	56.1	75.3	76.7	73.1

Flood map generated was compared with observed flood inundation data obtained from literature. According Wijesekera, et al, (2003) flood has submerged Hulandawa, Akuressa, Malimbada areas by 10 m which could not be verified independently but the model simulated flood maps indicated a maximum of 2.25 m of flood water depth. But the model was capable of predicting these areas as inundated regions despite the underestimation of the flood inundation depth (see figure 5.20 and 5.21 for flooding at Hulandawa, Akuressa, Malimbada). This was mainly due to the fact that the model has underestimated the river discharge which was about 1000 m^3/s (Pacific, 2007) on the 18-May-2003 at Pitabeddara, according to the Department of irrigation but the corresponding discharge has been determined by the model as 664 m^3/s. The Matara town has not got inundated since it is located in a slightly elevated piece of land relative to the surrounding terrain. This is clearly depicted by the generated flood map.



(a) Maximum inundation on 16-May-2003 (b) Maximum inundation on 17-May-2003

(c) Maximum inundation on 18-May-2003 (d) Maximum inundation on 19-May-2003

Fig. 5 Inundation during the May 2003 flood

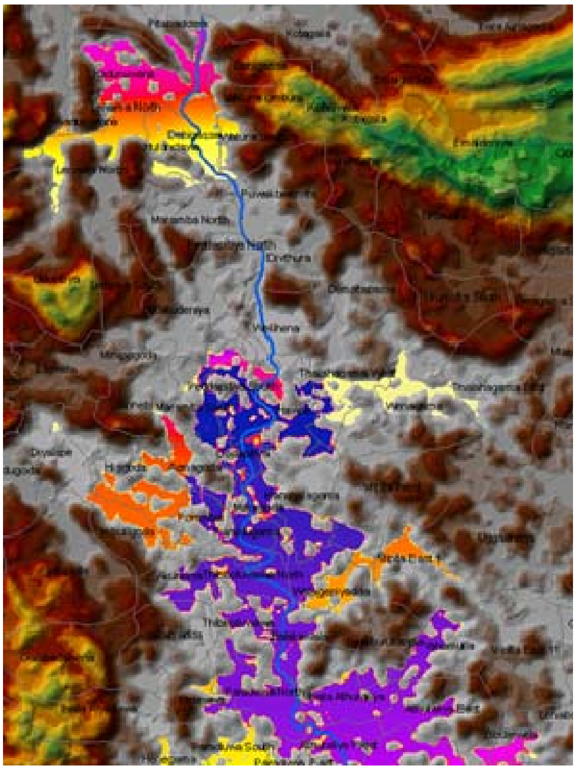


Fig 6 Inundated Grama Niladari (GN) divisions just downstream of Pitabeddara

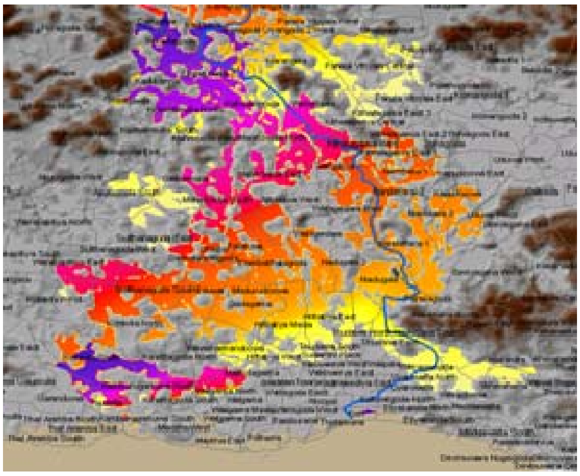


Fig. 7 Inundated Grama Niladari (GN) divisions just upstream of Matara

4. CONCLUSIONS

It could be concluded that the model physics combination consisting of Ferrier microphysics scheme, Kain-Fritsch cumulus scheme, RUC land surface scheme, RRTM longwave radiation scheme, Dudhia shortwave scheme and YSU planetary boundary layer scheme has yielded better precipitation predictions over the Nilwala river basin. However, the total rainfall failed to generate the observed runoff indicating the model under estimated the total rainfall. However the model was capable of predicting the inundation area with reasonable accuracy. The technique can be used to downscale GCM results to predict local effects of climate change.

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IMPACT OF SEA LEVEL RISE ON INUNDATION IN THE KUSHIRO WETLAND

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ABSTRACT

Climate change has been found to increase the occurrence of natural disasters, such as storm surges or flood events, leading to environmental damage which can in turn increase the impact of natural disasters. Due to the large coastal population, the severity of impacts from increasing floods or storm surges is expected to be much greater in Japan, where 46% of the total population resides in coastal areas covering only 32% of the land area. While there are a great many scientific questions relating to the Kushiro Wetland in Japan that need to be solved with some urgency, including water circulation, mass transport and morphodynamics, understanding sea level rise may be the most urgent. Seal level rise is expected to lead to increased flood events and, consequently, to serious damage to the ecological system of the wetland, as well as to the surrounding developed area. Therefore, in this study we make an attempt to understand the impact of sea level rise on the ecological system of the wetland and to investigate the influence of flood events. A simple distributed hydrological model was developed that allows us to evaluate the effect of sea level rise on inundated areas with minimal run-time cost.

1. KUSHIRO WETLAND

In Japan, there are many areas which are registered by the Ramsar treaty and designated as World Heritage, including Shirakami, Yakushima and Shiretoko and the Kushiro Wetland. Several of these natural systems of global significance are located on the island of Hokkaido in northern Japan, where they remain little affected by human activity. The Kushiro Wetland in particular requires protection because it is the largest the area of wetland and was the first area in Japan to be registered under the Ramsar treaty. However, before the Kushiro Wetland was registered under the Ramsar treaty much of the coastal area had been developed and human activities begun to affect the ecological system. As an example, the 154 km long Kushiro River that flows through the wetland was straightened and the downstream portion protected by dikes in consideration of the surrounding human population, which numbers about 230,000 within the 2,510km2 river basin (Figure 1).

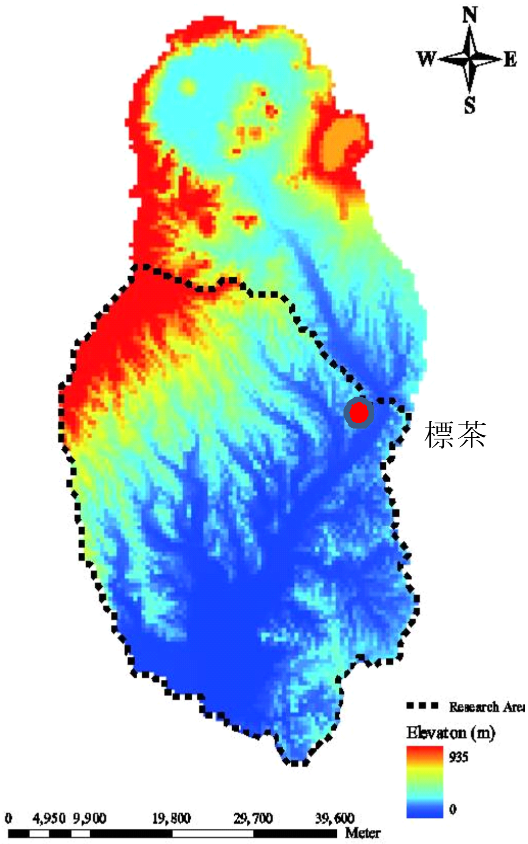

Fig.1: Kushiro River basin

The Kushiro Wetland has been shown to be an important ecological system and to contain biodiversity worthy of conservation. However, in recent years changes to the ecology of the wetland have occurred as a result of decreases in vegetation and excessive sediment input. Furthermore, the influence of climate change has begun to be documented and is expected to increasingly deteriorate both the ecological system and the safety of human life. Climate-related sea level rise in particular has the potential to increase the danger to humans residing in the coastal areas of the wetland by increasing inundation levels. Therefore, the Kushiro Wetland is expected to be greatly influenced by increasing flood events and is considered one of the most suitable areas to investigate the effect of sea level rise on a natural system coupled to a developed area.

2. DISTRIBUTED HYDROLOGICAL MODEL

In previous studies, distributed hydrological models based on physics have been developed in order to estimate discharge, to evaluate the transport of sediment and to understand the circulation of nutrients

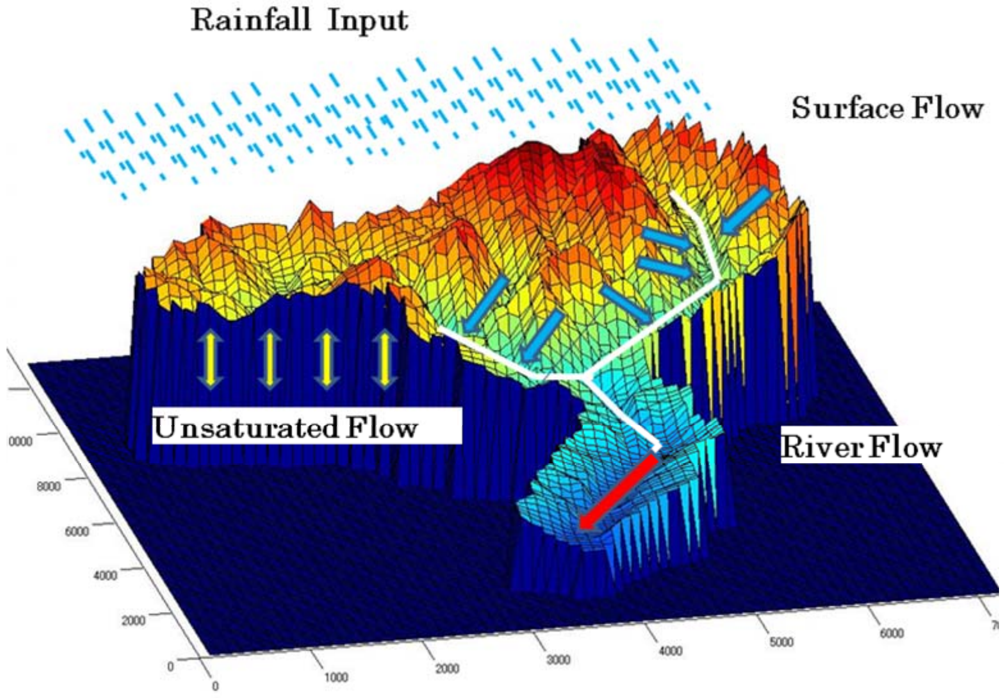

Fig.2: Schematic diagram of distributed hydrological model.

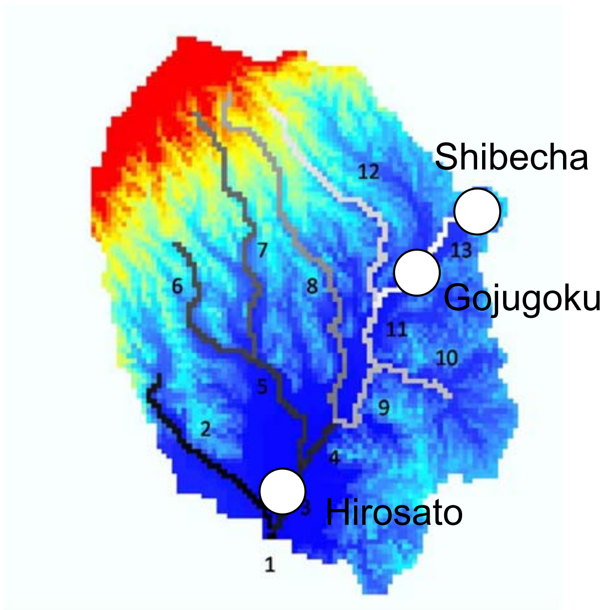

Fig.3: Kushiro River used in the DHM computations

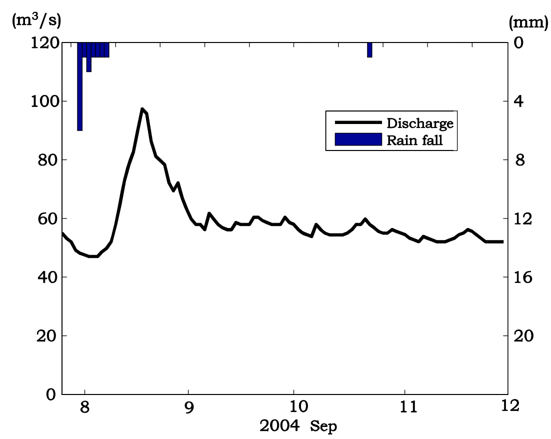

Fig.4: Hydrograph in September 2004.

(Storck et al, 1998; Kenward et al, 2000; Vazquez et al, 2002; Sivapalan et al, 2004; Nakayama et al, 2005; Alam et al, 2008; Dutta and Nakayama, 2009; Alam et al, 2009). Here we made an attempt to develop a distributed hydrological model to examine sea level rise using kinematic equations for surface flow, long-wave equations for inundation flow, Richards equations for unsaturated flow and kinematic equations for river flow (Figure 2). In the model, a log-law was implemented for estimating roughness in river networks, with other coefficients based on physics provided from field experiments.

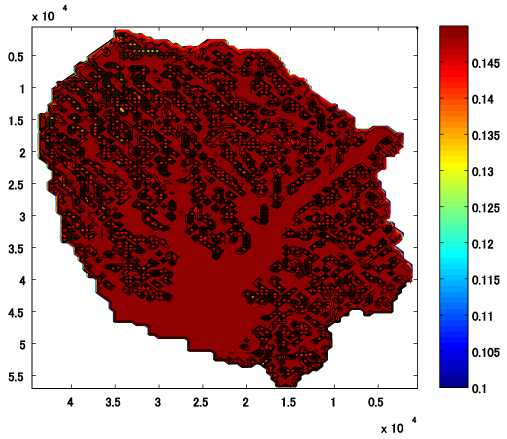

Fig.6: Water content in unsaturated layer during normal discharge.

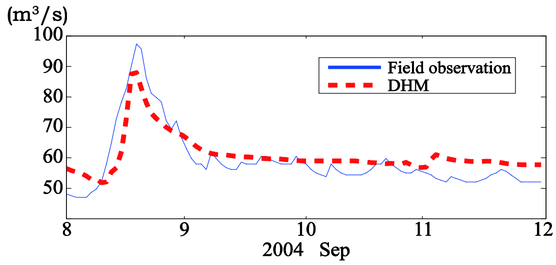

Fig.7: Comparisons of discharge at Hirosato

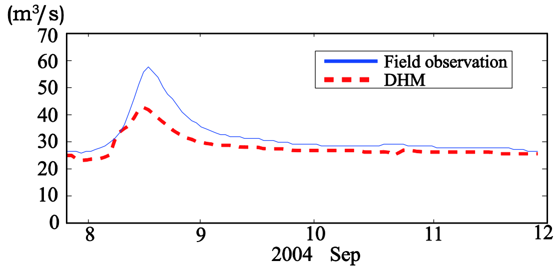

Fig.8: Comparisons of discharge at Gojugoku

3 APPLICATION OF DHM INTO KUSHIRO RIVER

As this study aims to estimate the change in inundation due to sea level rise, only the river basin downstream from Shibecha was targeted in the numerical computation since upstream areas are unlikely to be affected by sea-level rise. The temporal change in discharge measured at Shibecha was used as input data for the model (Figure 3). The river basin was modeled by using a mesh interval of 500 m and a time step of 10 s, resulting in 13 river branches (Figure 3). The application of simple models to developed distributed hydrological models significantly reduces the run-time cost; in this case computational time was only 140 s for the 7 days computation with a mesh of 90 x 115 using a Core™2 Duo CPU P9300 2.26 GHz.

In the Kuroshio Wetland an unsaturated flow layer with mean depth of 5 m exists above the impermeable layer (Kushiro Wetland Restoration Committee, 2005). Permeability coefficients for each layer are 10^{-5} and 10^{-8} m s^{-1}, respectively. As a result the peak discharge lag-time, confirmed in the hydrograph on September 8th to 11th 2004 (Figure 4), is longer than other typical Japanese rivers (where the thickness of the unsaturated flow is generally only 1 to 2 m). A hydrograph including the longer peak discharge lag-time was applied for calibration of the distributed hydrological model. The model results showed very good agreement with field observations, though the reproduced peak discharge was a little smaller than observed in the field (Figures 5 to 7).

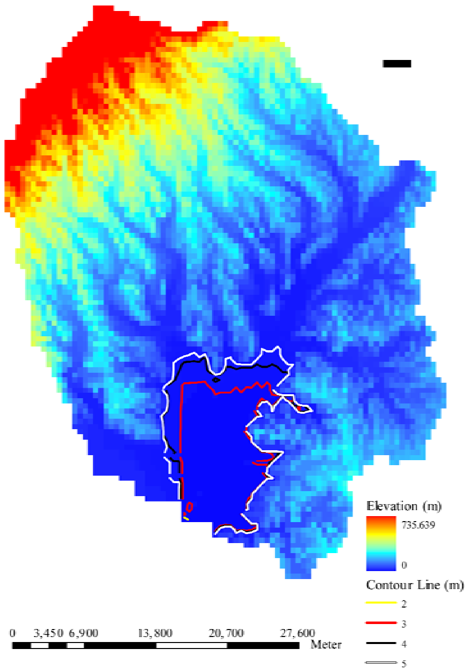

Fig.8:Altitude in Kushiro River basin..2 m, 3 m, 4 m and 5 m.

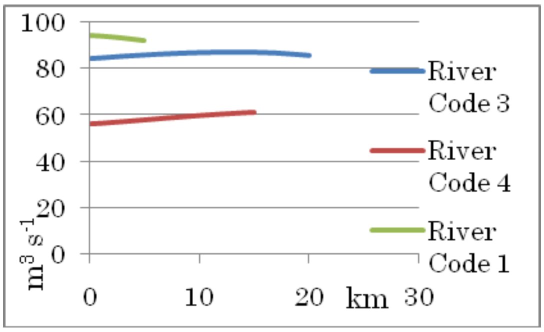

Fig.9: Discharge along River Code 1, 3 and 4.

4 ESTIMATION OF INUNDATION AREA AROUND KUSHIRO WETLAND

The Kushiro Wetland has a very flat topography, with most of the coastal area less than 1 m above datum. Therefore, in order to protect from floods, the downstream areas of the Kushiro River are protected by dikes. Lateral dikes have been built from Hirosato to the western side of the Kushiro Wetland (Figure 3). Despite the protection by dikes, a risk of inundation remains should any of the dikes fail, such as due to collapse, which would likely result in inundation of the entire coastal area (Figure 8). Our investigation focused on these high risk coastal areas, downstream from the river mouth to Hirosato, by using numerical computation results for September 8th to 11th 2004 (Figure 9). The discharge from river code 3 was almost equal to the discharge from river code 1, and was much larger than from river code 4 due to the confluence of the Setsuri River around Hirosato. Since river code 3 occupies the largest area of the coastal zone, it may be that river code 3 is the most significant consideration when examining the risk of inundation.

5 CONCLUSION

(1) A distributed hydrological model was developed by applying kinematic equations for surface flow, long-wave equations for inundation flow, Richards equations for unsaturated flow and kinematic equations for river flow, which demonstrated that the run-time cost is very cheap for reproducing discharge with this type of model

(2) The distributed hydrological model enables us to evaluate the discharge profile along rivers, which provides the potential to better clarify changes in inundation during flood events.

ACKNOWLEDGEMENT

We thank to the Ministry of Land, Infrastructure, Transport and Tourism for supplying the data sets regarding the Kushiro Wetland.

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EFFECT OF SEA WATER LEVEL CHANGE ON THE MANAGEMENT IN THE LOWER THACHIN RIVER THAILAND

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ABSTRACT

Climate change and associated rise in sea level have affected the salinity levels in many rivers around the world. The objective of this study is to evaluate the effect of sea level change on salinity level in lower part of Thachin River, one of the important rivers in Thailand, by using MIKE11 model. The study covered the area from Phophraya Gate, Suphanburi Province to the Thachin River Estuary, Samutsakhon Province. The model was divided into two parts, hydrodynamic module and advection-dispersion model. Calibration of each part was done by adjusting its important coefficients. It was observed that the coefficient dispersion of mass and manning (M) were in the range of 100-1,000 m^2/s and 28.5-30.33, respectively. The value of 1,000 was suitable for factor distribution of mass. The results of comparison between models and observation data revealed order of forecasting error (RMSE) in the range of 0.15-0.20 m for water level and 0.10-1.80 g/l for salinity, respectively. In addition, it was indicated that sea water level at the Thachin estuary had rising and betaking tendency to intrusion of water level, and the salinity was also in the same manner. The results obtained from this study will give guideline in water resources and environmental management at Thachin River Basin.

1. INTRODUCTION

In the recent years, there is widespread evidence of climate change of upland, intermediate land and lowland river systems. The changes in climate and land use can act as triggers for increases in sea water level, salinity and sediment transport. Within the estuaries, sea water level can be the important controls of water level and salinity. Although the precise effect of climate change on estuaries dynamics and its processes in the alluvial river system is still not clear, there seems to be no doubt that they influence sea water level and salinity intrusion.

Recently, numerical modelling has been shown to answer some of these problems. A number of works have used numerical models attempting to simulate river catchment hydrological processes of rainfall-runoff, sediment transport and salinity intrusion processes as well as to study the impact of climate change. In addition, the numerical model has been exploited to predict hill slopes and river channels through regular and irregular mesh (eg. AIT, 1978; Abbott et al., 1986; Kirby, 1987; Wicks and Bathurst, 1996; DHI, 2000; Wongsa and Shimizu, 2004; Wongsa, 2004). Thus, it is clear that the numerical models appear to have considerable potential as tools for investigating hydrodynamic, sediment transport and water quality over long period simulation. However, their ability to simulate flow and sediment in natural river systems characterized by complex slope and channel network has not yet assessed fully. In addition to these problems, many existing numerical model are limited to some parameters from field and experimental data. Wassmann et al. (2004) have been exploited numerical model to predict sea level affecting rice production in Mekong Delta, Vietnam, during the flood season. However, there are a few application studies in Thailand.

This paper addresses these issues by using a proposed MIKE11 numerical modelling to simulate the effects on water level change and salinity intrusion in the estuaries systems. Performance of the numerical model was applied to simulate flow events in 2060, effect of climate change and an associated rise in sea level processes on water level change and salinity intrusion in the Lower Thachin River catchments, Thailand.

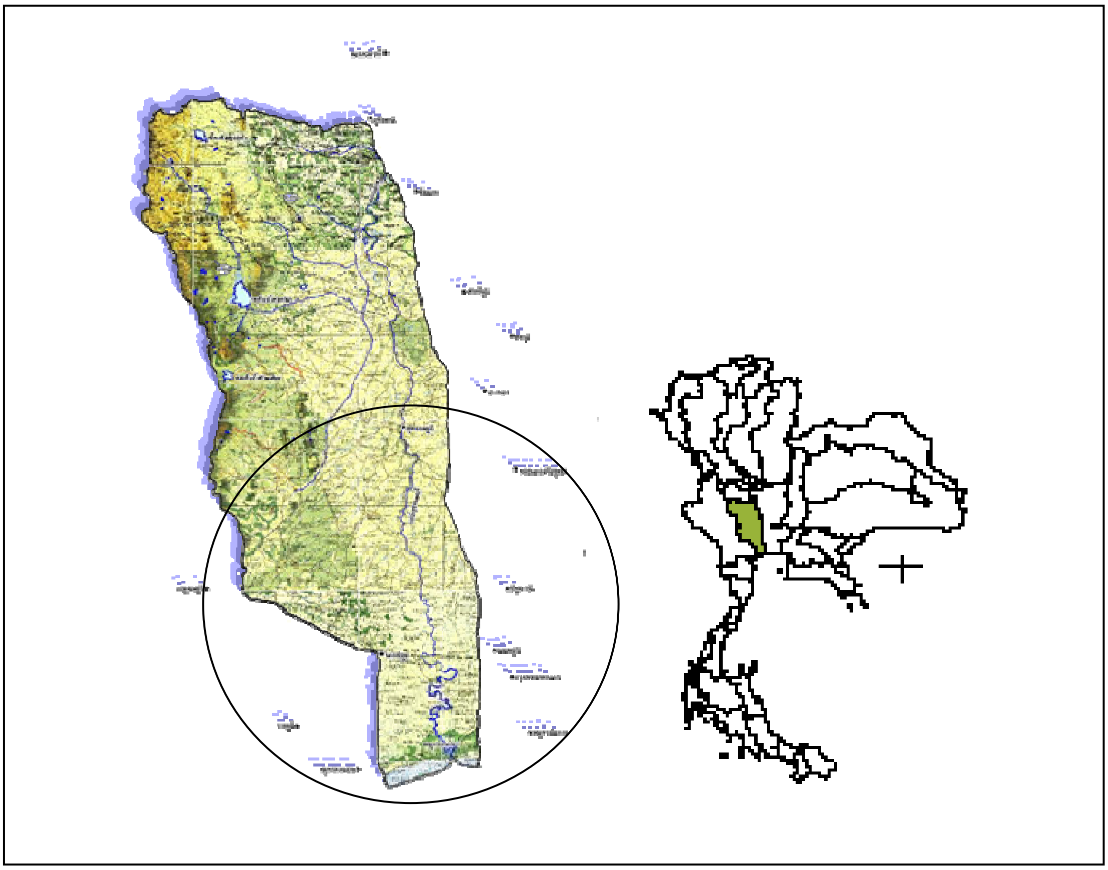

Figure 1: Study area (the Lower Thachin River Catchment)

2. STUDY AREA DESCRIPTION

The proposed model was applied to Lower Thachin River catchment from Suphanburi Province to river estuary at Samutsakhon Province, which is located at central part of Thailand. Figure 1 shows the selected study area. The flow and catchment characteristics of the selected catchments are shown in Table 1. In the Lower Thachin River catchment, the average annual flow and the average annual rainfall are over 1,364 MCM, and 1,040 mm, respectively. However, some parts of the catchment continue to suffer from drought problems due to the uneven distribution of rainfall. Some areas experience both flooding and drought conditions in a single year, due to temporal and spatial uncertainties in the monthly rainfall or the poor management of the conveyance infrastructure. The Thachin River is also importing water from Mae Klong River (right bank) to boost water supply multiplies the risk of flooding in the downstream area and Bangkok metropolitan area as well. The common practice in Thailand is to manage the risks after considering which areas are likely to be vulnerable to either flood or drought. Failure to manage risk by addressing one aspect at a time can lead to adverse results; therefore, climate change and an associated with managing flood and drought risks is a new challenge in Thailand and is becoming increasingly important as a result of climate change.

Table 1: The Lower Thachin Catchment climate characteristics (Thai Meteorological Department).

Items	**Maximum**	**Minimum**	**Average**
Temperature (^{o}C)	38.4	17.3	27.9
Wind speed (Notts)	32.7	0	3.0
Evaporation (mm/month)	195.9	129.5	154.5
Relative humidity (%/year)		25	74

3. MODEL DESCRIPTIONS

To assess the influence of the water flow and salinity impacts on climate change of the Lower Thachin River catchment, the MIKE11 model has been used. This numerical model simulates water flow and salinity as a consequence of low flow conditions. The shallow-water equation for one-dimensional unsteady flow can be expressed as following,

Continuity equation:
$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

Momentum equation:
$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{M^2 AR^{4/3}} \tag{2}$$

where, Q = flow discharge (m^3/s), A = flow section area (m^2), q = side flow discharge (m^2/s), h = flow depth (m), R = hydraulic radius (m), g = acceleration (m/s^2), α = momentum correction factor, M = Manning's Number (M = 1/n; n = Manning's roughness coefficient), x and t = flow direction and time, respectively.

For transportation of mass, such as, salinity can be obtained from,

Advection-Dispersion equation:
$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -AKC + qC_2 \tag{3}$$

where, C = salinity concentration (mass/volume), D = dispersion coefficient (m^2/s), K = consumption rate (s^{-1}) and C_2 = Source/Sink Concentration (mass/volume).

4. MODEL SETUP

For modelling the river network of the Lower Thachin, a digital elevation map (DEM) has been used. The model input data cross-section, flow discharge, water level, side flow and salinity. The MIKE11 program, 6-points Abbott's finite difference scheme was used to solve governing equations, consisting of separate modules each representing a different procedure in calculation process. A first module calculates hydrodynamics of river flow (HD module), and in the next module of transportation of mass (salinity intrusion; AD module). The model setup of plan view and longitudinal profile of the Lower Thachin are shown in Figure 2.

5. MODEL SIMULATION

The Lower Thachin River catchments were used for calibration and validation of the proposed model. The calibration and validation has focused on the applicability of water flow and salinity intrusion by using flow conditions in the year of 2000 and 2004, respectively. Performance of the foregoing numerical model was applied to simulate 2 scenarios from IPCC SRES, consisting of A1FI and B1 scenarios, which is the predicted global average sea level rise 1990 to 2100 for the SRES scenarios by using GCMs. A1FI and B1 scenarios are more economic development and highly use of fossil energy and more environmental consideration, respectively (IPCC, 2001). For model simulation, flow discharge at Phophraya Gate and water level at Thachin River Estuary were adopted for upstream and downstream boundaries, respectively. Before the water flow and salinity calculation was carried out, the model was run to provide the steady state of necessary flow variables.

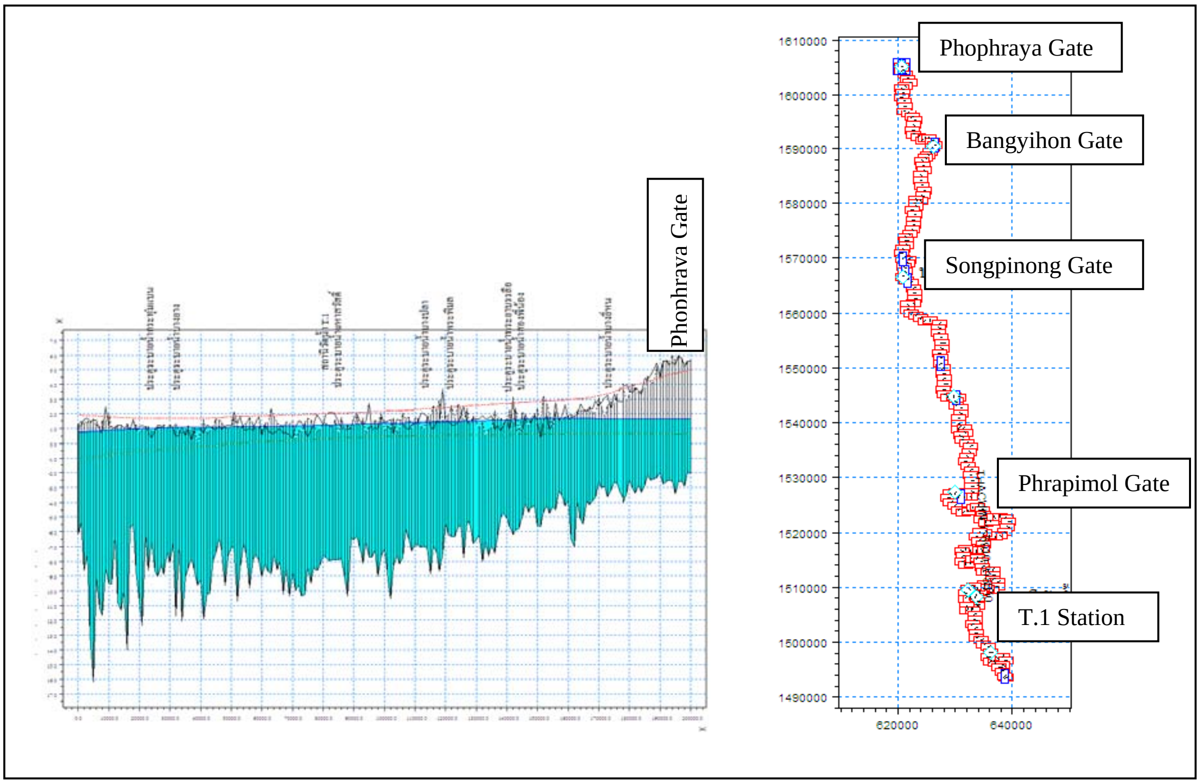

Figure 2: Model setup

Table 2: Manning's factors (M) for model calibration.

Distance, km	Manning's M	Distance, km	Manning's M
142	28.5	233	28.5
175	28.5	289	30.33
206	30.5	293	30.33
209	28.33	309	28.5

Table 3: Coefficients for transportation of mass model.

Distance, km	Constant
Global Dispersion Factor	1,000
Global Exponent	0.4
Global Min. Disp. Factor, (m^2/s)	100
Global Max. Disp. Factor, (m^2/s)	1,000
Kmix, (hr^{-1})	1.0

Table 4: Root mean square errors for calibration and validation.

Location	Calibration	Validation
Bangyihon	0.15	0.17
Songpinong	0.19	0.13
Prapimol	0.18	0.15
T.1	0.20	0.20

5.1 Model calibration

The comparison of time series of measured and simulated water surface level and salinity at four major gauge stations and Manning's factors (M) are shown in Figure 3-4, and Table 2-3, respectively. Good agreement between the simulated and measured hydrographs for the low flow events was achieved by considering side flow and pumps in the areas. The root mean square errors (RSME) have been used as the main criteria to judge whether the data fitted between measured and simulated. The comparison model was followed by adjusting important coefficient for two parts. The study results, coefficient dispersion of mass and manning (M) were in the range 100-1,000 m^2/s and 28.5-30.33, respectively, indicating that the value of 1,000 is suitable to factor distribution of mass. The results of comparison between models and observation data revealed order of forecasting error (RMSE) in range of 0.15-0.20 m for water level and 0.10-1.80 g/l for salinity, respectively. These indicate well fit between measured data and this proposed model (Table 4).

5.2 Model validation

The comparison of time series of measured and simulated water surface level and salinity at four major gauge stations are shown in Figure 5-6. Good agreement between the simulated and measured water surface level was achieved by considering side flow and pumps in the areas. It was observed that the values of RSME for four major gauge stations in calibration period were between 0.13 - 0.20 m, indicating well fit between measured data and this proposed model. Good performance of simulated results was observed in both water flow and salinity intrusion characteristics, therefore, indicating that model simulation is reasonable.

5.3 Model application

For model application, two scenarios from IPCC report were simulated, in which the scenarios A1FI (more economic development and highly use of fossil energy) and B1 (more environmental consideration), respectively. The comparison of time series of measured and simulated flow discharge at the major gauge stations are shown in Fig. 7-8. It was found that sea water level at the Thachin estuary had rising and betaking tendency to intrusion of sea water level and salinity is in the same tendency. For IPCCSRES, sea water level rising in B1 and A1FI were 0.19 and 0.23 m, and salinity were 0.401 g/l and 0.502 g/l, respectively. We could, also, observe that these affects gain a more conspicuous large against higher sea water level rising.

6. CONCLUSIONS

Climate change and an associated rise in sea level have affected the salinity level in many rivers around the world. The objective of this study is to evaluate the effect of sea level change on salinity level in lower part of Thachin River, one of the important rivers in Thailand. The study covered the area from Phophraya Gate, Suphanburi Province to the Thachin River Estuary, Samutsakhon Province. In this study, it was found that sea water level at the Thachin estuary had tendency to rising and betaking to intrusion of water level and salinity is in the same tendency. A comprehensive understanding of the nature of the problems and their potential severity helps in risk management planning, water resources and environmental management in the Lower Thachin River Catchment.

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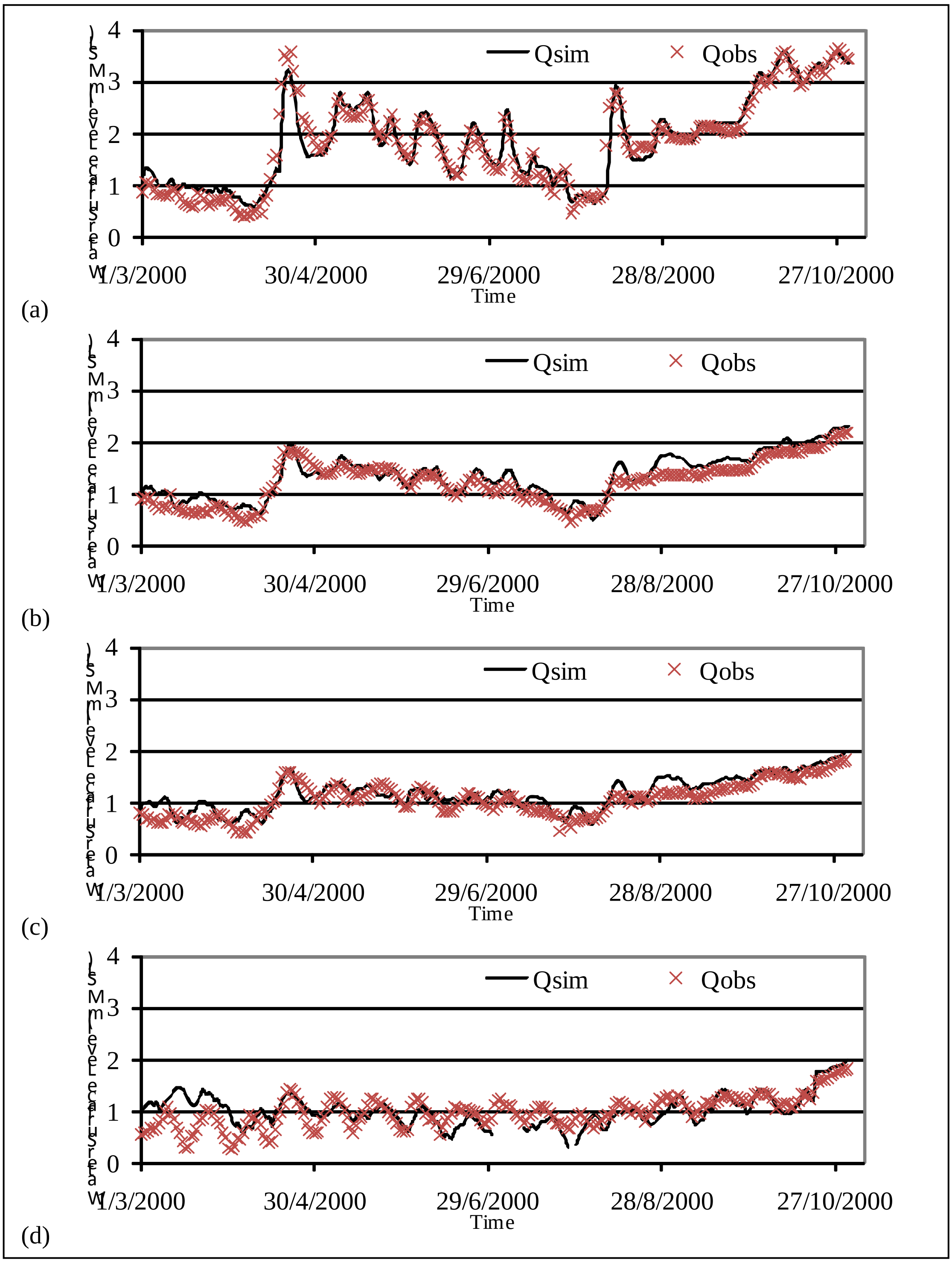

Figure 3: Comparison of time series of stage hydrograph between simulated results (smoothed-line) and measured data (crossed) at major gauge stations; (a) Bang Yihon, (b) Songpinong, (c) Prapimol and (d) T.1. (for calibration)

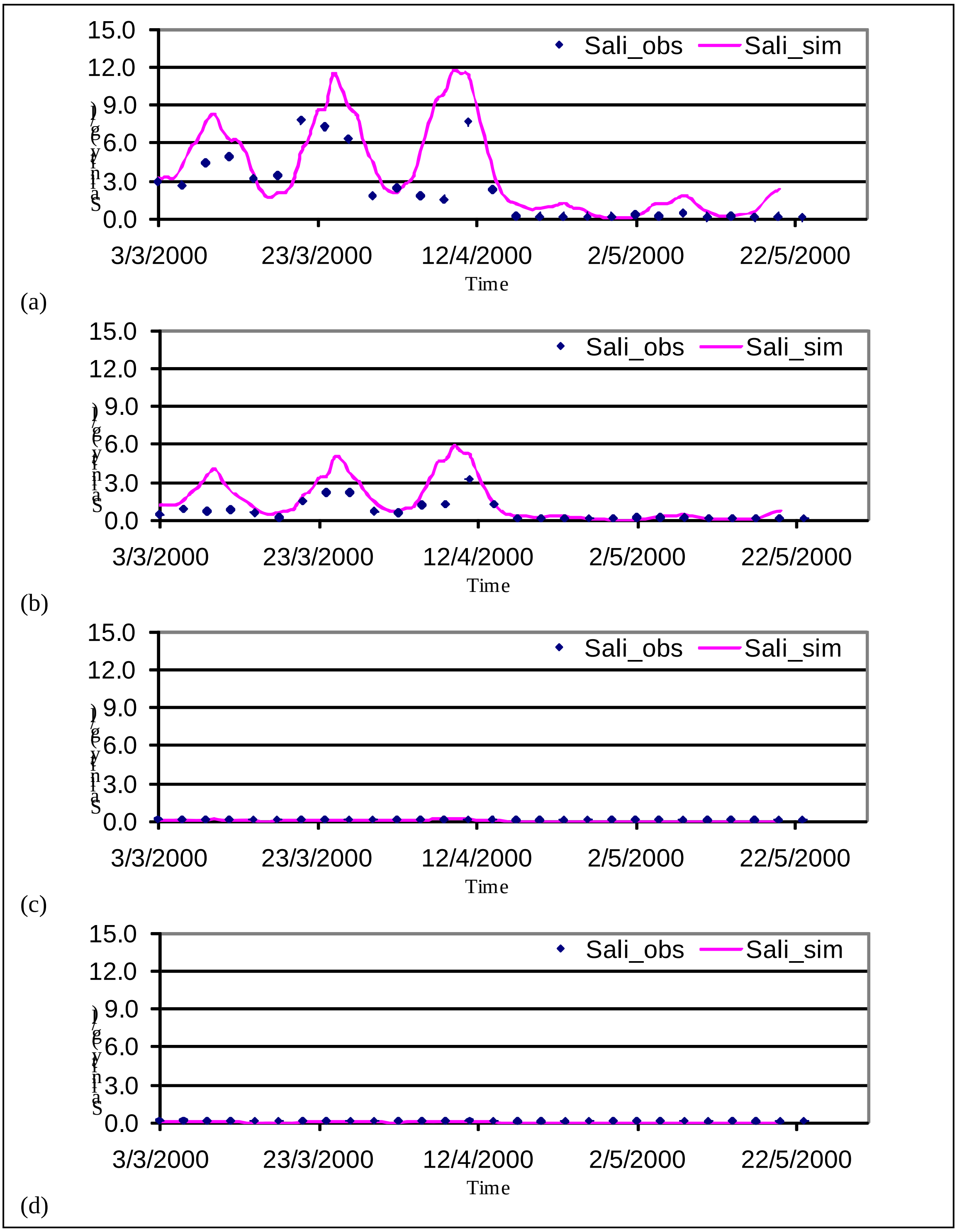

Figure 4: Comparison of time series of salinity between simulated results (smoothed-line) and measured data (dotted) at major gauge stations; (a) Samutsakhon, (b) Kratunban, (c) Sampran and (d) Jedeebusha. (for calibration)

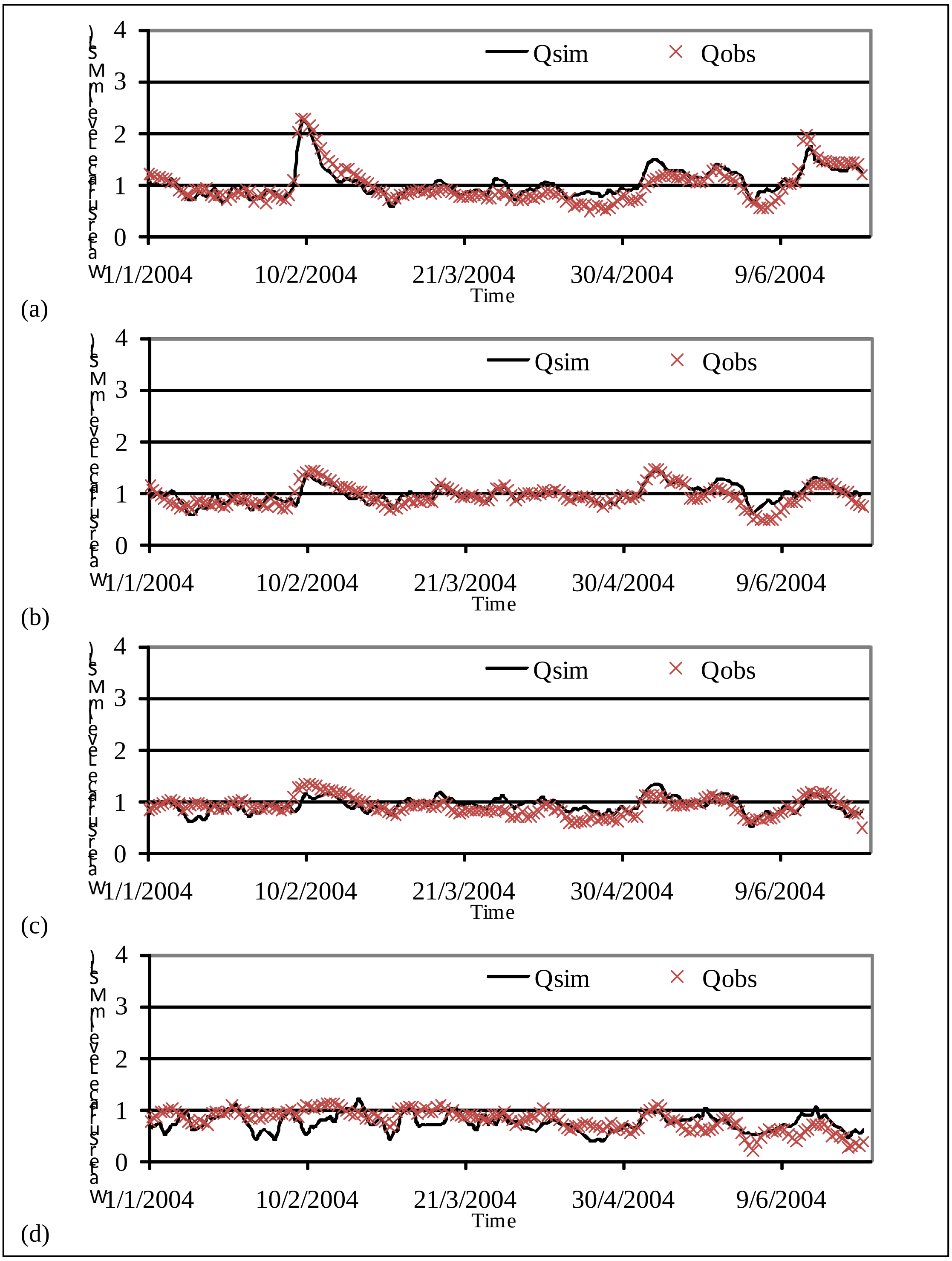

Figure 5: Comparison of time series of stage hydrograph between simulated (smoothed-line) and measured data (crossed) at major gauge stations; (a) Bang Yihon, (b) Songpinong, (c) Prapimol and (d) T.1. (for validation)

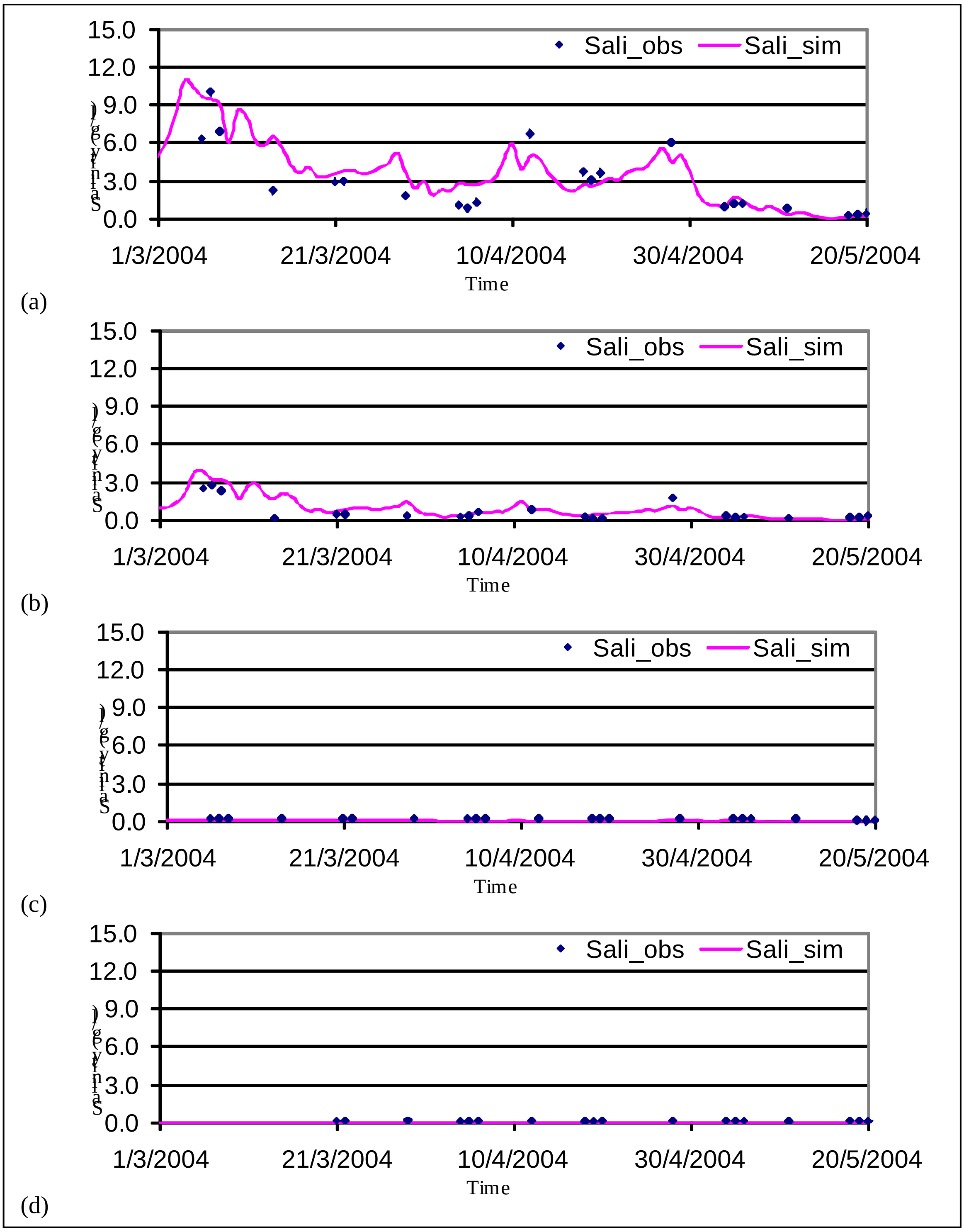

Figure 6: Comparison of time series of salinity between simulated (smoothed-line) and measured data (dotted) at major gauge stations; (a) Samutsakhon, (b) Kratunban, (c) Sampran and (d) Jedeebusha.(for validation)

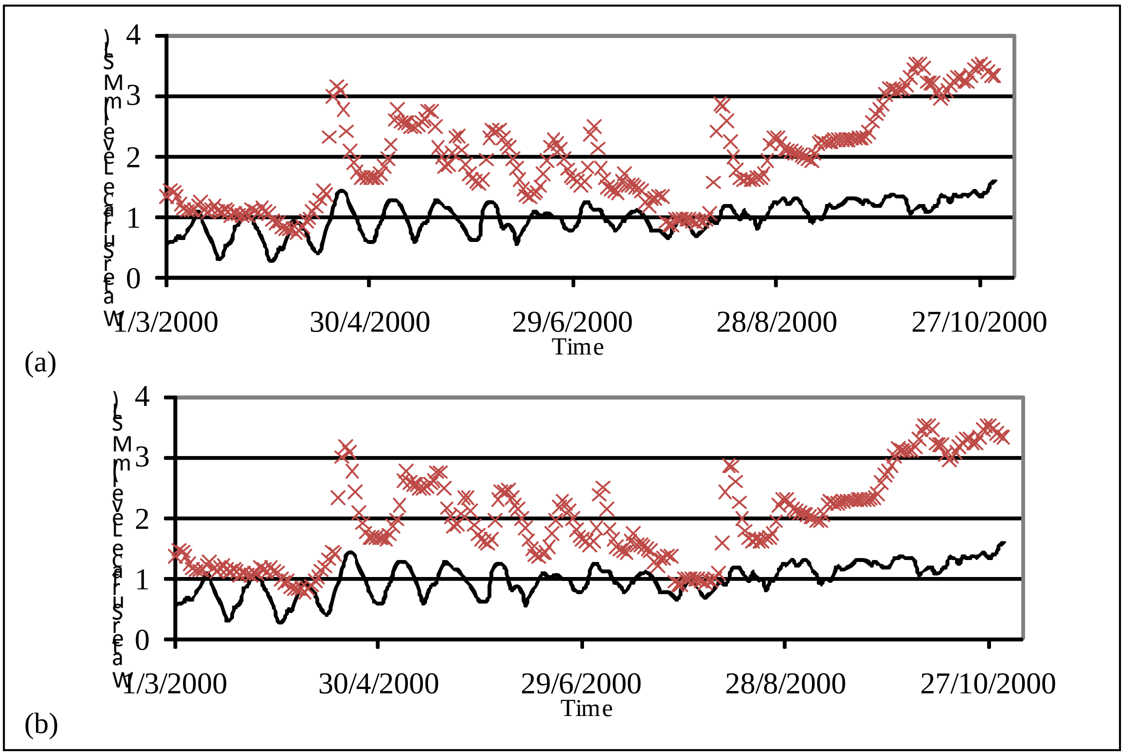

Figure 7: The time series of stage hydrograph simulated results in the year of 2060 at station T.1. (a) B1 scenario and (b) A1FI scenario

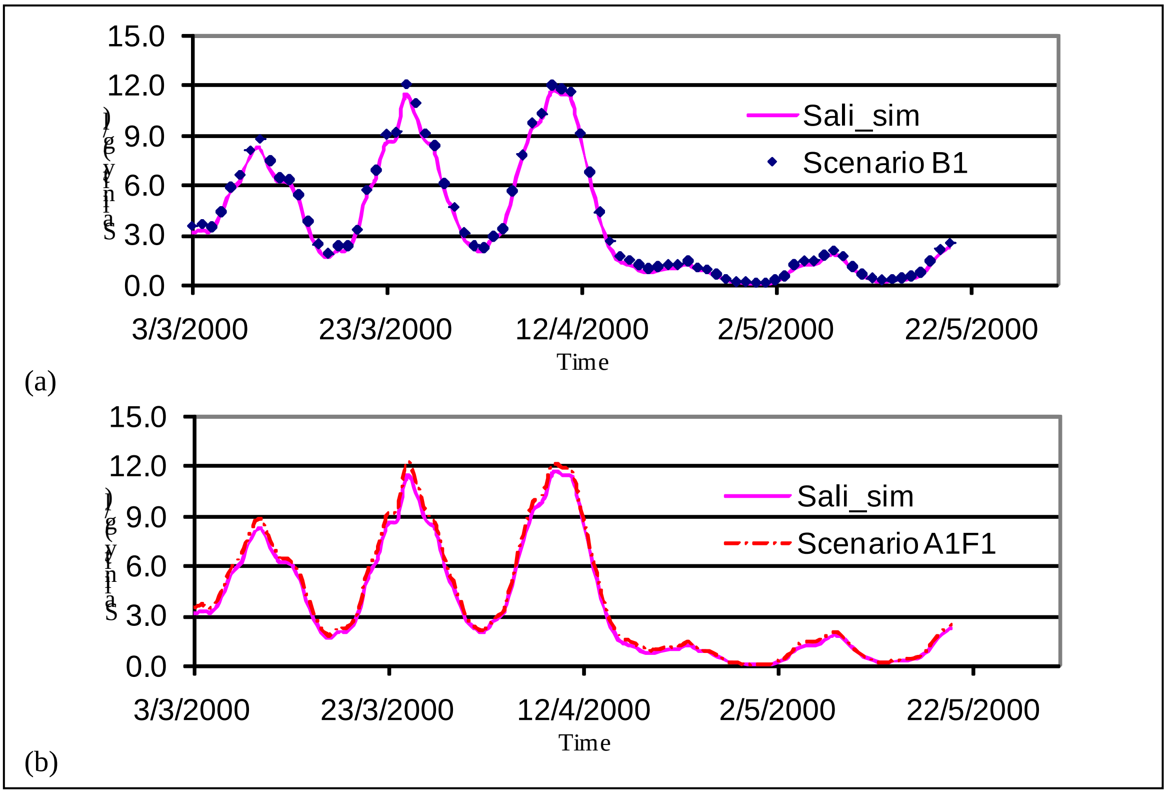

Figure 8: The time series of salinity intrusion hydrograph simulated results in the year of 2060 at Samutsakhon. (a) B1 scenario and (b) A1FI scenario

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IMPACT OF CLIMATE CHANGE ON WASTE WATER RETICULATION SYSTEM IN CHURCHILL, VICTORIA

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ABSTRACT

Australia being an island continent is highly vulnerable to coastal erosion and infrastructure damage due climate change. The sewer reticulation systems are not an exception. Research needs to be carried out to quantify the impacts of climate change and design criteria be reviewed, to mitigate or adapt to the impacts of climate change in the waste water reticulation system. Although much of Australia is expected to dry because of climate change, due to decrease in total rainfall, increase in extreme rainfall events are still expected in many regions. This will affect the sewer reticulation system in many ways.

The aim of the research is to quantify the impacts of climate change on a sewer reticulation system in the Gippsland region, Victoria. The specific objectives are to simulate the impacts of climate change in a working calibrated sewer model and to analyse, understand and quantify the impacts in an existing waste water reticulation system based on the modelling. The model is used to simulate various scenarios individually and collectively to assess the impacts of climate change and quantify them. The simulated outputs give us a chance to quantify the impacts of the possible effects of climate change on the catchments and their characteristics. These results would help in designing the sewer reticulation systems in future to cater for the impacts of climate change.

Key Words: Waste Water Reticulation Systems, climate change, impacts and adaptation.

1. INTRODUCTION

"Climate change is a reality. We cannot change Climate change. All we can do is to adapt to the change…" (Watson et al., 2008).

According to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the 100-year linear trend (1906-2005) of average temperature rise of 0.74°C [0.56 to 0.92]°C is larger than the corresponding trend of 0.6°C [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR). Australia's average temperatures have already risen by around 0.7◦C over the last century. By 2030 warming in Victoria is likely to range from 0.6°C to 1.2°C on 1990 temperatures and by 2070 from 0.9°C to 3.8°C. Victoria has warmed by 0.6°C since the 1950s and the last ten years have been hotter than average, with 2007 being the hottest year on record.

CSIRO have predicted that future climate change will bring to Victoria, higher temperature, lesser rainfall but frequent storm events of high intensities, more frequent extreme events such as floods and droughts. These will have their impacts on the infrastructure including the waste water systems (Howe *et al.*, 2005)

In Australia, especially in rural towns, flows into the sewer treatment plants are being affected due to the water restrictions, more efficient water-using appliances and recycling of water in homes and on farms.

Managing director of agricultural research consultancy Arris Pty Ltd, Dr Daryl Stevens, reportedly stated that "flows into most Australian sewage treatment plants are declining dramatically, especially in drought-affected country towns". He says water restrictions, more efficient water-using appliances and recycling of water in homes and on farms are all contributing, and Australia's sewage system may struggle to cope with waste, (Grant, 2009).

The amount and volumes of water have decreased 25 to 50% going in to some sewage treatment plants. The whole sewage system is designed on a certain volume of water flushing through it to carry all the solids that are mixed up in the water. This has resulted in less waste water in the pipes as drains and sewers dry up. This is an example of how climate change alters the behavioural patterns and water usage of people.

Some impacts of climate change are, increase in rainfall intensities, reduction in the total rainfall, reduction in sewer flows due to grey water reuse and water restrictions, increase in ground water table due to sea level rise or decrease in ground water table due to use of ground water to supply water to the reticulation system, change in the physical catchment characteristics, etc.

The solutions may vary from , “Do nothing”, or increase the slope of the pipes, or change the material of the pipe, increase or decrease the diameter of the pipes, Increase the capacity of the wet well and or emergency storage, special odour control systems etc. The paper presents the outcomes of the project with a case study application in Churchill township in the Gippsland Region of Victoria.

2. CLIMATE CHANGE PROJECTIONS

CSIRO carried out a study for Melbourne water in 2005 and have projected that there would be the following consequences due to sea level rise and climate change (Howe *et al.*, 2005). According to this report, potential average annual temperature increases are projected to range from 0.3 to 1.0°C in 2020, and 0.6 to 2.5°C in 2050. The annual average precipitation is suggested to have changes of -5 to 0% in 2020, and -13 to +1% in 2050. More extreme events are likely to occur - with more hot days, more dry days and increased rainfall intensity during storm events. This means that the intensity of the rainfall will increase in the short periods and cause flash floods, which we are already experiencing.

These potential changes will have the following consequences on the waste water reticulation system,

- Increased Frequent need for replacement of assets
- Need for specialized treatment of Odour
- Reduction of liquid in the waste water flow and self cleansing velocities
- Increased Infiltration
- Potential overflows during rainfall events, (Howe *et al.*, 2005).

3. CASE STUDY AREA

Central Gippsland region water corporation trading as “Gippsland Water” (GW) provides water and sewer reticulation systems services for the town Churchill. Figure 1 shows catchment areas and the townships served by GW including Churchill. Churchill is located about 160 km east of Melbourne. The Churchill-Yinnar-Boolarra sewage catchment contains approximately 66 km of sewer and 22 km of pressure main and covers a gross area of 496 hectares servicing a population of 6,000 persons approximately. The catchment is predominantly residential with some commercial, Industrial and public use area. The required level of service by GW is to fully contain all flows from the system for all 1 in 5 year design storm.

Figure 1: Gippsland Water general Operations (Wilbraham, 2007)

The existing reticulation systems have been designed initially using Water Services Association of Australia (WSAA) guidelines and Gippsland water's Wastewater Systems Design Performance Criteria. This has been developed based on the experience and the observed results over the years. GW's Engineers over the years have formulated these guidelines and are still improvising them as required.

In a Greenfield situation, GW follows the Water Services Association of Australia (WSAA) guidelines to design its reticulation system. WSAA estimates the design flow using the formula (WSAA, 1999):

Design Flow = PDWF+ GWI+ IIF

Where,

PDWF = Peak Wet Weather Flow
GWI = Ground Water Infiltration
IIF = Inflow Infiltration

However like most of the water authorities, GW has its own "Wastewater Systems Design Performance Criteria" as mentioned above. The assumptions are to be tested in conjunction with the impacts of climate change and there is a need for further research in this area.

The basic assumptions Gippsland Water's Wastewater Systems Design Performance Criteria are:

- Average Dry Weather Unit flow = 650L/Lot/d
- Ip (Permanent Infiltration) = 500L/ha/d
- Is (Storm dependant infiltration)= 25,000L/ha/d

These assumptions are revisited as the climatic conditions and the usage patterns have considerably changed in the recent years. Further to achieve this, a calibrated model is used to simulate the impacts of climate change on the existing systems and sub catchments to verify the assumptions.

GW engaged Montgomery Watson Harza (MWH) to install flow meters and rain gauges at various locations in the above mentioned catchment and to record the readings in five minute intervals for three months continuously. These readings were used to calibrate the model (Info works) used by GW. The flow meter readings were used to analyse the various parameters like Average Dry Weather Flow (ADWF), Peak Wet Weather Flow (PWWF), Stormwater Infiltration (Is) and Dry weather Infiltration (Ip).

From the flow meter readings for three months for Churchill catchment were analysed and it was found that the values were different for different sub-catchments. For example at Churchill Table 1 shows the Average dry weather unit flow per lot per day which is less than the assumed flow of 650L/Lot/day in the GW's Wastewater Systems Design Performance Criteria. This clearly shows that the conservation and reuse of water by the people is eminent. The flow meter locations can be seen in Figure 2.

Table 1: Average Dry weather unit flows for Churchill catchment

Sub catchment	Average Dry weather unit flow (L/Lot/day)
CH 01	550
CH 02	390
CH 03	400
CH 04	490

The Average Dry weather unit flow per lot per day is lesser than the assumed 650 L/Lot/ Day. The Ip and Is are varying and they depend mostly on the condition of the pipes. The age and material of the pipes play a vital role. The reduction in the sewage flow is due to various reasons like water restrictions, grey water reuse and water saving devices.

Approximately 33% of the pipes within the Churchill Catchment were constructed prior to 1970. Approximately 57% of the pipes within the Churchill-Yinnar-Boolarra Catchment are 150 mm in diameter or less, 13% are 225-300 mm in diameter, while another 25% of the modelled pipes are the pressure pipe within the system. This is due to the large lengths of the transfer (pressure/rising) mains in between towns located within the Churchill-Yinnar-Boolarra sewer catchment. The remaining 5% have diameters within the range of 375 to 450 mm or are pressure pipes (Theodorolis, 2006).

4. INFO WORKS MODELING SOFTWARE

Info works Wallingford sewer modelling Software CS was used for this study. This model was developed in UK and is now used worldwide as one of the most reliable models. The model has the features to simulate and run different scenarios and the predicted impacts of climate change are being applied to the calibrated model and the results are analysed. The model has been calibrated by MWH for Gippsland Water and GW has given the 1st author permission to use this calibrated model for the research. Quantity analysis of the data was done by MWH and it was found that 99% of the data recorded were good. For each catchment waste water generations were created separately for residential and non residential profiles. Specialist profiles have been created for Schools, Hospitals, Bowling clubs, Hostels, power houses, Universities etc.

The Churchill –Yinnar –Boolarra hydraulic model is represented by 1205 nodes connected by approximately 66 km of sewer. The model has not been simplified (Theodorolis, 2006). The Quality of the data is summarised in Table 2 with the allowable tolerances.

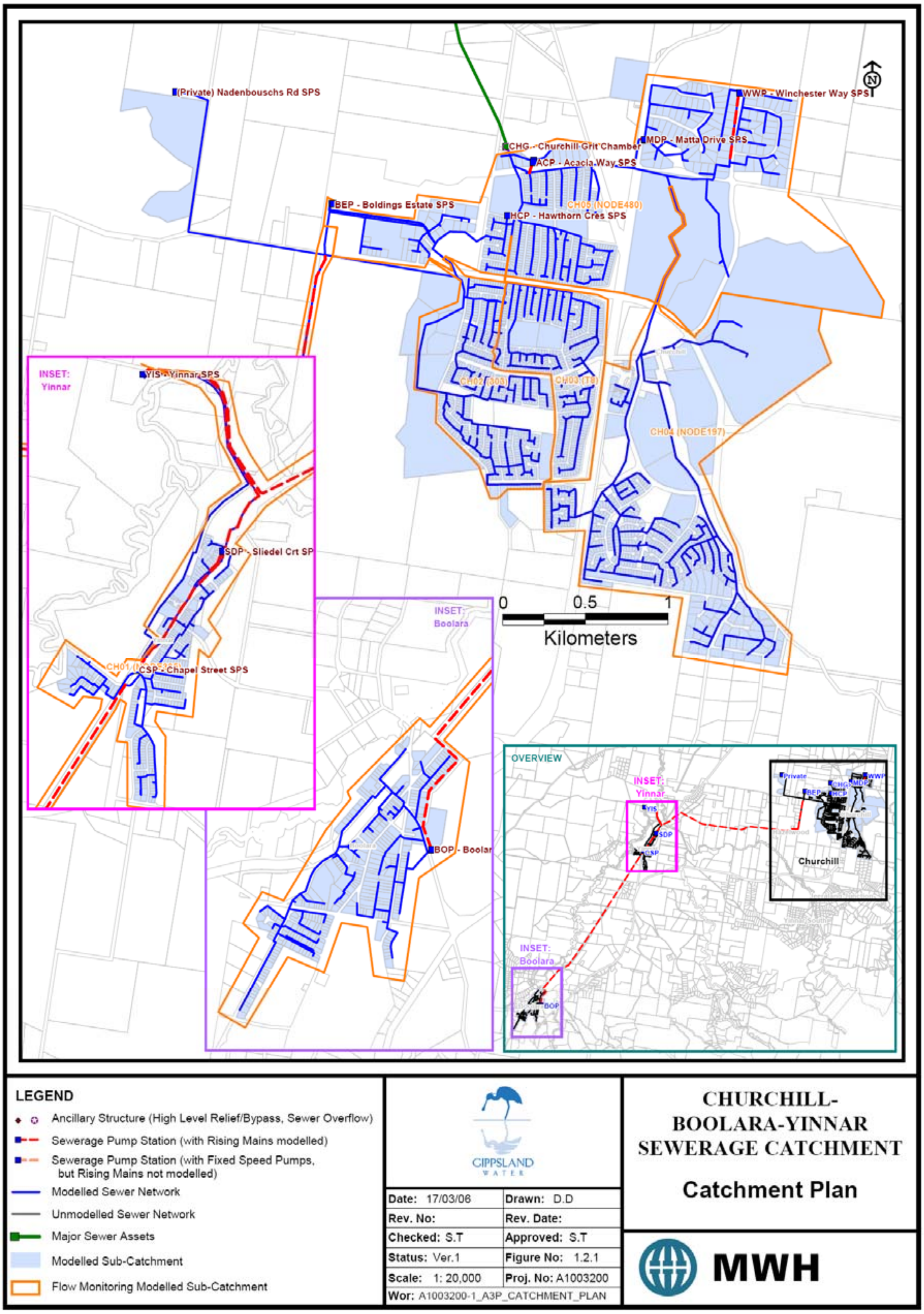

Figure2: Churchill- Boolarra- Yinar Sewerage Catchment Plan (adopted from Theodorlis, 2006)

Table 2: GW's requirements for dry and wet weather modelling.

Wet weather model requirements	Dry weather model requirements
±10% for peak discharge;	±5% for peak discharge;
·±10% for daily flow volume;	±5% for daily flow volume;
Peak timing ±30 minutes;	Peak timing ± 30 minutes;
±20% for depth of flow; and	±15% for depth of flow; and
Shape representative of observed flow pattern	Shape representative of observed flow pattern

Climate change would bring more extreme rainfall events. It is predicted that there would be higher intensity rainfalls for shorter periods like a flash floods and on the other hand there will be a reduction of rainfall and droughts too. To analyse the flash flood scenario, the rainfall intensity in the calibrated model was increased by 10% and the impacts on the downstream flow were observed. Increase in rainfall intensity by 10% & increases the downstream flow as shown in Table 3.

Table 3: Increase in down stream flow due to increase in Rainfall Intensity.

Item	Without Change	With Change	Difference
Unit	L/Day	L/Day	L/day
Max D/S Flow	1166835.46	217861.56	51026.11
Ave. (M3/sec)	310938.76	314747.22	3808.46

Figure 3 shows the changes in downstream flow due to increase in rainfall intensity. Climate change will bring frequent events like this.

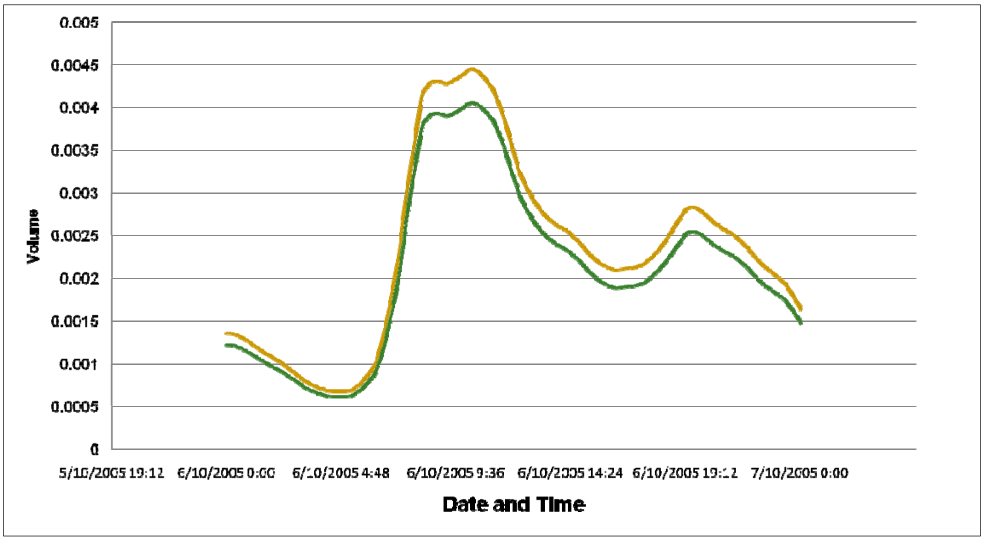

Figure 3: Increase in Downstream flow at Churchill due to increase in rainfall intensity (unit of volume: m3/sec)

Reduction of Water in the Waste Water reticulation System

Another impact of climate change as discussed before is reduction of inflow in the waste water reticulation systems due to water restrictions, water saving devices and grey water reuse. The model was simulated to this scenario. The inflow was reduced by 10% and the changes in velocities are presented in Table 4.

Table 4: Change in velocity due to change in inflow.

Description	Without reduction	With reduction	Difference
Unit	mm/sec	mm/sec	mm/sec
Max	1030.61	969.303	61.31
Average	414.57	385.873	28.70

Figures 4 and 5 give us a clear picture of the reduction in the velocity due to the reduction in inflow by 10% and 20% respectively.

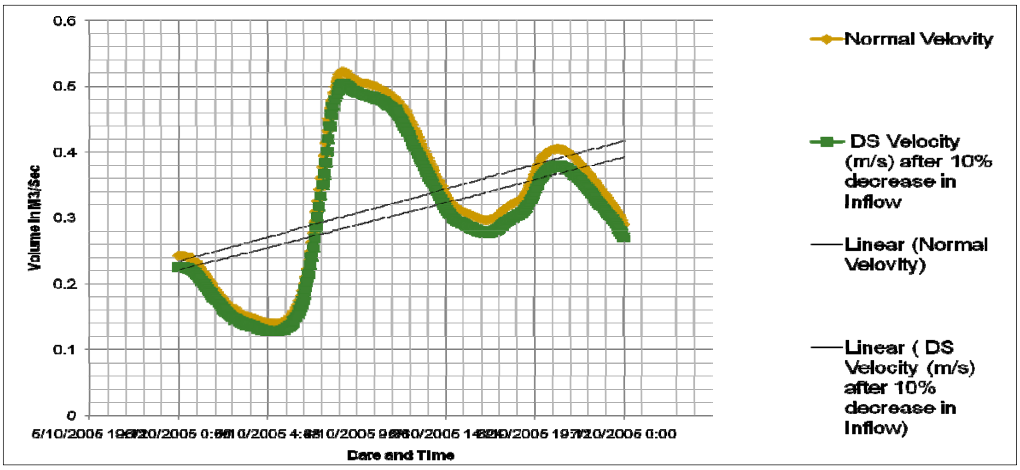

Figure 4: Decrease in velocity due to reduction in inflow by 10 %

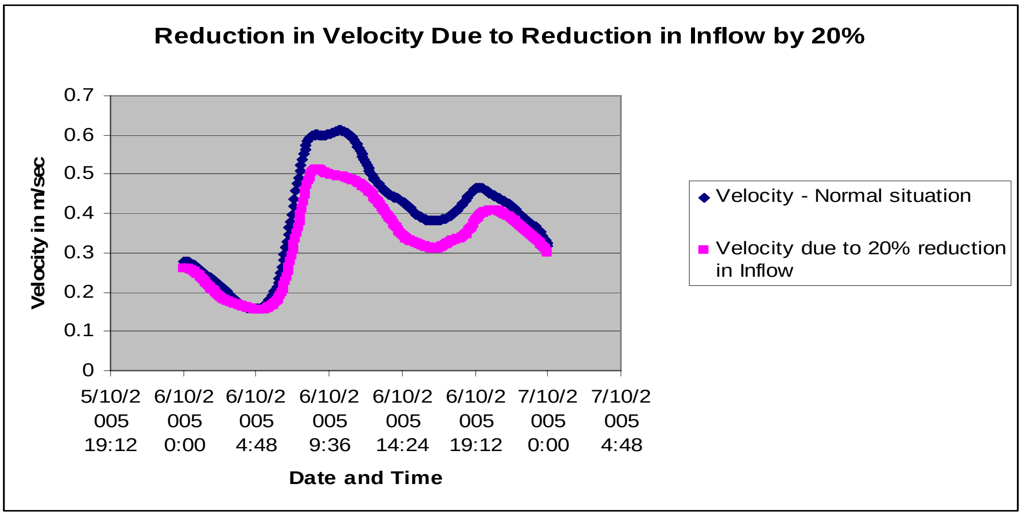

Figure 5: Decrease in velocity due to reduction in inflow by 20 %

The depth of flow in the sewer is a major factor responsible for the sewer transport. The sewer consists of solids and liquids and if the depth of flow in the sewer is very less, it leads to settlement of solids to the bottom of the pipes and due to the nature and the texture of the waste; it starts to build up and ultimately blocks the sewer. The following graphs are the results of the simulation. When the flow is reduced to 10% and 20% the corresponding reduction in depth is evident and it is detrimental to the sewage transport. The sewer pipes are generally designed and assumed to run half full. Reduction in the depth of the pipes affects the sewer system and sometimes the results are very undesirable.

Reduction in depth in pipe due to reduction in inflow by 10%

Figures 6 & 7 present the simulated depths of water with reduced inflow. It was observed that the velocity and the depth of flow in the sewer system were reduced as the inflow reduced. These play a vital role in the transport of sewer in the pipes. This will have its impact on the self cleansing velocities in the sewer system. Previous research on self cleansing velocities state that reduction in depth in the sewer flow to more than 0.5 of the pipe would result in considerable amount of deposition and reduction in the shear force required to cleanse the system. Self cleansing velocities also depend on the diameter of the sewer pipe. (Nalluri *et al.*, 1994). It is clear that a reduction in 20% of the inflow to the reticulation system affects the hydraulics of the system considerably. In reality we have seen from reports that the inflow to the waste water treatment plants are already reducing by 25 to 50%. Further research is being done on how to mitigate this impact of climate change and how to avoid the blocking of sewers due to reduction in self cleansing velocities and the shear force required to strip the solids adhered to the bottom of the pipe.

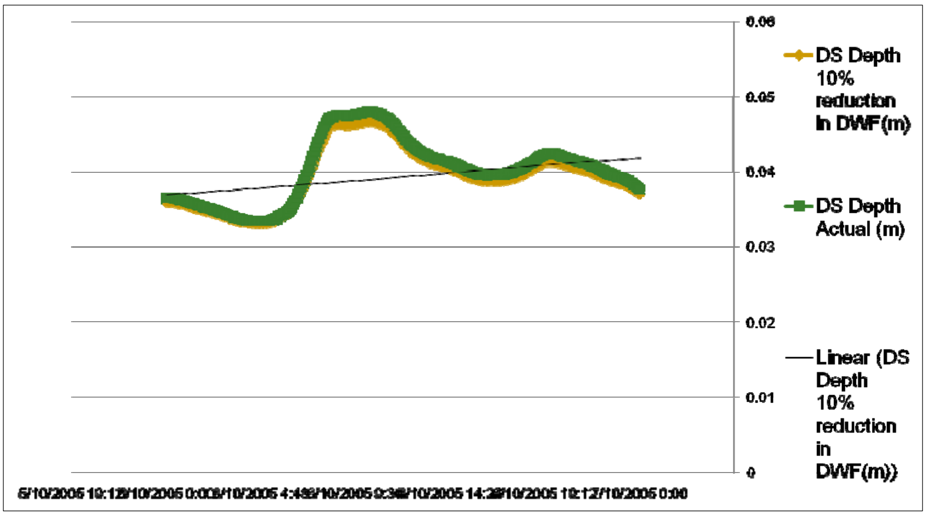

Figure 6: Reduction in depth due to 10% reduction in inflow

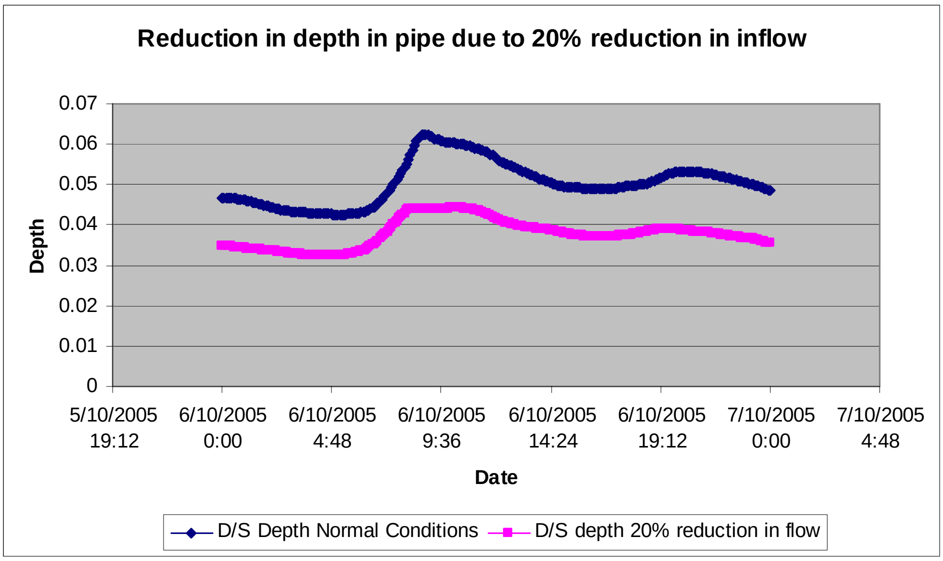

Figure 7: Reduction in depth due to reduction in inflow by 20%

5. CONCLUSIONS

The paper presented the outcomes of a case study conducted to analyse the impacts of climate change in the waste water reticulation system in Churchill township of Gippsland Region using an established mathematical model. It is evident that the impacts of Climate change would affect the waste water reticulation system and the various parameters. The reduction in inflow would result in the reduction of the velocity of flow, which in turn would reduce the self cleansing velocities. The depth of the flow is also reduced due to the reduction in the inflow to the reticulation systems. The increase in rainfall intensity increases the volume of the flow. The system needs to be checked for its capacity whether it would meet the performance criteria.

Further simulations with altered values for the catchment properties and parameters need to be run and the results need to be analysed for developing suitable adaptation strategies.

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FRAMEWORK FOR MULTICRITERIA DECISION MODELING FOR ANALYSING SUSTAINABLE MANAGEMENT STRATEGY

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ABSTRACT

Protection of coastal regions due to changed climatic conditions has become a serious concern over recent years. According to many published research, vulnerability of the coastal structures and risks in social, environment and economic health in coastal regions due to climate change is at the highest stake. Sustainable decision making requires an assessment of impacts and consequences of underlying factors impacting development and operational of projects. An appropriate response strategy should be devised to achieve the desired project outcomes and long terms prosperity of the coastal regions. In order to devise sustainable management strategy, relative importance of the factor impacting social, economical and environmental concerns are investigated by using a structured questionnaire survey approach. Two separate survey questionnaires were conducted questions covering 22 criteria and 11 sub-criteria under three board impact areas: Social, Economical and Environment. Based on a brainstorming session with five country collaboration, five possible alternative strategies have been devised. By utilising the Analytical Hierarchy Process (AHP), relative impacts of the criteria on the alternative strategies have been analysed towards establishing the optimal strategy. The outcomes of this study should assist the management decisions among policy makers in determining the effect on diverse challenges due to climate change and suggest possible improvements to establish the appropriate management procedures for sustainable outcomes.

1. INTRODUCTION

The impact of climate change in environment has already been evident across the globe. The eminent consequences of extreme events such as heavy rainfalls, draughts etc. have been realized across many dimensions. For instance, drainage infrastructures in many urban cities are no more adequate to tackle the extreme rainfall. In the other hand, sewer networks are clogged by concentrated sewage due to drought conditions. Road and rail infrastructures in many countries have proven to be no more resilient to extreme flood condition. Potable water supply distribution systems are evidently failing from reliable and sustainable delivery under extreme flood and drought conditions. Ecological imbalance and adverse consequences in the agricultural and farming sectors have been a major problem across the world.

While there is a little chance to act against rules of nature, strategies for adaptation these changes could be a potential solution. However, in order to devise appropriate solutions for adaptive policies, information uncertainty and conflict management are thus critical issues. Environment related problems are characterised by complexity, uncertainty and irreversibility. Evaluation methods are not always quite straight forward Improvement of one problem dimension can not compensate for deterioration in another dimension.

As the projects' environments are multi-dimensional, factors affecting economic, social and environmental aspects are required to be identified and their relative impacts on the underlying issues should be assessed holistically. Many conflicting views may emerge in evaluating alternative plans. Especially contemporary approaches like multicriteria analysis may serve as a meaningful evaluation vehicle for tacking explicitly account of such conflicts regarding the foreseeable impacts of an adaptive plan (Nijkamp et al, 1990).

2. RESEARCH METHOD

The implications of an unsustainable management practices are significant due to the resulting consequences such as poor land use planning, poor conservation of natural resources and also being unsafe and unproductive. This research focuses on factors affecting the sustainability and devising a management strategy for improvement relevant to both government and private policy makers and the community at large. A questionnaire survey identifying important factors affecting social, economical and environmental issues was prepared based on available literature and expert inputs from country based Project Reference Group meetings. The input also covers the reviews of research conducted in various areas of sustainable management of other regions for a point of comparison. Total of 22 criteria were selected to cover breadths and depths of identified issues important to the management of coastal regions. Each of these criteria was further sub-divided into 11 sub-criteria based on the potential impacts. The preliminary data was then analysed by using the AHP (Saaty, 1980), which established the prioritised solutions to setting up a benchmark for sustainable management practice.

3. THE FRAMEWORK FOR ANALYSIS

Selecting the most appropriate alternative from a set of alternatives and eliciting the consistent subjective judgement from the decision makers in the selection process require a holistic analysis. In general, this selection process is more effectively performed with the aid of computerised decision support systems. Some of the past researchers have adopted questionnaire survey approach for data collection in measuring various success and failure attributes and employed mathematical tools such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Artificial Neural Networks (ANN) and statistical techniques such as factor analysis and multivariate regression etc. for analysis and drawing conclusions.

AHP is a multi-objective decision making approach that provides a convenient set of mathematical tools to identify an optimal alternative given a set of competing objectives. One of the major advantages of the AHP is that the analysis does not always require statistically significant sample size. AHP uses a number of pairwise comparisons between quantitative or qualitative criteria to assess the relative importance of each criterion. These can be arranged in a hierarchical manner known as a 'value tree' for sets of attributes, and qualities (levels) within these attributes. The simplicity of AHP approach is that, unlike other 'conjoint' methods, the qualities (or levels) of different attributes are not directly compared (Dyer and Foreman, 1992). The AHP approach thus removes the need for complex survey designs and can even be applied (in an extreme case) with only a single respondent (Saaty,1980). As the input data in AHP analysis is based on expert's perceived judgment, a single input usually represent a group of representatives in the sample data. Other conjoint methods such as choice experiments do not realise statistically robust results unless there is a sizable number of usable survey responses. Most of the conjoint analysis place quite a high 'cognitive burden' on respondents in that they are asked to make comparisons across options that have a large bundle of attributes and levels of these attributes. In contrast, under AHP, respondent are not asked to make choices between all criteria and thus respondents are less likely to adopt mental short cuts by concentrating disproportionately on one attribute or level (Saaty, 1980).

3.1. Measuring Consistency in Judgements

In the application of AHP, inconsistency in pairwise comparisons may be introduced as a result of a number of factors such as lack of adequate knowledge, improper conceptualisation of hierarchy and even lack of statistically significant sample size etc. A consistency ratio is generated for each prioritised scale upon completion of carrying out the pairwise comparison. It is used to determine the consistency of the judgments. The consistency ratio is defined as the consistency index for a particular set of judgments divided by the average random index as shown in following equation.

$$CI = {(\lambda \max - n)} / {(n-1)} \quad \text{and} \quad CR = {CI} / {RI} \qquad \text{(Eq. 1)}$$

Where, λ_{max} is maximum eigenvalue, n is size of the judgment matrices, RI is random index. The values of RI for different size of judgment matrices are found in existing literatures including in Saaty (1980)

Based on the various numerical studies, Saaty (1980) stated that to be acceptable (ie. for tolerable inconsistency), the CR must be less than or equal to 0.10 (irrespective of the nature of the problem); if this condition is not fulfilled, a revision of the comparisons is recommended. Perfectly consistent judgments would be represented by a consistency index of zero, the same as the consistency ratio. It must be stressed, however, that an acceptable CR does not guarantee a good final selection outcome. Rather, it ensures only that no intolerable conflict exists in the comparison made, and that the decision is logically sound and not a result of random prioritization (Doloi, 2008).

3.2. AHP Framework and the attributes associated with coastal regions

In the AHP method, the first step is to set up the objective of decision making (Saaty, 1983). In this research, the objective is to determine what attributes impact the issues that were identified in relation to management of coastal regions and how important the individual attribute are for achieving the optimal management strategy in coastal zone management. Therefore, the main objective, '*sustainable management strategy*' should be placed at the top in the analytical hierarchy framework.

While using the 22 criteria, 11 sub-criteria and five alternative strategies in the hierarchical framework, the questions for pairwise comparison for AHP were far too many (in the order of 500 questions). During the pilot implementation, it was found that the questionnaire of this length will neither practical nor feasible for respondents to respond voluntarily. Thus, the overall problem has been broken down into two hierarchy for simplicity. Based on the perceived responses from brain storming workshops, the 11 subcriteria have been grouped into three representative categories namely Sea Level Rise (SLR), Short Term Flooding (STF) and Overall Climate Change (OCC). The first hierarchy has been developed incorporating all 22 criteria and three sub-criteria. In order to evaluate the impacts of risks associated with all the criteria and the sub-criteria, the main objective "Risk Effect in Macro Level" was placed at the left most level in the three level hierarchy as shown in Figure 1.

The second step is the break down the objective into criteria and sub-criteria and organise them within an analytical hierarchy. As stated earlier, the second level hierarchy was divided into 22 main criteria as shown in the figure. The decomposition of the criteria to the next level is performed by identifying three sub-criteria groups. There is no single correct hierarchy for a given system, and several different hierarchies can be built depending on difference perspectives. A hierarchy of objectives, criteria and sub-criteria is constructed in order to gauge the extent to which each option contributes to the fulfillment of the overall objectives.

Table 1 describes all the 22 criteria and shows the respective impacts in terms of three impact areas: *Social*, *Economical* and *Environmental*.

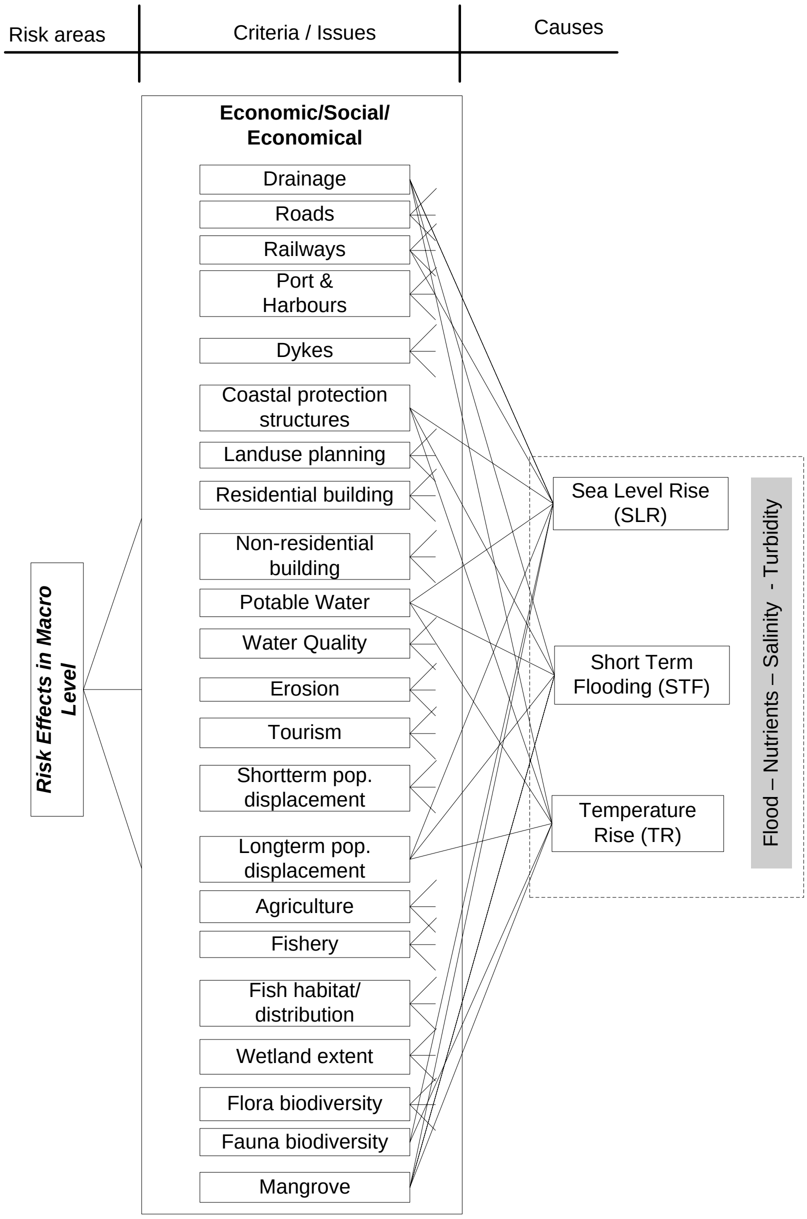

Figure 1: Hierarchy for determining risks across the identified issues

3.3. Framework for analysis of alternatives

Figure 2 shows the hierarchy comprising all three sub-criteria groups and the five identified strategies. The main objective of this hierarchy is to identify the “Sustainable Management Strategy” and this it is placed at the top of the hierarchy as shown. The next level is the three sub-criteria groups followed by the five alternative options or strategies at the bottom of the hierarchy.

Table 2 describes all the 11 sub-criteria and three representative groups used in the hierarchy for multi-criteria analysis. Table 3 shows five alternative strategies to make appropriate comparison relative to the criteria and sub-criteria. It is worthwhile to mention that all these initial criteria, sub-criteria and the alternative management strategies were developed based on country based PRG meetings and project planning workshops held in Bangkok in November 2007.

Table 1: Criteria for MCDM Analysis

Criteria	**Description**	**Impacts (S, E, Ev) S- Social, E- Economic, Ev- Environmental**
Drainage (D)	Structural and non structural elements associated with drainage infrastructure	S, E, Ev
Roads (RD)	Structural and non structural elements associated with road infrastructure	S, E, Ev
Railways (RW)	Structural and non structural elements associated with railway infrastructure	S, E, Ev
Port and harbours (PH)	Structural and non structural elements associated with port and harbour infrastructure	S, E, Ev
Dykes (DK)	Flood protection dykes and associated structures	S, E, Ev
Coastal Protection Structures (CPS)	Structural and non structural elements associated with coastal protection structures	S, E, Ev
Landuse Planning (LP)	Landuse planning for improvement and developments	S, E, Ev
Residential building (RB)	Buildings used for residential purposes	S, E, Ev
Non residential building (NRB)	Buildings used for commercial and institutional purposes	S, E, Ev
Potable water (PW)	Potable water and associated infrastructures	S, E, Ev
Water quality (WQ)	Allowable standard for water quality	S, Ev
Erosion (E)	Extend of erosion due to flooding, sea level rising or other associated factors	S, E, Ev
Tourism (T)	Tourism related infrastructure including service delivery	S, E, Ev
Population: Short term displacements (PSD)	Short term population displacements resulting from temporary disturbances such as short term flooding and other natural disasters	S, E, Ev
Population: Long term displacements (PLD)	Long term population displacements resulting from temporary disturbances such as long term flooding and other natural disasters	S, E, Ev
Agriculture (AG)	Agricultural lands and produces	S, E, Ev
Fishery (F)	Fishery infrastructure including both structural and non structure elements	S, E, Ev
Fish habitat/distribution(FH)	Fish habitats and distributions	S, E, Ev
Wetland health extent (WE)	Extents of wetland	S, Ev
Flora biodiversity (FLB)	Flora biodiversity along the coastal regions	S, Ev
Fauna biodiversity (FAB)	Fauna biodiversity along the coastal regions	S, Ev
Mangrove (MG)	Mangrove along the coastal regions	S, Ev

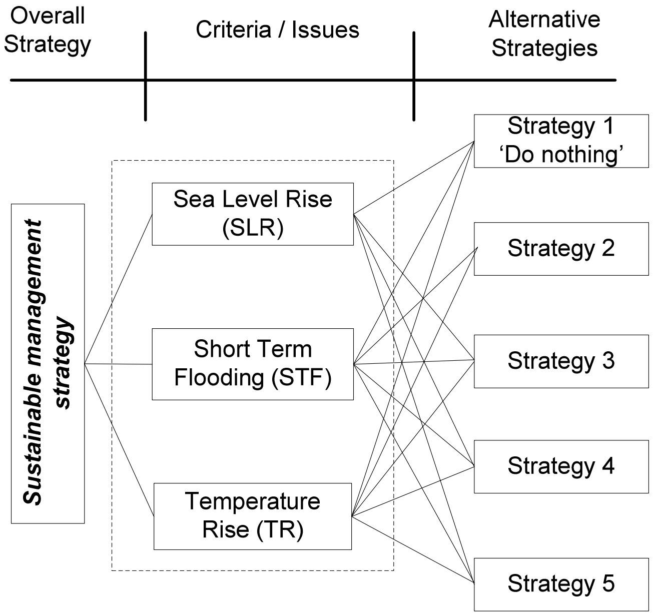

Figure 2: Hierarchy for determining sustainable management strategy

Table 2: Sub-Criteria for MCDM Analysis

Categories	Consequences or sub-criteria	Description/Impacts
1. Sea Level Rise 2. Short Term Flooding 3. Overall Climate Change	Depth	Water depth resulting from flood
	Duration	Flood duration
	Velocity	Water velocity resulting from flood
	Frequency	Frequency of occurrence of flood events
	N	Nitrogen
	NO2	Nitrogen dioxide
	NO3	Nitrogen trioxide
	TP	Total phosphate
	PO4	Phosphate
	Salinity	Increased in water salinity due to sea level rise
	Turbidity	Water turbidity due to flood

4. SURVEY DESIGN

A pilot survey was conducted to measure how the decision makers perceive the relative importance of the identified functions associated with sustainable management in the hierarchy as shown in Figures 1 and 2. The questionnaire was designed as a tool for assessment of the differing levels of criteria that provide the alternatives for the AHP model. In a questionnaire survey approach, there are several ways of including the views and judgments of each respondent in the priority setting process. In a common objective context where all respondents have the same objectives, there are four ways to set the priorities: 1) consensus; 2) vote or compromise; 3) geometric mean or the individuals' judgments; and 4) separate models or players (Dyer and Forman, 1992).

Table 3: Strategies for sustainable management

Strategy	Description	Explanation
Strategy 1	No Intervention Required	No intervention required refers to no action and continue with business as usual.
Strategy 2	Investment in Structural Measures	This includes construction of dykes, coastal protection structures and other structural measures.
Strategy 3	Investment in Nonstructural measures	Investment in Nonstructural measures/ Capacity Building (Individual, Institutional, Community, Organisational, National, Investment in R&D
Strategy 4	Effective Implementation of Existing Policies	This includes revisiting the existing strategies and their implementation strategies in the context of current changed environment due to climatic variations and extreme conditions.
Strategy 5	New Policy development	This includes revisiting the existing policies and their implementation strategies in order to devise an appropriate policy in the context of current changed environment due to climatic variations and extreme conditions.

The survey was conducted using web-survey tool. A nine point likert scale was used in each question for respondents to indicate a preferred response. The compositions of the questions included in the questionnaire are aimed at gaining responses that provide increased clarity to the issues regarding adaptive management of consequences due to climate change. The available answers to the questions provide a spectrum indicating the relative importance of each particular issue. A decision maker can express a preference between each pair of criteria as equal, moderate, strong, very strong and extremely preferable (important). The choice to remove the possible selection of neither agrees nor disagrees provided the respondents with a clear choice of judgment. With reference to the responses provided in the basis questions, the same likert scale was used to compare the elements of each level of hierarchy with one another in pairs in relation to their respective 'parents' at the next higher level. The nine point scale is shown in Table 4. Respondent's emphasis and selections directly determine the weighting of the evaluation criteria used in the matrix of the analytical hierarchy process and hence achieved the effectiveness in the data analysis.

4.1. Determination of the Relative Important Index (RII) for developing the judgment matrices

The Relative Importance Index (RII) is found to be an important measure for establishing the initial judgment matrices among the criteria and sub-criteria in the hierarchy framework (Doloi, 2007). In order to rank the criteria and the sub-criteria in the order of their criticality, the mean scores of responses for different project attributes can be calculated and interpreted using descriptive statistics from the questionnaire. However, Chan and Kumaraswamy(1997) suggested that the mean and standard deviation of each individual attribute is not reliable statistics to assess the overall rankings because they do not reflect any relationship between them. Hence, all the numerical scores of each of the identified factors were necessary to transform to relative importance indices to determine the relative ranking of the attributes. The relative ranking of the attributes can be evaluated based on the Relative Importance Index (RII), which is evaluated using the following formula (Chan and Kumaraswamy, 1997; Iyer and Jha, 2005).

Relative Importance Index $RII = \frac{\sum wI}{AxN}$; $(0 \le RII \le 1)$ (Eq 2)

Where 'w' is the scale index (in the range of 1-9) used by the respondents to respond to their selection and 'I' is the respective number of respondents selecting the same index. 'A' is the highest weight in the likert scale (which is 9) and 'N' is the total number of respondents responded to the given question in the sample. The highest RII values indicate the most critical attributes, the lowest values indicate the less significant attributes which then provide a sound basis to establish the initial judgment matrix.

Table 4: AHP pairwise comparison scale

Value rating for judgment	**Linguistic judgment**
1	Elements are equally preferred
3 or (1/3)	One is moderately preferred to the other
5 or (1/5)	One is strongly preferred to the other
7 or (1/7)	One is very strongly preferred to other
9 or (1/9)	One is extremely preferred to the other
Note: 2,4,6,8 are intermediate judgmental values between adjacent scale values	

5. BRIEF EVALUATION OF RESULTS AND FINDINGS

5.1. Descriptive results

The perceived practices and respondents' preferences can be easily described using the basic statistics such as mean, median, standard deviation and correlation analysis. Such descriptive analysis can then be used to contrast and verify the findings from the MCDM analysis. As there are total of six country collaboration in the project, the data is expected to be collected locally in order to establish appropriate benchmarks at the country levels. Finally, the same data will be used to establish an overall benchmark for decision making at a global level.

5.2. Results from AHP analysis

Figures 3 and 4 show weighted priority vectors across all the alternatives for comparison purpose. Figure 3 shows the preferences on alternative strategies for sustainable management in Australian context. A similar analysis is expected to perform across all collaborating countries using their own case study data in order to develop the consensus on the preferred strategy as appropriate. Figure 4 shows a comparison on the preferences of strategies across all six countries. As seen, it is clear that the most preferred solution in one country may not be the solution to others in terms of developing adaptive measure for sustainable future.

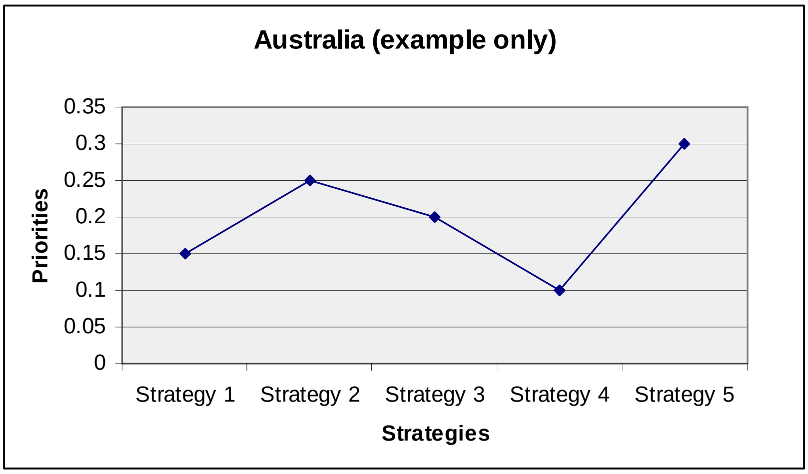

Figure 3: Percentage representation of overall priorities for three individual cases

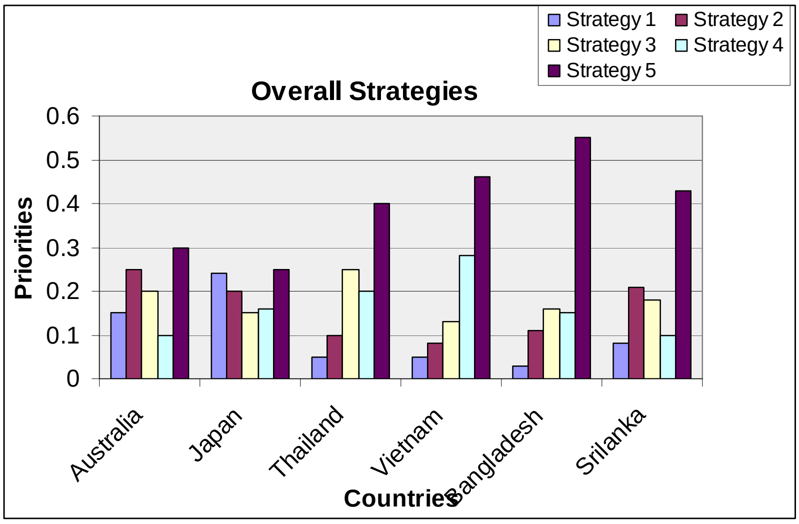

Figure 4: Percentage representation of overall priorities for optimum management strategy

6. CONCLUSION

Based on the pilot study, a framework has been established for analyzing sustainable management strategy. The multicriteria decision analysis has been employed incorporating conflicting criteria and subcriteria in order to analyse the trade-off between feasible alternative strategies for sustainable management practice. The framework will facilitate the evaluation of sustainable solutions using large data sample from demographic cross sections. MCDM analysis based on AHP methodology allows incorporating the causes and effects of all the identified criteria and sub-criteria in order to devise the best possible solution at both local and global levels. One other important aspect in MCDM analysis is the possibilities for change of preferences on the criteria and sub-criteria which might lead to change of rankings in the overall strategies. Thus sensitivity analysis is an important measure to ensure consistent outcomes. The framework is still in progress and further discussion on the findings will be continued as the project progresses.

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APPENDIX A

1. Priority Vector Matrix for Segment 1

$$\begin{bmatrix} S1 \\ S2 \\ S3 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} & a_{18} & a_{19} & a_{110} & a_{111} & a_{112} & a_{113} & a_{114} & a_{115} & a_{116} & a_{117} & a_{118} & a_{119} & a_{120} & a_{121} & a_{122} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} & a_{28} & a_{29} & a_{210} & a_{211} & a_{212} & a_{213} & a_{214} & a_{215} & a_{216} & a_{217} & a_{218} & a_{219} & a_{220} & a_{221} & a_{222} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} & a_{37} & a_{38} & a_{39} & a_{310} & a_{311} & a_{312} & a_{313} & a_{314} & a_{315} & a_{316} & a_{317} & a_{318} & a_{319} & a_{320} & a_{321} & a_{322} \end{bmatrix} x \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \\ a_7 \\ a_8 \\ a_9 \\ a_{10} \\ a_{11} \\ a_{12} \\ a_{13} \\ a_{14} \\ a_{15} \\ a_{16} \\ a_{17} \\ a_{18} \\ a_{19} \\ a_{20} \\ a_{21} \\ a_{22} \end{bmatrix} = \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix}$$

2. Priority Vector Matrix for Segment 2

$$\begin{bmatrix} A1 \\ A2 \\ A3 \\ A4 \\ A5 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \\ a_{41} & a_{42} & a_{43} \\ a_{51} & a_{52} & a_{53} \end{bmatrix} x \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \end{bmatrix}$$

MONITORING OF LONG-TERM TRENDS OF WINTER WEATHER IN HOKKAIDO

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ABSTRACT

In Hokkaido and other cold, snowy regions, snowmelt is an important source of water. The accumulation of snow in winter greatly affects the amount of snowmelt runoff in spring, and is also an important factor in developing a safe river channel plan in terms of flood control. The impact of global warming has recently been considered as a factor behind changes in winter weather trends, and it is particularly likely that the recent changes in temperature and snowfall patterns are a result of this phenomenon. This paper on the trends of snow season weather in Hokkaido as summarized using weather maps and data from the prefecture's weather stations and the Automated Meteorological Data Acquisition System (AMeDAS) from the 1960s to recent years (as of 2006).

1. INTRODUCTION

In Hokkaido and other cold, snowy regions, snowmelt is an important source of water (as an example, winter runoff into the Ishikari River accounts for approx. 1/3 of annual water resources in the local area. This river has the second largest drainage area in Japan.) Winter weather trends have affected snowmelt runoff (amount, features), and have a profound effect on water sources for dams. The accumulation of snow in winter greatly affects the amount of snowmelt runoff in spring, and is also an important factor in developing safe river channel plans for flood control.

The impact of global warming (an increase in the global average temperature due to elevated CO_2 concentration in the atmosphere) has recently been considered as a factor behind changes in winter weather trends, and it is particularly likely that the recent decrease in snowfall and changes in weather map patterns (seasonal winds → dominant low atmospheric pressure) are a result of this phenomenon. Specifically, eastern Hokkaido has experienced heavy snow in midwinter in recent years, while this used to be a late-winter phenomenon in the region.
This study was conducted with the aim of summarizing the long-term interannual weather trends that have impacted Hokkaido's snowmelt runoff in recent years.

2. COLLECTED DATA

The data used were accumulated over a period of 46 years between 1961 and 2006 at the 22 weather stations shown in Figure 1. Although the weather stations also have data from before 1961, these figures were not used because they are not in digital format. In addition to information from weather stations, data are also available from many AMeDAS stations throughout Hokkaido. However, since these data are constantly updated, they were used accordingly for analysis.

The target period of the weather data used for analysis was from December to March, and the target weather elements were the maximum, minimum and mean temperatures, snow cover, snowfall depth, daily precipitation and weather maps.

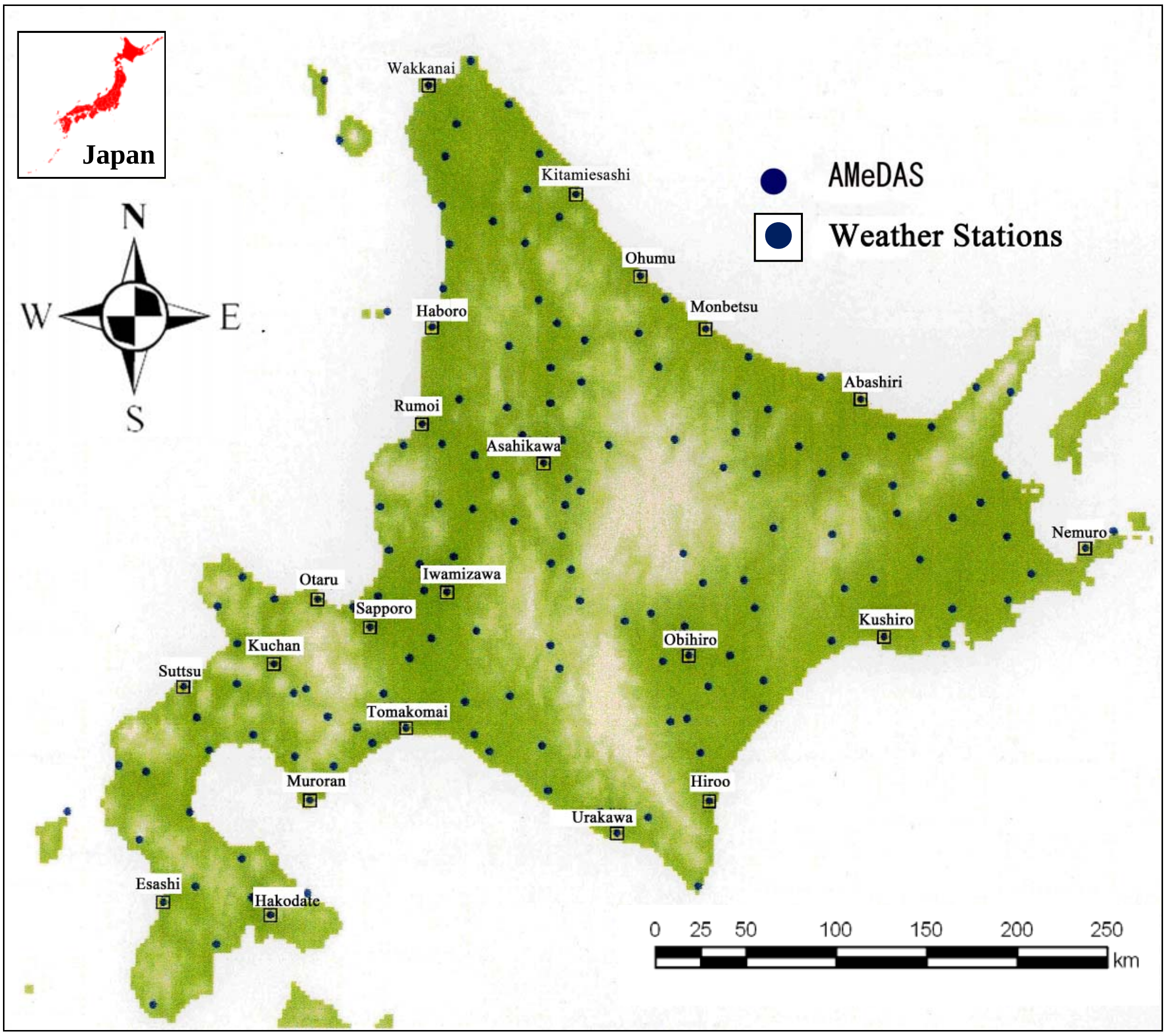


Figure 1: Locations of weather stations and AMeDAS stations

3. LONG-TERM CHANGES IN WINTER TEMPERATURES AND SNOW ACCUMULATION

Figure 2 summarizes temporal changes in the daily mean and daily maximum/minimum temperatures in winter between 1961 and 2006 for Sapporo. In the figure, no significant changes in the long-term trend of daily mean and maximum temperatures are seen over the last 40 years. The daily minimum temperature, however, shows a significant increasing tendency compared with the daily mean and maximum temperatures. It can be seen that the mean value for the 10-year period between 1997 and 2006 was approximately 1.5°C higher than that between 1961 and 1970.

Figure 3 outlines the temperature increases at 22 weather stations in Hokkaido. Here, these increases are based on the following definition:

Temperature increase = (mean winter temperature between 1997 and 2006) – (mean winter temperature between 1961 and 1970)

It can be seen from the figure that, while temperatures showed an increasing tendency, the increase in the daily minimum temperature generally tended to be greater than that of the daily maximum temperature, indicating that this was a prefecture-wide tendency.

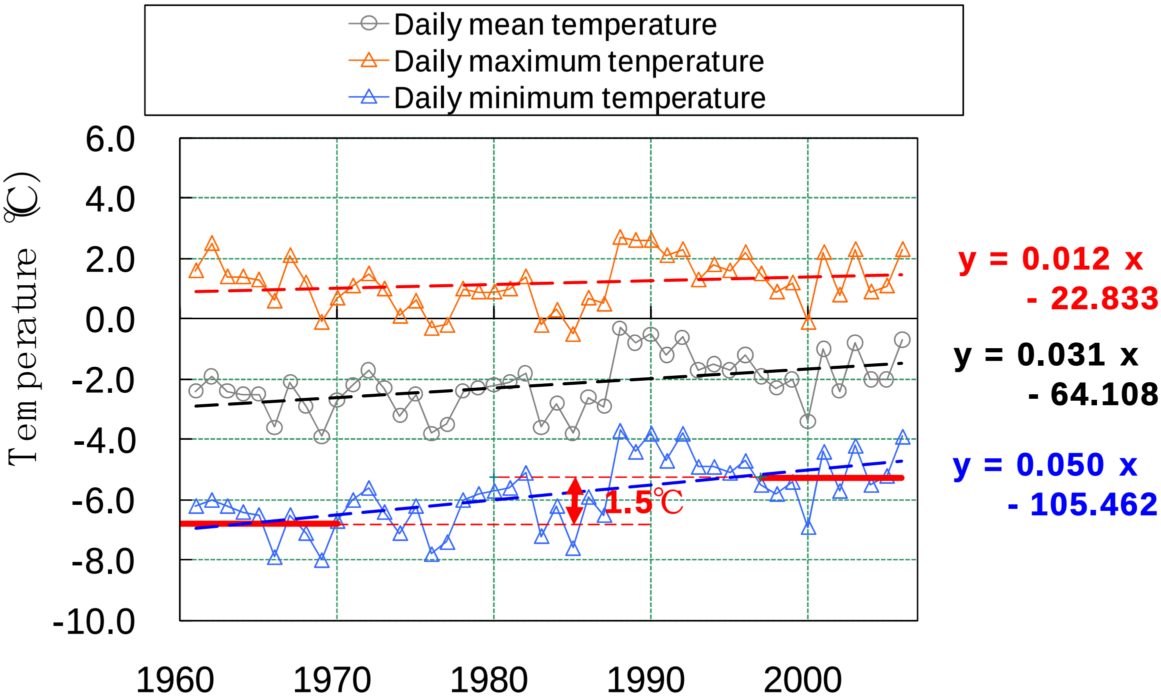


Figure 2: Changes in winter temperatures in Sapporo (Winter temperatures are the mean values between December of the reference year and the following March.)

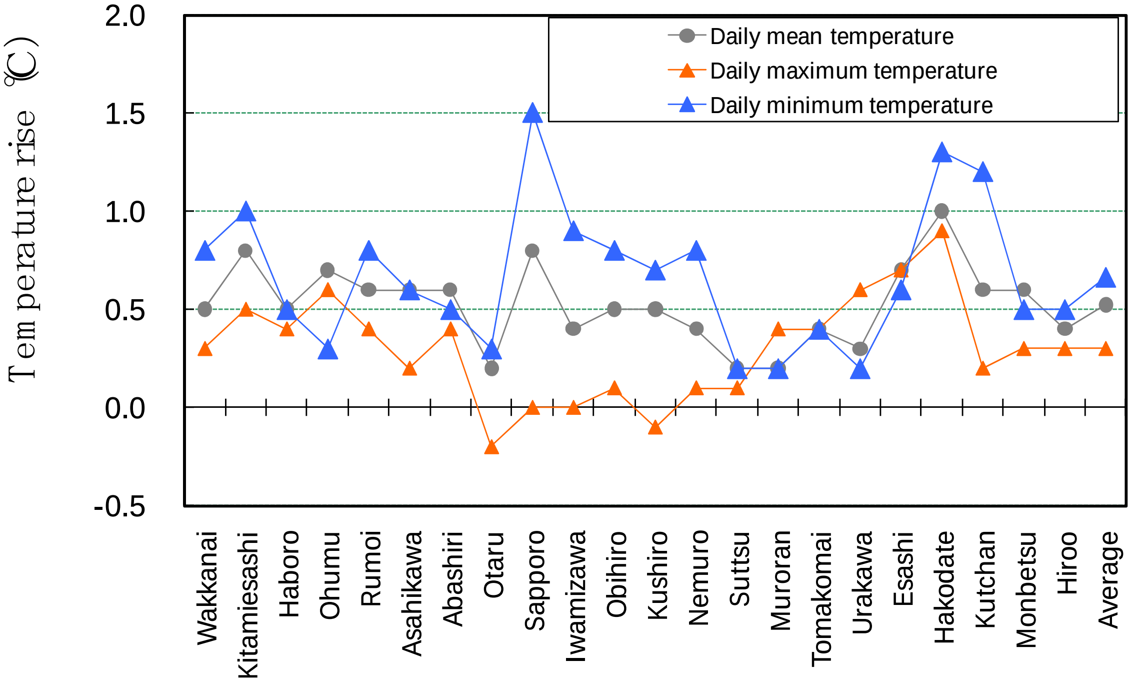


Figure 3: Increases in winter temperatures at weather stations throughout Hokkaido

Figure 4 outlines the increases in snow cover and snowfall depths at weather stations in Hokkaido. The definition of these increases is as follows:

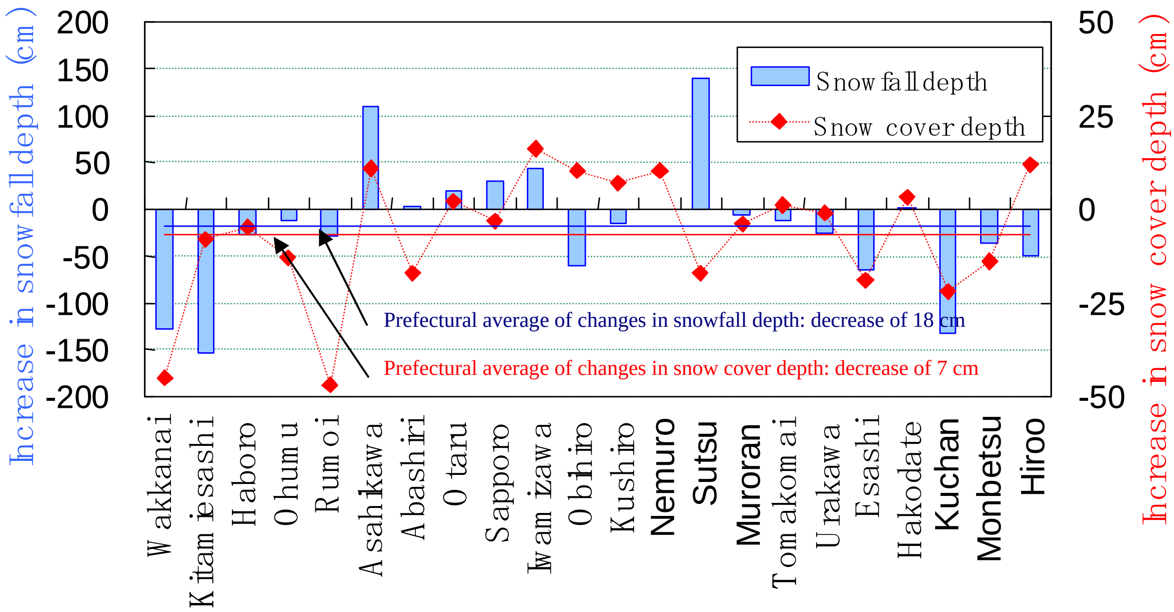


Figure 4: Increases in snow cover and snowfall depths at weather stations throughout Hokkaido

Snow cover or snowfall increase = (mean winter depth between 1997 and 2006) – (mean winter depth between 1961 and 1970)

In the figure, significant decreases in snow cover and snowfall depths are seen in Wakkanai, Kitamiesashi, Esashi and Kutchan, while significant increases are seen in Asahikawa and Suttsu. At other weather stations, no significant changes are seen. Accordingly, it cannot be concluded that snowfall in Hokkaido generally increased or decreased compared with levels seen 40 years ago.

4. TREND ANALYSIS OF WEATHER MAP PATTERNS FOR HEAVY RAIN AND SNOW IN THE SNOW SEASON

This section considers the trend of weather map patterns when heavy snow or rain falls during the snow season. The target precipitation data were accumulated over the 46-year period between 1961 (when collection of digitized data began) and 2006, and were gathered from 22 weather stations and 160 AMeDAS stations throughout Hokkaido (AMeDAS data collection was started at different times by individual stations).

Table 1 shows the criteria used to identify heavy rain and snow events during the snow season, and Table 2 details the classification of weather map patterns. Table 3 gives descriptions of the weather map patterns indicated by the symbols listed in the subclassification category of Table 2.

Table 1: Criteria used to identify heavy rain and snow events during the snow season

Item	Identification period	Identification criteria	No. of events
Heavy rain	Dec.～Feb.	①Daily mean temperature≧0℃ ②Daily precipitation≧30mm	72
Heavy snow	Dec.～Feb.	①Daily mean temperature＜0℃ ②Daily precipitation≧30mm	126

(Snow was melted and measured in terms of daily rainfall.)

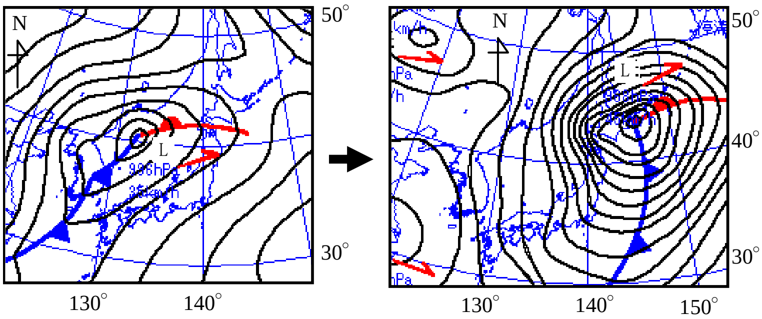
Table 2: Classification of weather map patterns

General classification	Subclassification	Subclassification conditions
Low pressure	Lj,Ln,Ls,Le,Lt,Lp,Ld,L	8 categories by path of low pressure
Winter pressure pattern	Mo,Mk	2 categories by position of low pressure
Small low pressure	S1,S2,S3,S4	4 categories by position of low pressure
Stationary front	F	

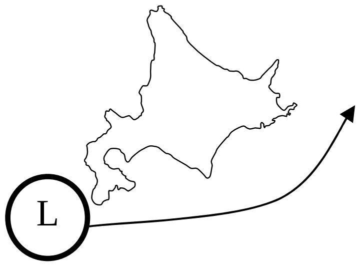
Table 3: Subclassification of weather map patterns

Lj	Low-pressure system heading northeast over the Sea of Japan before reaching Sakhalin
Ln	Low-pressure system heading east over the Soya Strait
Ls	Low-pressure system heading northeast over the southern coast of Hokkaido (off Sanriku)
Le	Low-pressure system heading north over eastern Hokkaido
Lt	Low-pressure system passing over the Tohoku region
Lp	Low-pressure system heading northeast over the Tokai region of mainland Japan
Ld	Hokkaido is sandwiched between two low-pressure systems (one over the Sea of Japan and the other over the Pacific Ocean)
L	Hokkaido is hit by a low-pressure system
Mo	Winter winds (low-pressure system situated over the Sea of Okhotsk to the west of the Shiretoko Peninsula)
Mk	Winter winds (low-pressure system situated from over the Kuril Islands to the Kamchatka Peninsula)
S1	Small area of western low pressure (low-pressure system situated off Haboro to the north of Cape Ofuyu)
S2	Small area of western low pressure (low-pressure system situated over Ishikari Bay to the north of the Shakotan Peninsula)
S3	Small area of western low pressure (low-pressure system situated off Hiyama to the south of the Shakotan Peninsula)
S4	Small area of low pressure (low-pressure system situated over the Sea of Japan)
F	Stationary front

As an example, subclassification Ls (aqua part) in Table 3 indicates the following weather map pattern:



This pattern shows a phenomenon in which a low-pressure system over the Sea of Japan develops while passing the south coast of Hokkaido toward the northeast.

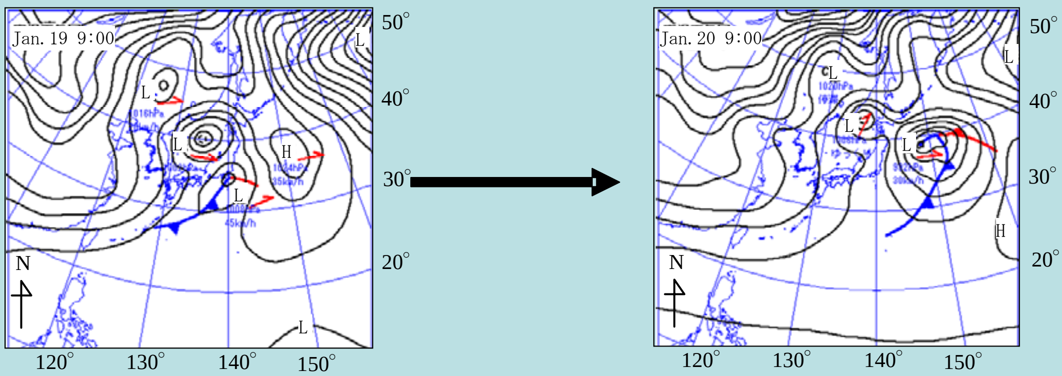


(L is a low-pressure system)

Figure 5: Explanatory diagram for the Ls pattern

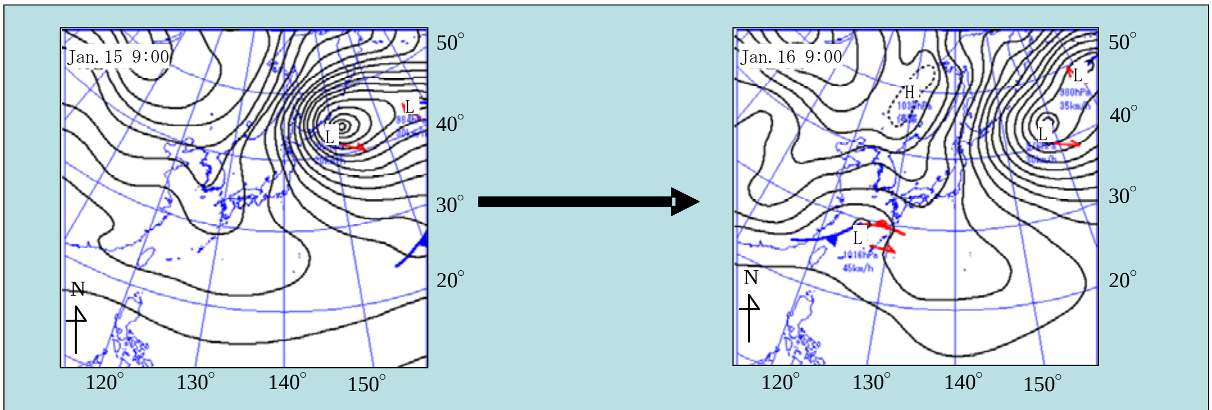
Figures 6 and 7 show examples of typical Ld and Mk patterns.

In the classification of low pressure in Table 2, “low pressure” (L) in the general classification category indicates heavy rain and snow events caused by traveling lows, and “winter pressure pattern” (M) indicates cases caused by the conventional west-high/east-low pressure pattern.



Ld (Hokkaido is sandwiched between two low-pressure systems): Jan. 19 – Jan. 20, 2004

Figure 6: Weather maps for the Ld pattern



Mk (winter winds with a low-pressure system situated over the Kuril Islands): Jan. 15 – Jan 16, 2004

Figure 7: Weather maps for the Mk pattern

Figures 8 and 9 show temporal changes in the numbers of heavy snow and rain events during the snow season, respectively.

From Figure 8, it can be seen that the frequency of heavy snow events was at its lowest in Period 3 of the last 46 years, but that it has increased again in recent years. In the figure, winter pressure patterns (a cause of heavy snow) are marked with blue frames, and the frequency of heavy snow events caused by such patterns shows a decreasing trend. On the other hand, the frequency of heavy snow events caused by travelling lows (marked with red frames) demonstrates an upward trend in and after Period 3 (i.e., in and after 1978). This is thought to indicate an increased incidence of the phenomenon in which travelling lows cause relatively warm airflow from the south.

In Figure 9, it can be seen that the frequency of heavy rain events during the snow season was also at its lowest in Period 3, but that the figure has significantly increased in recent years compared to levels seen 30 to 40 years ago. From the changes in the prefectural mean temperature for each period in the figure, it is also seen that the temperature in Periods 4 and 5 was approximately 1°C higher than that in Periods 1 to 3. This is thought to be the main cause of increased heavy rain during the snow season.

5. CONCLUSION

This paper summarizes changes in the long-term trends of snow season weather in Hokkaido.

Regarding long-term changes in winter temperatures in Sapporo, no significant increases were seen in daily maximum and mean temperatures, while a significant increase was seen in the daily minimum temperature. A similar trend was seen at other weather stations throughout Hokkaido. The depths of snow cover and snowfall have not significantly changed compared with the levels seen 40 years ago (although there were significant changes at some weather stations).

The summarization of the weather map patterns for heavy rain and snow events during the snow season showed a recent increasing tendency of heavy rain. It was also shown that the main cause of heavy snow has shifted from the conventional west-high/east-low winter pressure pattern to traveling areas of low pressure.

The long-term changes in weather factors shown here do not necessarily represent an immediate influence on global warming. However, as certain changes in weather trends were identified, further studies will be necessary.

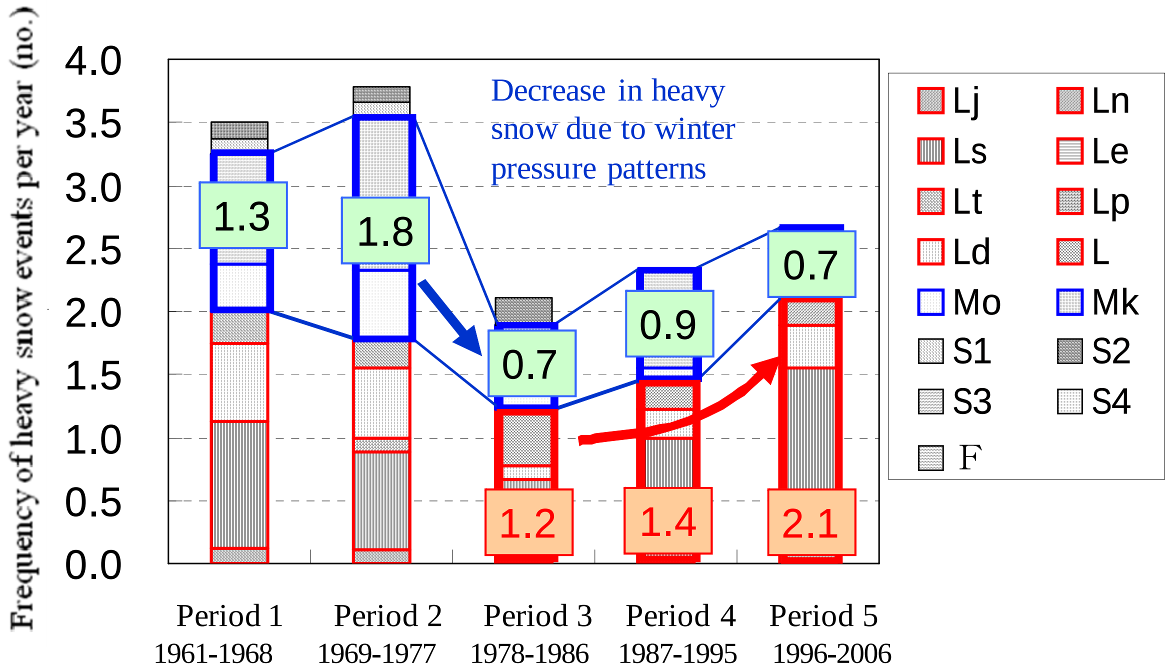


Figure 8: Temporal changes in the number of heavy snow events

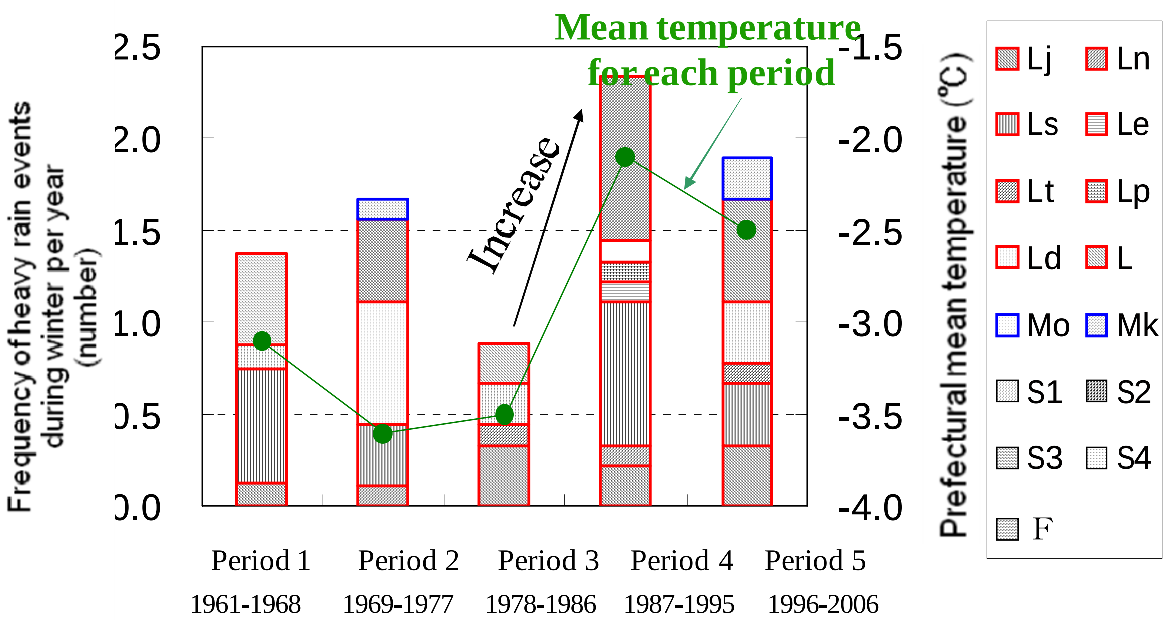


Figure 9: Temporal changes in the number of heavy rain events

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EFFECT OF CLIMATE CHANGE IN COASTAL BELT OF BANGLADESH

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ABSTRACT

The least developed countries like Bangladesh that is highly exposed to those disasters. The impacts of climate change on coastal areas in Bangladesh could be severe and in some areas catastrophic. It is estimated that a 1-m rise in sea level could displace nearly 15 million people from their homes in Bangladesh. Coastal areas include coastal plain islands, tidal flats, estuaries and offshore waters. It extends to the edge of a wide continental self. A vast river network, a dynamic estuarine system and a drainage basin intersect the coastal zone, which made coastal ecosystem as a potential source of natural resources, diversified fauna and floral composition, though there also have immense risk of natural disasters. There are six seasons in Bangladesh which is disappearing due to climate change. Summer & rainy seasons are prolonging, whereas winter season is shrinking. In Bangladesh, natural disasters have occurred frequently. Cultivable land has damaged by saline water intrusion from Bay of Bengal and every year rivers engulf enormous agriculture fields and homesteads, makes the peoples homeless. About 75% area of mangrove forest, Sundarban will submerse if the sea level will increase 45 cm. If the sea level rise 1 m then the islands of Bay of Bengal and whole Sundarban will destroy including its fauna & flora. Low-lying non-embankment coastal area may be completely inundated. It will increase the risk of coastal salinity. Rainfall patterns are changed due to climate change – crops yields are expected to drop significantly. More droughts are decreasing food production and increase malnutrition. Scarcity of saline free drinking water will increase highly. Death rate and diseases of fish will be increased. Production of sweet water fish will shrink and extinct if the sea level rise. More floods are contaminating water. Increasing water borne diseases such as cholera, diarrhoea etc. High salinity in water will affect human health. Finally, if the global temperature rises by 2° Centigrade, 30% of all land species will be threatened by an increased risk of extinction.

Key words: Bangladesh; climate change; cyclones; sea- level rise, coastal area; salinity

1. INTRODUCTION

Bangladesh is located in the north eastern part of South Asia between $23^0\ 34'$ and $26^0\ 38'$ north latitudes and $88^0\ 01'$ and $92^0\ 41'$ east longitudes. The country is bounded by India on the west, north and north-east and Myanmar the southeast and Bay of Bengal on the south (Figure 1). Bangladesh is likely to be one of the most vulnerable countries in the world to the impacts of climate change. This is due to its unique geographic location, dominance of floodplains, and low elevation from the sea, high population density, high levels of poverty, and overwhelming dependence on nature, its resources and services. Bangladesh has a long history of severe impacts from climate-related hazards such as floods, droughts, tropical cyclones and storm surges. Over the last ten years, Bangladesh has been ravaged by floods of catastrophic proportion in 1998, 2004 and 2007 (GoB, 2007). Despite the fact that the lives and livelihoods of the people living in the low-lying coastal areas and the islands (chars) in rivers and estuaries are frequently threatened by flooding and tropical cyclones, the fertile alluvial land is used intensively for agriculture which provides the main stake of the country's economy. The people and social system have knowledge and experience of coping with their effects – to some degree and extent. Variability in rainfall pattern, combined with increased snow melt from the Himalayas, and temperature extremes are resulting in crop damage and failure, preventing farmers and those dependent from meaningful earning opportunities. Climate change threatens settlements and the number of people displaced from their land due to riverbank erosion, permanent inundation and sea level rise is increasing rapidly every year. Bad weather keeps the coastal waters risky for fishing expeditions. Sea level rise in the coming decades will create over 25 million climate refugees. This is twice the entire population of the Netherlands

In fact, globally most of the coastal areas of the world are at risk from natural hazards resulting from geological and meteorological disturbances. In Bangladesh, coastal areas are ecologically sensitive and climatically vulnerable because of the continuous process of erosion and accretion. It also contains one of the largest (5000 sq. km) mangrove forests in the world. The coastal area covers over 6.8 million of households (Karim, 2005) in 147 Upazila (Sub-district) along the coastal belt, which considered as risk prone. Large-scale subsidence of coastal areas combined with climate change induced sea level rise results in a relative rise in sea level which is more than twice the predicted global rate. Das and Radhakrishna (1991) documented a rise in mean sea level in the Bay of Bengal of 2.5 mm per year since the 1950s. An additional increase of 15 to 38 cm is expected by 2050 (Kumar et al., 2002). Without the protection of low-lying coastal areas elevated sea levels could lead to large-scale intrusion of salt water into surface and groundwater systems. This could have serious implications for drinking water supplies and food production. Sea level rise may also result in drainage congestion and water logging in the delta during high flow periods in the three major rivers.

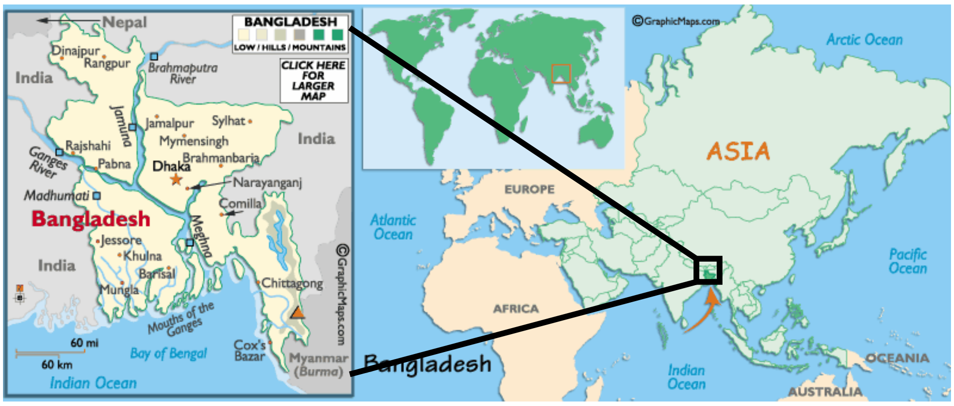

Figure 1: Map of Bangladesh (Source: GraphicMaps.com)

2. THE GEOGRAPHIC LOCATION OF COASTAL AREAS OF BANGLADESH

The coastal areas of Bangladesh is facing the Bay of Bengal with an area of 47,201 sq.km., covering 19 districts: Bagerhat, Barguna, Barishal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshimipur, Narail, Noakhali, Potuakhali, Pirojpur, Satkhira and Shariatpur (Karim, 2005). These coastal districts in particular are the cyclone prone area, and are shown in the following map of Bangladesh (Figure 2). It should be mentioned here that all 19 coastal districts have an estimated population of about 46 million, which is 33 percent of the total population of the country (WB: 2003). On the basis of physiographic characteristics, the coastal areas of Bangladesh can be grouped into three distinct categories, and these are: (i). Pacific type (Eastern Region): a narrow strip with a long sandy beach in Cox's Bazar, (ii) Atlantic type (Western Region): This region at Sundarbans is largely covered by mangrove forests; (iii) Central region: Ganges – Brahmaputra-Meghna river systems fall into the Bay of Bengal through Meghna (Haider et. al: 1991).

The topography of the coastal area is flat low-lying land having elevation mostly 3m above the mean sea level (msl). Geologically, the area suffers from subsidence to some extent, and this is due to consolidation of the new deposits of sediments and settlement of the base strata (Hoque: 1992). It is a part of the humid tropics with the Himalayas lying in the north and the funnel shaped coast touching the Bay of Bengal in the south. This type of geography of the country produces life-giving monsoons but also the catastrophic ravages of disasters.

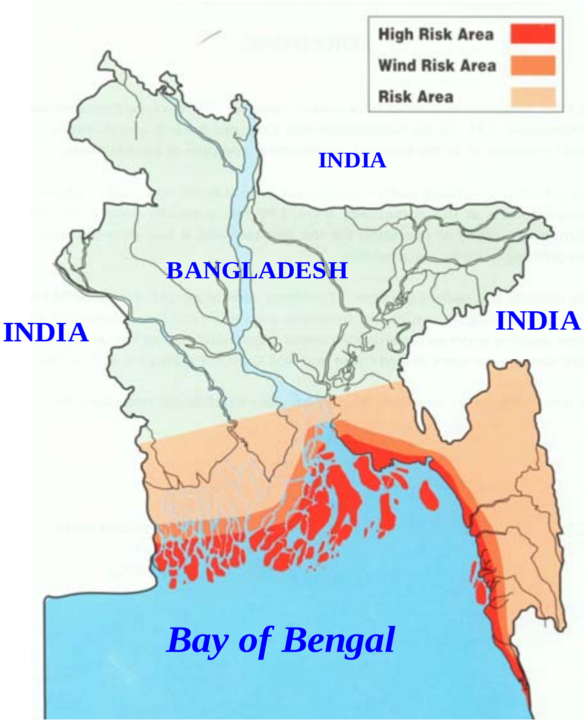

Figure 2: Map of Bangladesh showing coastal areas affected by cyclones and the major river system.

Therefore, the Bay of Bengal is the ideal breeding ground for tropical cyclones. Here severe cyclones occur mostly during pre-monsoon (April-May) and post-monsoon (October-December) periods. The cyclones generate surges up to a height of several meters, which sweep through the flat coastal region killing people, animal and destroy other fauna and flora. Records of last 200 years show that at least 70 major cyclones hit the coastal belt of the country. It is also recorded that during the last 35 years, nearly 900,000 people died due to catastrophic cyclones (Rahman : 2001).

3. OBSERBED CHANGE IN CLIMATE TRENDS AND IMPACT

Bangladesh is already evidencing the adverse impacts of climate change. The following impacts have been observed cited in various literatures (Karim, 2005; Ali, 1999; Shamsuddoha, 2007; GoB, 2007; Agrawala, 2003; Ericksen et al. 1997; Easterling et al. 2000). Summers are becoming hotter, monsoon irregular, timely rainfall, heavy rainfall over short period causing water logging and landslides, very little rainfall in dry period, increased river flow and inundation during monsoon, increased frequency, intensity and recurrence of floods, crop damage due to flash floods and monsoon floods, crop failure due to drought, prolonged cold spell, salinity intrusion along the coast leading to scarcity of potable water and redundancy of prevailing crop practices, coastal erosion, riverbank erosion, deaths due to extreme heat and extreme cold, increasing mortality, morbidity, prevalence and outbreak of dengue, malaria, cholera and diarrhea, etc. Intensity of Impacts on Different Sectors due to Climate Change are shown in figure 3.

4. FUTURE PROJECTION OF CLIMATE CHANGE IMPACTS IN COASTAL BELT OF BANGLADESH

4. 1. Sea level rise

Being a low laying deltaic country, Bangladesh will face the serious consequences of sea level rise including permanent inundation of huge land masses along the coast line (Shamsuddoha, et al., 2007).

There is a clear evidence of changing climate in Bangladesh which is causing changes in the precipitation, increasing annual mean temperature and sea level rise. World Bank's study on the impact of Sea level rise in Bangladesh reveals that, 100 cm sea level rise within next 100 years will inundate 15 to 17 percent of country's land area i.e. 22135 to 26562 square kilometers, which will make 20 million people environmental refugee. Again, 2 degree temperature and 45 cm sea level rise would increase 29 percent risks of flooding of country's low laying areas and may cause permanent inundation of 145 km long coastline stretches from Cox'sbazar to Badar Mokam. Finally, the risk of coastal salinity will increase, scarcity of saline free drinking water will increase highly and current agricultural practices will be changed.

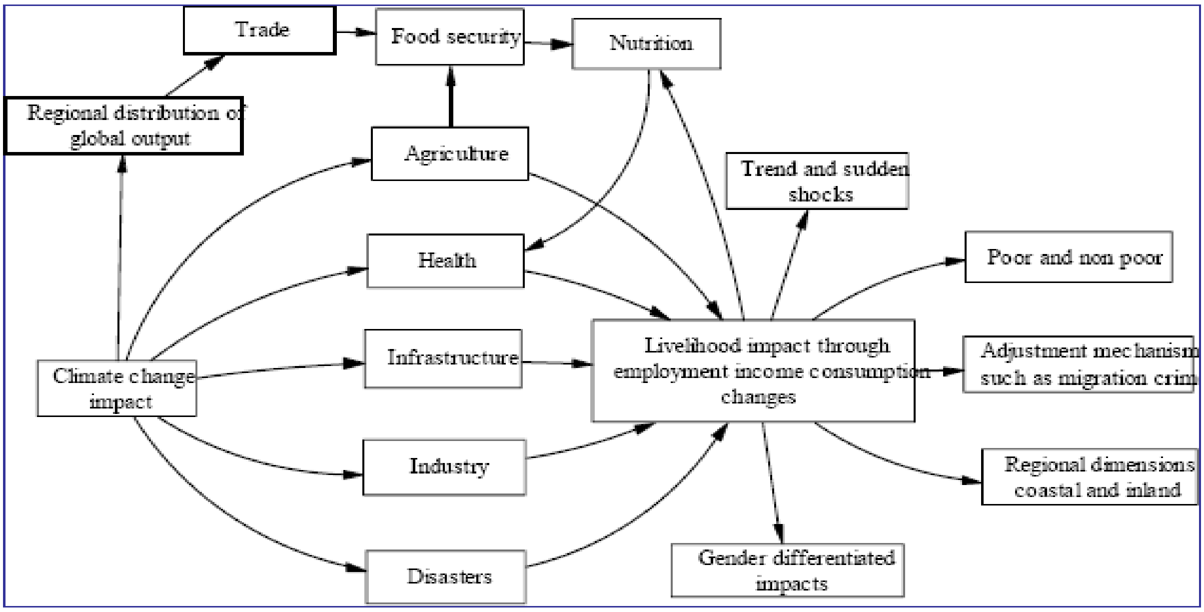

Figure 3: Intensity of Impacts on Different Sectors due to Climate Change

4. 2. Flood and Water Logging

Bangladesh has to receive and drain-out huge volume of upstream waters due to geographical setting. In the summer, the melting of glaciers in the Himalayans makes the rivers in Bangladesh live. Therefore, the combined effect of upstream flows, huge precipitation in rainy season and terrestrial run-off resulted to over flooding, causing water logging and prolong flood almost every year. Sea level is causing water level rise in the rivers and thereby accelerating risks of flood and water logging. Some areas are under risk of over flooding due to back water effect.

The problem of water logging might be more dangerous than flooding. Already many coastal places, where sustainable drainage network system hasn't developed, are facing water logging problem and the intensity of problem is appearing as a disaster day by day. Similarly densely populated coastal areas, Sundarban, the world's largest stretch of mangrove forest, is also vulnerable to the consequences of global warming and sea level rise. As the tidal flow and wave action is high in the mangrove forest area so only 45 centimeters sea level rises would inundate about 75 percent of forest area and 67 centimeters rise in sea level would submerge the entire Sundarbans. Though, in congruence with sea level rise, siltration process would cause relative elevation of Sundarban but this relative elevation might not be enough to combat the risk of sea level rise. In fact the risk of over flooding and inundation of Sundarban is still a concern.

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4. 3. Salinity

As sea level continues to raise the associated effects of permanent inundation is expected to increase the salinity near coastal areas. A recent study shows that 5 ppt saline front will penetrate about 40 km inland for SLR of 88 cm which is going to affect the only fresh-water pocket of the Tetulia River in Meghna Estuary (Shamsuddoha, et al., 2007). A big chunk of the fresh- water zone that will be disappearing due to sea level rise near to the estuary will have a far reaching effect on the country's ecology and will extinct some of its endangered species (marked by IUCN) for ever. In dry season, when the flows of upstream water reduce drastically, the saline water goes up to 240 kilometers inside the country and reaches to Magura district (Shamsuddoha et. al., 2007). Presently around 31 upazillas of Jessore, Satkhira, Khulna, Narail, Bagerhat and Gopalganj districts are facing severe salinity problem.

The anticipated sea level rise would produce salinity impacts in three fronts: surface water, groundwater and soil. Increased soil salinity due to climate change would significantly reduce food grain production. Agricultural activities as well as cropping intensities have been changing; now farmers can't grow multiple crops in a year. Even at present, some parts of coastal lands are not being utilized for crop production, mostly due to soil salinity; and this situation would aggravate further under a climate change scenario. A modeling exercise has indicated that, under the changed climate conditions, the index of aridity would increase in winter (Shamsuddoha, et al., 2007; Huq, et al. eds.1999). Consequently, higher rates of capillary action from an increased rate of topsoil desiccation would accentuate the salinity problem. Loss of biodiversity, e.g. decrease in tree species and freshwater fish, and creates socioeconomic problems, generally women will be more vulnerable.

4. 4. Salt water Intrusion

Salt water intrusion in Bangladesh coast is very seasonal. In the rainy season salt water intrusion is less than the salt water intrusion in winter due to extreme flow of fresh water. Saline water goes upward gradually in winter. In the rainy season where saline water ingress to 10 percent of country's area, in the dry season saline water reaches to country's 40 percent area even.

Due to changing climate the ingression of salinity might be increased through following way.

- Sea level rise will cause water ingression in the rivers. Decreasing trend of fresh water flow from the upstream will cause salt water intrusion.
- Upward pressure of the saline and fresh water interface in the level of underground Aquifer.
- Downward seepage of saline water from surface and salinisation of underground water. The pace of evaporation in winter will increase soil salinity.
- Frequency and intensity of tidal surges will increase ingression of saline water.

4. 5. Coastal Erosion

Erosion in the coastal area of Bangladesh is another big point of concern for Bangladesh. River erosion and loss of coastal habitable and cultivable land is an acute national problem and one of the major natural hazards. Although erosion does not cause loss of lives, but it cause huge economic loss; makes people asset and rootless but it is silent disaster. Heavy discharge currents through the Ganges, Brahamaputra and Meghna river system, wave action due to strong southwest monsoon winds, high astronomical tides, and storm surges in the Bay of Bengal are the main causes of erosion (and accretion) in the coastal area of Bangladesh. Superimposed on these causes, SLR has a long-term effect on coastal erosion in the country.

4. 6. Cyclones in Bangladesh Coast

The entire coastal zone is prone to violent storm and tropical cyclones during pre monsoon and post monsoon season. Therefore, the Bangladesh coastal zone could be termed a geographical 'death trap' (Shamsuddoha et. al., 2007) due to its extreme vulnerability to cyclones and storm surges. Nearly one million people have been killed in Bangladesh by cyclones since 1820. As many as 10 percent of the world's cyclone develop in the Indian Ocean but they cause 85 percent of the world's cyclonic havoc (Gray, 1968). The cyclone accompanied with torrential rain and devastating tidal surge causes havoc to lives and property in the cyclone path, and the environment in the affected area. In the islands and coastal mainland of Bangladesh the major aftermaths of a cyclone are loss of human lives, livestock's, fishes, agricultural properties and production, inundation of land and ponds by saline water, loss of houses, break-down of sanitation system, non-availability of safe drinking water and food stuff.

Approximately 45 damaging cyclones were reported in the coastal areas of Bangladesh from 1793 to May 1997, thus cyclone frequency during this period averaged once in every 4.5 years. Among which the devastating cyclones occurred are given in Table 1.

Table 1 severe cyclones hit at the coastal belt

Cyclone	**Location**	**Max. Wind Speed (km/h)**	**Loss of Life**
Oct- 1960	Shitakunda	208	5,149
May- 1961	Kalapara	142	11,468
May- 1963	Shitakunda	175	11,520
May- 1965	Patharghata	161	19,270
Dec- 1965	Cox's Bazar	175	873
Oct- 1966	Mirsharai	145	850
Nov- 1970	**Bhola-Noakhali**	**222**	**300,000**
Nov- 1974	Char Rangabali	161	20
Nov- 1983	Chakaria	122	-
May- 1985	Bashkhali	145	20
Nov- 1986	Sundarban	116	14
Nov- 1988	Sundarban	150	1,498
Apr- 1991	**Patenga**	**224**	**138,000**
Nov- 1996	Cox's Bazar	110	-
May- 1997	Patenga	200	-
Sep- 1997	Shitakunda	150	-
May- 1998	Patenga	165	-
Nov- 2007	**Patharghata**	**240**	**3,199**

The last devastation cyclones that hit Bangladesh occurred respectively 12 November 1970, 29 April 1991 and 15 November 2007. Cyclone in 1970 caused death of 300,000 people with a financial loss of USD 86.4 million. In 1991 cyclone an estimated 131,000 to 139,000 people died, with the majority of those dying being below the age of 10, and a third of them below the age of five; also more women than men died (Talukder and Ahmed, 1992). An estimated 1 million homes were completely destroyed, and a further 1 million damaged. Up to 60% of cattle and 80% of poultry stocks were destroyed and up to 280,000 acres of standing crops destroyed; 740 km of flood embankments were destroyed or badly damaged, exposing 72,000 hectares of rice paddy to salt water intrusion. The floodwaters brought disease and hunger to the survivors. The total economic impact of the cyclone was US$2.4 to 4.0 billion (Kausher et al., 1996).On the other hand cyclone SIDR that hit Bangladesh coast on 15 November 2007 caused death of 3199 people with huge economic loss estimated as USD 3 billion. The damage caused by cyclone SIDR is listed in Table 2**.**

4. 7. Coral bleaching and Fisheries

Corals are vulnerable to thermal stress. If the sea surface temperature increases 1-3° C then corals bleaching will occur frequently. Death rate of shrimp's fingerlings and diseases of fish will increase. Carps culture may reduce due to saline water intrusion in the ponds and open water bodies. Production of sweet water fish will shrink and extinct if the sea level rise.

Table 2: Damage caused by cyclone SIDR

Particulars	
Population affected	69,00,000
Total family affected	16,00,000
Death	3199
Missed	1180
Crop land damaged (hector)	16,10,000
Livestock perished	468000
Education Inst. damaged	9,248
Embankment damaged (Km)	614
Roads (both earthen and brick-built) damaged	89,428
Total economic loss	USD 3.00 b
Preliminary Assessment by Ministry of Food & Disaster Management, Source New Age on 26.11.07	

4. 8. Human health

The combination of higher temperatures and potential increases in summer precipitation could create the conditions for greater intensity or spread of many infectious diseases. Increased risk to human health from increased flooding and cyclones seems most likely. The climate change is expected to present increased risks to human health in coastal belt of Bangladesh, especially in light of the poor state of the country's public health infrastructure. Life expectancy is only 61 years, and 61% of children are malnourished (World Bank, 2002).Figure 4 shows the relationship between climate change and human health.

- More floods are contaminating water. Increasing water borne diseases such as cholera, diarrhoea etc.
- More droughts are decreasing food production and Increasing malnutrition.
- More greenhouse gases are increasing air pollution and rising respiratory diseases.
- Rise of temperature will favor for pest and pathogen that will increase dengue, malaria, diarrhea etc.
- Injuries, disabilities, psychosocial stress and death are becoming severe for more floods, fires, droughts, heat waves & cyclones.
- High salinity in water will affect human health.

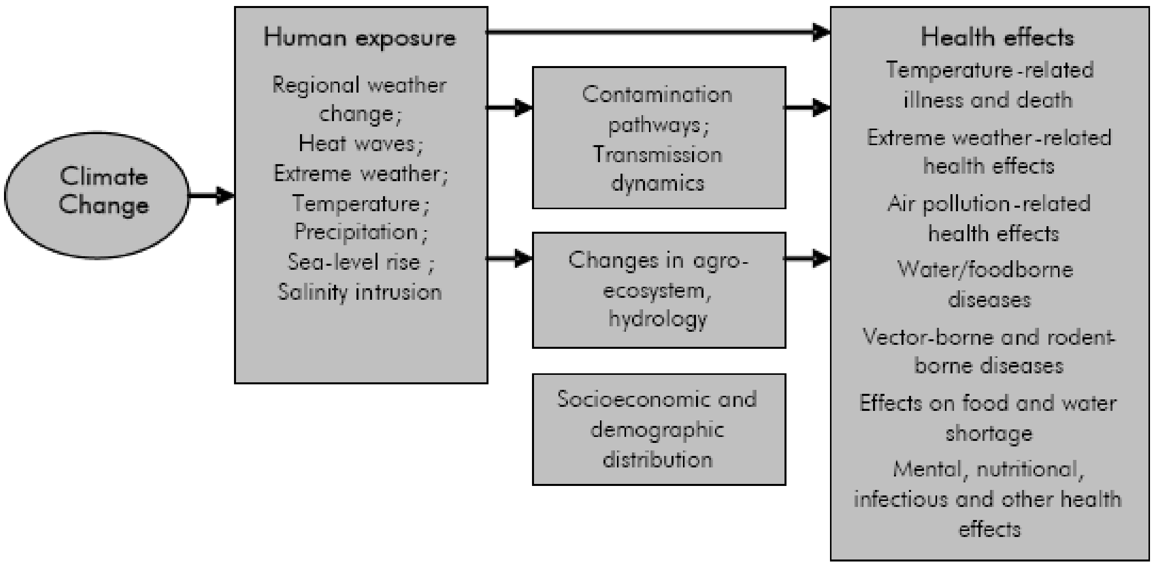

Figure 4: Relationship between climate change and human health (Source: WHO, 2003).

4. 9. Priority ranking of risks

Vulnerability is a subjective concept that includes three dimensions: exposure, sensitivity, and adaptive capacity of the affected system (Smith et al. 1998). The sensitivity and adaptive capacity of the affected system in particular depend on a range of socio-economic characteristics of the system. Several measures of social well-being such as income and income inequality, nutritional status, access to lifelines such as insurance and social security, and so on can affect baseline vulnerability to a range of climatic risks. Other factors meanwhile might be risk specific – for example proportion of rain-fed (as opposed to irrigated) agriculture might only be relevant for assessing vulnerability to drought. There are no universally accepted, objective means for "measuring" vulnerability. This section instead subjectively ranks biophysical vulnerability based on the following dimensions.

A score of high, medium, or low for each factor is then assigned for each assessed sector. In ranking the risks from climate change, the scoring for all four factors was considered, but the most weight was placed on the certainty of impact. Impacts that are most certain, most severe, and most likely to become severe in the first half of the 21st century are ranked the highest. The results of this analysis are summarized in Table 3.

Table 3. Priority ranking of climate change risks for Bangladesh

Resource/ranking	Certainty of impact	Timing of impact	Severity of impact[a]	Importance of resource
Water resources (flooding)	Medium-high	High	High	High
Coastal resources	High	Low	High	High
Human health	Low-medium	Medium	Medium-high	High
Agriculture	Medium	Low-medium	Low-medium	High

a. Note scoring is relative; significance is a function of severity of impact and importance of resource. (Source: Agrawala, et. al., 2003)

5. CLIMATE JUSTICE, REGIONAL CO-OPERATION, GLOBAL RESPONSE AND EXPECTATION

Climate Justice has both a global context and a national context. Globally, climate justice demands that today's developed countries compensate the poor developing countries for the sufferings imposed on them as a result of human-induced climate change caused by global warming due to GHGs emitted mostly by them. About 80% of the total accumulated GHGs in the atmosphere at the present time have been emitted by the developed countries. Also, even today, they are responsible for about 60% of the annual GHG emissions. It may also be noted that per capita GHG emissions is negligible for Bangladesh as compared to the developed countries and is not required by any international treaty or negotiation process to commit to any reduction targets or timelines. The developed counties have the main responsibility, in terms of justice and equity, to save the global human society and the planet. They must cut back sharply on their GHG emissions by, say, 80% by 2050.

Climate change is a development concern with severe implications in South Asia. All countries in the region are already affected by adverse climate impacts. Countries in the region need to prepare from now to manage what is unavoidable, and avoid the unmanageable. The South Asian countries, particularly the poorest in the countries, are already suffering from negative impacts due to extreme events and variability. Changes are already having major impacts on the South Asian economies and on the lives and livelihoods of millions of poor people. The impacts result not only from gradual changes in temperature and sea level but also, in particular, from increased climate variability and extremes, including more intense floods, droughts, and storms. Climate impacts will affect the entire population in South Asia in the coming decades, in one form or the other. Hence there lies the need for a systematic recognition across sectors and countries. Adaptation to climate change is already an urgent priority for Bangladesh - most vulnerable countries. Bangladesh and its people can become less vulnerable if sustainable development and other goals address and integrate climate risks. Developed countries who have obligations must ensure that adequate resources are available accessible in time to invest in sustainable development and also to make development resilient to negative impacts of the changing climate.

Key expectation from the global community is that equity is ensured, justice delivered, and commitments are adequate and in time while compensating climate victims, climate refugees, and helping those vulnerable to cope with climate challenges. Climate risk management and adaptation is a survival as well as development concern. The international community should ensure an equitable regime that proactively applies “precautionary” and “no regrets” principles while funding adaptation needs and priorities

6. CONCLUSION AND RECOMMENDATION

Climate change will worsen many of the existing problems and natural hazards that the country faces. There are various coping mechanisms, formal and informal, in place urgency of the matter to be integrated within the development process so that when the Climate Change impacts become more clearly discernible, the nation shall be ready to handle it. The strategic goals and objectives of future coping mechanisms are to reduce adverse effects of climate change including variability and extreme events and promote sustainable development. More promising anticipatory adaptations are changes in behavioral patterns, human practices and international actions. It is expected that proper planning, good governance can also mitigate or reduce any sort of hazard, migration and can increase the socioeconomic situation through different income generating schemes in collaboration of government, nongovernment and international agencies. In this regard following recommendations can be made for mitigating and reducing sufferings of the coastal people.

Future Coping Strategies and Mechanisms

- Development of Techniques for Transferring Knowledge and experiences from one area/ecosystem to another.
- Communication of adaptation measures to community Level.
- Monitoring of actual impacts of climate change (Then, we can target the problems for solution)
- Research to study problems and to find coping strategies.
- Strengthening of insurance mechanism for crop failures, losses due to cyclones, storm surges and natural hazards.
- An integrated system approach (Integration among Production system, Human System and Physical System) to deal with SLR.
- Strengthen integrated coastal zone management, focusing on protection, land use and water management.
- Develop a plan of action for awareness building. Prepare practical guidelines to include climate change issues in procedures for planning and design, and explore the possibility and feasibility of Climate Change Impact Assessments.
- Promote structure and support international activities.
- Emphasis must be given to disaster prevention and community preparedness measures for protection of human lives and properties.
- Construction of cyclone shelters should be well constructed with multi-purpose use, facilities and should be located at a place where access will be direct and easy during cyclone and storm surges.

- Forest belt should be developed along the coast. Facilities should be made to preserve sufficient amount of drinking water and be stored for post-cyclone use.
- GOs and NGOs should take infrastructure development and income generating schemes for the overall development of the costal belt.
- Must ensure peoples' participation in every planning and design of any developmental schemes.

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COMMUNITY-BASED VULNERABILITY AND ADAPTATION CAPACITY ASSESSMENT TO FLOOD RISKS UNDER THE IMPACTS OF CLIMATE CHANGE AND RAPID URBANIZATION IN HO CHI MINH CITY, VIETNAM

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ABSTRACT

This research focuses on assessing the vulnerability and capacity of coastal communities to flood risk under the impact of rapid urbanization and climate change, especially considering gender perspective when analyzing vulnerable groups in which the role of men and women should be analyzed in assessing their vulnerabilities and adaptive capacity in order to enhance resilience and reduce vulnerability. Two communities at two districts of Ho Chi Minh City (hereafter HCMC) were chosen as study areas in order to assess their different vulnerabilities to urban flood risk as well as their adaptation capacity to risks from flood and pollution. By applying Rapid Vulnerability Assessment (hereafter RVA) to assess direct and indirect vulnerability as well as the community-based adaptation capacity to flood, this research found that under same natural conditions, people living in more-urbanized community have to suffer more inundation and risks from polluted floodwater than those who live in less-urbanized district. Meanwhile, people in lower urbanized district are more vulnerable since they have low capacity to cope with flood and pollution due to flood-prone living conditions, poverty and lack of awareness on the changing variability and water pollution. This paper recommends that the climate change policy-makers should take into account the vulnerability and adaptation capacity assessment at community level for enhanced resilience of coastal communities to fulfill the knowledge gaps in understanding the physical, societal and environmental vulnerabilities subject to climate variability and assessing the adaptation strategies to support policy makers in integrative decision making process.
***Key words**: Sea level rise, Flood risks, Rapid Vulnerability Assessment (RVA), Community-based, Adaptation capacity, Urban water resources management, Water pollution*

1. BACKGROUND AND HAZARD CONDITIONS

The temperature in Vietnam has increased 0.6^{o}C within 40 years and the sea level has raised 6cm within 20 years (Dasgupta et al., 2007). Moreover, the sea water level monitored at 4 Vietnamese stations varying from 1.75 to 2.56mm/year that is in comparison with sea level rise in region and the world (Pham and Furukawa, 2007). According to Ninh (2007) and Yanagi and Akaki (1994), sea level in Vietnam is expected to rise up to 9cm (in 2010), 33cm (in 2050), 45cm (in 2070), and 1m (in 2100). Located in southern Vietnam, near the Mekong Delta River basin, HCMC is the largest and most developing city in Vietnam facing impacts of climate variability since the temperature will increase up to 3^{o}C and 50 cm increase of sea level in year 2070 (ISDR, 2005), increasing its vulnerabilities to possible sea level rise, extreme temperature, increasing natural disaster, and critical pollution especially to the water resources.

Since October 2004, there have been many heavy tides, causing 41 broken dams and flood to 484.5ha, affecting life of over 1,382 residents at 14 wards of 7 districts along Saigon River. The recent flood in August 2008 also caused serious effects to resident life in HCMC particularly transport and urban infrastructures. HCMC Flood and Storm Prevention Agency (HFSPA) has provided statistics on the damages of some common hazards to HCMC such as storm, whirlwind, landslide, as well as high tide and heavy rain. These effects have caused extreme losses to human being and livelihoods; infrastructure (houses/buildings, roads, irrigation systems, dykes); agricultural and aqua-cultural activities; as well as construction. Among these common hazards, storm caused the most serious monetary losses while high tide and heavy rain extremely affected houses and agriculture. The total monetary losses within 10 years were nearly 12 million USD (Le, 2007 and Pham, 2007).

While climate variability is being a critical topic for not only scientists, researchers, governments at different scales but also communities; residents in HCMC is now recognizing the potential impacts of climate change related risks to their health and livelihood, especially become worsen under its low land conditions and effects of rapid urbanization on the city. The population of the city is increasing rapidly, 4 times increasing within 50 years (2 millions in 1950 and nearly 8 millions in 2005), which is estimated to be 12 millions in 2020 without and relevant policy and regulation (ISDR, 2005). Compared to the population situation in 1990, the increasing population is expanding to the more lowland areas that are very near to the river and water surface systems, putting pressure on the natural environment, urban infrastructure and services.

2. RESEARCH METHODOLOGY

2.1 Summary of literature review

Coastal cities, located on coasts and rivers under the urbanization and migration of population, are having urban vulnerability to climate change and rapid economic growth. Rapid developing Asian coastal cities; under the condition of overpopulation, debilitated ecological base, over-dependence on climate-sensitive sectors, inequities in access to resources and wealth among groups, weak socio-cultural infrastructural, financial/market, legal and governance structures; face many serious problems such as land subsidence and flooding; loss of marine and other ecological resources; lack of basic water supply and sanitation services; municipal and industrial effluent; solid and hazardous waste disposal; and increasing water tables under the impact of sea level rise, etc. Potential impacts of climate change in many development sectors are known but adaptation strategies are lacking due to reasons such as lack of common understanding in the concept of vulnerability especially between men and women, and no common standing points to approach the vulnerability.

The key to adaptation in most instances is competent, capable, accountable urban governments that understand how to incorporate adaptation measures into most aspects of their work and departments. The relationships of risk, hazard, and disaster are determined for the urban environmental vulnerability assessment, focusing on adaptive capacity and systemic properties and solutions can be found in sustainable development. However, in term of flood disasters, the impacts to water quality has not been identified and paid attention. In contrary, the important role of water quality during flood must be determined and aware by the communities, policy makers, and leaders. Any understanding gaps on the vulnerability of water quality in the flood related risks must be fulfilled in order to develop appropriate adaptation strategies.

2.2 Research methodology

This study used RVA process with the Floods Impact Assessment instrument adapted from ZVAC (2007 and 2008) for the identification of human and environmental vulnerability to flood risk as well as the interaction among human and environmental sectors under the impacts of flood. Mixed method was employed in the research with qualitative was predominant method. Qualitative method was utilized firstly to give prior knowledge on the concepts of vulnerable city including social, economic and environmental vulnerabilities; impacts of floods to the city; adaptation capacity against vulnerability; and methods to prevent, prepare, mitigate and respond those disasters and hazards. This method was also be applied to deal with data collected from HCMC Government about their existing flooding management, the information about adaptation capacity against flooding, as well as water resources management of the city. Quantitative method was used to depict the quality of Saigon River and related canals/streams, the existing environmental vulnerable situation of HCMC in terms of information about regular flooding, water pollution, impacts and consequences of previous flooding events, and activities as well as programs that the city's Government already carried out in the past to prevent, prepare, mitigate and respond to those impacts.

Primary data collected by focus group structured interview to residents in study areas through RVA to understand their awareness on regular and recent unexpected floods, their vulnerability and adaptation capacity to floods, and determine what changes have been taken place in term of urban environmental management within their communities recent years. The fieldwork data collection had been done within 5 days for 40 households in two communities of District 2 (Thao Dien Ward) and Binh Thanh District (Nguyen Huu Canh Street, Ward 22) with male and female interviews to ensure gender equity in getting information for the research. Secondary data about impacts of floods to the city, existing flooding management, adaptation capacity against vulnerability; and methods to prevent, prepare, mitigate and respond those disasters and hazards that was collected by document review and individual unstructured questionnaire interviews with experts/staffs in related agencies. This research applied the gender analysis based on the Capacities and Vulnerabilities Analysis Matrix (March, 1999) and Gender Conscious Assessment (ADPC, 2004). The matrix helps in analyzing the different vulnerabilities and capacities of men and women in terms of physical/material, social/organizational, and motivational/attitudinal factors.

3. RESEARCH RESULTS

3.1 Vulnerability to Flood Risk

3.1.1 *Data collection and analysis*

Table 1: General characteristics of two focused districts

Criteria	Unit	District 2	Binh Thanh District
Location		southeast area of East side of Saigon River	central area of West side of Saigon River
Population	Persons	145,136	446,397
Population density	Persons/sq.km	2,917	21,674
Total number of ward	wards	11	20
Total Area	Km^2	49.74	20.8
Topography	m	≤ 1.5	≤ 2.0
Natural land surface	Km^2	15	3
Total number of road	Roads	120	290
Number of flooded road	Roads	30	116
Total number of houses	Houses	30,000	110,000
Number of flooded houses	Houses	6,000	33,000

Source: Data collected during interview, 2008

Two communities in District 2 and Binh Thanh District were selected to represent different vulnerabilities to flood risks under the impacts of climate change and levels of urbanization, as key characteristics given in Table 1. The two districts are located close to the Saigon River affected directly from river tides and other natural changes. The two study communities have differences in terms of social and economic activities, such as more industrial activities in community of Binh Thanh District than District 2 with mostly commercial activities, domestic construction and transportation (Tu, 2009).

Rapid Vulnerability Assessment (RVA) was conducted to collect data for analyzing the direct vulnerability of society (including human health and movement, housing and road, and communication and transportation) and environment (including water resource quality and quantity, sanitation). Moreover, the RVA also provided information in assessing the residents' perception about impacts of flood to their livelihoods, their awareness on the vulnerability to flood risks, as well as their adaptation capacity to cope with impacts of flood and polluted water.

Secondary data collected by document review and individual unstructured questionnaire interviews together with primary data collected by focus group structured interview to residents in study areas through RVA to understand their awareness on regular and recent unexpected floods, their vulnerability and adaptation capacity to floods, and determine what changes have been taken place in terms of urban environmental management within their communities recent years. Male and female residents were interviewed to ensure gender equity in getting information for the research.

3.1.2 *Comparative assessment results*

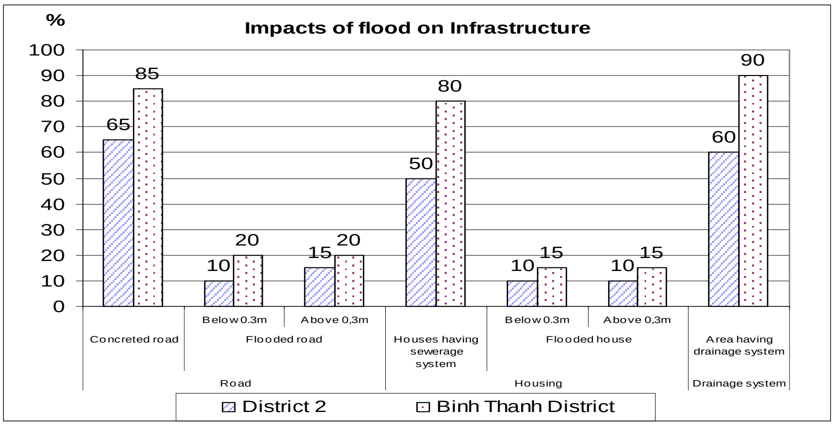
The results from RVA show that study areas in Binh Thanh District and District 2 have the same flood characteristics in terms of meteorological factors. However, Binh Thanh District has less natural surface infiltration capacity and more channel network than District 2 that make it more vulnerable to flood and pollution than District 2. In terms of human factors aggravating natural flood hazard, both communities have changed in land use, with the sealing surface due to urbanization and deforestation, and increase in the runoff ability and sedimentation. While District 2 has changed from agricultural to domestic use, Binh Thanh District has used land for industrial and commercial activities together with domestic use. Most of the floodplain areas in these two districts have been occupied by informal houses and construction sites.

Results from RVA show that, among 100 existing flood points in HCMC, more than 25 points are in Binh Thanh District, with 30% population affected in 9 wards out of 20. This is because most people in the district are middle class and poor - historically, they are living along canals and river bank. When the economy grows, the district has been urbanized into one of important industrial zones. As a result, more people migrate to the district, deforestation occurs, and land is concretized reducing natural infiltration capacity. Day by day, under the impacts of urbanization and climate change, they are more and more vulnerable to pollution and floodwater.

In District 2, 20% population is affected in 7 out of 11 wards, and 10% of flood points in HCMC are in this district. There are two different groups in District 2: poor people who have lived for a long time and rich people from other places who have just bought land to build resorts and high buildings. Urbanization has occurred in this district, reducing the natural condition and environment, and has caused inequity in terms of facilities and services among residents. Poor people with worse living conditions become more vulnerable to flood risks. The impacts of flood on infrastructure can also be observed. The number of road/land that are concretized, number of households having sewerage system, and number of area having drainage system are some indicators to assess the vulnerability.

According to results from RVA, as also given in Figure 1, Binh Thanh District is more vulnerable to flood than District 2 in terms of road, housing, and drainage system. Binh Thanh District has more flooded road below and over 0.3 m – the water level at which human transport and movement are obstructed while people are more vulnerable to polluted floodwater in terms of their properties, health, and also risk from electrocution. Although Binh Thanh District has more households with sewerage and drainage system, records show that more houses are flooded in the district rather than District 2.

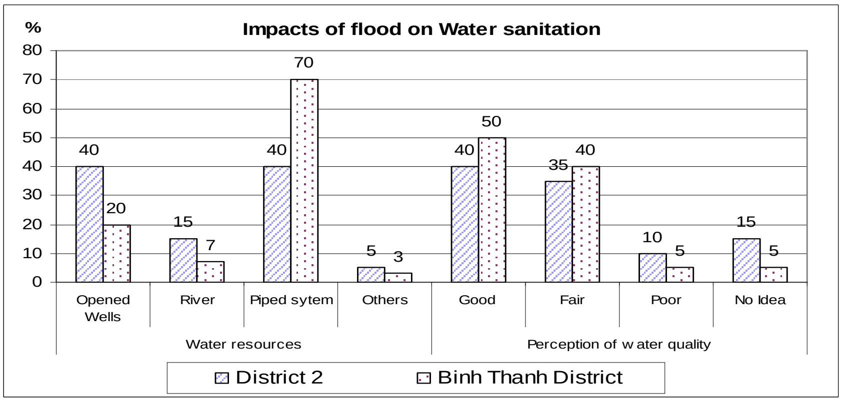
From interviewing people in chosen communities in both districts, there are different perspectives about the impacts of flood to water quality and their health. Rich people use pure water from piped water supply system, and discharge wastewater into sewerage system, through drainage system and to the river. Poor people mostly use water from wells (either protected or unprotected) and river, and discharge wastewater directly into canals and river. Therefore, poor people are more vulnerable to floodwater and pollution when flood occurs.



Source: Data analyzed from interview, 2008

Figure 1: Impacts of flood on infrastructure

However, in some cases, the vulnerabilities of rich people are also increased due to pollution caused by poor people. Since inundation in HCMC is due to urban flood rather than flash flood, there is no need people are not aware that they are more vulnerable to flood in terms of water pollution and impacts on health. The results from interviewing 40 households in the two communities, about their vulnerabilities and impacts of flood to water sanitation and their health, are quite different among the two communities (see Figure 2).

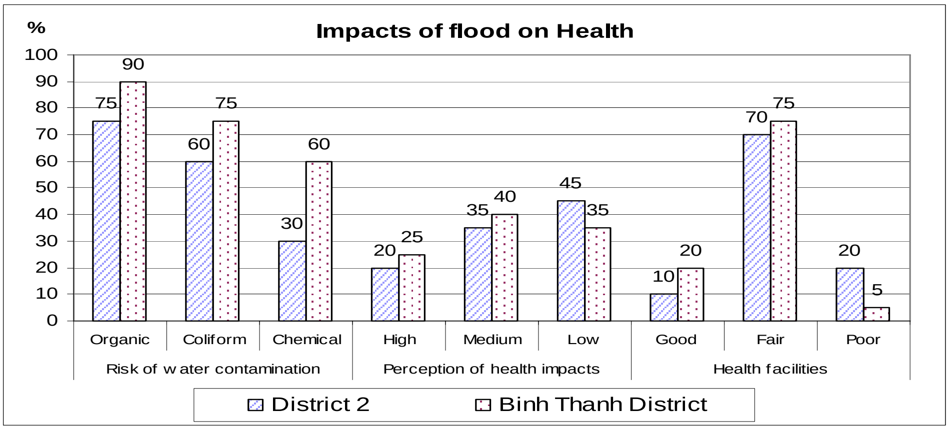


Source: Data analyzed from interview, 2008

Figure 2: Impacts of flood on water sanitation

Their perceptions on water quality and risk related to health are still lower than in the monitoring reports because they are not really aware that polluted floodwater may damage their health. They just observe that the water color is black or gray, having smell or not; rather than detail and specific information on the pollution within their living areas. The results show that both communities are vulnerable to water pollution because they have to face regular flood bringing polluted water closer to their lives, and lack of health facilities as well as access to existing facilities. Residents in Binh Thanh District seem to be more aware about water pollution and impacts on health, while people in District 2 have to live more vulnerable but less health facilities (as illustrated in Figure 3).

In term of vulnerability to flood at the same time and same level of inundation, women are more vulnerable than men in health, especially during their monthly periods or pregnancy. For those women who use private transports such as motorbikes and cars and being trapped by floodwater on the street, they are more vulnerable in paying repairing fees because most of them do not know how to fix the machine that they have to pay money for those people who take advantage of the pedestrian to earn money from fixing the broken transports. Moreover, these women may also be vulnerable to sexual harassment during the night time being trapped in floodwater with few people around.



Source: Data analyzed from interview, 2008

Figure 3: Impacts of flood on health

3.2 Adaptation Capacity

3.2.1 *Community-based adaptation capacity*

Table 2: Community-based adaptation capacity in the study areas

Factors	Community in District 2	Community in Binh Thanh District
1. Physical/Material factors		
1.1 Location	Both focused communities are located at low land area nearby the riverbank (at two side of the Saigon River)	
1.2 Structure of buildings/houses	Simple structure of houses with concrete and level of 1 or 2 floors	Concreted houses with up to 3 floors with higher design
1.3 Extent and quality of infrastructure and basic services	Roads are concreted with few drainage systems and drinking water supply	Roads are concreted with enough but old water supply and drainage systems
1.4 Human capital	Low-income level with less than 100 USD per month (main labor)	Higher level of income with about 200 USD per month (main labor)
1.5 Environmental factors	Water in the canal is black, stinky, and occurs oil layers on the surface. Lack of wastewater and solid waste management	Water in canal is also black and stinky. Even there are solid waste collection facilities, garbage still flow onto canals
2. Social factors		
2.1 Family or kinship structures (weak/strong)	Women and children are most vulnerable because of their roles in the family, they are at home most of the time and they have to handle problem of inundation and pollution in longer time	
2.2 Gender and age	Women, the elderly and children have lower capacity to adapt because of physical power	
3. Motivational/Attitudinal factors		
3.1 Attitude towards change	Most of them are aware that flood is natural phenomena. However, they do not pay much attention on the change in flood's magnitude as well as rainfall and water level.	
3.2 Awareness about hazards and consequences	They are not aware about the consequences and impacts of increasing magnitude of rainfall, inundation and pollution in their communities. Therefore, they prioritize their properties rather than their health and sanitation as well as water supply.	

Source: Data analyzed from interview and focus group discussion, 2008

Residents in focused communities are aware that flood is regular phenomena they have to face. They also observe that blocked drainage system makes the flood situation more serious, and the intensity and magnitude of flood have been increased. However, their current concerns when flood occurs are their properties, access to services, and transportation rather than health impacts. Therefore, their basic adaptation solutions are to prevent and reduce floodwater flowing into their houses by sand bags or concrete walls, rather than protecting water resources. In general, individuals in focused communities have limited adaptation capacity because of low awareness in considering flood and polluted water as serious problems. Their vulnerability characteristics, in other words, factors affecting their adaptation capacity, are physical, social, motivational and attitudinal issues. These factors have interrelationship that influencing each other and may increase the vulnerability of people to flood risk and water pollution. Table 2 presents the factors affecting adaptation capacity and the actual capacity of focused communities in the two districts, as well as demonstrates clearly their vulnerabilities. The major factors are occupation, traditional living culture, physical ability (gender, age), and their poverty (income).

3.2.2 *Organizational/Institutional adaptation capacity to flood risk*

One of the most important issues that limit the organizational adaptation capacity at city level is the lack of appropriate attention and investment to make changes in reducing and minimizing flooded points. Table 3 indicates the organizational/institutional factors that affect the adaptation capacity to flood risk in HCMC as well as the actual capacity of HCMC in adapting to flood risk and water pollution issues.

Table 3: Organizational/Institutional Adaptation Capacity in HCMC

Factors	Adaptation Capacity
Economic activities	Rapid urban development and economic growth have put pressure on infrastructure and services, increasing the concretization process that reduce the infiltration area and increase the water flow rate.
Organizational structure in developing project management	Ineffective organizational management in project planning, implementation, monitoring and evaluation; especially developing project to maintain and improve the drainage system, water supply system, and sanitation.
Legislation	Lack of strict regulation in inspecting, punishing, preventing the illegal flattening of river and waterways with blur responsibility of city's government and local bodies.
Administrative structure and institutional arrangements	Lack of appropriate cooperation among related department and government bodies such as Department of Transport and Public Works, Department of Natural Resources and Environment, Department of Agriculture and Rural Development, Project Management Units, etc.

Source: Data analyzed from interview and focus group discussion, 2008

3.3 Gender analysis results

Living in flood-prone areas, men and women can save money from buying land to support for other purposes. However, they become more vulnerable to flood risk under the impacts of climate change and rapid urbanization. The research has developed the gender analysis in vulnerability and capacity assessment, perception on risks, as well as different roles of women and men in adapting to flood risks. In the flood risk assessment, the research found out that both men and women living in the same area may face the same possible hazards but they have different risks because their vulnerabilities and capacities are different. Men tend to have higher ability to access to information and services/resources as well as earning more money. Having lower physical capacity, women are more vulnerable to health and sexual harassment once they are trapped on the flooded road especially in night time. Moreover, they have longer time suffering to flood risks due to their roles in the families as well as different occupation, cultural barriers, social/cultural beliefs, and attitudes. In some cases, these responsibilities are benefit for women because they may gain more experience in understanding

the situation of their family to flood that increase their capacity buildings in order to have appropriate adaptation actions.
Moreover, the perception of men and women on flood risks, both men and women consider flood as natural phenomenon that is increasing in magnitude. Moreover, men and women determine the causes of flood differently depend on their own understanding and observation. While men observe during their ways to work that flood in their living areas is because of inadequate drainage systems and ineffective on-going sanitation projects, women experience that flood is caused by more frequent and heavy rains together with higher tides from river because they stay at home most of the time. Their perceptions on possible risks of flood and pollution are also different, especially in term of impact on heath. According to both men and women, flood affects their properties, income, transportation, access to services, and even lives due to electrocution. However, only women do really concern that floodwater may affect their skin and health as well as the water resources of the community.

In analyzing gender participation in adaptation process, this research also focus on understanding their different needs; their active roles before, during, and after flood occurs; as well as in decision making process. Furthermore, the analysis also identifies the impacts of adaptation strategies to the changes of women and men in terms of labor, time, resources, and culture indicators. Both men and women participate in reducing the risk of flood as well as to adapt to flood risk such as preparing basic needs, repairing and cleaning houses, joining community meeting; in which men still dominate especially in decision making process. Moreover, the effect of adaptation strategies on women and men also was analyzed especially in terms of change in labor, time, resources, and cultural behavior. Men will have better understanding on the situation of their family and themselves to flood with higher participation in the community, sharing the work and responsibility with their wives that reduce the time for themselves. Besides, women can increase their roles not only in their families but also in the flood risk management of their communities for decision making with higher accessibility to resources and information as well as training related to flood risk management.

These gender analyses help to understand the difference in vulnerabilities, capacities, perceptions, and roles of men and women so that the adaptation measures and decision making process can be done effectively and unbiased as well as considering the potential effects of these measures and decision differentiate to men and women.

4. FINDINGS AND RECOMMENDATION

Under similar natural conditions that are affected by changing climate, residents in District 2 is vulnerable to floodwater differently from people who are living in Binh Thanh District because these two districts have different level of urbanization and infrastructure conditions as well as economic activities. Not only having difference in vulnerability of residents to flood between the two districts, there is also different vulnerabilities among people in each of the districts depended on their gender and age, attitude and motivation, occupation and income, their living locations and conditions. Supported by simple assessment tools, the adaptation process with three man phases of determining and assessing vulnerability factors, identifying adaptation options, and assessing adaptation strategies could be developed and used in this case study.

This research has developed better understanding on the vulnerability of representative communities in different levels of urbanization to flood risk as well as their adaptation capacity under the same natural conditions. It was found out that HCMC, due to its location near Saigon River, is vulnerable to flood under the impacts of climate change especially South China Sea level rise in relations with rapid urbanization in the city that increase its own vulnerability, to water resources, human health and livelihood in particular, as well as economic activities. Moreover, this research has contributed for better understanding on the theme “Vulnerability, impact, and adaptation assessment” identified by Great Lakes Water Quality Board for researches on climate change, beside monitoring, surveillance, and analysis; climate change scenarios; model development; economic assessment; adaptation; and communication.

The adaptation process including the VCA can be applied for other countries having different contexts at different levels (from national and/or program level to community and household levels) under different projected climate change related risks. Moreover, it can also perform a range of functions in scoping and screening, baseline studies, as well as in monitoring and evaluation of projects. This process should be supported by additional effective tools that require good baseline data, higher trained skills and finance such as multiple vulnerability assessment tool and benefit-cost-effectiveness analysis. Practically, the HCMC Government should cooperate with local government and other related agencies in providing warning systems to inform people about the flooded road line to avoid congestion, especially during out-of-work time. Not only considering the vulnerability of surface water resources to flood risks, there is also a need of further research about the impacts of flood to groundwater resources, especially at the shallow level; mostly direct impacts from flood to surface water quality, and direct effect from surface water quality to groundwater quality.

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ISSUES OF GROUNDWATER MANAGEMENT IN ASIA REGION

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ABSTRACT

Groundwater is and has been a reliable resource for drinking and other needs both in terms of quantity and quality. However, this valuable resource is now under severe stress in many parts of Asia as a result of poor management in the course of socioeconomic development. Problems such as water table drawdown, decreasing well yield, land subsidence, and salinity intrusion that have emerged as the results of overexploitation of groundwater is common. Today it is well understood that these problems are either irreversible in nature or require extended periods to abate and therefore, it is of utmost importance for these cities to adapt to the prevailing conditions and make necessary changes in management to conserve this precious resource while taking full advantage of it.

The overexploitation of groundwater has already created many problems in cities such as Tianjin, Bandung, Ho Chi Minh City (HCMC), Bangkok, Colombo and Kandy. For example, the cumulative groundwater drawdown in Bandung over the last 50 years exceeds 84 m and the cumulative land subsidence in Bangkok exceeds 93 cm. As some of these groundwater problems are still not well recognized, in cities like Ho Chi Minh City experiencing rapid population and economic growth still is dependent more on groundwater to meet the growing demand for water. Therefore this investigation was focused in assessing the strategies taken by these cities to overcome these problems and their effectiveness.

The review of the history of adaptation to groundwater issues in case study cities indicate four major elements in groundwater management: (a) regulations to control groundwater use, (b) provision of alternative water, (c) economic incentives/disincentives to control groundwater use, and (d) encouraging water saving. However except in Tianjin, the available policies do not adequately include supporting measures for water saving activities as a main management element of groundwater. Rather than the promotion of water rationalization, the provision of alternative water resources with groundwater abstraction control has often come first as a countermeasure. Though this approach has some success in Tianjin and Bangkok it had filed in Bandung. Main reasons identified in this regard include lack of alternative sources and the insufficient amount of taxation. Therefore, the obtained results show that such reliance on alternative resources without a change in the water- use patterns is less successful. For example the experience in Osaka the promotion of water rationalization through the reuse and recycling in groundwater management is a good example for the other cities. In addition during the investigation it was well recognized that the groundwater management in the region is needs much more improvement. In this regard, important aspects such as promoting the rational use of water, strengthening pollution control measures and its strict enforcement and the need to consider groundwater conservation at urban planning is vital to make the groundwater resource sustainable and for people to adopt to the problems in the region.

1. INTRODUCTION

The reality that the world faces severe water shortages has become increasingly clear in recent years. Challenges remain widespread and reflect severe mismanagement of water resources in many parts of the world. According to the UN World Water Development Report 2004, the continuous increasing water withdrawal trends globally implies that the water stress will increase significantly in well over 60% of the world. Of the regions, the Asian-Pacific being the region with the highest economic growth rate, has witnessed continuous depletion and degradation of its freshwater resources. Moreover the recent climatic variations experiencing in the region could make the condition worse in the future. Particularly in most urban centers in Asia-Pacific, the water scarcity is strongly inclined by the urbanization, rapid population and increase economic growth. As a result, water abstraction in the urban areas has recently shifted from agricultural sector to domestic and industrial sectors to cater the increasing amount of residential supporting activities.

In year 2000, twenty-three cities with more than 10 million populations around the world have being classified as megacities. Notably, of the twelve most populated cities around the world eight are in Asia. According to the UNEP (2003), over half of these megacities was relying upon, or make significant use of, local groundwater. This is because, among water resources available, groundwater has played a very important role in development of these cities as it provides reliable, high-quality and low-cost water for all domestic, industrial and agricultural purposes. In addition its importance stems from its ability to act as a large reservoir of freshwater that provides "buffer storage" during periods of drought. As per the most recent figures available, the total contribution from groundwater for global drinking water as of year 2000 was almost 46% (WWDR3 2009). China alone had more than 500 cities, and two-thirds of the water supply for these is drawn from aquifers. In addition the contribution towards other sectors irrigation water demand and the industrial water demand from groundwater accounts for 17.4 % and 12.5% of the totals respectively. Adding these contributions totals to 18.25% annual water withdrawals (WWDR3 2009).

Increased groundwater uses in the world as well as in Asian region however, have intensified the stress placed on this precious resource. Figure 1 shows the estimated extent of groundwater used for drinking water in Asia. In response to the growing demand for water, often groundwater has being haphazardly over extracted with no due consideration given to the possible consequences. Water level drawdown sometimes associated with land subsidence is observed as a negative result of overexploitation. Such negative impacts are irreversible or take long time to recover. In addition, aquifer contamination due to both natural and anthropogenic reasons also is a serious concern. In most Asian cities such groundwater problems have caused considerable concerns. Thus, With the significance of sound groundwater management in Asian cities in mind, the groundwater management polices and practices adopted in several Asian cities is compared in this investigation to highlight the groundwater management issues, adaptation strategies and its successes in the region.

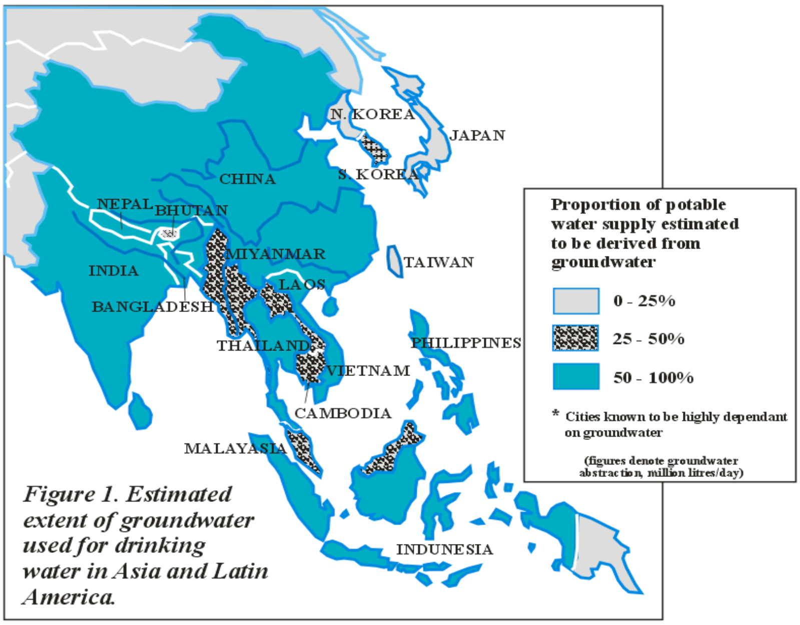


Figure 1: Groundwater Use in Asia (Source; UNEP 2003)

2. STUDY AREA

The selected six Asian cities for this investigation include; Bangkok, Thailand; Ho Chi Minh City, Vietnam; Bandung, Indonesia, Tianjin, China and Colombo and Kandy Sri Lanka (Figure 2). In addition the groundwater management in Osaka Japan will be considered as a comparative case for this investigation. Of the selected cities, five are coastal cities while Bangkok, HCMC, Tianjin and Bandung are megacities. The following paragraphs introduce the basic outlines of these cities.

Bangkok: This study region is located on the lower alluvium plain of the Chao Phraya River delta that includes the Bangkok city and six provinces surrounding it, Nonthaburi, Samut Prakan, Pathum Thani, Samut Sakhon, Nakhon Pathom and Ayutthaya, covering a total area of 10,318.5 km^2. As of 2003, the total population in this region was almost 10.6 million out of which nearly 6 million reside within the Bangkok city (Ohgaki, 2006) The entire Bangkok city (1-2 m above mean sea level MSL) and the surrounding is just few meters above MSL, making it very prone to flooding.

Figure 2: Case study cities

Bandung: The study area is Bandung basin or the upper Citarum River basin, located in the western part of the Java Island, covering a land extent of 2,341 km^2. This basin characterizes the densest populated area in the West Java Province with a total population of 5.85 million as of 2003 (Ohgaki, 2006). On average the upper Citarum basin is 650 to 800 MSL with a set of volcanic cones encircle in Northeast and South basin raging 2000 to 4000 MSL. The topography in the area can be classified as plain to mild sloping (45% of total land area), moderate sloping with 8-25% inclination (29% area) and steep sloping with over 25% inclination (26% area).

Ho Chi Minh City (HCMC): The case study area located on the lower alluvium plains of the Don Nai and Saigon rivers is the biggest centre of cultural, social, trading and economic activities, as well as the key area for technology and international communication activities in the whole Vietnam. HCMC has an area of 2,095 km^2, with a total registered population of 5.63 million in 2003 (Ohgaki, 2006), but with the unregistered figures included, the total population is likely to be around 7.5 million.

Tianjin: Tianjin is located 137 km southeast of Beijing, or northeast part of a large alluvial plain named the North China Plain, sitting on the downstream of the Hai He River basin. Total land area of Tianjin is 11,919 km^2. The total registered population of Tianjin is 9.19 million in 2002 (Ohgaki, 2006) of which about 40% of population lives in the urban area. 94% of Tianjin area is plain and altitude is higher in the north and lower in the south; higher in the west and lower in the east.

Colombo and Kandy: Regionally, Colombo and its suburbs accommodate the densest population in Sri Lanka. As of 2001, the total population living in Colombo study area was 4.3 million. The 2001 population in Kandy study area was 1.27 million (Department of census and statistics Sri Lanka, 2009). The average population growth rates during the past 20 years in the Colombo and Kandy regions are estimated as 1.7% and 1.0% respectively. Of the two study areas, Colombo is located in the coastal plains of the western region of the country. The terrain in Colombo is of gently undulating plains with highly dense drainage paths. Kandy area is a plateau in the central mountainous region and is around 500 to 700 meters above sea level. The terrain in Kandy does not contain many steep, plunging slopes except in the surrounding mountains. The topography in this plateau consists of undulating plains with hillocks separated by drainage paths. The land coverage in the Colombo and Kandy case study areas are 1575.6 km^2 and 322 km^2 respectively.

3. WATER DEMAND

3.1 Water withdrawals and water stress

Over the last century, Asia has witness significant increase in water consumption. It is believed that a number of factors have contributed to this demand increase. Of them the increasing population, economic activities and the climate change has being identified as the main contributing factors. Anyhow, even today of the total water use in the region, about 80 percent is consumed by the agricultural sector. However, recent estimates show that the industrial and domestic consumption too has been rapidly increasing following economic development and the resultant change in lifestyles. Table 1 below shows the renewable surface water and groundwater resource and the volume of extractions in the case study cities. Abstraction figures given represent overall water extractions within the study regions and the high extractions itself reflect the high water demand prevailing in those cities.

Table 1: Water Resources Status in Case Study Cities

	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Groundwater (million m^3/year)						
Renewable amount	1,159	827	183	2,844	588	176
Abstracted amount	170	748	342	800	160	29
Water stress %	14.7	90.4	186.9	28.1	27.2	16.5
Surface water (million m^3/year)						
Renewable amount	-	2,290	734	30,000	9,269	2,384
Abstracted amount	-	1,679	405	30,000	1,879	1,900
Water stress %	-	73.3	55.2	100	20.3	79.7

Using the renewable resources available and the consumption details, the water stress in the area was estimated. Water stress is taken here as the ratio of abstracted volume to the renewable resource available. According to this estimation, Tianjin showed a high level of stress both for surface water and groundwater (Table 1). Further, groundwater abstraction in HCMC exceeds the so-called safe yield by almost 200%. The renewable surface water resources are almost fully utilized in Tianjin and Bangkok meaning the scope of using surface water as the alternative to already stressed groundwater in those cities is limited. Although not reflected with the volume flow-rate figures, in other cities, too, the surface water is stressed due to other reasons. In HCMC and Bandung, the surface water bodies are highly polluted, and in Colombo, the availability is highly variable throughout the year.

3.2 Historical Groundwater Use

In a city water is used for various purposes, such as for public or private domestic water supply, industrial or commercial use and for agricultural use. In most cases, the groundwater has been the most attractive source to meet water requirements especially for industrial and domestic purposes. Records in Table 2 show that in Bandung, HCMC and Bangkok, most of the abstracted groundwater is used for industry. Hence the future groundwater demand in these cities is contingent on the relationship with the water usage of industry. On the other hand, agricultural use is dominant in Tianjin, while other cities make minimal use of groundwater in irrigation.

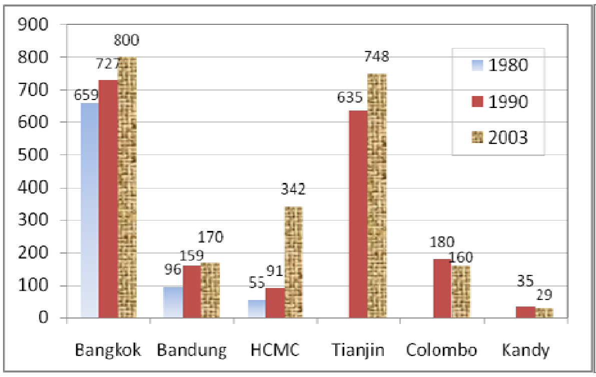


Figure 3a: Groundwater exploitation with time
(Exploitation in million cubic meters a year)

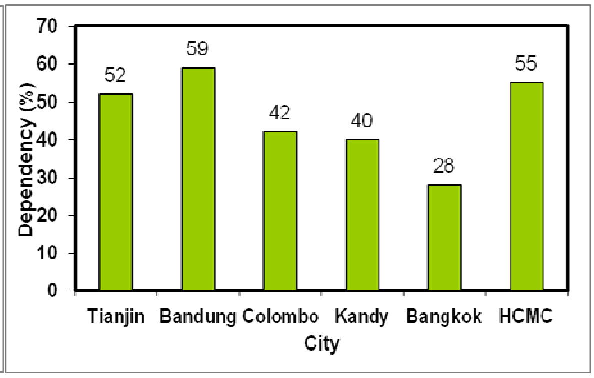


Figure 3b: Dependency on Groundwater

Groundwater use in the six study cities over time is graphically presented in figure 3a. These data clearly signify several interesting observations. The overall groundwater extraction is still continuing to increase in almost all cities even today. However, the recent groundwater use figures in Bangkok show some decline. It is also noted here that in these cities, the contribution from groundwater to portable water requirement is in excess of 40% in all cases except in Bangkok. The recent groundwater dependency values are shown in figure 3b.

Table 2: Beneficial groundwater use in case study cities

	Bandung	**Tianjin**	**HCMC**	**Bangkok**	**Colombo**	**Kandy**
Industry %	80	15	57	64.5	>10	>5
Domestic %	20	23	43	34	<90	<95
Agriculture %	0	62	0	1.5	>0.5	>0.5

4. IMPACTS FROM GROUNDWATER USE

There are a number of well-known undesirable consequences of improper groundwater development. Most aquifers tend to exhibit temporary decline in the water level as part of their natural cycle even when they are not exploited. This may be seasonal, during a normal dry season, or it may be longer term in response to a prolonged drought. However, in extreme situations such as in the case of over exploitation, an aquifer can easily become effectively dewatered, with groundwater levels having become so severely depressed that the aquifer approaches exhaustion resulting in rapid declines in yield and even ultimately wholesale abandonment. In most cases such adverse consequences are slow to develop, and are not apparent until the problem is well-entrenched. For water levels to recover under such circumstances, the resultant forced reduction in abstraction needs to be very stringent, exceeding the long-term rate of recharge. The process may take many years or even decades to occur and, in the worse, the aquifer may not recover at all. Additionally, when alluvial deposit formations are formed as soft sand, silt or mud, groundwater pumping and subsequent drawdown can result in the effect of reducing the pore water pressure and thus increasing the effective stress from the overlying strata on the matrix of the aquifer. In such instances, if the increase in effective stress is greater than a critical value, the land will subside.

During this investigation, problems such as water table drawdown, decreasing yield, land subsidence, saline water intrusion created by over extraction, and coliform, nutrient, heavy metal contamination created by untreated waste disposals was observed in many cities and a summary of such issues are highlighted under the two topics water level changes and water contamination.

4.1 Water level depletion and land subsidence

As a result of over exploitation, groundwater level depletion was observed in many cities. For example, the cumulative groundwater drawdown in Bandung over the last 50 years exceeds 84 m in some locations. Total land subsidence in Bangkok was over 93 cm. Further, the recent data show continuing water level depletions in most case study cities. The land subsidence observed in Bandung and HCMC in comparison, with the subsidence experienced in Bangkok and Tianjin, is very modest. The groundwater drawdown and the land subsidence level in case study cities are given in table 3 below.

Table 3: Observed maximum Groundwater Drawdown and Land Subsidence

	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Drawdown (m)	84	8.75	16.5	16.5	20	50
Land subsidence (mm)	28	61	0	93	0	0

4.2 Groundwater Contamination

The problem of contaminated groundwater and its associated health risks is a major issue in many of the Asian cities today. Typical groundwater pollutants observed in Asia include arsenic, fluorine, heavy metals, coliform, salinity, pesticides, nitrate, ammonia and Volatile Organic Compounds (VOCs) such as trichloroethylene. The root of contamination in these cases can be broadly categorized into two, namely: (1) naturally causes, and (2) anthropogenic causes. In addition the aquifer contamination caused by the tsunami observed in the Asia-Pacific following the earthquake under the Indian Ocean on December 26, 2004 is also worth noting as a different cause of contamination.

Table 4: Pollutants Observed in the Case Study Cities

	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Fluoride	-	x	-	x	-	-
Iron & Manganese	x	-	x	x	x	x
Heavy metals	x	-	x	-	-	-
Nitrates	x	-	x	x	x	-
Coliform	x	x	x	-	x	x
Salinity	-	x	x	x	x	-

The table 4 above summarizes the typical groundwater pollutants observed in the case study cities, based on the case studies conducted. The table includes the cases of pollutants exceeding the prevailing quality standards.

4.3 Socio-Economic Changes and Their Impact on Groundwater Use

During this investigation it was reveled that the factors such as urbanization and land use change, poor pipe water supply and sanitation and rapid economic growth are the other key elements influencing the sustainability of the groundwater resource in the region.

4.3.1 Urbanization and land use

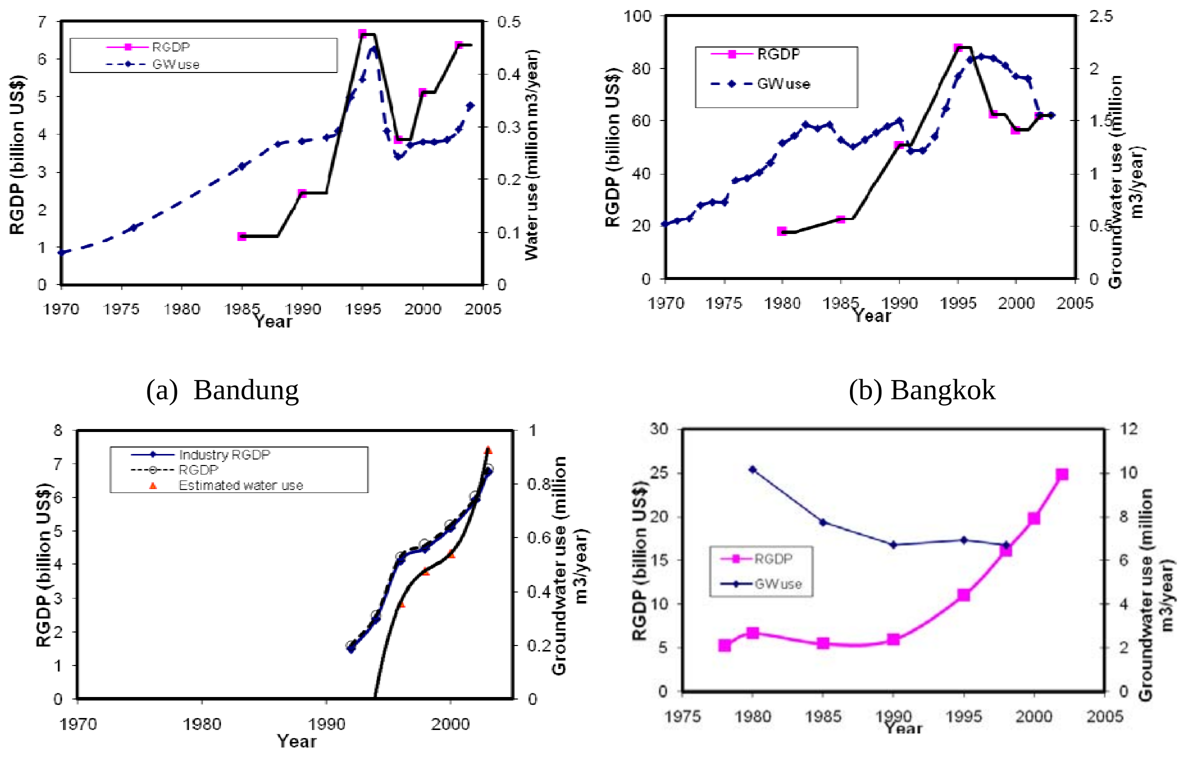
The process of rapid urbanization observed throughout the Asia region, including the cities concerned, has altered the natural setting of the environment in many ways. In this process the land coverage is completely disturbed and changed to either denuded or paved surfaces. Such changes not only reduce the groundwater recharging but also change the direct infiltration of excess rainfall causing flash flooding. Information from the case study cities show that the built-up areas in all cities and, most significantly, in Colombo have expanded rapidly, replacing either the forest coverage or agricultural land. In the case of Bandung, and especially in Colombo and Kandy, the change in agricultural land is mainly from paddy land. Further, in Colombo and Kandy, the cropping efficiency in the late seventies was nearly 200% with two cultivation seasons, while in the last decade, this dropped to an average of 140%. This has tremendously impaired the degree to which the paddy fields are waterlogged and thereby reduced the subsurface flow and recharge influencing the groundwater resources in the regions.

Another key factor influencing the so-called “safe yield” of an aquifer is the degree of recharging capacity available. Most groundwater resources are mainly recharged directly from precipitation through infiltration into the saturated zone. In this regard, a key challenge today is to demarcate and preserve the recharging area within the aquifer basin. Although identifying the exact recharging area for an aquifer is almost impossible, it is believed that vegetation cover, water logged areas and the water bodies within an area are the main potential recharging zones.

4.3.2 Economic Growth and Groundwater Abstraction;

Except in Tianjin, historical groundwater use and the economic growth (Regional GDP - RGDP) in the cities of concern shows that there is a strong correlation between the two (figure 4). In Tianjin, the trend is the opposite where groundwater use is declined with increased RGDP. This difference in the correlation is a good example for effective adaptation and groundwater abstraction control. In Tianjin, groundwater strict abstraction control measures were implemented in the 1980s, which is the cause of the decline seen. In Bangkok, groundwater abstraction control was introduced in 1977 but because the control was rather ineffective, groundwater use itself was increased. The recent decline in groundwater use despite economic recovery is thought to be the result of the recent strengthening of groundwater control measures in Bangkok after 2000. The correlation between the economic growth and the groundwater use is rather strong in Bandung and HCMC, where there are no effective practical measures taken.

Most RGDP in the case study cities is received from industrial activity, signifying that the two are in directly proportion. Therefore, groundwater use in the industrial sector is one of the key to future groundwater control, particularly in cities where the dependency on groundwater in the industrial sector is high, namely Bandung, Bangkok and HCMC.



(a) Bandung (b) Bangkok

(c) HCMC (d) Tianjin

Figure 4: Historical Groundwater use and Economic Growth

4.3.3 Water Supply and sanitation

Another factor identified related to excessive groundwater use in the case study areas was the poor piped water supply coverage. Coverage details within the case study cities are presented in table 5. The situation is all cities are that the condition is very severe in suburban areas compared to the city centers. In Bandung, even in the urban area, coverage is only 40%. Also, the increased coverage in Bangkok during the past two decades was assumed to be a key critical factor in the recent reduction in groundwater use.

Table 5: Recent pipe water coverage as a percentage in case study cities

Pipe water	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Urban	40	NA	77	89	64	80
Sub-Urban	9.1	NA	21	15	22	21

Additionally in all case study cities sanitation conditions have not being properly developed along with urbanization. As a result, sanitary conditions in the cities are very poor. In most existing sanitary facilities, waste disposal is made through on-site septic tank systems. Though these on-site systems are safe to use in most cases their construction and management was often improper, allowing the untreated wastewater discharged into the environment. Such malpractices appear to have caused significant shallow aquifer contaminations. Further surface water bodies too in these areas are heavily polluted contributing to the contamination of groundwater through the interconnection with aquifers.

5. ADAPTATION MEASURES FOR EFFECTIVE GROUNDWATER USE

The review of the history of adaptation to groundwater decline in Asian case study cities indicate four major elements in groundwater management: (a) regulations to control groundwater use, (b) provision of alternative water, (c) economic incentives/disincentives to control groundwater use, and (d) encouraging water saving. Table 6 summarizes the measures taken in each city.

Table 6: Adaptation Measures in each case study city

Regulatory Measure	Regulations to control GW use	Provision of alternative water	Incentives to reduce GW use	Incentives for water saving activities
Bandung	Control abstraction through permit system	Enhancing surface water use considered	User tax	No specific measures
Tianjin	Control of abstraction through permit system	Surface water transfer from other basins	User tax	Mandatory water recycle conservation policy for industry
HCMC	No Specific Measures but User Tax and enhancing surface water supply considered			
Bangkok	National law to regulate GW extraction	Increased piped water supply from surface water	User tax and preservation charge	No specific measures
Osaka	National laws to curtail use, ban the use or construction of wells	Low cost surface water supply to the industrial sector	No user tax but a waste water charge	Financial support for water-saving technology (1960s)
Colombo-Kandy	No Specific Measures but general agreement not to use crevice groundwater for large scale abstractions and replacing GW with surface water supply			

Except for Tianjin, these groundwater management policies do not sufficiently incorporate the supporting measures for water saving activities as the main management element of groundwater. Rather than the promotion of water rationalization, the provision of alternative water resources with groundwater abstraction control with regulations often has come first as a countermeasure. However, such reliance on alternative resources without a change in the water- use patterns may bring other environmental risks. It may also bring the financial problems and the environmental risk in the infrastructure development of new water sources. On the other hand, as the experience in Osaka the promotion of water rationalization through the reuse and recycling in groundwater management could be an effective tool to reduce groundwater demand. The following section elaborates the effectiveness of the measures taken at each city in detail.

5.1 Policy achievement

5.1.1 Bangkok

Since late 1960s, Bangkok has suffered from the drawdown of its water table and the resultant land subsidence. Records show that the groundwater level dropped by about 5 – 10 m from the late 1970s to the early 80s. The recorded land subsidence rate was up to 10 cm/year in the eastern part of Bangkok and the incident has extended to the outskirts of the city. The city has regulated groundwater abstraction with a system of charges but the effectiveness of the control measures has not been observed until recently.

The recent encouraging groundwater control in Bangkok was attained by the introduction of a combination of measures; the extension of the public water supply coverage and by a sharp increase in groundwater-related charges. The groundwater user charge was rapidly increased from THB 3.5 (USD 0.09)/m^3 to THB 8.5 (USD 0.22)/m^3 between 2000 and 2003, and the public water supply coverage in the metropolitan Bangkok area has reached 90 per cent of its population by 2004. As a result, the the groundwater use began to decrease during that period. Since the progress was not up to expected levels, again in 2004, an incremental charge called the "groundwater preservation charge" was introduced to groundwater users in Bangkok and its vicinity (the critical zones). Since the introduction of this charge, the total tax on groundwater use became almost equal to the cost of pipe borne water.

5.1.2 Bandung

With the rapid water table drawdown observed, in Bandung introduction of groundwater abstraction control measures was way in the 1970s. Again in 1974 a groundwater user tax was introduced. However, these measures have not being very effective so far and issues continue to increase. One reason being the conflicting interest between groundwater control and economic development. Also the taxation on groundwater use was very marginal ranging from IDR 1750 (USD 0.19) to IDR 3138 (USD 0.34)/m^3 compared to the charge for accessing the public water supply IDR 2725 (USD 0.29) to IDR 9600 (USD 1.05)/m^3. Because of the inherited advantages and comparative strength other of groundwater in terms of cost and the insufficient alternative resources (pipe water coverage less than 25%), industry continues to use groundwater.

5.1.3 Tianjin

Tianjin too has suffered from the drawdown of its water table and resultant land subsidence since the late 1970s. However unlike in other cities considered, strict groundwater abstraction control was implemented especially in areas with significant land subsidence impacts. A groundwater user charge was imposed to discourage groundwater use in the city. Further, to improve the surface water availability, water has been transferred from other basins. Sea water desalinization was practiced in the coastal industrial zones as an alternative to groundwater resources. In addition to the control of groundwater use, the municipality promoted water rationalization in the industrial sector by setting targets for water use and imposing more charges to those who exceed their groundwater-use targets. Agricultural use of groundwater is still dominant in the city as controlling such abstraction is poor.

5.1.4 Osaka; what happened after the success?

In many Japanese cities, groundwater management was introduced way back in the late 1950s to control rapid water level drawdown and land subsidence. In Osaka, as in many large cities in Japan, the industries were the dominant users of groundwater. Therefore strict groundwater abstraction controls were introduced with the industrial users. Anyhow to supplement this reduction, a new water supply called the Industrial Water Supply Works (IWSW), provided surface water with minimum treatment as an alternative water source exclusively for the industrial sector. The combination of these two measures was very effective in the abatement of excessive groundwater use in Osaka in the early 1960s. However in early 1970s, with the introduction of compulsory wastewater treatment, water recycling and structural charge in industries for less water use have reduced the demand for water from IWSWs. This made the IWSWs financially not feasible. Thus it is noted here that though in response to the emergent problems, the new infrastructure development to provide alternative water resources was useful and contributed to the industrial development at that time, the financial difficulties and unsold water has become a social problem now. In addition nowadays many other problems due to rise in water table (as the groundwater extractions are minimum) too exist in Osaka.

5.1.4 Other case study cities

In HCMC Vietnam and Colombo, Kandy Sri Lanka no specific policy or regulation is available for groundwater management. However in Sri Lanka, authorities concern has taken various measures such as to limit the groundwater extraction especially in hard rock, improving re-charging areas etc. to improve groundwater sustainability. This was not before problems and is mainly because of the various difficulties they faced with groundwater resource.

5.1 Recommendations for improved groundwater management

With the findings of this investigation, though some cities have gained certain success, it is clear that the groundwater management in the region is needs much more improvement. Thus the following section recommends important aspects that need attention to make the groundwater resource sustainable and for people to adopt to the problems in the region.

1. Charging for groundwater usage pattern and promoting the rational use of water in the industrial sector. Promotion of water rationalization should be given priority considering the benefits of groundwater conservation as well as the conservation of water resources as a whole, and its long-term cost-effectiveness. In this regard the following can be done; economic instruments to motivate water reuse/recycle, incentives for water-saving practices and the use of water saving or recycling technologies, disincentive for the excessive use of water such as additional charges for targeted water use volume and make available technical guidelines and training for those involved.

2. Strengthen pollution control and its enforcement as a tool for reduction of water demands. In many parts the groundwater contamination especially the shallow groundwater contamination is a major issue. This is because still majority of city dwellers rely on shallow groundwater for their basic needs. Thus enforcing quality standards for effluence discharge from factories and domestic units need strengthening. Otherwise to establish wastewater treatment systems and a charge for wastewater treatment. Also establishment of records and reporting system to promote voluntary improvements in industry units especially for industries using toxic and hazardous chemicals.

3. Groundwater conservation needs to be incorporated in urban planning. As the water resources are heavily exploited and land surface is completely disturbed and changed in urbanization, it is necessary to take these facts into account in urban planning. In this regard the following could be included in urban planning; protect and make available suitable groundwater re-charging areas as replenishing zones, introduce decentralized recharge schemes in household or community areas such as backyard rainwater tanks, installation of water-saving technology stipulated in the building code (e.g. recycled water for flushing toilets etc) etc.

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METHANE DISCHARGES FROM A TROPICAL ESTUARY TO COASTAL OCEAN

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ABSTRACT

Wetlands and coastal regions play major roles in the global budget of methane, a strong greenhouse gas, and coastal oceans are known to hold disproportionately large share of oceanic methane. Methane discharges from the Ashtamudi estuary (Ramsar site no. 1204), in the western coast of South India to the adjoining coastal ocean was investigated. Samples were collected from different depths at a number of locations in the estuary having a water cover area of 55 km^2 and from about 380 km^2 in the adjoining region of coastal ocean and analysed. It is observed that methane concentration ranges from 54 to 1490 nmol/L in the estuary, and from 2 to 94 nmol/L in the ocean, during pre-monsoon season. The vertical distribution of dissolved methane in both estuary and coastal ocean were determined at a number of locations. Estuarine water has higher concentration in the bottom layers compared to surface, whereas a reverse trend is observed in the ocean, which suggest production in estuarine sediments as the dominant methane source in both estuary and adjoining coastal ocean.

1. INTRODUCTION

Methane is a strong greenhouse gas, which is nearly 23 times more potent than carbon dioxide in global warming, when reckoned over a 100 year time horizon. The atmospheric residence time of this gas is also high, estimated as nearly 11years. The relative contributions of CH_4 and CO_2 to global warming are estimated to be 18 % and 50 % of the total. Major known sources of methane are wetlands, enteric fermentation in the guts of ruminants and termites, cattle manure, mining, combustion of fossil fuels, agriculture under waterlogged conditions, etc. Among these, wetlands are a significant source (Fung et al, 2002), contributing around 21% of global methane emission.

Estuaries are partially enclosed wetland bodies of water which is an interface between saltwater from the sea and freshwater from rivers, streams, etc. Dissolved methane in estuarine waters are known to be significantly higher than the atmospheric equilibrium, and depend on the balance between various sources and sinks (Middelburg et al, 2002).

Oceans are also known to hold huge quantities of methane in various forms, mostly as dissolved methane in sea water and as gas hydrates in the ocean floors. Methane concentration in the sea water is much higher than its corresponding atmospheric equilibrium, making the oceans a net methane emitter (Brooks et al, 1981). Continental shelf regions which are only about 15% of global oceans are responsible for nearly 68% of global oceanic methane emission (Bange et al, 1994). It has been found that methane concentration in open ocean surface waters in Arabian Sea is of the order of 2 to 3 nmol/l. Dissolved methane concentration in coastal waters is two to three times more than in the open ocean (Lal et al, 1996). In situ production in marine sediments is being considered as the major source of oceanic methane (Karl and Tilbrook, 1994).

Methane distribution in an estuary on the south-west coast of peninsular India and in a segment of the adjoining coastal ocean was measured, with a view to see their relationship.

2. METHODOLOGY

2.1 Study area

The Ashtamudi Estuary (Ramsar site no. 1204) in south-west India and a portion of the adjoining coastal ocean lying between 76°22' - 76°33' E and 08°50' - 09°00' N, is covered in this study. Ashtamudi estuary covers an area of 5,500 ha (Sankar et al, 1998), lies between 76° 31' - 76° 41' E and 8° 54' - 8° 59' N, and receives fresh water input from the Kallada river originating in the Western Ghat mountain range. The estuary is connected to the Lakshadweep Sea through a tidal channel at Neendakara. Fig 1 is a sketch map of the study area. There are various human interventions in this estuary which include coconut husk retting for coir fiber extraction (Zachariah and Johny, 2006) and fishing. Measurements were carried out in the estuary and in the offshore region from the coast to a distance of about 9 nautical miles, during February 2008. Figure 1 shows a sketch map of the study area.

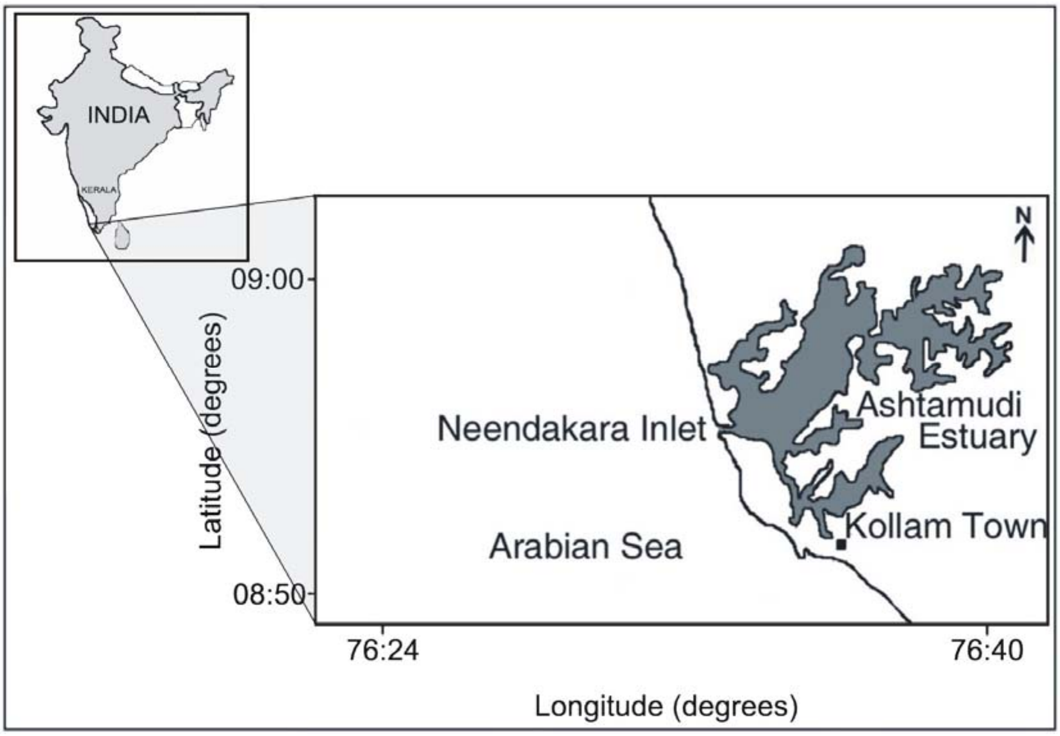

Figure 1: Sketch map of the study area

2.2 Sample collection

Water and sediment samples were collected from 16 locations in the estuary covering nearly 55 km^2 and 10 locations in the coastal ocean covering 380 km^2. Sampling was done from motor boat, at approximate grid interval of ~ 5.5 km in the ocean. Sampling intervals in the estuary were kept closer considering the higher spatial variability in the estuarine environment. Water samples were collected at depth intervals of 5m in the ocean and 2m in the estuary.

Water sampler capable of drawing water slowly into a container without disturbing dissolved gases in the water was used. A small quantity of $HgCl_2$ was added to the sample to prevent further bacteriological activity and changes in composition, and stored chilled without freezing till analysis.

Sediment samples were collected from each location using a sediment grab, stored chilled till analysis.

2.3 Analysis

Water samples were analysed for dissolved methane, pH, Dissolved Oxygen (D.O.), and salinity, and sediment samples were analysed for Total Organic Carbon (TOC) at each location.

Dissolved methane in the water was determined by extracting it into pure nitrogen gas. The chilled water samples were slowly warmed to room temperature. 10 ml from this was taken into a gas tight syringe containing 30 ml of pure N_2 gas, closed, and shaken vigorously on a shaker for 1 minute to extract the dissolved methane into the nitrogen gas. The resulting gas mixture was analysed using an FID on a gas chromatograph to determine the concentration of methane in it. The extraction from the same sample was repeated with fresh N_2 gas till the methane concentration in the extracted mixture fell below detectable limit. Methane concentration in nmol/L was computed from the total amount of methane extracted from the 10 ml sample.

Isothermal separation at 70^{o}C in a packed (PORAPAK Q, 80/100 mesh size) stainless steel column (1/8” x 2m) was used to separate methane. The FID was calibrated using standard gas mixtures of methane in pure nitrogen.

Salinity of the water samples was measured using a meter calibrated using standard calibration solutions, and pH using pH electrode and meter calibrated with standard pH solutions.

The sediment samples were dried in a refrigerator and ground to fine particles. The Total Organic Carbon (TOC) was estimated by the Walkley method.

3. RESULTS AND DISCUSSION

Dissolved methane in the surface water, dissolved oxygen, salinity, pH, and TOC, observed in the Ashtamudi Estuary are given in Table 1. Methane concentration is seen to be highly variable across the estuary.

Table 1: Dissolved methane, dissolved oxygen, salinity and pH in the surface water and TOC in the sediments of the Ashtamudi Estuary during post-monsoon season in 2008

Sl no	**Latitude**	**Longitude**	**TOC** (%)	**Dissolved Oxygen** (mg/L)	**Salinity**	**pH**	**Dissolved CH_4** (nmol/L)
E-1	08:53:28	76:35:08	9.10	6.86	12.3	7.35	685.9
E-2	08:54:10	76:35:28	6.92	7.84	19.6	8.08	300.4
E-3	08:54:57	76:36:27	8.66	6.86	24.6	7.43	419.4
E-4	08:54:33	76:34:51	6.33	8.16	22.8	8.13	454.9
E-5	08:55:33	76:34:35	4.01	8.16	25.1	8.06	94.4
E-6	08:55:56	76:34:12	2.19	7.51	24.8	8.03	48.7
E-7	08:55:52	76:34:17	2.28	8.46	11.9	8.40	292.4
E-8	08:57:00	76:35:21	2.55	8.78	10.8	8.45	181.5
E-9	08:58:20	76:35:45	3.38	4.46	8.1	8.04	381.5
E-10	08:58:19	76:36:53	3.59	8.78	10.1	8.18	273.3
E-11	08:58:08	76:38:29	5.09	7.80	10.0	8.19	176.9
E-12	08:59:14	76:35:13	3.96	6.50	6.0	7.88	559.5
E-13	08:59:46	76:35:09	1.61	8.78	2.4	7.30	454.1
E-14	08:58:17	76:34:50	3.93	8.78	9.0	8.45	362.2
E-15	08:56:57	76:34:12	1.83	8.46	9.3	8.57	164.7
E-16	08:57:18	76:32:40	3.44	8.46	10.4	8.47	174.9

Table 2 gives the dissolved methane, dissolved oxygen, salinity and pH in the surface layer and TOC in the sediments in the coastal ocean. Locations at sl. nos. O-1, O-2, and O-10 in Table 2, where high methane concentrations have been observed, lie close to the discharge point of the estuary.

Table 2: Dissolved methane, salinity, DO, and pH, in the coastal ocean during pre-monsoon season in 2008

Locations			**Salinity**		**pH**		**Dissolved Oxygen** (mg/l)		**TOC** %	**Dissolved Methane (surface)** (nmol/L)
Sl.No	**Longitude**	**Latitude**	**Top**	**Bottom**	**Top**	**Bottom**	**Top**	**Bottom**		
O-1	76:32:09 E	08:55:56 N	NA	NA	NA	NA	NA	NA	NA	93.82
O-2	76:30:54 E	08:55:55 N	29.2	30.4	8.20	8.19	4.47	4.47	NA	16.18
O-3	76:26:54 E	08:56:05 N	30.9	30.2	8.26	8.28	5.28	6.09	0.89	7.89
O-4	76:22:50 E	08:56:08 N	30.9	30.4	8.19	8.24	4.47	4.88	0.89	1.87
O-5	76:26:04 E	08:52:01 N	29.9	30.6	8.24	8.22	8.54	7.72	1.04	5.15
O-6	76:29:38 E	08:52:06 N	30.2	30.5	8.25	8.23	5.69	5.28	1.78	8.40
O-7	76:33:40 E	08:51:15 N	31.1	26.8	8.23	8.28	4.88	4.06	NA	3.72
O-8	76:22:45 E	09:00:23 N	26.5	26.9	8.31	8.30	2.44	2.84	1.34	3.23
O-9	76:26:21 E	09:00:19 N	30.2	27.9	8.23	8.31	4.88	6.09	1.04	5.48
O-10	76:29:56 E	08:59:27 N	26.7	26.9	8.22	8.29	2.44	2.84	1.19	19.76

Vertical distribution of dissolved methane at two locations within the estuary are given in Figure 2. Methane concentration is seen to increase sharply with depth. The methane concentration observed in the bottom layer at location E12 is very high though similar high values have been reported from other locations elsewhere also. Methane concentration up to 9070 nmol/L have been reported from Gulf of Mexico (Brooks et al, 1981). Similar very high sediment pore water methane concentrations have been reported from the Scheldt estuary in Denmark (Van der Nat and Middelburg, 2002).

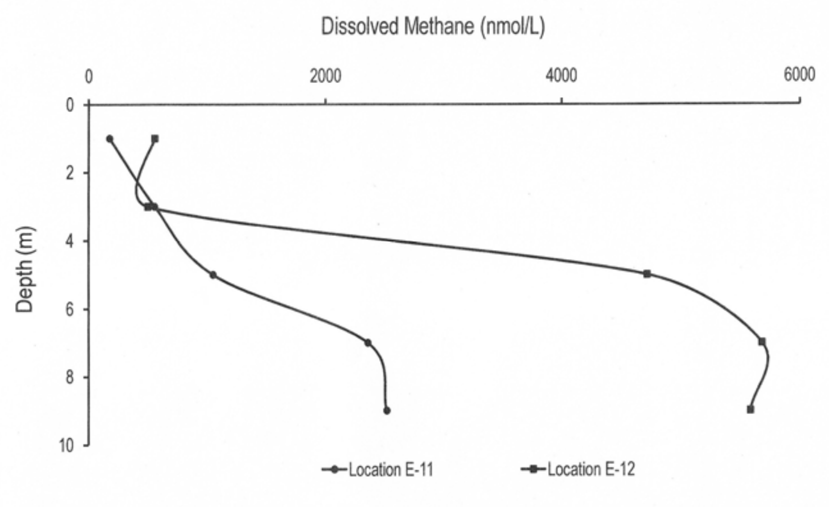

Figure 2: Vertical distribution of dissolved methane in the Ashtamudi Estuary (location details in Table 1)

Figure 3 shows the vertical distribution of dissolved methane in the coastal ocean, which was plotted for 8 locations in the coastal ocean which were at least 15 m deep. It is observed that the predominant trend at these locations is higher concentration near surface, which is different from that observed in the estuary. Increasing methane concentration towards surface layer is seen at five out of eight locations in Figure 3. It is reasoned that this could be caused by the methane rich estuarine discharges.

An analysis of the oceanographic processes and salinity gradients in the ocean are required for explaining this accurately, which is beyond the scope of the present discussion.

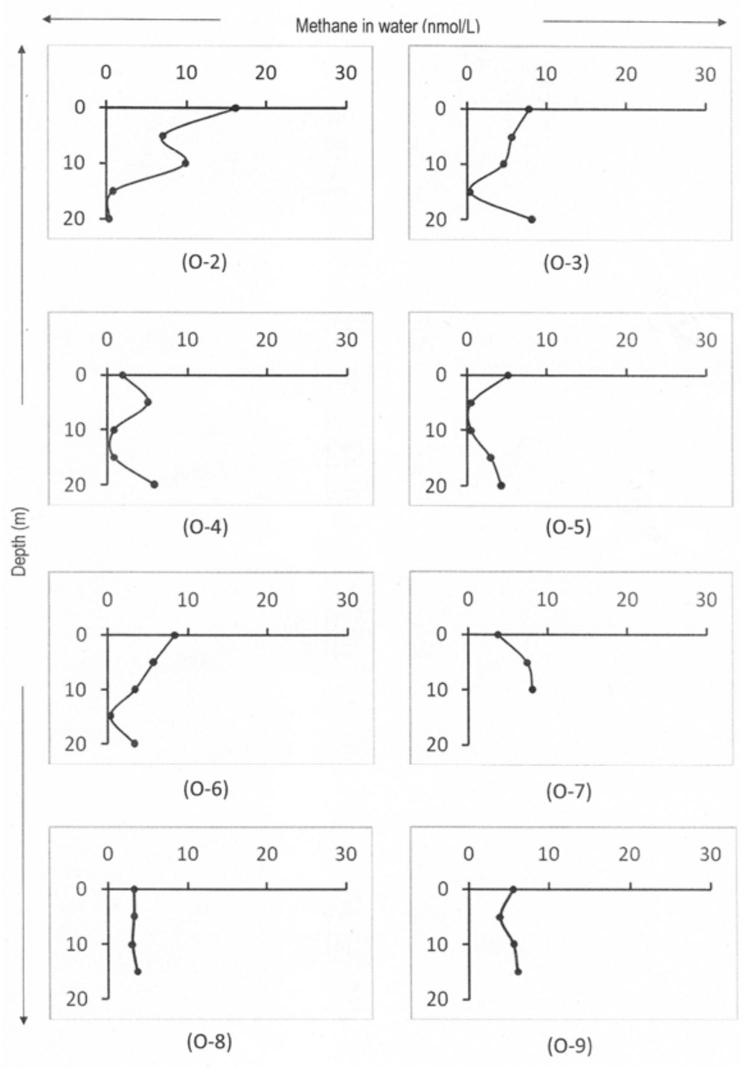

Figure 3: Vertical distribution of dissolved methane in the coastal ocean off Neendakara (index number details given in Table 2) during February 2008

A summary of dissolved methane observations in the Ashtamudi estuary during the pre-monsoon period is given in Table 2.

Table 3: Dissloved methane in the Ashtamudi estuary during pre-monsoon period.

	Dissolved CH_4 (nmol/L)
High	1492
Low	54
Mean	302
Median	360

Studies at other estuaries in the region also show a similar range of methane concentrations. Methane in the surface water measured at Pulicat Lake adjoining Bay of Bengal in South India (Shalini et al,

2006) ranged from 94.14 to 500.62 nmol/L. They have observed low methane concentrations in the sea water mixing zones, implying dilution of the estuarine water by the seawater. Tidal flushing is suggested to be playing a major role in the in the spatial variation of dissolved methane in the Pulicat lake.

The Arabian Sea waters have been reported to be supersaturated with methane, by various investigators. Owen et al (1991) have reported super saturation ranging between 157 - 268 % at depths less than 200 m in the Arabian Sea. Lal et al (1996) reports Methane concentration ranging between 2 - 9 nmol/L, with peak concentration at depths around 100 - 200 m. Arabian Sea is reported to be supersaturated with methane at all depths upto 400 m (Lal et al 1996), with peak concentration ranging from 200 - 400 %. It is also reported that there is a large variation in supersaturation from the coast to open sea, with maximum near the coast. High concentration of methane in the coastal waters of the Arabian Sea was observed by Jayakumar et al (2001). Near shore surface saturations of methane have been very high. Methane concentration which is super saturated by 1818±1396 % have been reported off mouth of Mandovi, which were attributed to fluxes from adjoining wetlands.

Methane concentration of 1437 nmol/L is reported from the Rhine estuary in the freshwater regime. The corresponding value in the marine end of Rhine was 125 nmol/L (Middelburg et al, 2002). Humber and Tyne Estuaries adjoining the North Sea have methane concentrations in the range 190-670 nmol/L and 650 nmol/L (Goddard et al, 2000) respectively.

Methane concentrations in the sediment pore water have been investigated in various estuaries. In the Scheldt Estuary, a tidal freshwater marsh in the Netherlands, methane in pore water in the top layers of the sediment was in equilibrium with the overlying water and increased to ~ 8,00,000 nmol/L at 60 cm depth (Van der Nat and Middelburg, 2002). Surface water methane concentrations in the Gulf of Mexico (Brooks et al, 1981) ranges from 37 - 12,700 nl/l [ie., ~ 26 - 9070 nmol/L]. They have observed maximum concentration at a depth of around 50 m.

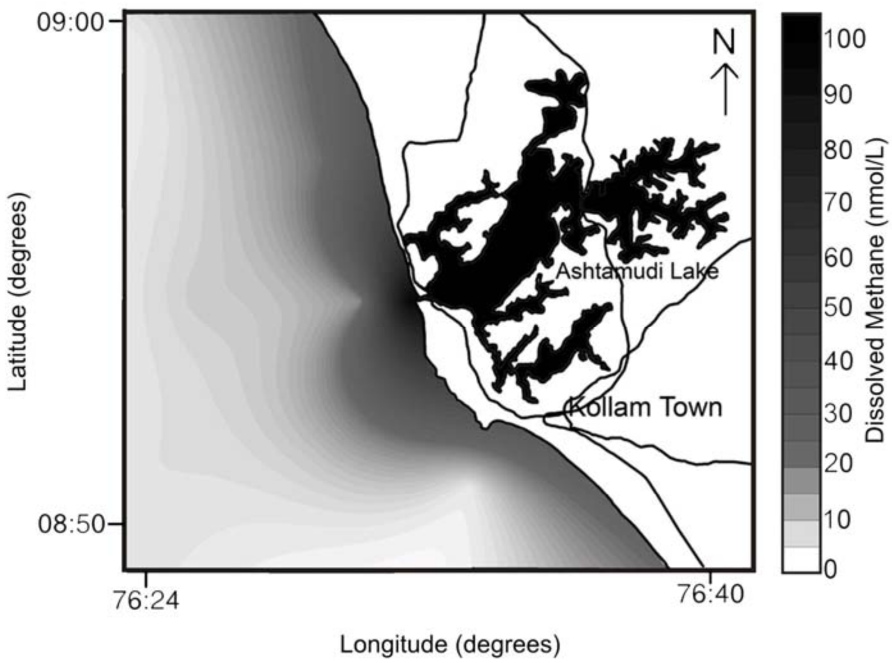

Figure 4: Methane in the coastal ocean off Neendakara (surface), during February 2008

Fig.4 shows a contour plot of the methane concentration in water in the coastal ocean. The gradient in dissolved methane concentration from the coast to open ocean is well pronounced in the plot. The methane concentration is seen to slowly reduce to the open ocean values reported by other observations (Goddard et al, 2000).

In general, highest methane concentrations are observed in sediment pore water. Estuarine water have methane concentrations lower than the underlying sediment pore water, but significantly higher than the adjoining coastal ocean. A gradient in methane concentration from coast to open ocean has also been observed. The role of estuarine discharges in enriching the coastal ocean with dissolved methane has been suggested in a number of different observations (Jayakumar et al, 2001, Shalini et al, 2006, Mukhopadhyay, 2007).

Water budget of the estuary was determined according to LOICZ biogeochemical modeling guidelines (Gordon et al 1996). Average salinity in the ocean was taken as 34.9 (Gopalakrishna et al. 2005), and corresponding average value for the estuary based on the measured data was 26.9. Annual freshwater runoff into the estuary from Kallada River is 1300 million m^3 (Nair and Azis 1987). This water flows through the estuary and finally reaches the coastal waters. Accordingly it is estimated that 4986 x 10^6 m^3 water exchange through tidal flow take place annually between estuary and sea. Annual precipitation to the estuary is 132 x 10^6 m^3, calculated using monthly rainfall data. Annual water loss from estuary through evaporation process is calculated using the evaporation rate of 1.2 m/year (Baungatner and Reichel 1975) is 66 x 10^6 m^3. This leads to a gross water flow out of 6352 x 10^6 m^3 methane rich water from the estuary to the coastal ocean enriching it with methane.

4. CONCLUSIONS

Arabian Sea is found to be super saturated with methane. The steady fall in methane concentration as distance from the estuary discharge point increases indicates estuarine discharges as a significant source of methane in the area under observation. The amount of methane rich water reaching the coastal ocean through water discharge from the estuary is estimated to be 6352 x 10^6 m^3, annually. Higher concentration of dissolved methane in the bottom layers of the estuary compared to the surface suggest production of methane in the estuarine sediment as a major source of methane in both estuary and adjoining coastal ocean. This indicates that estuarine discharges also should be considered when methane budget of the coastal ocean is calculated.

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CLIMATE CHANGE IMPACTS IN COASTAL ZONES: CONTEXT BANGLADESH

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ABSTRACT

Elevated CO_2 level has made vulnerable the entire planet and Bangladesh in no more exception, rather is extreme in its coastal zones in respect of sea level rise, intensified-long duration rain and frequent catastrophic cyclones. Apart from sea level rise in fact vulnerbility is lying with other climate induced impacts like erosion, salinity and repeated hit by 5-10m high surges along the cyclones. As a result total livelihood of 30m people in 730 km long coast line is endangered. The purpose of this paper is to find out the magnitude of these impacts and their possible solution. A model study was conducted by Institute of Water Modeling (IWM) under the ministry of Water Resources and this paper adopted some of the findings of the study with their probable solutions, limitations , results and indications. Saline travel path as well as its concentration has been represented in a coastal-zone map.Simultaniously the change in fresh water area in corresponding percentage also have been obtained from the study. In Bangladesh coast line, number of the climate affected people are increasing day by day. Result of the same also have been shown in this paper. As structural measure , afforstation and dykes are acting as barrier to protect the wave thrust and sea water intrusion. Bangladesh so far has developed state of art technology both in cyclone and flood forecast with strong disaster Management policy SOD (standing Order of Disaster) and achieved good progress for the mitigation of the disasters specially decreasing the loss of lives. Similarly NAPA (National Policy for Adaptation) for the climate induced disasters has been introduced. Mitigation and Adaptation are now working hand-in-hand and is a way for the regillience of climate Change impacts. Results of the study are being used for the planning of measures to be taken with budget provision. Climate justice is very importanat in this regard.

1. INTRODUCTION.

Climate Change is the result of a great many factors including; the dynamic processes of the Earth itself, external forces including variations in sunlight intensity, and more recently by human activities. External factors that can shape climate are often called climate forcings and include such processes as variations in solar radiation, deviations in the Earth's orbit, and the level of greenhouse gas concentrations. Now climate change is one of the most critical global challenges. Rising global temperatures will bring changes in weather patterns, sea level rise and frequency and intensity of extreme natural events. The Bangladesh coast is threatened by rising sea level due to various factors. The results based on the analysis of past 22 years of tidal data of the Bangladesh coast reveal that the annual mean tidal level in the eastern Bangladesh coast is rising at an alarmingly high rate of 7.8 mm/year, which is almost twice the observed rate in the western region (O. P. Singh, Marine Geodesy-2002) which is 4mm/year.

A significant global-mean sea level rise is expected due to human-induced warming during the 21st century. In the Third Assessment Report (IPCC, 2001) of the Intergovernmental Panel on Climate Change (IPCC) projected sea level rise from 1990 to 2100 was 9 to 88 cm. Bangladesh has been identified as one amongst 27 countries that are the most vulnerable to the impacts of global warming induced accelerated sea level rise. The high degree of vulnerability of Bangladesh can be mainly attributed to extensive low-lying coastal area, high population density, frequent occurrence of cyclone and storm, high storm-surge. The life and livelihood of coastal dwellers are directly dependent on the natural resource bases of coastal ecosystems. Climate change induced rise in sea surface temperature, change in frequency and intensity of cyclone and sea level rise may aggravate the potential risks to coastal zones. The rise of sea level could result in loss of cultivable land due to inundation, salt water intrusion into coastal ecosystems and into groundwater system and loss of terrestrial and marine biodiversity. Some of the Climate induced impact scenarios and subsequent model results based on the existing situation also have been discussed in the following section.

Bangladesh Map, showing coastal zone in the mouth of Bay of Bengal

2. COASTAL ZONE OF BANGLADESH

The coastal zone has several ecosystems that have important conservation value: mangrove, marine, estuary, islands, coral, sandy beaches which provides habitat for an abundance of plant species as well as an array of fish and wildlife. The largest single tract of mangrove ecosystem in the world, the Sundarbans, is located in the southwest corner of Bangladesh. Coastal zones refer to areas where land and sea meet together. The coast of Bangladesh is approximately 730 km long, as estimated by measuring the distance around the Bay of Bengal between Indian and Myanmar (Burma) borders.. The coastal zone is low-lying with 62% of the land have an elevation less than 3 metres and 86% less than

5 metres. There are 123 embanked polders, which were constructed in late sixties to protect the land from tidal and monsoon flooding, saline water and to increase the crop production. At present, the Sundarbans covers 6017 km^2. It is intersected by numerous rivers and canals (around 30% area is under rivers, channels, stream and canals). In the Sundarbans, land level varies from 1m to 2m and flooded during high tides. There are many small and large islands are located in the coastal zone of Bangladesh. Most of the large islands are protected by coastal embankments. Unprotected land masses are the mud flats and subjected to tidal flooding during high tide.

3. SCENARIO SELECTION

Taking the greenhouse gas-emission scenarios from 3rd IPCC (IPCC, 2001, 3rd IPCC considered for its emission scenerios), it is estimated that the global rise in sea level from 1990 to 2100 would be between 9 and 88 cm. Global sea level rise for the projected year 2050, 2080 and 2100 has been selected from Third Assessment Report (TAR) of IPCC 2001 for high and low emission scenarios of SRES (Special Report on Emission Scenarios). SRES scenarios in 3rd IPCC have four families, A1, A2, B1, B2 and six emission scenarios. Considering the continuously increasing global population projection and high CO_2 emission (>1800 GtC), A2 has been selected as high emission scenario. Also due to lower CO_2 emission, B1 is considered as the low emission scenario. Table 3.1 presents the projected sea level rise in the year 2050, 2080 and 2100 for A2 and B1 respectively. Sea level rise in those years are considered to be the rise after base/reference year 2005.

Scenario	**Sea Level Rise**		
	2050	**2080**	**2100**
A1	27 cm	62 cm	88 cm
B1	23 cm	48 cm	-

sea level rise for projected year 2050, 2080 and 2100

4. SELECTION OF BASE/REFERENCE YEAR USING HYDROLOGICAL ANALYSIS

In order to select the base/reference year for the impact analysis of sea level rise, the most recent hydrological year having average upstream flow is considered. The time series data of annual maximum flow on the Padma river(down of the confluence of ganges and Jamuna is called Padma.) is used for frequency analysis to select hydrological year for baseline conditions. The hydrological year 2005 has been selected for baseline condition on the basis of extreme flow analysis and considering the availability of relevant data and calibrated models.

5. MODELS USED IN THE STUDY

The mathematical modelling is used for investigating the impacts of relative climate change (resulting from global climate change, changes in river-flow and coastal development) on salinity intrusion, flooding and drainage congestion and flooding due to cyclonic storm surge.

The river network in the deltaic southwest and southeast region are very complex and characterized by many channels and loops with small water level differences within the area. The flow pattern is dominated not only by the upstream flow conditions in the major rivers but also to a very large degree by backwater and tidal effects propagating in east-west as well as north-south directions. The eastern hill region is dominated by flash flood from upstream and tidal influence in the downstream part. . In order to meet the demand for different combination of impact to be modelled, e.g. flooding pattern, salinity intrusion, cyclone; mathematical model developed for the river and bay of southwest region, southeast region, eastern hill region and Bay of Bengal has been applied.

Bay of Bengal model comprises of the northern region of the Bay of Bengal with the coastal belt of Bangladesh and part of India and Myanmar, extended up to 17 ^{0} latitude. The model has a wide, deep, open ocean boundary in the south situated along the line extending from Vishakhapatnam of India to Gowa Bay of Myanmar. Predictions on water levels of these stations have been made from Admiralty tide table. The water level along the open boundary is obtained by interpolating the two predicted water levels. To the north of the model has a narrow open boundary in the Meghna River. Measured water level of Chandpur station has been used as a boundary at this end of the model.

The southwest region model (SWRM) has been used in this study. The river network of southwest region is a complex one. River system of this area is the combination of both tidal and non-tidal. This model contains 189 river branches, all the polders and almost all the regulators. The model of southeast area is called south east region model (SERM) has been used in this study. The model area is bounded on the west by Meghna River and on the south by Meghna estuary and the Bay of Bengal. Much of the eastern boundary is formed by the international border with India.Another model which is called eastern hilly region model (EHRM) has been used in this study. Actually it consists of five river basins, which are not hydraulically connected.

A two-dimensional model of the northern Bay of Bengal and Meghna Estuary and the one-dimensional model for the rivers in the coastal area have been used to assess the sea level rise impact for the study. The Bay of Bengal model has been used to generate the downstream boundary of the river models for base condition whereas the propagation of tide in the rivers and flood plain are modelled using river model.

A numerical 2-dimensional and 1-dimensional model named MIKE21 and MIKE11 developed by DHI Water & Environment have been used for simulation. The hydro-meteorological characteristics and its contribution to the catchments of the southwest, southeast and eastern hilly region have been generated using the Rainfall Runoff Model (NAM), a module of MIKE 11.

The governing equations used in MIKE21 in solving hydraulic problems in coastal areas are:

Conservation of Mass Equation

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0\,; \ (1)$$

Conservation of momentum equation

The momentum equation in the x-direction is given by:

$$\frac{\partial p}{\partial t}+\frac{\partial\left(p^{2}/h\right)}{\partial x}+\frac{\partial\left(pq/h\right)}{\partial y}+gh\frac{\partial \varepsilon}{\partial x}+\frac{f}{2}\frac{\sqrt{p^{2}+q^{2}}}{h^{2}}p-\frac{1}{\rho}\frac{\partial \tau_{xy}h}{\partial y}-\Omega q-\frac{\rho_{a}}{\rho}C_{w}WW_{x}+\frac{h}{\rho}\frac{\partial p_{a}}{\partial x}=0 \ (2)$$

The momentum equation in the y-direction is given by:

$$\frac{\partial q}{\partial t}+\frac{\partial\left(q^{2}/h\right)}{\partial y}+\frac{\partial\left(pq/h\right)}{\partial x}+gh\frac{\partial \varepsilon}{\partial y}+\frac{f}{2}\frac{\sqrt{p^{2}+q^{2}}}{h^{2}}q-\frac{1}{\rho}\frac{\partial \tau_{yx}h}{\partial x}+\Omega p-\frac{\rho_{a}}{\rho}C_{w}WW_{y}+\frac{h}{\rho}\frac{\partial p_{a}}{\partial y}=0 \ (3)$$

Where,

p and q flux in x and y directions respectively ($m^3/s/m$).
t time (s), x and y (m) are Cartesian Co –ordinate (s).
h water depth (m).
g acceleration due to gravity (9.81 m^2/s) .

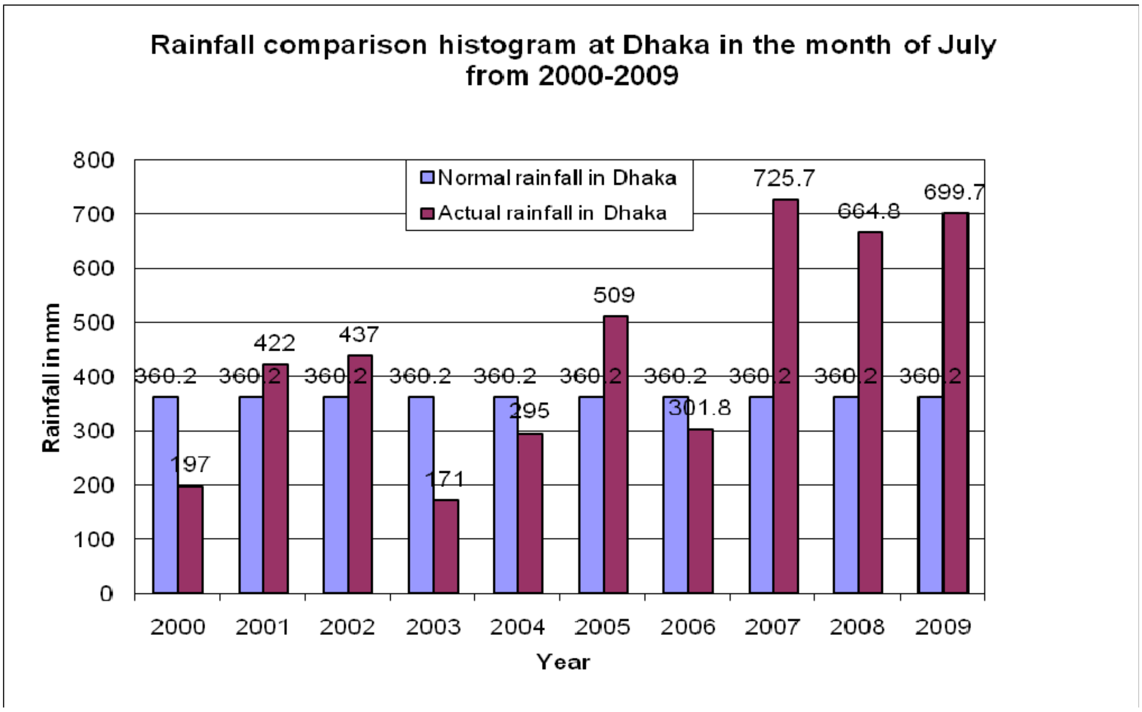
ε	sea surface elevation (m).
ρ_w & ρ_a	air and water density respectively (kg /m^3),
C_w	wind friction factor = 0.0008 + 0.000065W in accordance with Wu (1982).
W	wind speed (m/s).
Ω	Coriolis parameter =5.2*10^{-5} s^{-1} in the Bay of Bengal.
P_a	atmospheric pressure (kg/m/s^2).

This study was carried out in regional scale and has limitations. The models characterize a fixed representation based on land elevation. They do not consider land subsidence, erosion, accretion. Despite the limitations, the models illustrate the position of land areas susceptible to SLR and allow for reliable characterizations of the potential impacts on Bangladesh.

6. PHYSICAL IMPACT OF CLIMATE CHANGE

6.1 Impact on Inundation Depth due to Sea Level Rise and Rainfall

The potential impact of sea level rise along Bangladesh coast provide an information about the land which could be inundated and the population that would be affected provided no adaptive/protective measures are taken. From the model results it has been found that during monsoon in the year 2080 due to 62cm sea level rise for high emission scenario (A2 scenario), an additional area of 4,69,000 ha (13% of land area of coastal region) will be remain inundated compared to the base condition of year 2005. Whereas in the dry season about 364,200 ha (10%) more area will be inundated (inundation more than 30cm) for A2 scenario in the year 2080. Due to climate change rainfall will increase in the monsoon season. If 10% increase of rainfall is imposed in 2080 with 62 sea level rise 16% more area will be inundated during monsoon.



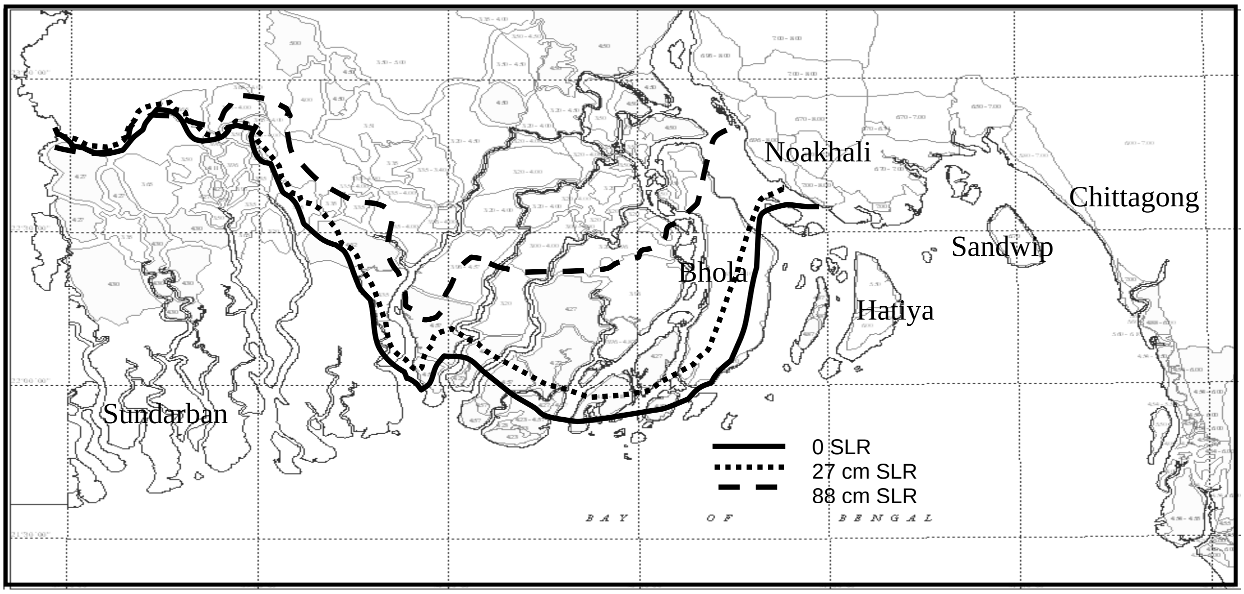
Increased trend of rainfall in Dhaka City, Propotionate in coastal belt also.

	Monsoon Season		Dry Season	
Scenarios	**Inundated area, [ha]**	**Increase in inundation area, [ha]**	**Inundated area, [ha]**	**Increase in inundation area, [ha]**
Base	1,720,200 [50%]		404,500 (12%)	-
B1, Yr 2080 (SLR 15cm)	1,863,600 [54%]	143,500 [4%]	Insignificant change	-
A2, Yr 2050 (SLR 27cm)	1,972,200 [57%]	252,000 [7%]	559,100 (16%)	154,600 [4%]
A2, Yr 2080 (SLR 62cm)	2,189,200 [63%]	469,000 [13%]	768,600 (22%)	364,200 [10%]
A2, Yr 2080 (SLR 62cm+10% rainfall)	2,271,700 [66%]	551,500 [16%]	-	

Area [ha] inundated due to sea level rise during monsoon and dry season [Land area in coastal region = 3,455,800 ha]

6.2 Impact on Salinity Intrusion

The impact on salinity in the Southwest region both in terms of its level and landward intrusion due to different sea level rise scenarios has been assessed using existing Bay of Bengal and South West Regional models. This is because southwest region is more vulnerable to salinity intrusion due to gradual decrease of upstream flow. Sea level rise would increase the extent of saline water intrusion by pushing the saline water front landwards. During monsoon, it is found that 1 ppt salinity line moves towards upstream by 10km and 20 km mainly in the central part (through Baleswar-Buriswar rivers) due to 27cm SLR and 62 cm SLR respectively. Whereas maximum intrusion of 5 ppt saline line will 9 km due to 27 cm SLR and 90 km due to 88 cm SLR which has been shown below



Movement of 5 ppt saline line due to different sea level rise

From the model results it is found that in Hatia and Manpura island in the Meghna Estuary, maximum salinity level will be increased to 3ppt and 5ppt due to 27cm and 62cm sea level rise respectively. However, for 62 cm and 88 cm sea level rise, the freshwater pocket in the Tentulia river is affected remarkably during dry season. The Sundarbans, which is already experiencing high salinity, will be affected more by salinity water intrusion due to increased sea level both in dry and monsoon season.

As the salinity front will move towards land a significant changes in fresh water zone and brackish water zone will be found. Considering the threshold value of salinity for agriculture, drinking water and biodiversity, changes in freshwater and brackish water area for dry and monsoon have been calculated from the model result. It is found that due to 27 cm and 62 cm sea level rise brackish area will be increased by 6% and 9% during dry season and 2% and 6% during monsoon.

Scenario	Dry season				Monsoon season			
	Fresh water area (sq.km) (<1 ppt)	**Change (%)**	**Brackish water area (sq.km) (>1 ppt)**	**Change (%)**	**Fresh water area (sq.km) (<1 ppt)**	**Change (%)**	**Brackish water area (sq.km) (>1 ppt)**	**Change (%)**
Base	25,125		21,020		37,796		9,403	
27cm SLR	22,233	-6%	23,912	6%	36,654	-2%	10,508	2%
62cm SLR	20,857	-9%	25,288	9%	35,028	-6%	12,111	6%

Changes in fresh and brackish water area in dry and monsoon

6.3 Impact on Storm Surge Inundation

The increased peak intensity of cyclone along with sea level rise has been modelled to find the cyclone induced storm surge inundation in the coastal districts. The peak wind speed of 1991 which is the main driving force for storm surge generation during cyclone has been increased by 10%. If this increment (10%) of wind speed with SLR 27 cm will occur at a time, will create much higher surge level and more area will be inundated. It has been found that surge level along Hatia island will be 5.8m to 6.5m compared to the surge level 5.0m to 5.5m in 1991 cyclone. This increased surge level will overtop the embankments (height varies from 5.5m to 6.0m) of Hatia island and thus inundated the Hatia island. Also near Chittagong-Cox’s Bazar coast, surge level is found to be increased by 1m to 1.5m and completely inundated Kutubdia and Cox’s Bazar. It has been also found that about 22% (20,700 ha) more land area in Cox’s Bazar district will be exposed to a risk of severe inundation (>1m inundation). In the Chittagong district, 21% (52,200 ha) more area will be exposed to risk of severe inundation due to sea level rise associated with increased peak intensity of 1991 cyclone.

7. IMPACTS ON COASTAL COMMUNITY AND LIVELIHOODS

7.1 Population exposed to inundation due to SLR

The exposed population in the settlement area is estimated using *Risk Class* for different inundation depth (WARPO, 2001). Total population exposed under each risk zone has been estimated and presented in below

SLR	Population (million) Under Risk of SLR induced flooding				
	No Risk	**Low (<25cm)**	**Medium (25-50cm)**	**High (50-100cm)**	**Severe (>100cm)**
15 cm SLR	25.59 (56%)	19.87 (44%)	0	0	0
27 cm SLR	36.55 (53%)	25.65 (37%)	6.96 (10%)	0	0
62 cm SLR	41.51 (49%)	17.42 (20%)	12.03 (14%)	14.36 (17%)	0

Population in the settlement area under risk of different SLR induced inundation

In the year 2050 under A2 scenario (SLR 27 cm) 37% (25.65 million) and 10% (6.96 million) of the population will be exposed to a risk of low (<25cm) and medium (25-50cm) inundation. From the model results it has been found that about 58% of this exposed population will be from Khulna, Jhalokathi, Barisal and Bagerhat districts.

In the year 2080 under A2 scenario (SLR 62 cm), about 17% of the population will be exposed to the risk of high inundation. From the model results it has been found that population in the settlement areas of the districts Barisal, Jhalokathi, Bagerhat, Patuakhali and Pirojpur are moderately exposed to inundation risk and about 64% of the exposed population are from these districts.

7.2 Socio-economic impacts on livelihoods due to SLR

Farmer

The investigation under this study shows that 25% of the households (HH) in the coastal region are farmer. Framer's livelihood is directly dependent on the agricultural lands. Hence, their livelihood has been estimated based on change in agricultural land types (F0 and F1 type lands) under different SLR. With the increase of SLR the area of farming land will be decreased, that will result decrease in farming opportunity. Under A2 scenario this opportunity will decrease by 13.5% and 25.1% in years 2050 (27 cm SLR) and 2080 (62 cm SLR) respectively. But under scenario B1 this decrease is less (9.6% and 13.4%) as shown in Table 7.3.

	Farmer	Base	Decrease in farming opportunity (A2)		Decrease in farming opportunity (B1)	
	(% of Total HH)	2005	2050	2080	2050	2080
Farmers	**25**	9,907,761	1,341,843	2,487,466	947,285	1,325,204
Decrease (%)			13.5%	25.1%	9.6%	13.4%

Impact of SLR on farmer livelihood

Fishermen

In the coastal zone of Bangladesh the fishermen are of mainly two types: (1) full time fishermen, and (2) seasonal fishermen. This can be further classified as fresh water fishermen and marine fishermen. Also there are culture fisheries where fishermen invest and live on ponds. The full time fishermen in this zone depend of quantity, quality, affordability and accessibility of the habitats.

In this study, the impact of SLR on freshwater fisherman is considered with the assumption that freshwater fish will decrease due to salinity intrusion and thereby opportunities of freshwater fisherman will decrease. The study estimated impacts on the fishermen due to reduction in fresh water habitat with different SLR under different population scenarios as shown in Table 7.4.

	Fishermen	Base	Impacted fishermen (A2)		Impacted fishermen (B1)	
	(% of Total HH)	2005	2050	2080	2050	2080
Total	**3**	1,124,812	91,028	168,446	64,262	89,730
Decrease (%)			8%	15%	6%	8%

Impact of SLR on fishermen livelihood

The table shows that about 91,000 and 168,000 professional fishermen will be impacted in years 2050 and 2080 respectively under projection scenarios A2. But under scenario B1 these number will be about 64,000 and 90,000.

Wage labour

About 70% employment in coastal zone is dependent on agriculture. Due to SLR the agricultural land type will be changed, and that will also change the opportunity of works of the wage labours. The analysis based on the land types under different SLR scenarios show that the wage labour opportunity will decrease by 14% and 25% in years 2050 and 2080 respectively under A2 scenario. This decreasing is found less in same years (10% and 13%) under scenario B1. The summarized result is shown in Table 7.5 and district wise result is shown in Appendix.

	Base	**Decrease in wage labour opportunity (2)**		**Decrease in wage labour opportunity (B1)**	
	2005	**2050**	**2080**	**2050**	**2080**
Wage labour	9,305,187	1,317,959	2,322,474	930,421	1,237,301
Decrease (%)		14%	25%	10%	13%

Impact of SLR on wage labour

8. ADAPTATIONS OPTIONS

8.1 Standing order on Disaster (SOD)

The Standing Orders have been prepared with the avowed objective of making the concerned persons understand their duties and responsibilities regarding disaster management at all levels, and accomplishing them. All Ministries, Divisions/Departments and Agencies shall prepare their own Action Plans in respect of their responsibilities under the Standing Orders for efficient implementation. The National Disaster Management Council (NDMC) and Inter-Ministerial Disaster Management Coordination Committee (IMDMCC) will ensure coordination of disaster related activities at the National level. Coordination at district, Thana and union levels will be done by the respective District, Thana and Union Disaster Management Committees. The Disaster Management Bureau will render all assistance to them by facilitating the process.The Ministries, Divisions/Departments and Agencies will organise proper training of their officers and staff employed at District, Thana, Union and village levels according to their own Action plans so that they can help in rescue, evacuation and relief work at different stages of disaster. The local authority shall arrange preparedness for emergency steps to meet the disaster and to mitigate distress without waiting for government help. The Standing Orders is followed during Normal times, Precautionary and Warning stage, Disaster stage and Post-disaster stage.
SOD now a days have been proved as a excellent tool for the mitigation of any sort of disaster.

*8.*2 ***National Adaptation Programme of Action* (*NAPA*), Bangladesh**

The National Adaptation Programme of Action(NAPA) is prepared by the Ministry of Environment and forest (MOEF), Government of the People's Republic of Bangladesh as a response to the decision of the Seventh Session of the Conference of the Parties (COP7) of the United Nations Framework Convention on Climate change (UNFCCC). The preparation process has followed the generic guiding principles outlined in the annotated guideline prepared by LDC Expert Group (LEG).

The strategic goals and objectives of future coping mechanisms are to reduce adverse effects of climate change including variability and extreme events and promote sustainable development. Future coping sstrategies and mechanisms are suggested based on existing process and practices keeping main essence of adaptation science which is a process to adjust with adverse situation of climate change.

8.3 Disaster Early warning system

Flood forecasting is done by Bangladesh Water Development Board (BWDB) by MIke11 model setup for 3-day determistic and 7-days probablestic approach. Digital elevation model is also run for the flood affected areas. This flood forecasting event has reduced the loss of life and properties in coastal areas also.

Bangladesh Meteorological Department (BMD) is entrusted with all sorts of weather forecasting. Weather warning system including cyclone came into being historically through evolution in order to mitigate suffering of people. It is observed from recent past cyclone (1997) the accurate and timely forecasting system and timely publicity, mobilization and action were very effective to reduce the loss of life and damage to properties. The severity of cyclone 1997 (maximum wind speed 220km/hr) was similar to the severity of 1991 where maximum wind speed was 225km/hr, but number of death was only 134 compared to number 138,882 in 1991. The local community voluntarily participated in dissemination of cyclone early warning under Cyclone Preparedness Program (CPP) project.

It is feared that the cyclone frequency and intensity will be increased due to climate change and thus more people will be exposed to this disaster. As proven under CPP, the early warning with more innovative approach could be one of the most effective coastal defences. The dissemination technology should adapt the advance communication media like mobile system and community radio alongside CPP approach. The current warning signalling system should also be modernized and people oriented.

8.4 Safe heaven facilities

Recent history proven the effectiveness of killas (raised earthen mount) and cyclone shelters as safe heaven during the cyclone induced storm surges. It is expected that the high risk and risk zone will expand and this will create more population and property exposed to the cyclone induced hazards. In year 2050 the estimated additional exposed population will be 20 million. To address this, more cyclone shelters and killas will be required.

8.5 Coastal embankments

Bangladesh already employs coastal embankment towards management of coastal the embankment crest levels were designed using historic water level analysis without considering any probable sea level rise in future. Present study found that with 27cm sea level rise 4 numbers of polders will be submerged, and this number will increase to 13 polders with 62 cm sea level rise. The embankment inundation can be avoided by raising the crest according to the influence of SLRs. The drainage will be slower because of higher rainfall and higher downstream water levels. This could be partially addressed by increasing the sluice openings (number of vents).

8.6 Increase of freshwater flow in upstream rivers

To reduce the threats of increasing salinity, particularly during low flow period, increase in freshwater flow through upstream river specifically through Gorai is one the physical adaptations to offset salinity ingress. The study recommended that about 200 cumec water should allowed to flow through Gorai river system, particularly during critical dry period of April. The increase of freshwater flow through Gorai could be achieved by diversion from Ganges Barrage or through dredging of Gorai offtake. The study shows that this amount of freshwater flow during dry season will push the 1ppt saline line by 45km seaward. From the model result it has also been found that due to 100 cumec flow it will push the 1 ppt saline up to 25km seaward. The Gorai river is an important source of freshwater supply to the southwest region of Bangladesh and is the only remaining major spill channel of the Ganges river flowing through the region where Sundarbans is located in its southern most part.

8.7 Afforestation

Dr. Joseph stiglifz, the nobel lauratie, Professeor of Economics, Columbia University has advised the LDCs to invest more in afforestation,rain forest,etc for a green belt in the coastal area. Mangrove forests functions as natural physical barrier against tidal and ocean influences by means of their large above-ground aerial root systems and standing crop. Mangroves act to trap and stabilize sediment and reduce the risk of shoreline erosion. Mangroves also reduce the wave height due to their ability to dissipate wave energy. The study shows that the mangrove forest with width of 400m and 600m decreases the surge height of approximately 0.45m and 0.55m at the east side of Sandwip. From the model result results it has also been found that mangrove reduces the current speed which reduces the probability of embankment breaching.

The World Conservation Union (IUCN) compared the death toll from two villages in Sri Lanka that were hit by the recent devastating Tsunami. Two people died in the settlement with dense mangroves, while up to 6,000 people died in village without similar vegetation.

Due to climate change sea level will rise and cyclone will come with more intensity and frequency. If so that will be hazardous for our coastal people. So in that case mangrove afforestation around our coastal area will be better solution.

8. CONCLUSION

Bangladesh is very much vulnerable to climate change. It will continue to affect Bangladesh coast through inundation due to increased rainfall, sea level rise and cyclonic storm surge, drainage congestion in the polders and also over topping of polders, increased salinity intrusion of low-lying areas and increased intensity and frequency of cyclonic storm surge. This will impact significantly on coastal livelihood, food security and the bio-diversity of coastal area. So our coastal area is going to face severe difficulties in the near future due to climate change. Now it is the time to revisit the planning and design of existing coastal infrastructure and to rehabilitate these structures to make it climate resilient. Besides this new risk zone has to be identified for future planning and design of coastal structure. Also proper adaptation measures both structural and non-structural are to be planned in order to find a climate resilient coastal environment for food security and livelihood security. The paper has given some climate change scenarios for Bangladesh and some adaptation measures. The Impact assessment due to the sea level rise for the coastal area of Bangladesh and adaptation measures have been made on the basis of existing literature and models. But still there remain some uncertainties such as limitations of models, the lack of full understanding of the climatic parameters and their variation, etc. The assessment results need to be updated continuously and hence more in-depth research efforts should be put into this.

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INDIAN FISHERY – A VICTIM OF CLIMATE AND TECHNOLOGICAL CHANGE

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ABSTRACT

It is an unfortunate but acceptable fact that the fisheries are on a decline in a world wide scale primarily because of two reasons: human greed in the form of over-fishing and coastal ecological changes resulting in declining fish stock. Indian fishery sector is no exception which over the last two decades has become victim of both climate change and modern western fishing techniques. Climate changes have altered the production and distribution of some commercially important pelagic fishes from Indian waters like the sardines and mackerels. Like many other tropical pelagic fishes, Indian mackerel and Indian oil sardine have shown population crashes. The negative impact has been huge and the traditional fishing community has been worst hit.

In addition, the replacement of small scale traditional fisheries with large scale mechanised fishing techniques have resulted in throwing the fishermen out of gainful employment for no fault of theirs. Their fishing practices have been proved as ecologically and environmentally friendly as they respect the limited renewable capacity of the oceanic resources – mostly varieties of fish and vehemently oppose over-fishing practices. They limit their fishing efforts as per the fishing season thereby ensuring renewal of fish stock. The advent of western technology and its indiscriminate application to Indian tropical waters have played havoc with "mother nature" resulting in not only alarming rate in depleted Indian fish stock but also displacing the fishermen economically. In addition, the role of the women in traditional Indian fishery sector is declining who are engaged in secondary and tertiary sector in marine fisheries forming 48% of total labour force in these segments. Women, who are involved in drying, curing, vending and auctioning fish, are often the most invisible amongst the marginalized. Also, these traditional fishermen make their own boats and nets and so are artisans too. On top of this the Government prohibition or enforced ban on fishing for some limited time period hit these traditional fishermen. They are forced to migrate to other areas and also adopt new means of livelihood which are mostly not related to fishing at all. There are several such fishing villages which are near extinction along Indian coastline.

The coastline of India is 8129 kms with 3202 marine fishing villages which is a home to 5 million marine fishing population, currently residing in marine coastal villages of over 2000 in number. The incidence of poverty in Indian marine fishery sector is much higher than any other backward sectors in the country. Fisher families living below poverty line is estimated about 60% which is much higher than the national average of 26%. The reasons can be varied of which the predominant one is over exploitation of marine resources leading to lower per capita production, earnings and disguised unemployment.

The aim of the paper is to highlight the plight of these traditional fisher folk who are at the crossroads of climatic and technological change and lack adaptability to combat this crisis. The paper also aims to exemplify this case with some practical case studies.

1. BACKGROUND

It is an unfortunate but acceptable fact that the fisheries are on a decline in a world wide scale primarily because of two reasons: human greed in the form of over-fishing and coastal ecological changes due to climate change resulting in declining fish stock. Indian fishery sector is no exception which over the last two decades has become victim of both climate change and modern fishing techniques.

The coastline of India is 8129 kms with 3202 marine fishing villages which is a home to 5 million marine fishing population, currently residing in marine coastal villages of over 2000 in number. The incidence of poverty in Indian marine fishery sector is much higher than any other backward sectors in the country. Fisher families living below poverty line is estimated about 60% which is much higher than the national average of 26%. The reasons can be varied of which the predominant ones are over exploitation of marine resources and climate change leading to lower per capita production, earnings and disguised unemployment.

Climate change is projected to cause massive changes in the environment which are on a scale unprecedented in the last 1,000 years. The causative factors of climate change are the greenhouse gases, viz., carbon dioxide, methane, ozone and nitrous oxide. The most confident projections on the fall-out of climate change are for the amount of warming and changes in precipitation.

Climate change has major impact on fisheries sector. The gradual increase in temperature could have had a critical effect on marine fisheries which calls for a detailed study. Lack of economic security often leads to indiscriminate harvest of resources resulting in irreparable damage to the sector. In India too, climate changes have altered the production and distribution of some commercially important pelagic fishes from Indian waters like the sardines and mackerels. Like many other tropical pelagic fishes, Indian mackerel and Indian oil sardine have shown population crashes The negative impact has been huge and the traditional fishing community has been worst hit. Stressing the need for increasing fish production through freshwater aquaculture is perhaps one solution.

India being a developing nation has several problems typical of a transitional economy. On one hand, we have a huge population to be gainfully employed and on the other is the severe resource crunch. In such a situation our problems are enormous. The Indian fishery sector too is not free from such problems. Being in the primary sector but still of lesser significance than agriculture and allied activities because of the sheer number of people engaged in it (about1%), makes fishermen so unique. They are at the crossroads of modernisation and indigenous artisanal craftsmanship and are victims of displacement, mostly occupational in nature. This paper attempts to understand the internal and external forces that might have played in the Indian fishery sector and have affected the traditional indigenous fishermen in particular.

Considering the enormity of the problem and the need to address the issues connected with climate change and technological change in fishing methods affecting sea food security and livelihood of population dependent on it, the paper attempts to highlight these issues and forward suggestive measures for implementation of a comprehensive, inexpensive and eco-friendly policy in the benefit of the Indian fishery sector in general and the traditional fishermen in particular.

2. TECHNOLOGICAL CHANGE AND INDIAN FISHERY

Irrespective of our technological choice, there are certain features of our seas which we cannot alter[1]. The tropical waters by nature are relatively poor in fish resources as all the favourable factors for fish spawning and growth is present in the temperate waters. Secondly, temperate waters have the advantage of fewer species but more in number which makes large-scale commercial fishing profitable by trawler and purse-seining. In contrast, Indian Ocean for e.g., there are too many varieties of specie which make commercial exploitation of selected few difficult. The fishing technologies of the foreign vessels are more suited to the temperate waters, where large stocks of each specie are available. So when similar technology is applied to tropical seas here, where comparatively only

[1] Ibid.

smaller stocks of many different species with varying sizes are found, this will definitely lead to fast depletion of selective stocks at a faster rate. Fish is a renewable natural resource, but the large varieties like tuna, perches, shark and cat fish once depleted, will take many years to recover. Each fish variety in a particular region is a link in the chain of total fish resources. The destruction of one link will break the entire chain, which can lead to total collapse of the fishery as a whole.

The marine fisher population in India has been growing at a faster rate than the overall population. Out of this, 3.5 million fisherfolk live along the coastline and the rest along the banks of rivers, lakes and backwaters. Among the sea-going fishermen, more than 80% are in the artisanal sector that operates small-scale traditional crafts and gear. India has a coastline of about 7,000 kms and EEZ of 2.20 million sq.km. The fishermen live in about 2500 villages along the coastline[2]. Annual potential catch is around 5 million tonnes of which 53% is from inshore waters and 36% from off-shore waters. The dug-out canoes are mostly seen in the west coast because of calmer waters, whereas catamarans are seen mostly in the east coast under high surf conditions. Large drift nets are used for demersal species, while seines are most efficient where pelagic fish abound (inshore). Hooks and lines are most appropriate for deep water fishing[3]. The most distinctive feature of this artisanal fishing technology in India is its heterogeneity, conditioned by the physical geography of the coast and partly by the nature of the resource base. Considerable change took place in the artisanal sector during the last 50 years. The introduction of nylon nets in place of cotton nets was significant. Compared to modern large-scale fisheries, artisanal sector is decentralized, of lower costs and absorb all available labour force.

Modernisation in the fishing sector has meant trawling and purseining in the EEZ (200 nautical miles) extensively to exploit fishery resources to the fullest. It is also the shallow waters which become an attraction for the pelagic and demersal fish shoals of the deep waters as they come to feed on the small fish life on the coast. This vast coastal nursery in shallow waters supplies fish to both traditional fishing and mechanised trawling. This precisely is the bone of contention. Instead of going outwards into deeper waters, the mechanised boats turn inwards to shallow waters and fish in the area that is essentially within the reach of traditional small-scale fishermen. While mechanised boat owners and trawlers consider it their right that their boats be anchored here, the traditional fisher-people see it as yet another assault on their already shrinking space in the marine sector and are trying to resist it. The Centre however, has asked all maritime states to strictly enforce the Marine Fishing Regulation Act to enable artisanal fishermen to have exclusive fishing rights within 10 kms from the coast.

On top of this the Government prohibition or enforced ban on fishing for some limited time period hit these traditional fishermen. They are forced to migrate to other areas and also adopt new means of livelihood which are mostly not related to fishing at all. There are several such fishing villages which are near extinction along Indian coastline. The fishing prohibition-induced loss of livelihood stakes has never been taken seriously. Greenpeace, international body espousing environmental issues, had chalked out a comprehensive compensation package for traditional fishermen affected by fishing restriction.

2.1 Comparison between Traditional and Industrial Fishermen

It is interesting to note that on one side there is the traditional low skilled fisherfolk who are striving for existence today as they emerge as weak competitors against the industrial group. It is noteworthy at this point to summarize the chief characteristics of traditional fishery which co-exist even today with modern technologically based fishing methods.

1. With regard to fishing vessel and equipment.
2. Part-time vs. full-time occupation.

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[2] A. J. Vijayan, " Fisherman in India : Struggle for Survival".
[3] Ibid.

3. Sharing vs. ownership of vessel and gear.
4. Traditional fishermen far outnumber industrial fishermen
5. Contribution to GNP is opposite.
6. Selective catch as opposed to miscellaneous.
7. Different source of capital, moneylender vs. financial institutions.
8. Aquaculture
9. Marketing strategies
10. Role of women in traditional fishery sector.

There is however, a lot of difference between company owned boats and artisanal fishery, in terms of employment. The number of fishermen employed in company-owned fishery is 10-100 for an investment of $1 million whereas in the artisanal fishery about 1,000 to 10,000 people get jobs for the same investment.

2.2 Phases of Deep Sea Fishing and Implications of Population Displacement

In the initial phase, both in the developing and developed countries, the marine fishery was essentially small in scale. Particularly in traditional fishing, there were only cases of direct displacement whereby fishermen were displaced because of some developmental projects (eg. New Mangalore port displaced local fishermen at the port site) that needed coastal location. In the transitional phase when there was adoption of new technologies, within the traditional fishing community, the fishermen who were economically poor got marginalised. But for those who benefited from improved fish catching mechanisms and improved productivity, enjoyed better life at large. It must be noted that the Government never intervened in this stage. Following this, came liberalisation with positive state intervention towards foreign investment and joint ventures. The domestic fishermen were exposed to international competition and the traditional fishermen were further marginalised, now at an international level. In extreme cases, fishermen, most of who do not own land, often simply picked up stakes and moved to another location. Boats and gear were sold back to suppliers who then resold them. Traditional small-scale fishermen therefore[4] struggle at two levels - against exploitation within their community (money- lenders and merchants) and outside, against the mechanised fishing sector. Over capitalisation in the modern fishing sector has created misery for the traditional lot. It has resulted in growing unemployment and underemployment among the boat workers and women in particular who are redundant due to mechanisation of the processing plants. Thus we have a growing number of migrant labour forces who are economically marginalised and displaced. In extreme cases, they change occupation or in other words are occupationally displaced more than being physically displaced.

Capitalist development brought new economic agents into the sea[5]. It has to be understood that, the modern technology (mainly trawling and purse-seining)[6] which is appropriate in the West cannot be indiscriminately applied to tropical waters which have completely different scenario. To begin with, there is a huge artisanal traditional fishing sector who practice the so-called passive fishing methods which are slow or of low intensity and where yield per effort is not too high. They exclusively fish in the inshore shallow belt which has been gradually encroached by the large industrial multinational

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[4] Op. cit. Footnote. No. 1.

[5] John Kurien, “Opportunity and Participation in Developing Countries” in UN’s DPCSD, CSD, Trivandrum, Kerala.

[6] Trawling and Purse-seining : Trawling is conducted by dragging heavy weights and beams on the sea-bed in order to squeeze the prawns out of the sea bed. This process of dragging has a ploughing effect on the sea bed in which the fish eggs and larvae breeding in the soft sediments are brutally killed. Since the shallow water is a “nursery” teeming with millions of under-size fish these also get entangled in the trawl and are killed by disturbance and abrasion denying them the chance of breeding and propagation of fish population.

Purse-seining is meant to tap pelagic fish resources and is overefficient and destructive method which leaves no scope for young pelagic fish species and shoals to grow and proliferate.

giants who practice "purseining" which is over- efficient but environmentally destructive. The new technology along the west coast in the name of diversification is purse-seining. The visible change being fish was harvested quickly and the fishing season got shorter. This led to over fishing and soon a crisis developed due to the disappearance of several fish specie. The resource crisis affected the fishing industry in general and the small-scale sector in particular. Thus the struggle between the small-scale artisanal fishermen and the modern industrial fishing giants started. The mechanised fishing trawling and purseining has been denying lakhs of traditional (artisanal) fishermen of India their basic fundamental right to carry on their profession and occupation as enshrined in the constitution of India Article 19/1(g). Traditional fishermen of India pay taxes on their fishing implements to carry on their profession legally entitled to secure an adequate fish catch to earn their livelihood[7]. There is nodoubt that too many fishermen are chasing too little fish. Reducing per capita fishing effort is one solution to renew the stock. But the first impact of this is more on the small-scale fishermen who either move to wage employment in coastal based industries or to other tertiary sector jobs. The majority of fishermen do not own vessels and many do not own fishing gear, but rather work as share or wage labourers on other vessels. Another Asian phenomenon is the migration of youth, women and to some extent small-scale fishermen to the Persian Gulf countries to undertake unskilled and semi-skilled jobs.

The argument often offered in favour of the deep sea fishing policy is that the joint ventures will provide more employment opportunities for the fisherfolk. But perhaps this is not so. The processing, grading, packing of the products will be done on board. So once again the argument that the shore labour would get employment does not hold ground. The entire marketing of the catch would be done in the overseas market which means that even on the market front any generation of employment would be nil[8].

There is now a trend to go back to softer smaller scale fishing technology[9]. In the recent past, organisations like the UNDP, FAO, UNESCO, World Bank have emphasized the merits of small-scale fisheries and the need to ensure the participation of fishworkers in the implementation of fisheries development and management programs. Even in the major maritime countries like Canada, Norway and Denmark, the movements to highlight small-scale fishing as a way of life has recently gained prominence. The gradual overcapitalisation and industrialisation of the fishery in these countries has threatened the livelihood of many coastal communities. But since the Governments are alert, the affected population is taken care of in some compensatory manner. These richer nations are therefore rushing into the less exploited regions like our Indian Ocean under the cover of "joint ventures" or " co-operative fishing ventures"[10]. In the current liberalized and globalised environment, when domestic and foreign corporate investments and joint ventures are being initiated on a massive scale in the deep seas that comprise India's Exclusive Economic Zone (EEZ), the indigenous fishing sector is being threatened. The traditional fishermen ply their craft within the coastal area, which is up to a depth of 50 mts., which is being increasingly cornered by trawlers, mechanised boats and their destructive fishing technology. Enmeshed in a net of problems, deep sea fishing off India, is heading for deeper conflicts. Infact, there are no deep sea fishing regulations in India.

As deep sea fishing has proved not so successful in India, the Government has come up with the new deep sea fishing policy, which allows foreign companies to operate in the country's EEZ. There is already a warning the world over not to increase the fishing pressure. Under this situation the Indian Government defends its position as over half of India's EEZ (which extends to 120 fathom line) is 'unexploited'. The fish available in the EEZ was four million tonnes annually, whereas the Indian fishermen were able to take only a little over 2 million tonnes, as they do not exploit the entire area.

[7] "The Traditional Fishermen of India Demand Appropriate Technology in the Indian Fisheries Sector" in Workshop on " An Alternate Approach to the management of Research and Education in Science and Technology", IIM, Bangalore, June 23-27, 1986.
[8] Times of India, 31. 07. 1994.
[9] Op. cit. Foot note No. 7.
[10] Ibid.

National Fishworkers Forum voices the demands and agony of the traditional artisanal fisherfolk. They claim that the gear and the vessels which the foreign companies have deployed in India's EEZ have been banned in a majority of the western countries (US and Japan also). These countries have depleted their own stocks and were searching for greener pastures. As a reaction fishermen from various coastal states are up in arms over the 'foreign invasion' of India's fishery sector. According to the Forum, the new deep sea fishing policy should ensure the expansion of the ambit of operations of small fishermen to deeper waters. The policy should ensure liberalised central subsidies and credit for small fishermen who venture into the deep seas. It should also lead to increased supply of fish for domestic consumption. Moreover, the Government should confer legal rights and reserve exclusive fishing zones for small scale artisanal fishermen, at least upto the contiguous zone.

2.3 Indian Aquaculture –The Industry of the Future

According to the definition of Marine Products Export Development Authority (MPEDA), "*aquaculture is a viable means of diversification of fisheries, to increase fish production both for domestic consumption and export, rural upliftment, employment and income generation to a large section of the people*". The shrimp industry has expanded in the last two decades under the rationale of providing economic benefits at national, regional, community and household levels. The foreign exchange argument however, has been the most forceful. Nowhere is there an analysis of the foreign exchange earnings from shrimp culture.

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By nature, shrimp culture is concentrated in tropical countries, which also tend to be low income, food deficit countries, while the market for shrimp is concentrated in temperate developed countries. India is the world's biggest producer of wild caught shrimp[11]. After thirteen years, India is now a lead marketer in Japan. But India now imports shrimp too. Several issues need to be addressed - ranging from acquisition of land to export of shrimps, child labour, displacement, eco devastation, food vs. goods, human rights issues, joblessness, land rights –the list is never ending.

Moreover, the expansion of shrimp culture represents a move to mono-culture-away from multi-product focus. Therefore, it has all the evils of monoculture. Shrimp aquaculture has damaging environmental effects on the land which gets diverted from its earlier use for agriculture and fishing and salt manufacture. In addition, the impact on rural economy is huge. Changes in land use and land ownership lead to conflict between dispossessed groups and the new capitalist owners. So there are associated problems of displacement (more of economic marginalisation), denudation and desertification. Major players in shrimp aquaculture are the industrial houses of Tata, Sriram, Thapar, India Tobacco, Hindustan Lever and allied multinational corporations. The common interest is that in aquaculture, the internal rate of return is greater than 50%. It is this high rate of return on capital investment which is behind this massive push being given to this area. So at the core lies sheer business interest, this is well integrated into the whole vision of liberalisation.

Aquaculture has a huge potential in the export market. This "the industry of the future", may lead to multi-user conflicts, increased demand for land resources, salination of productive agricultural land as well as fresh water aquifers. If unchecked intensive and semi-intensive aquaculture farming eventually destroys cultivable land making it unfit for anything. Effluents from aquaculture farms contain inorganic nutrients and pesticide residues which can cause harm to coastal ecology.
It may further devalue marginal agricultural land and drinking water resources. These factors can have adverse social side effects, such as:

- Denial of access to coastal fishermen of basic amenities and fish landing centres
- Denial of job opportunities to agricultural labourers
- Blocking of drainage channels for drawing water
- Flooding of low lying areas leading to further displacement of population.(a case of indirect displacement)

[11] Ibid.

Mushrooming of shrimp farms along the 1,000 kms. coast in Andhra Pradesh has led to an exodus of traditional fishermen to the hinterland. Fishermen in several hamlets in the Nellore coast which has been witnessing a "Blue Revolution" , has been pushed inland due to conversion of 1000s of hectares of land along the coast into modern shrimp farms during the last four years. The nouveau rich farmers also started buying coastal villages for raising farms, leading to clashes between rival groups[12].

3. CLIMATE CHANGE AND INDIAN FISHERY

The frequent flooding of low-lying coastal areas along the Indian coast, especially the eastern side has been often unpredictable. So has been the occurrence of cyclones like Aila. A study by TERI and MOEF, GOI published in 1995 projected that a 1 metre sea level rise could put as many as 7.1 million people -- including all coastal fishing communities whose livelihood is directly linked to the ocean -- at risk of displacement.

Climate change has major impact on fisheries sector. In fact, impact of global warming on fisheries sector could be gauged from a rising sea surface temperature. The gradual increase in temperature could have had a critical effect on marine fisheries. The distribution of the oil sardine for instance, has responded markedly to increase in sea temperature. With the northern latitudes becoming warmer, the oil sardine, which is essentially a tropical species, is able to establish itself in the new territories and contribute to the fisheries along the northwest and northeast coasts of India. The vulnerable groups such as the corals are in peril too. It is found that extensive coral bleaching occurred in Gulf of Mannar and Andaman and Lakshadweep Seas. The intensity of bleaching was directly related to the number of days the higher temperature prevailed.

Mangroves are critical bio-systems which grow in inter-tidal regions and act as a primary nursery area for a number of commercially important marine species. They are also the breeding ground for other species like phytoplankton, seaweeds, sea grasses, sponges, corals which sustain the oceanic food chain. Studies indicate that global warming and rising sea levels have significantly shrunk mangrove areas. It remains to be seen whether the fishing communities in coastal tidal areas like Orissa coastline and Sunderbans area of West Bengal will be able to survive and combat declining mangrove forests.

Yet, climate change is not a priority area of research in this country, even though several global studies name India among the nations that are particularly vulnerable. In addition, the replacement of small scale traditional fisheries with large scale mechanised fishing techniques have resulted in throwing the fishermen out of gainful employment for no fault of theirs. Their fishing practices have been proved as ecologically and environmentally friendly as they respect the limited renewable capacity of the oceanic resources – mostly varieties of fish and vehemently oppose over-fishing practices. They limit their fishing efforts as per the fishing season thereby ensuring renewal of fish stock. The advent of western technology and its indiscriminate application to Indian tropical waters have played havoc with "mother nature" resulting in not only alarming rate in depleted Indian fish stock but also displacing the fishermen economically. In addition, the role of the women in traditional Indian fishery sector is declining who are engaged in secondary and tertiary sector in marine fisheries forming 48% of total labour force in these segments. Women, who are involved in drying, curing, vending and auctioning fish, are often the most invisible amongst the marginalized. Also, these traditional fishermen make their own boats and nets and so are artisans too.

4. ROLE OF THE INDIAN GOVERNMENT (MPEDA)

MPEDA (Marine Products Export Development Agency) claims that there are certain types of fishes which are over-exploited on one hand and gross under utilization of available industrial capacity for

[12] "Blue Revolution Causing Exodus of Fishermen", Financial Express, 27. 04. 1995.

processing, storage and marketing of marine products on the other. The Government has announced time and again a number of measures for providing impetus to the deep sea fishing industry in the country. This is in the form of subsidy of loans for acquiring deep sea fishing vessels. The Central Government has also sanctioned the deep sea fishery harbour project at Paradip in Orissa. Also, test fishing has been made a statutory requirement of the new deep sea fishing policy. MPEDA has been introducing new subsidy schemes for providing seed and feed at concessional rates to traditional farmers. It has been argued that Indian farmers who depend largely on crop husbandry could enhance their income and hence their living standard through the adoption of integrated fish farming system, such as agriculture-cum–fish culture. These practices have been successful in several countries of South-East Asia.

The Government has also initiated a network of 409 FFDAs (Fish Farmers Development Agency). With their assistance, about 36,000 hectares of water areas have been brought under scientific and intensive fish culture during 93-94. About 31,000 fish farmers were trained in improved methods of farming under the FFDA programme in the same year. Assistance under the scheme includes another added advantage has been that this scheme has eliminated middlemen.

The Government has recently developed a composite sea farming project to produce pearl oyster, edible oyster, calms, mussels, sea cucumber, prawn, etc. To encourage fish processing, the government has made it a delicensed industry and no permission is required for setting up fish processing units. To promote fish processing, the government provides financial subsidy to acquire fishing vessels, setting up cold storage chain and to process some of the varieties like tuna which are in great demand abroad. About half of the deep sea catch is made from the coastal areas- upto a depth of 50 metres. In these areas fishing is done by the traditional fishermen. Thus, half of the potential is exploited by our traditional fishermen. About 1, 42,500 traditional crafts, 34,000 mechanised fishing vessels and 180 deep sea fishing vessels are engaged in fishing operations. Processing units are primarily located around important fish landing centres like Porbunder, Ratnagiri, Karwar, Mangalore, Calicut, Cochin, Quilon, Tuticorin, Mandapam, Cuddalore, Madras, Panjim, Kakinada, Visakhapatnam, Puri, Calcutta and Bombay[13]

As many as 3773 farmers receive MPEDA's technical assistance in several maritime states in the country. Steps have been taken to bring an additioanl 1500 hectare under scientific shrimp farming expecting the production of about 2000 tonne of shrimp worth Rs. 15 crore[14].

5. CASE STUDIES

5.1 Orissa Coastal Fisheries

Orissa is an important maritime state located on the eastern coast of the Indian Peninsula. Due to a multitude of large rivers and dynamic estuarine areas, the 480 km. coastline supports a variety of ecological niches and habitats. Orissa is known for its diverse marine wealth –the Irrawady dolphin, horseshoe crab, olive ridley sea turtle, thick mangrove swamps, and rich commercial fish With fisheries-regulated economy being in the doldrums following strict enforcement of Orissa Marine Fishing Regulation Act (OMFRA) provisions, over 700 people who are either fishermen or boat makers or crews have left the fisheries sector for good. The government agencies are seemingly intent to save the Olive Ridley turtles because for them animals are more precious than human lives.

[13] Business Standard, 18. 07. 1994.
[14] SEN 04/07/91, Green File, Centre for Science and Environment, August 1994.

The fishermen communities in about 27 villages are beginning to look for livelihood options. Even as the government agencies, stubborn in their stand to conserve the turtles, refuse to budge an inch from partial relaxation of fishing prohibition, there are reports of large-scale inter-State migration of fish workers for subsistence.

The enforced ban on marine fishing has triggered physical displacement of fishermen in several seaside villages, severely impeding the economic activity of the region that is predominantly inhabited by traditional marine fishermen community. Slowly many are giving up traditional occupation and taking to interstate migration in search of alternate livelihood, according field level studies by a confederation of NGOs. The fishing prohibition-induced loss of livelihood stakes has never been taken seriously. Greenpeace had chalked out a comprehensive Rs 9.18 crore compensation package for traditional fishermen affected by fishing restriction due to turtle conservation in Orissa. But the state government is yet to implement it.

5.2 Dhabol

Besides mechanisation in the fishing sector, another equally pressing problem that has directly affected the fishermen at large is coastal pollution, mostly due to emission of industrial/chemical effluents by coast-based industries. Fishes die in large numbers because of this pollution throwing fishermen out of work. Moreover, even if they catch a few, indigenous fishermen fail to sell in the open market as buyers fear poisonous fish. This has been the case in many coastal areas in India. Though there exists a Pollution Control Board to check the polluting industries, law enforcement has been very weak and non-effective. Occasional closure of a few law-violating industries has not been a permanent solution. Effluent treatment is the only solution that needs strict enforcement. This scenario has been exemplified by an interesting case study of fishermen at the Dhabol Creek, situated at about 300 kms. south of Mumbai in Maharashtra. The focus has been to trace the apparent and not so apparent causes leading to a rapid decline in fish catch which has affected the livelihood of about 40,000 odd fishermen residing along the 18-km long creek. Field Survey at three selected fishing villages along the creek established this fact.

6. CONCLUSION

There is a dire need to help small-scale fishermen in India by upgrading the equipment and market facilities. There is an urgent need to provide for all weather fishing harbours and fish landing jetties and a judicious combination of both is required. These should be supported by an infrastructure for boat repair facilities, cold storage, freezing for processing plants and transport. Cooperative ventures among fishermen should be encouraged. (Fishermen's cooperative Society at Versova, Mumbai has been a successful story. The society has benefited 2,000 fishermen and has been running at a profit for the last 30 years). The measures for a self-reliant and sustainable small-scale fishery may be summarised as follows:

- Implementing aquarian reform which entails right of ownership to fishing assets for fishworkers
- The legal right to decide on the mode, structure and price of the first sale transaction of their fish
- Greater control over export
- Reinstating artisanal knowledge
- Blending and transferring technologies
- Empowering Fishworkers' Organisations
- Providing rightful role for Women

It has to be remembered that for a developing nation like India, we should embrace that technology which can bring " ----- *economic growth with social justice to the masses and reduce poverty and* *hunger and increase food security and employment at the same time! That introduction of anew technology in India must not displace even one single existing occupation and must not accentuate inequalities. Any new technologies, any mechanisation to be appropriate, must be population appropriate and income equality appropriate. It should be cheap, labour intensive and benefit every fisherman in the country"*[15]. But the modern fishing technology does not adhere to the above national interest and here lies the dilemma which has to be dealt with immediate effect.

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COASTAL ZONES AND CLIMATE CHANGE IN BRAZIL SOUTHEAST

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ABSTRACT

Current global climate change will potentially increase environmental risks for population settled in low elevation coastal zones. In the next decades those populations will face a growing number of extreme events such as landslides, floods and storm-surge floods, which could happen in association with the rising of the sea level. This paper focuses demographic and environmental changes relation on three coastal and metropolitan municipalities of São Paulo State, located on the Southeast of Brazil. These municipalities comprise most part of the urban processes that occur in the Brazilian coastal zone (tourism, petro-chemical industries and seaport transportation) These are Guarujá, São Vicente and Bertioga, all located in Baixada Santista Metropolitan Region. The total resident population is around 650.000 inhabitants. It contains the biggest seaport of Brazil – port of Santos – and has an intensive summer-related tourism. This scenario is responsible for irregularities in space occupation, resulting in segregation and different exposures to environmental risks. Bertioga is the smallest city in the region, but the one with the biggest population growth rate. It has tourism as its main economic activity, with large luxury condominiums for second residences. It already experiences floods in isolated points. Guarujá is totally located on the Santo Amaro Island, and even though it is primarily a touristic city, it partly contains the seaport of Santos. Most of their permanent dwellers live in places away from the sea, facing more serious floods and landslides. São Vicente, partially located on the São Vicente Island, has bigger commercial services and a smaller area for tourism. Their population copes with floods and problems related to the drainage system, mainly on the island portion. Considering this background, the main purpose of this article is to map sea level rising, landslides and floods risks, thinking that these risks will be improved due to climate change, and evaluate how many people will be exposed to these risks, such as the characteristics of this populations and their capacity to face these risks. To achieve this goal we use georeferenced tools that map the distance of the population to the sea, to the rivers, and to the hills, using census information from year 2000 (census tract spatial level) and 2007 (municipality level). Then we analyze the characteristics of the populations exposed to these risks and how the local public policies are (or are not) being planned in concern with climate changes and demographic issues, at municipality and state level. The primary findings make possible to conclude that: 1) in different levels, all the local population will be affected by the environmental changes, due to the environmental specificities (flat land close to high slope mountains); 2) the economic activities, like tourism and port, can be affected and create problems for the local economy; 3) even the rich population groups, part settled in front of the shoreline, will be affected; but the largest problems will be faced for the poor people, which live in some areas of the coastal zone.

1. INTRODUCTION

World coastal zones are high important in several ways (Martinez, Intralawanm, Vázquez et al, 2007). Geologically and ecologically they include soft-shores, rocky shores and cliffs, hilly or flat coastal plains, narrow or wide coastal shelves and a extensive variety of wetlands. In it economic importance the coastal zones provides goods and services highly valuable to human society. It is not new or surprising that a significant percentage of the world population is located in places near to coastal zones. Demographically, around 2.385 billion of people lives within 100km of the boarderline between land and sea in 2003 (Martinez, Intralawanm, Vázquez et al, 2007). According to Kron (2008) there is no region in the world as attractive as coastlands, in which favorable conditions to industries facilities, seaports proximity and better life quality exists. In other hand it is the riskiest place in the world (Kron, 2008). The main part of natural disasters occurs on coastal zones, or is related to meteorological and geological events that are produced in the shoreline or in oceans (Kron, 2008; Munichre, 2009).

This scenario is seems to change, today and in future. The "Fourth Assessment Report" of the IPCC (2007) indicates that environmental risks tend to be increased due to climate change caused by global warming. Environmental changes of the future will happen in prolonged periods, with many impacts happening through frequency increasing of extreme climatic events (Wygley, 2009). The global population, including those living coastal zones, will face a new and permanently situation.

Nevertheless, there will be a wide variety of local and regional impacts of climatic change and any generalization have to be avoided. Environmentally the changes will be diverse and the same is valid to social and, in special, how we focus, demographic tendencies. Geography and social process in coastal zones occurs in specific ways, and because of this, risks, resilience and vulnerability of populations will be different and a result of a wide set of spatial and social characteristics.

In this paper we analyze local risks to this environmental changes in three municipalities located in Brazilian Southeast: São Vicente, Bertioga and Guarujá. To discuss the main aspects of these changes we discuss three aspects. First, we think the relation between climate change, demographic dynamics and environment risks. Second, we describes the most important aspects of environment, urbanization and soil use in Brazil coastal zones and specifically in the three municipalities. Last, we map risks to environmental changes and demographic profiles of the populations living in these areas in the selected region of study. Within this we intend to achieve the purposes of this paper. First, describe different environmental risks that exist in coastal zones; second, evaluate how many people will be affected by these risks; third, analyze the main characteristics of the populations in each environment risk zone.

2. POPULATION DYNAMICS AND ENVIRONMENT CHANGE

The interaction between population dynamics and environmental change has been studied as a new field of science that already joins a considerable number of researchers with two basic questions: How human populations affect environment? How environment changes affect human populations? (LUTZ, PRSKAWETZ e SANDERSON, 2002). For this reason it's a interdisciplinary field, with investigations defending that both population and environment are modified due to this interaction.

Hogan (2007) identifies the specific elements of population dynamics that can be studied in its relation with the environment, considering the demography main factors – mortality, fertility and migration. The researcher points that the mortality patterns are affected by natural hazards, disasters, pollution increase and by the epidemiologic transition[1]; the fertility, that can be affected by environmental issues, as nutrition (related to food production) and biologic factors related to environment diseases proliferation; and finally the migration, the clearest case that environment acts, directing and conditioning fluxes and volume displacements. Hogan (2007) points that in all of this cases more demographic works is needed, primordially in the morbity/mortality and urbanization/migration issues.

[1] The epidemiologic transition consists in the morbity profile change. Infecto-contagious diseases decreases and degenerative diseases increases. So are more importance to man created disease, which are related to environmental aspects (Hogan, 2007).

With each time more evidences of global warming as a reality and a threat to human species, the interaction between demographics and environment has received considerable attention, and the debate is opened.

In one hand some scientists argues that the total size of population is essential to climate change. This view, inherited from the Malthus formulations, points that the global population is still exploding. To the "Optimum Population Trust"[2] the population increase that will occurs until 2050, of 2.3 billion people, is a threat to human consumption and to the nature resources still available. In this view, identified as neomalthusian, it is common labeling the Earth as a crowded planet (Palmer, Bernhardt, Chornesky et al, 2004; McNeill, 2006; Friedman, 2008). Mcneill writes that "The extraordinary growth of cities, together with the general **crowding** of the earth, is the greatest social transformation of modern times." (MCNEILL, 2006, p.190). Palmer, Bernhardt, Chornesky et al (2004) argues that ecology studies should be think in the future taking into account that the planet has a population beyond its torelable limits , with a growing consumption pattern. Friedman(2008), with his ideological book *"Hot, Flat and Crowded"* try to prove that "overpopulation" is the contemporary most scaring threat, because urbanization and population concentration in poor countries are demanding infra-structures that does not exists, causing serious environmental degradation. This author believes that the population increase is a risk in itself.

We differ with this interpretation of the demography phenomena. It is necessary to indicate that current population growth happens with a slower pace than in the past, and one of the dangers of malthusian view is that population growth, primordially in development countries, has to be controlled (Meyerson, 1997). There are no doubts that the total population increase occurring in the next decades is very important, but it does not matter alone. There is a range of other demography and social factors that counts for climate and environment change. It is needed to reflect about the complex interrelationships among economic growth, production, consumption and population growth. Demographically there is a rising importance to incorporate the dynamics of population when analyzing its relation with environment. Due to this efforts include population structure, composition and distribution together with variations in consumption and production is a way been taken (Gúzman, Martine, McGranahan et al, 2009). By this it is possible to understand population and environment interactions in a more critic and non malthusian way, considering that are many reasons to pursue a rights-based approach to reproductive health, as discussed in the 1994 Programme of Action of the International Conference on Population and Development (Gúzman, Martine, McGranahan et al, 2009).

2.1 Population and Environment in Coastal Zones

There are a growing number of factors that shows coastal zones importance to human kind. This happen in two main aspects. First, coastlands has been explored by societies over history taking in account its mains attractive: the sea proximity. As Moraes (2007) points, all the places are constructed by human kind through its productive potential, considering vocational characteristics and comparative attractive. By this coastal zones attributes are very exclusives. This is an terrestrial area of marine resources exploration, very favorable to goods movements, and, in modern times, is identified as a leisure area. It's a strategic place, with limited resources, specialized and sometimes exclusive functions. Second, coastal zones are considered the riskiest place in the world (Kron, 2008). Natural catastrophes are normally related to coasts. When they do not occur in this place their causes usually can be found in meteorological events related ocean dynamics or in geological events that happen at the crustal plate boundaries (Kron, 2008). Within this coastal zones concentrates both population and disasters. According to Monmonieer (2008) the sea provides food, transportation, and recreation, and the shoreline is a boundary, an attraction, a source of livelihood, but at the same time, a hazard.

[2] O site da organização está disponível em http://www.optimumpopulation.org. Acessado em 18 de dezembro de 2009.

This region is seemed to be at more intensive risk in the next decades. The IPCC (2007) projections of global warming implicates in a series of environmental changes that affects coastlands. It is very likely that extreme weather events occur in higher frequencies in the most part of global areas, with the heavy rainfall proportion raise. Associated to this changes there is the hypothesis of ocean warming, that causes melting glaciers and ocean thermal expansion. This two effects, together, lead to a bigger water volume on the oceans, affecting the natural systems of coastlands and causing sea level rise. According to Nicchols e Tol (2006) this changes will be felt in many ways, by the frequencies of inundation, flood and storm damage, in wetland loss (and change), in erosion, with the raise of saltwater intrusion and rising water tables/impeded drainage. Because this effects will happen associated with extreme rainfalls another environmental risk is the increasing of landslides, in coastal zones with mountain geography.

2.2 Risk in Population and Environment studies

The various studies about population dynamics and environment change have been advanced both in global(GUZMAN et al., 2009) and regional scales, considering the Brazilian specific case (HOGAN, 2007; HOGAN e MARANDOLA JR.,2009). There is a considerable opportunity and advance necessity of these studies with global warming. As Veiga (2008) shows, the central point to asses global warming impacts requires the understanding of complex forecasting climate models. Nevertheless, this question basis is related to a sociologic question: the risks perception. As important as the climate forecasting are the risks perception, that will guide attitudes and policy construction to risks decrease Veiga (2008).

In this way we consider risk concept essential to analyze the relation between demographic, environment and space. By this we pretend to achieve advances in the field, including the existing uncertainties of human dimension in climate change. However, this concept has controversies definitions and it is necessary to precise what is understood by risk in this paper.

Beck (1998) highlighted that in 1980 the world was permeate with uncertainties. It is the “risk society”, in which two basic phenomena happens: reflexive modernization and risk centrality. Beck´s theory showed scientific and industrial development was responsible by a set of unanticipated risks creation, which exists in a spatial-temporal dimension that cannot be limited by any boundaries.

In this scenario the world reflects about the insufficiencies and contradictions of the first modernity, in a reflexive modernity. The world thinks itself. The essential attribute of this new period is to face the set of risks generated in the first modernity, which are know globally widespread. The challenges incorporate unemployment, underemployment, individualization and global environment risks. This means that the emergent risks of reflexive modernity are different of the past risks because its global character, still who in fact deal with them are the individuals (Beck, 1986).

Considering this background one of the challenges to population and environment studies is analyzing risk as a general sociologic concept and as an empirical dimension of reality, that can be qualified and quantified (Torres, 2000). It occurs because nowadays risks have multiples dimensions, and can be known *VS* unknown, correctly calculated *VS* incorrectly calculated, controlled *VS* uncontrolled and percept as specific problems *VS* percept as general problems (Torres, 2000).

To define more precisely this empirical risks we agree with Veirett (2007), who points the risk is a perception of a possible hazard by some social group or individual. The risk is the probability that a hazard really occurs (Hogan and Marandola Jr., 2007).

Last, it is necessary to point that environment risks are multidimensional. They are natural, because are related to natural system dynamics; social, since results from social needs that contribute to a small life quality; and technological, due to industrial and productive process potential hazards (MMA, 2008).

3. ENVIRONMENT AND URBANIZATION IN BRAZILIAN COASTAL ZONES

In Latin America and Caribbean region the coastal zones were occupied in many ways. Caribbean coastlands are very sought because its tourism attractiveness, although the most Caribbean dwellers live in hinterland areas (88,4%), due to a culture more related to agriculture practices. So, the most Caribbean population, located far or near of shorelines, lives in rural conditions(Rodríguez and Windevoxhel, 1998). Brazilian reality it´s quite different. According to the official legislation coastal zones contain 39.781.036 inhabitants, corresponding to 23,43% of the total population. The method used to define this coastal population is based on administrative criteria: the municipalities located in coastal zones had it population accounted as coastal as well. (MMA, 2008). Besides the percentage of the population concentrated in Brazilian and Caribbean be almost the same, the conditions in which it happens are quite different. Brazil has a culture related to coastal intensive use (Carmo and Silva, 2009). There are 16 metropolitan areas in coastlands, concentrating 30.580.809 dwellers – 76,87% of the total residents of coasts. Urbanization is an important key to the dynamics of Brazilian coastal. Cities in the region are used to tourism, industries, seaports and fuel services, including oil and natural gas explorations.

Brazil urbanization process of Brazil was relatively fast and contradictory. Faria (1991), shows that urban Brazil was related to economic expansion process, benefiting workers by including them in formal jobs, but at the same time favoring income concentration and inequalities expansion. Urban space incorporates and created peripheral and segregated spaces in the big cities. Cities was not constructed to effective social function, but trough market relations, taking soil as a good (Singer, 1977). Some noble areas were created, and a lot of poor regions coexist. With this risk zones were occupied, where people lives at subnormal conditions and slums. In this spaces degrading environments, landslides, floods and inundations expositions are current issues. (Ribeiro, 2008).

4. ENVIRONMENT RISKS IN BRAZILIAN SOUTHEAST: THE CASE OF GUARUJÁ, SÃO VICENTE AND BERTIOGA, SÃO PAULO STATE.

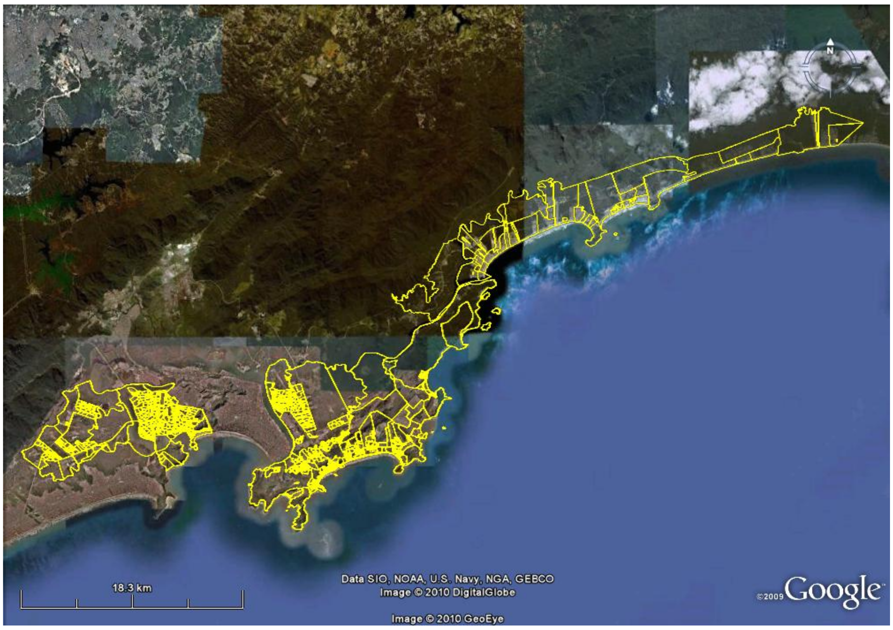
Guarujá, São Vicente and Bertioga are municipialities located in Baixada Santista Metropolitan Area (BSMA), in the central region of São Paulo state coast, southeast of Brazil (figure 1). It is situated between "*Serra do Mar*", a mountain range extending from South to Southeast Brazil coast, and the Atlantic Ocean. The majority of the population lives in the coastal plain, and almost 100% in urban areas (Afonso, 2006). There are around1.6million residents, which divide the space with intensive seasonal tourism activities and big industries poles (Zundt, 2007). Table 1 contains the demographic information of the nine metropolitan cities that are part of the region. The three municipalities of this paper are highlighted.

Analyzing table 1 it is possible to denote that those municipalities had an expressive population increment during the 1990 decade, and in the next decade it slowed. Santos had the smallest growth rates, partly because it plain territory has been almost totally occupied. In Bertioga other process happened and it grew strongly during the 1990s and continues to grow, partly by the expanding opportunities related to tourism. Growth in Guaruja and Sao Vicente, though small, are still remarkable and noteworthy, since both are located in central RMBS, an area with few appropriated spaces available for occupancy due to the existence of mountains and hills.

Table 1. Population and Population Growth rates of BSMA municipalities, 1991 to 2007.

Municipalitie	Year			Geometric Growth Rate	
	1991	2000	2007	1991/2000	2000/2007
Bertioga[1]	**11473**	**30039**	**39091**	**11,29%**	**2,97%**
Cubatão	91136	108309	120271	1,94%	1,17%
Guarujá	**210207**	**264812**	**296150***	**2,60%**	**1,25%**
Itanhaém	46073	71995	80778	5,08%	1,29%
Mongaguá	19026	35098	40423	7,04%	1,58%
Peruíbe	32773	51451	54457	5,14%	0,63%
Praia Grande	123492	193582	233806*	5,12%	2,12%
Santos	428923	417983	418288*	-0,29%	0,01%
São Vicente	**268619**	**303551**	**323599***	**1,37%**	**0,71%**

SOURCE: IBGE – Demographic Census and IBGE – Count Population.
(*) Estimated population. ([1]) 1991 Bertioga population refers to a Santos district.

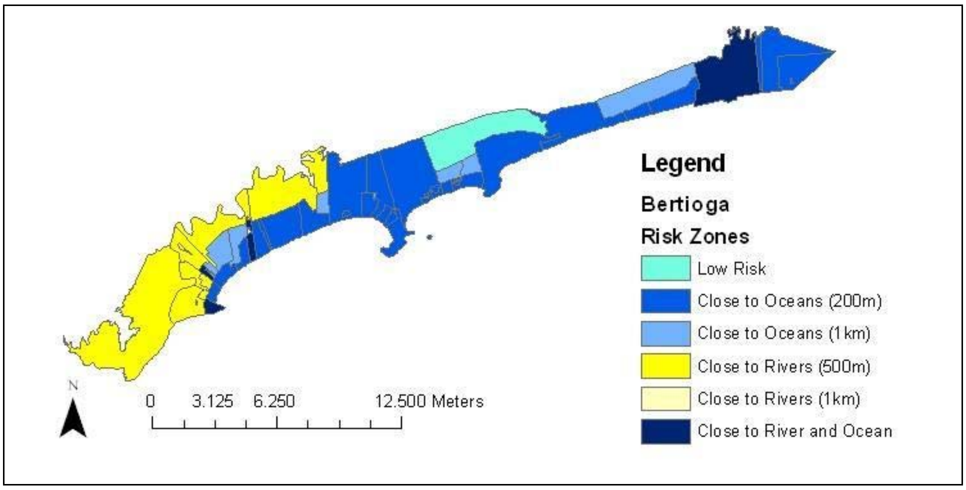


Source: Google Earth and IBGE – Demographic Census.
Figure 1. São Vicente, Guarujá and Bertioga locations.

4.1 Mapping environmental risks

We mapped risks considering the effects of climate change, thinking in the increases of floods, storm-surge floods and landslides. So it is important that we select environmental elements that should contribute to the increase of risks. These elements are related to local topography and hydrology. They are the main rivers, the mountains, slope mountains and the Ocean. We choose these elements because risks are special phenomena, and as close to those elements the population will face higher risks.

After the risks were mapped we select social, economic and demographic information to assess how many people are threatened by each risk, and the main characteristics of these populations. The results are in the map 1, 2 and 3 and in the tables 2, 3 and 4.



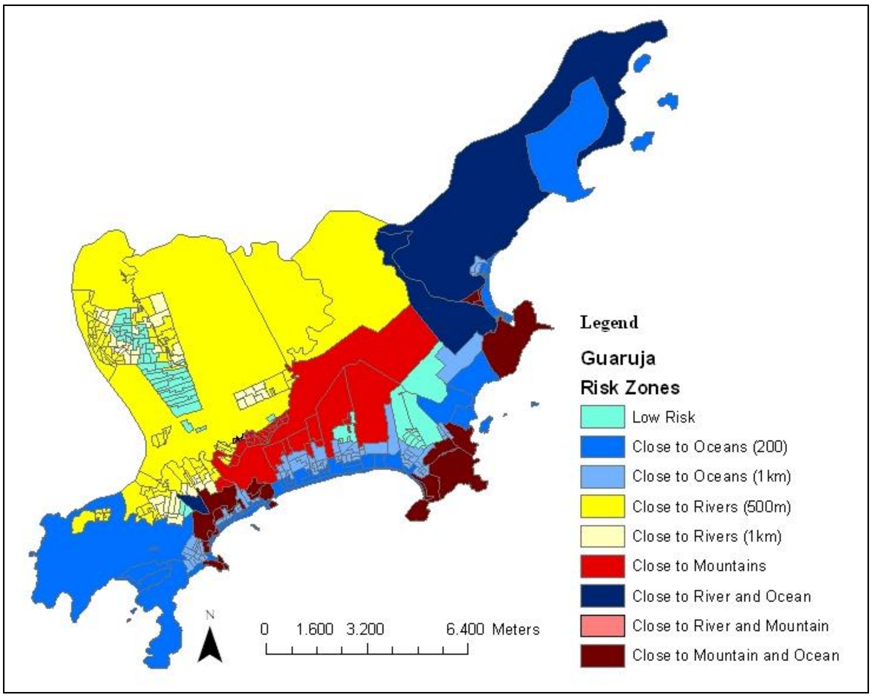
Source: IBGE – Demographic Census 2000.

Map 1. Bertioga zones risk.

Table 2. Demographic and socio-economic profile of Bertioga Risk Zones – 2000.

Risk Zone	Total census tract spatial	Subnormal Census tract (%)	Total Households	Total Residents	Average income per Household Head (R$)	Average Years of study per Household Head
Low Risk	1	0,00%	621	2315	440,61	4,87
Close to Ocean (200m)	30	16,67%	3687	13149	650,56	5,24
Close to Ocean (1km)	10	20,00%	1701	5977	651,40	5,52
Close to River (500m)	11	27,27%	1392	4578	926,03	6,76
Close to River (1km)	2	0,00%	293	936	880,39	7,02
Close to River and Ocean	4	0,00%	546	1752	1086,11	7,93

Source: IBGE – Demographic Census 2000.



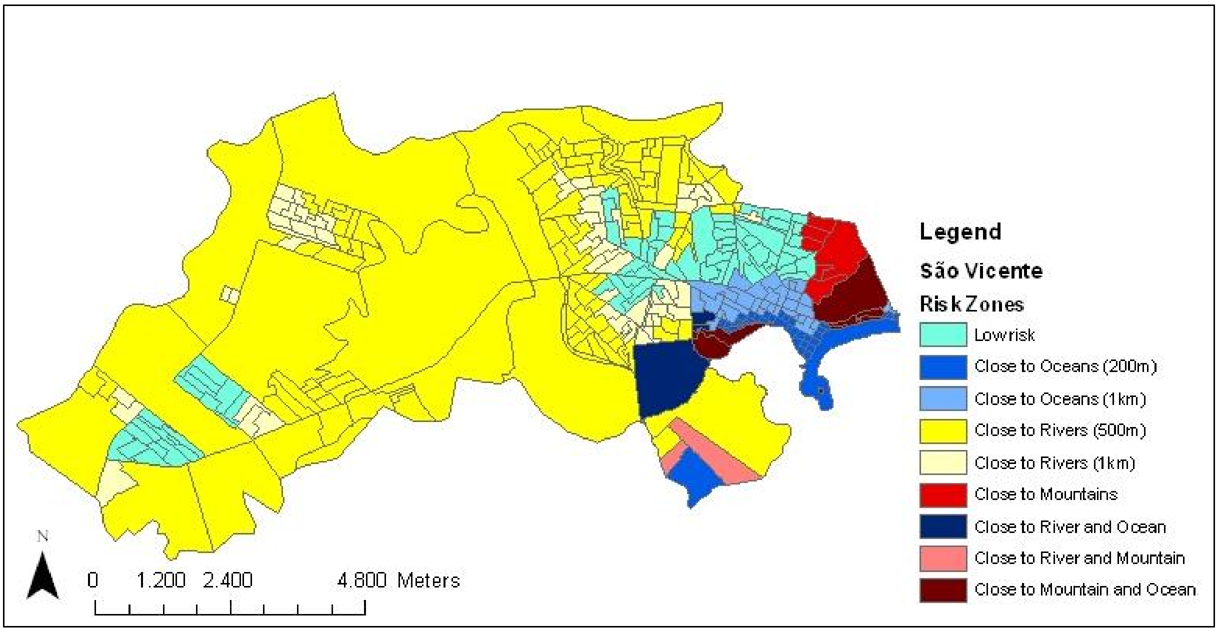
Source: IBGE – Demographic Census 2000.

Map 2. Guarujá Risk Zones.

Table 3. Demographic and socio-economic profile of Guarujá Risk Zones – 2000.

Risk Zone	Total census tract spatial	Subnormal Census tract (%)	Total Households	Total Residents	Average income per Household Head (R$)	Average Years of study per Household Head
Low Risk	59	23,73	14640	54301	612,99	5,64
Close to Ocean (200m)	49	6,12	4014	13127	1388,55	6,83
Close to Ocean (1km)	78	20,51	5914	18582	1229,62	7,47
Close to Rivers (500m)	94	50,00	22730	85097	545,53	5,47
Close to Rivers (1km)	48	12,50	12917	47957	671,96	5,91
Close to Mountain	33	81,82	7507	29192	455,79	4,25
Close to River and Ocean	4	25,00	1026	3452	1101,91	6,96
Close to River and Mountain	4	100,00	1007	3788	351,64	3,92
Close to Mountain and Ocean	20	10,00	2376	8116	1656,30	7,60

Source: IBGE – Demographic Census 2000.



Source: IBGE – Demographic Census 2000.

Map 3. São Vicente Risk Zones.

All the municipialities had several situations of expositions to environmental risks. Approximately 20% of the population lives in low risk areas, considering as low risk zones the ones that do not fit in any risk criteria established, but exists in coastal zones and due to it face coastal risks.

We can observe in the maps and tables that each risk threats in intensive ways a specific population. The categories related to the Ocean contain the richer and more educated people, especially in São Vicente and Guarujá. Theoretically it is this population who will face the bigger risks from sea level rise. In Guarujá the high areas near the Ocean are high valued, and, even though there are a series of risks in the region (with importance to landslides), population with a wider choice possibility lives in that place. This category is the one with the best housing conditions, and the total percentage of subnormal census tract is very low.

Table 4. Demographic and socio-economic profile of São Vicente Risk Zones – 2000.

Risk Zone	Total census tract level	Subnormal Census tract (%)	Total Households	Total Residents	Average income per Household Head (R$)	Average Years of study per Household Head
Low Risk	71	2,82	17924	65453	742,82	6,71
Close to Ocean (200m)	40	0,00	6691	16857	1624,43	9,88
Close to Ocean (1km)	33	18,18	7217	20822	1302,93	9,42
Close to Rivers (500m)	118	22,88	32989	128275	495,18	5,50
Close to Rivers (1km)	57	29,82	14554	55894	612,68	6,05
Close to Mountain	6	0,00	1463	5465	798,88	6,92
Close to River and Ocean	3	0,00	811	2651	842,62	7,90
Close to River and Mountain	2	0,00	575	2216	560,19	6,06
Close to Mountain and Ocean	10	0,00	1227	3204	1204,73	8,65

Source: IBGE – Demographic Census 2000.

In other side the poor lives in areas away from the ocean, where soil price is not high valued. These populations are settled near rivers and mountains, and the main risks are floods and landslides. At Guarujá the poorest people live in those zones, and sometimes there are a confluence of risks. It is the case of the people living next to mountains and rivers. A hundred percent of census tract in this zone are subnormal, and educational and income are the smaller of the city.

In this context it is necessary to remember that housing conditions are entered in processes that are relational. Why not have the necessary economic conditions to meet adequate housing, large groups of people lives in larger risk areas, in inadequate infrastructure households, near to the banks of rivers, estuaries and mountain.

5. CONCLUSIONS

An important advance of Brazilian government to reduce the impacts of climate changes in coastal zones was made with the achieve of Macrodiagnostic of Marine and Coastal Zone of Brazil, developed with the support of Environment Ministry. It details which ones are the municipalities and the risks faced by the population, and contributes with important knowledge to the specific government process of coasts. However it has to be implemented more wide.

In Baixada Santista Metropolitan Area and in the municipalities worked in this paper climate change is an important and urgent issue. The institutions responsible for natural resource management in the region, such as the Watershed Committee of Baixada Santista, are worried, at least partially, with the urban space transformation due to environmental changes related to water. The committee's proposal, through the Watershed Plan 2008-2011, provides 39.6 million reais investment in prevention and protection against extreme hydrological events, considering short, medium and long-term spends. This represents approximately 32.2% of the plan total resources.

Dwellers living in coastal zones, together with tourists and services, are at risk due to climate change. But it is not a simple risk, for the reason that as environment and population, risks are dynamics. A defined group living in a specific risk zone does not face just the risk more prominent of his residence area. Population moves towards the space to work, study and to live. All kinds of mobility and displacement contribute to the exposition of people to environment risks. However it is necessary to differentiate risks, as the population who faces it.

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EFFICIENCY OF BEACH NOURISHMENT PROJECTS IN PREVENTING EROSION ON THE EAST AND WEST COASTS OF FLORIDA

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ABSTRACT

Nourishment of the beaches of the State of Florida commenced approximately 40 years ago. The advantages of nourished beaches include reduced erosional trends and, restoration of recreational areas and habitats.

The historical shoreline position data base provided by the Bureau of Beaches and Coastal Systems of the Florida Department of Environmental Protection consists of historic shoreline positions at 3,866 monuments spaced at approximately 1,000 ft along 722 miles of sandy beach shoreline. These data were analyzed to quantify shoreline change trends for two different periods. The first period was used to identify the behavior of the shoreline prior to the beginning of most beach nourishment projects. This period differs for each of the 25 counties in the state but on average it ranges from the mid 1800's to the 1970's. The second period commences with data from the end of the early period and concludes with the most recent data (usually 2008) and was used to characterize the anthropogenic actions that changed the behavior of the shoreline (mainly beach nourishment projects).

The difference between the recent and early shoreline change rates was calculated to evaluate if the beach nourishment projects are effective in reducing erosion of Florida's beaches. Differences in shoreline change rates greater than 0.5 ft/yr were considered improving and, less than -0.5 ft/yr the shorelines were considered worsening and between the two values they were considered stable.

It was found that on the east coast of Florida 51.1% of the monuments improved, 31.5% worsened and 17.4% were stable. For the west coast it was found that 49.9%, 39.0% and 11.1% improved, worsened and were stable, respectively. However, the mean rate of change for the monuments that are receding on the east coast increased from -3.0 ft/yr in the early period to -5.2 ft/yr in the recent period and the monuments that are advancing decreased from 3.6 ft/yr to 3.4 ft/yr. In the west coast these results showed an increase from -3.5 ft/yr to -4.2 ft/yr in the receding pattern, but the depositional pattern also increased from 4.0 ft/yr to 5.7 ft/yr from the early to the recent period.

Even with the reduction of the total number of monuments that are worsening, the rate of recession in the recent period is larger than in the early period in the east coast. The areas that are worsening on the west coast (39.0%) are greater than on the east coast (31.5%), but the rate of recession on the west coast is almost constant in both periods and the rate of advancement increased.

1. INTRODUCTION

The worlds population living less than 100 miles from the coastal zones is approximately 50%, making the knowledge of the activities and processes happening in these areas extremely important. The sandy beaches present in those environments are directly related with the development of the coastal areas. They are important for tourism, economy, as recreational areas and for the marine ecosystem.

The erosional problems on sandy beaches can be created by natural or anthropogenic influences. Sea level rise is a current problem causing erosion in many beaches around the world. The Intergovernmental Panel on Climate Change (IPCC, 2007) estimates the global average sea level will raise by 7.2 to 23.6 inches by 2100 relative to 1980-1999. The accuracies of sea level rise predictions can also be influenced by the uncertainties related to the Antarctic and Greenland ice melting. The erosion of the beaches decreases the touristic and economic potential of coastal areas and can also adversely impact valuable habitats for marine organisms. The knowledge of the processes causing erosion and also alternatives to reduce or to mitigate this problem are very important for coastal management plans.

The traditional method to prevent beach erosion is the construction of hard engineering structures, such as groins, breakwaters and seawalls. These techniques can drastically change the sand transport in the area and are often ineffective to the point of causing loss of the intertidal beach (Pilkey and Wright, 1988). An alternative method to prevent erosion and to recover the beaches is know as beach nourishment, which consists in finding a source of sand, usually offshore and relocating this sand to the eroding beaches. This is known as a soft mitigation process, in contrast with the hard engineering techniques and it causes less interference in the natural sediment transport.

Beach nourishment is the current preferred alternative for shoreline stabilization in areas that suffer a deficit of sand due to either natural or man-made causes. Beach nourishment is attractive because of its non-structural nature, its benefits to adjacent shorelines, and its direct solution of the sand deficit (Browder and Dean, 2000). They provide protection against storms and restore recreational areas.

However, when analyzing the ecosystem, this technique can offer advantages and disadvantages for the marine organisms. Defeo et al. (2009) pointed that it can cause the mortality of buried organism and that differences in the beach width, beach steepness or sand compaction can change the original ecosystem. But beach nourishment projects can also be helpful to restore lost habitats, recreating a non-existing beach where sea turtles can use as their nesting areas.

The aim of the present paper is to determine the behavior of the shoreline changes prior and after the major anthropogenic activities and also to establish areas where the anthropogenic activities improved or worsened the rate of shoreline change on Florida's sandy beaches.

1.1 Study Area

The present research was focused on Florida's sandy beaches. The Florida coast is characterized by a long coastline with approximately 1,200 miles of extension with 35 coastal counties. Of the 35 coastal counties at Florida, 25 are composed by sandy beaches in a total of 722 miles. These sandy beaches are mainly composed by quartz and calcareous sediments between 0.14 and 2 mm (Dean and Dalrymple, 2002) and are influenced by longshore and cross-shore sediment transport due to the action of waves and currents. The Florida coast includes 25 predominantly sandy beach counties with 12 located on the east coast and 13 on the west coast (Figure 1).

2. METHODOLOGY

The historical shoreline position database was developed by the Bureau of Beaches and Coastal Systems (BBCS) of the Florida Department of Environmental Protection (FDEP). This data base contains information for the 25 predominantly sandy beaches counties along the Florida coastline. The position of the shoreline is evaluated using the monuments placed in the beach at nominal spacing of approximately 1,000 ft and using shore-perpendicular beach profiles with the mean high water line as a reference. The earliest entries in the database are in the mid 1800's and the last data available are from 2009 with a total number of 57,342 shoreline positions for the 3,866 monuments on the east and west coasts of Florida.

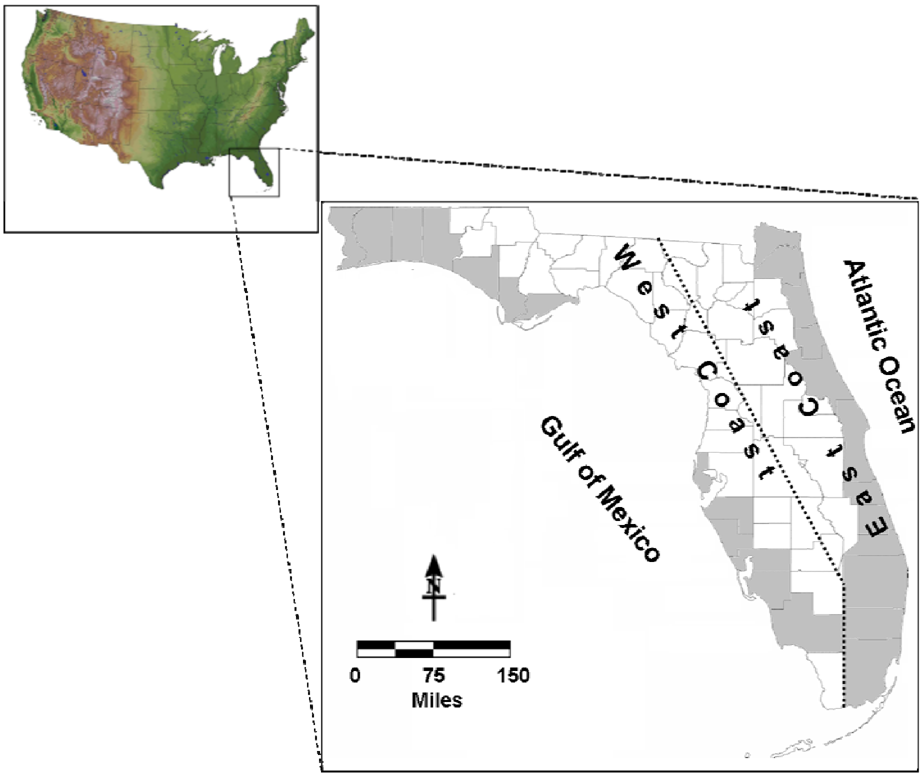

Figure 1: The 25 predominantly sandy beach counties at Florida shown in gray and the division between the east and west coast of Florida.

2.1 Description of the Periods of Analysis

Two periods were chosen to evaluate the shoreline changes along Florida's sandy beaches. The early period encompasses from the mid 1800's to the 1970's, when major beach nourishment projects commenced.

The second period commences with data from the end of the early period and concludes with the most recent data, usually 2008, but it is different for each county. This period was used to characterize the anthropogenic actions that changed the behavior of the shoreline (mainly beach nourishment projects) along the coast. The extension of the recent and early periods changes on each county according to the first data available and also to the beginning of the main anthropogenic influences.

The number of data available for the recent period is larger than for the early period, since most of the beach profiles were conducted in the last 40 years. On average each monument in the early period includes 4.7 data points and the recent period has an average of 10.8 different measurements for each monument.

2.2 Shoreline Trends

The shoreline change rates were extracted from the shoreline position at each the 3,866 monuments. The linear trend was obtained for the two periods explained above using the best least squares fit to the data. These trends were used to calculate the shoreline change rates for the early and recent periods and to identify different behaviors on the sandy beaches.

2.3 Shoreline Behavior

To indentify the shoreline behavior on the sandy beaches on the east and west coasts of Florida the linear trend of each shoreline position was calculated for the specific period that differed for each county.

The results showing the shoreline behavior will be presented in two different forms. The first are maps with the geographical location of the monuments with different shoreline behavior for the early and recent periods. The shorelines with changes greater than + 0.5 ft/yr were considered advancing, the shoreline rates less than - 0.5 ft/yr were considered receding and the values between - 0.5 ft/yr and 0.5 ft/yr were considered stable.

Another geographic map was created to specify if the shoreline was improving, worsening or stable. This analysis evaluated the change of the behavior between the two periods. If the difference in the shoreline change rate between the recent and early period was greater than + 0.5 ft/yr this shoreline was considered improving, if this value was less than - 0.5 ft/yr it was considered worsening and the values between them were considered as stable.

3. RESULTS/DISCUSSION

The results are presented separately for each period analyzed with maps representing the behavior of the beaches during the period. Also it shows the differences between the early and the recent periods and if the beaches are improving or worsening over time. In all situations the behavior of the shoreline will be described separately for the east and west coasts of Florida.

3.1 Early Characteristics

The overall behavior of the shorelines along the 25 predominantly sandy beaches at Florida is shown for the early period (Figure 2). The east coast of Florida presented an interesting behavior during the early period. The northern portion, with concave shape, was characterized with more areas in advancement and the beaches in the southern portion of the east coast shown more areas with recession and stability. For the entire east coast, 42.1% of the shoreline is advancing, 31.1% is receding and 26.8% is stable. This results are in accordance with the longshore sediment transport calculations made by Van Gaalen (2004) based on the Komar (1998) equations which showed a decrease of the longshore sediment transport along the concave northern area accumulating sediment in this portion and an increase of longshore transport along the southern convex portion with consequent recession of those beaches. The average shoreline change rate for the east coast was an advancement of 0.6 ft/yr.

The west coast showed a different behavior when compared with the east coast. The west coast presented more areas receding (45.1 %), 33.1% of the shorelines were advancing and 21.8% of the shorelines were stable. Also the mean rate of recession for the early period was greater in the west coast (-3.5 ft/yr) when compared with -2.9 ft/yr in the east coast. The mean rate of advancement was also greater in the west coast (4.0 ft/yr) when compared with the east coast (3.6 ft/yr). This is reflected in the shoreline change rate for the entire west coast, showing a recession of -0.3 ft/yr (Table 1).

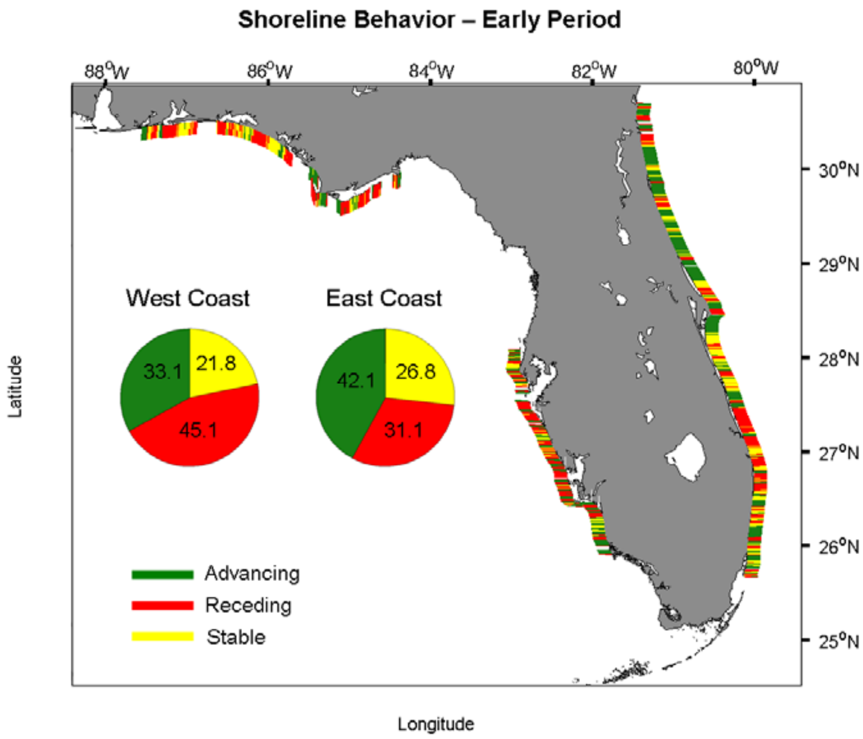

Figure 2: Shoreline behavior for the early period for Florida's sandy beaches and the percentage of monuments advancing, receding and stable for the east and west coasts.

Table 1:Summary with the percentage of areas advancing, receding and stable and the mean shoreline change rates for the early and recent periods.

	Early Period		**Recent Period**	
East Coast	Shoreline Behavior (%)	Shoreline Change Mean Rate (ft/yr)	Shoreline Behavior (%)	Shoreline Change Mean Rate (ft/yr)
Advancing	42.1	3.6	55.4	3.4
Receding	31.1	-3.0	22.4	-5.2
Stable	26.8	0.02	22.2	0.04
Weighted Average		0.6		0.7
West Coast	Shoreline Behavior (%)	Shoreline Change Mean Rate (ft/yr)	Shoreline Behavior (%)	Shoreline Change Mean Rate (ft/yr)
Advancing	33.1	4	47.3	5.7
Receding	45.1	-3.5	43.3	-4.2
Stable	21.8	-0.01	9.4	-0.05
Weighted Average		-0.3		0.9

3.2 Recent Characteristics

The results presented during the recent period shows the anthropogenic influences, mainly beach nourishment projects, in the Florida's sandy beaches (Figure 3).

The shoreline during the recent period presented a significant increase of areas with advancement. In the east coast, 55.4% of the shoreline was advancing, 22.4% receding and 22.2% stable. The areas of advancement also increased considerably in the west coast (47.3%). The monuments that were receding decreased to 43.3% and the stable areas reduced to 9.4%. The increase of areas with advancement can be explained by the large number of beach nourishment projects that occurred at Florida. The database maintained by the Program for the Study of Developed Shorelines (PSDS) reported a total of 362 beach nourishment projects and an approximated volume of 223,500,000 cubic yards of sand relocated to the beaches in the entire coast of Florida. From this total, approximately 132,500,000 cubic yards relocated to the east and 91,000,000 to the west coast.

Even with the realization of these beach nourishment projects and decrease in areas with recession, the mean rate of shoreline recession in the east (-5.2 ft/yr) and west (-4.2 ft/yr) coasts increased during the recent period. When analyzing the overall shoreline change rate, the east coast presented an advancement of 0.7 ft/yr (similar to the early period) and the west coast presented an advancement of 0.9 ft/yr (Table 1).

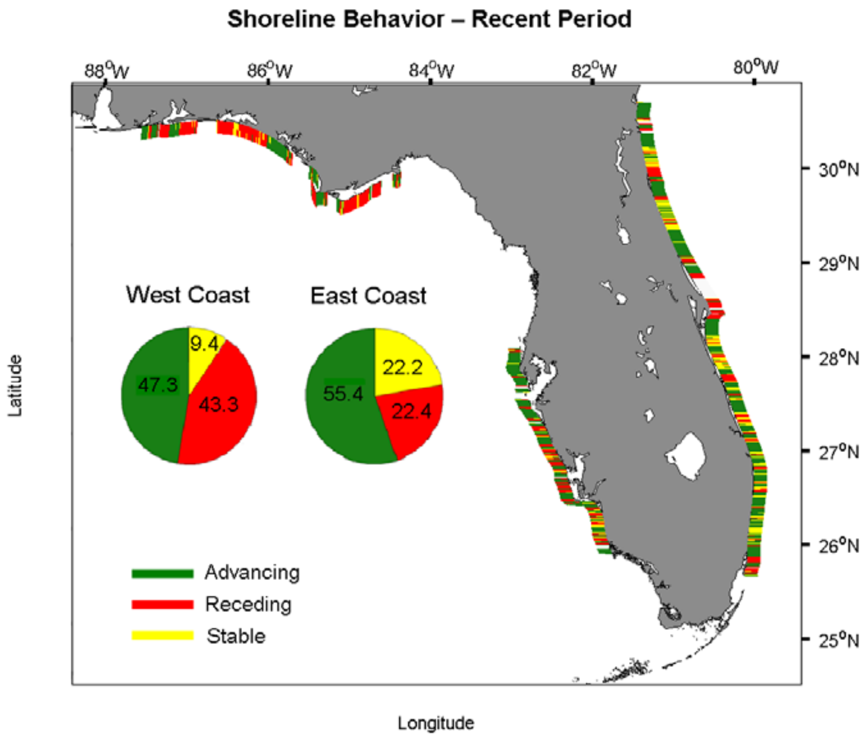

Figure 3: Shoreline behavior for the recent period for Florida's sandy beaches and the percentage of monuments advancing, receding and stable for the east and west coasts.

3.3 Improvement / Worsening Shorelines

A comparison between the early and recent periods can also assist in identifying the influence of anthropogenic activities, mainly beach nourishment projects, in Florida. For the east coast it was found that 51.1% of the shoreline positions were improving, 31.5% worsening and 17.4% stable (Figure 4). The west coast presented a similar behavior with 49.9%, 39.0% and 11.1%, improving, worsening and stable, respectively.

Thus, Florida's sandy beaches on the east and west coasts presented a considerable improvement on their shorelines. The improvement can be explained by the large volume of sand added during beach nourishment projects mainly on the beaches that were eroding on the east and west coasts of Florida, since the natural scenario considering the sea level rise would be larger areas of erosion along the coastline.

The beach nourishment project at Perdido Key was used in the present paper as an example of influence of anthropogenic activities on beaches. This is a sandy beach of approximately 6.5 miles which is located at the westernmost limit of Florida, bordering the State of Alabama. Three nourishment projects occurred in this beach. The first one added 5.36 million cubic yards of sand in 1980, the second 2.43 million cubic yards in 1985 (NOAA, 2002) and the third one started in 1989 and placed a total of 9.3 million cubic yards. A detailed research about the third beach nourishment project and the behavior of the Perdido Key beach during 8 years after the nourishment project can be seen on Browder and Dean (2000).

The recession at Perdido Key during the early period was estimated to be 2.0 ft/yr between 1856 and 1970. It is important to note that the three nourishment projects in this beach occurred after the end of the early period. This pattern changed for an advancement of 1.8 ft/yr in the recent period (1970-2008), showing the influence of the beach nourishment projects preventing erosion in the area. The improvement at Perdido Key considering the sand volume added during the three beach nourishment projects was 3.8 ft/yr.

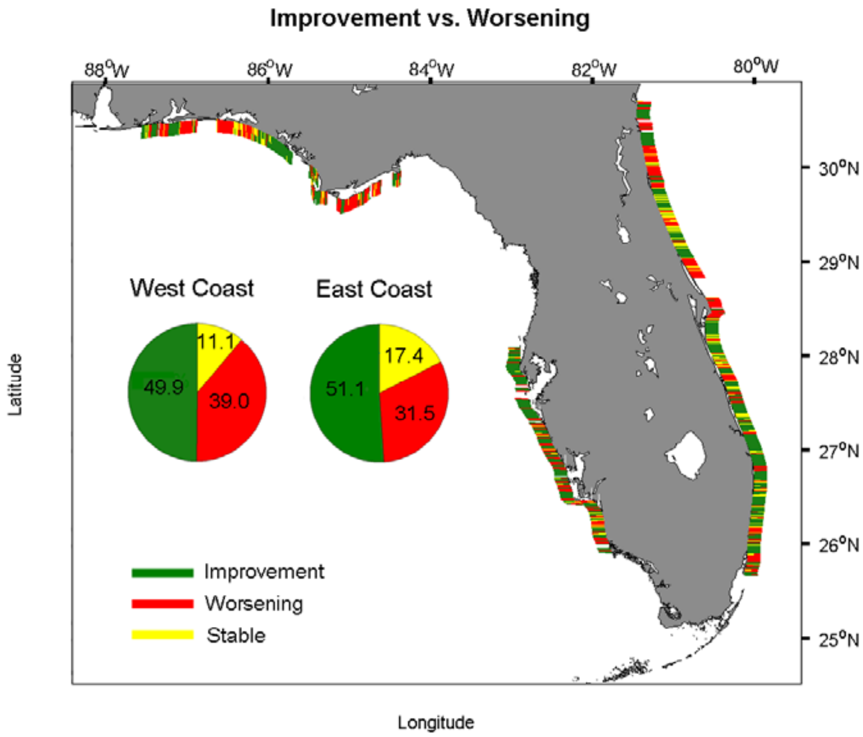

Figure 4: Geographical location of the shoreline that are improving, worsening or stable at Florida's sandy beaches. The pie charts show the percentage of each behavior for the east and west coasts.

4. CONCLUSION

The beach nourishment projects conducted during the last 40 years on the Florida's sandy beaches resulted in the reduction of erosion on the east and west coasts. This conclusion can be observed analyzing the considerably improvement in approximately half of the shoreline change rates. It is also important that the overall shoreline change rate in the east coast stayed almost constant and in the west coast it presented an increase 1.2 ft/yr when comparing the early and recent periods. This increase in the shoreline change rate can be explained by the large amount of sand relocated to the beaches during beach nourishment projects.

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KUSHIRO WETLAND RESTORATION PROJECT

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ABSTRACT

With the recent expansion of industrial and commercial activities (e.g. development of farmland and residential land, the straightening of rivers, the deforestation in the surrounding area), Kushiro Wetland – Japan's largest wetland and first Ramsar site– has decreased by more than 30% over the last 60 years, and the coverage of alder forest (which grows in drier areas than reeds and is the index of the aridification) has increased fourfold in the same period. Therefore, the Kushiro Wetland Restoration Committee was established by local residents, NPOs, experts and the national and local governments and six implementation programs has been formulated in order to conserve and restore the Wetland. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is currently engaged in two such programs and in this paper, we introduce the present situation of Kushiro Wetland and MILT's restoration projects .

1. OUTLINE OF THE KUSHIRO RIVER BASIN AND KUSHIRO WETLAND

Kushiro River is located in the eastern part of Hokkaido. Its basin covers an area of 2,510 km^2, and the length of the main river channel is 154 km. It flows from Lake Kussharo and runs through the areas of Teshikaga Town, Shibecha Town, Kushiro Wetland and Kushiro City before flowing into the Pacific Ocean (Figs. 1, 2, 3). The population of Kushiro City – a major urban area of eastern Hokkaido – is about 200,000. Agriculture thrives in the basin, and 21% of its land is used for this purpose (Fig. 4).

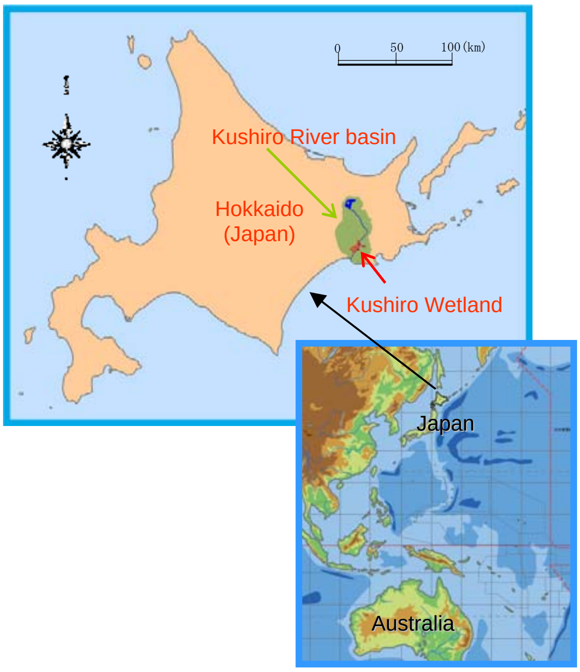


Fig. 1: Location of the Kushiro River basin

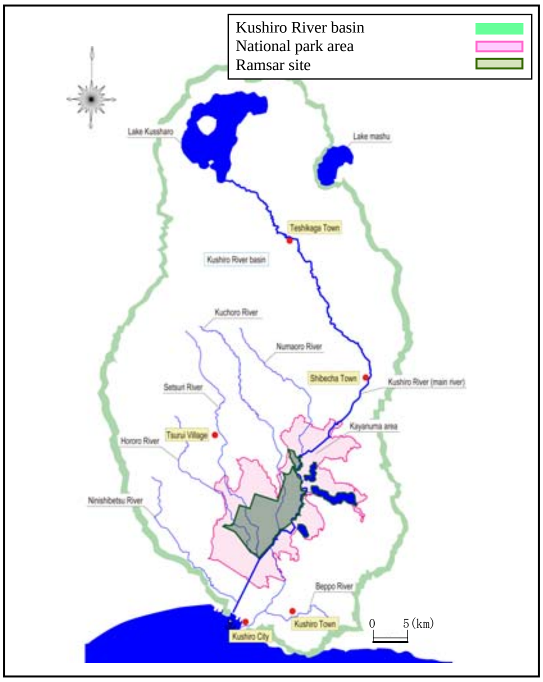


Fig. 2: The Kushiro River basin

Kushiro Wetland is located in the lower reaches of the Kushiro River. In 1980, Kushiro Wetland – Japan’s largest wetland, covering an area of about 200 km^2 – was registered as the first Ramsar site in Japan. Kushiro Wetland has more than 2,000 wildlife species and magnificent natural environment. Kushiro Wetland also plays a great role in flood control for people living around the coastal areas.

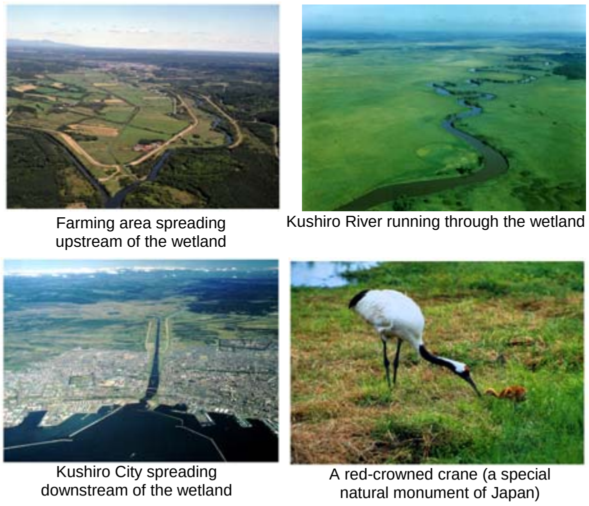


Fig. 3: Images of the Kushiro River basin

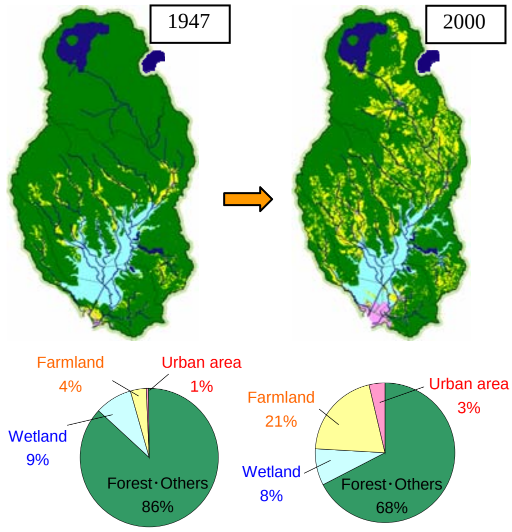
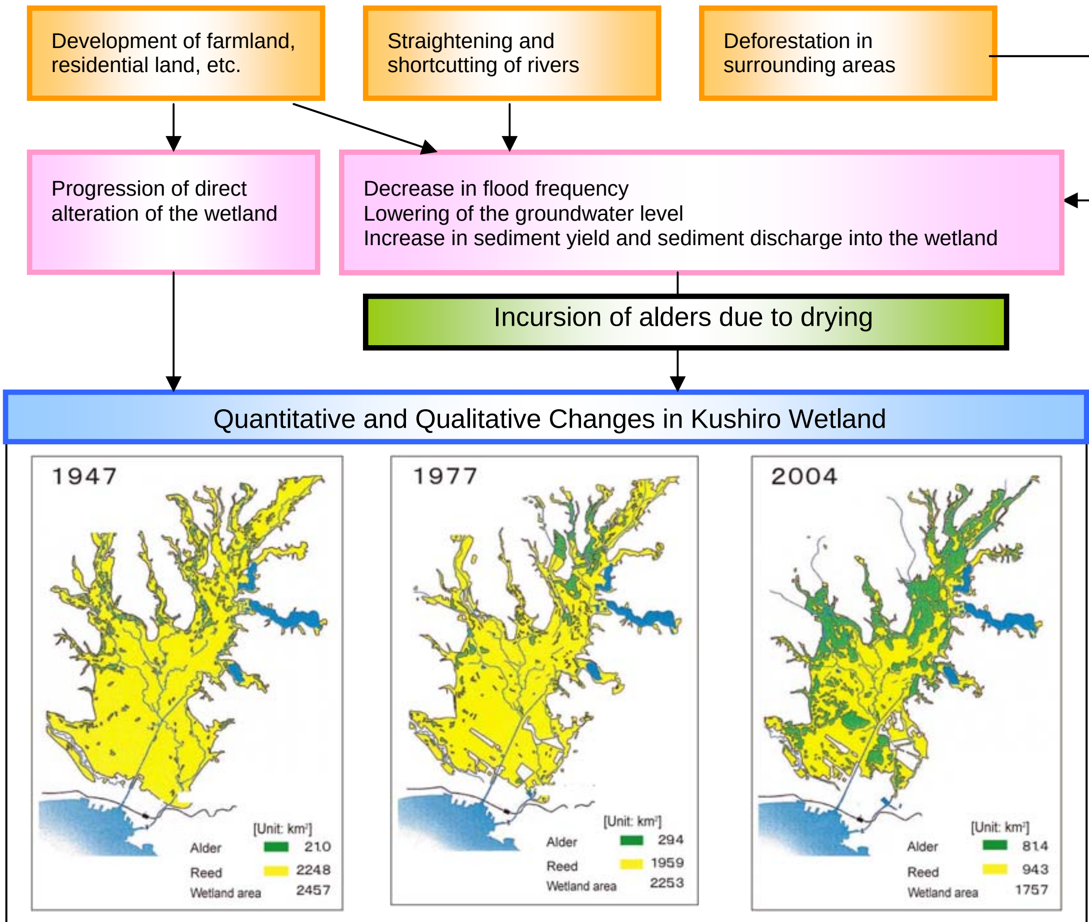


Fig. 4: Land use in the Kushiro River basin (1947 and 2000)

2. PRESENT SITUATION OF KUSHIRO WETLAND



Wetland area: 1947 (approx. 250 km^2) → 2004 (approx. 180 km^2): a reduction of more than 30% in 60 years
Alder forest: 1947 (approx. 20 km^2) → 2004 (approx. 80 km^2): a fourfold increase in 60 years

Fig. 5: Causes of changes in Kushiro Wetland

With the recent expansion of industrial and commercial activities (e.g. development of farmland and residential land, the straightening of rivers, the deforestation in the surrounding area), the area of the wetland has decreased dramatically, and wetland vegetation has also changed significantly. In concrete terms, the area has decreased by more than 30% over the last 60 years, and the coverage of alder forest (which grows in drier areas than reeds and is the index of the aridification) has increased fourfold in the same period. The causes of these changes are considered to be as above (Fig. 5):

3. KUSHIRO WETLAND RESTORATION PROJECT

3.1 Background

In the 1970s, a campaign to stop disorderly development was launched in Kushiro, and in 1980, Kushiro Wetland was registered as the first Ramsar site in Japan. The wetland was also registered as a national park of Japan in 1987, but resort-related development progressed in the surrounding areas. This situation caused a national trust movement, and conservation efforts shifted to take on a basin-wide scale. In 1997, The River Law was revised, and improvement/conservation of the river environment were added to the law as objectives. In 2003, the Law for the Promotion of Nature Restoration was enacted, and the Kushiro Wetland Restoration Committee was established based on this law.

3.2 Kushiro Wetland Restoration Committee

In 2003, the Kushiro Wetland Restoration Committee was established by local residents, NPOs, experts and the national and local governments in order to promote Kushiro Wetland restoration projects through cooperative efforts. The committee has 125 members (as of November 2009) and six subcommittees (Public Awareness, Sediment Control, Hydrologic Cycle, Forest Restoration, Old River Channel Restoration, Wetland Restoration). The members of the committee, such as MLIT, MOE, MAFF, etc., formulate draft plans of implementation programs, while the subcommittees discuss each draft plan in detail. The main committee discusses and approves each draft plan in addition to formulating the Comprehensive Concept. After main-committee approval, the members of the committee formulate and initiate the implementation program.

3.3 Comprehensive Concept

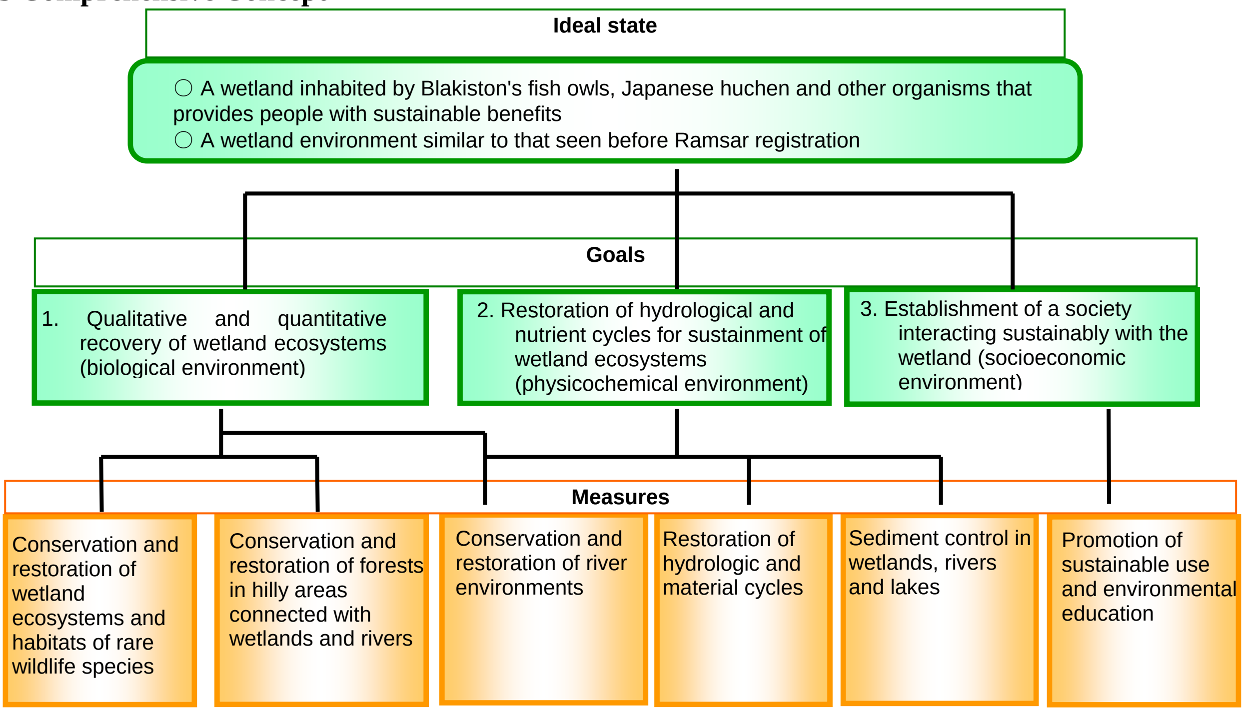


Fig. 6: Overview of the Comprehensive Concept

Fig. 7: A Blakiston's Fish Owl

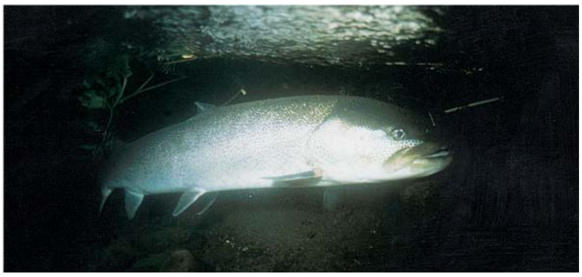


Fig. 8: A Japanese huchen

In 2005, the Kushiro Wetland Restoration Committee formulated the Comprehensive Concept presenting the basic policies of nature restoration. This Comprehensive Concept (Kushiro Wetland Restoration Committee,2005) includes goals of nature restoration, methods for achieving goals, principles for the implementation ,etc. An overview of the Comprehensive Concept is given above (Figs. 6, 7, 8):

The Kushiro Wetland Restoration Committee has established the following 10 key principles for the implementation of nature restoration.

1. Principle of catchment perspectives
2. Priority for conservation of the remaining natural environment (principle of passive restoration)
3. Scientific understanding of the present state
4. Setting of clear goals
5. Principle of adaptive management
6. Restoration of favorable functions of nature (rehabilitation)
7. Balance of effective local industries and flood control measures
8. Principle of participation by diverse stakeholders
9. Principle of information disclosure
10. Necessity of practicing environmental education

3.4 Activities based on implementation programs

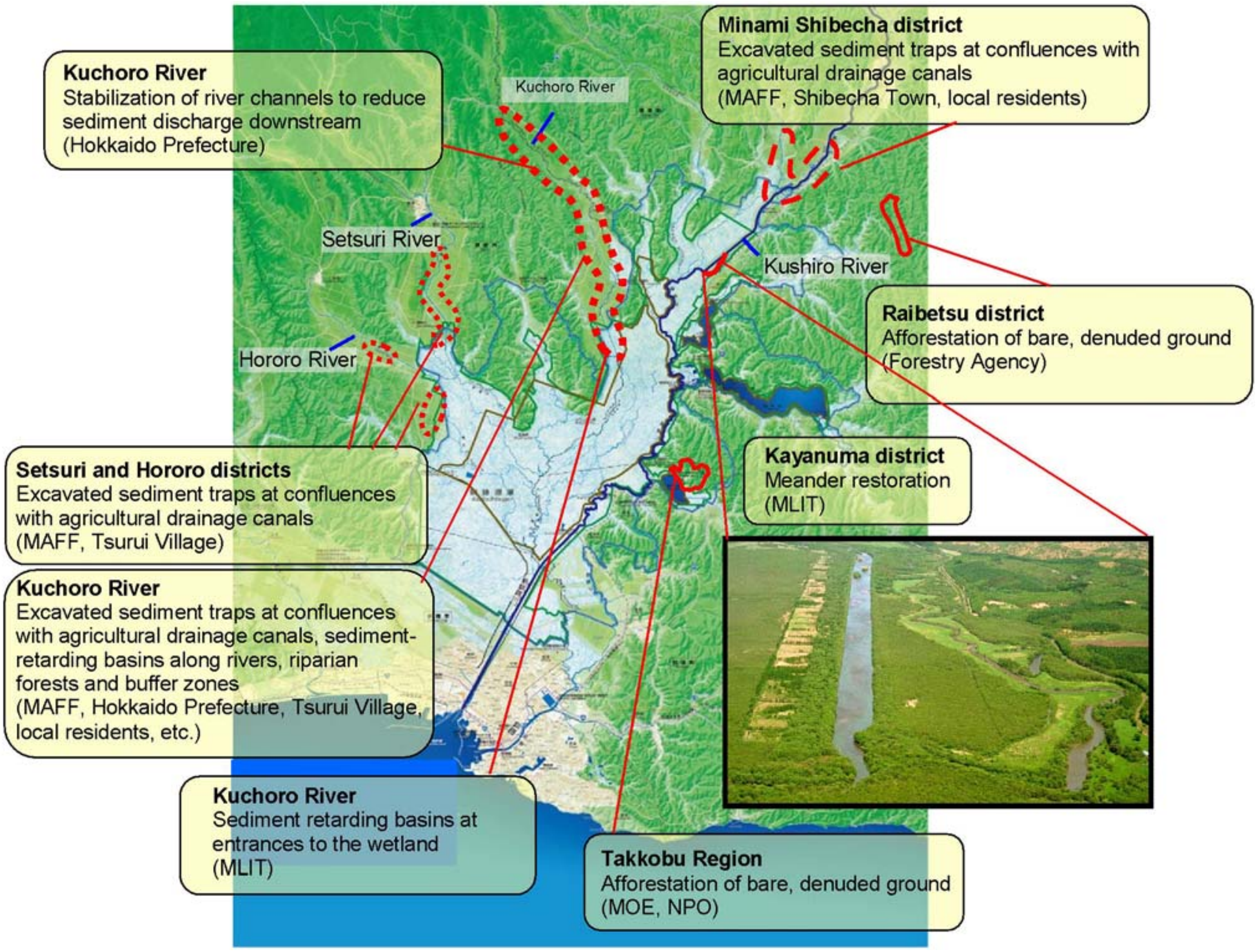


Fig. 9: Activities based on implementation programs

By 2009, six implementation programs based on the Comprehensive Concept had been formulated and initiated by the national government, the local government, NGOs and so on, and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is engaged in two such programs. An overview of these activities is given above (Fig. 9):

4. IMPLEMENTATION PROGRAMS BY MLIT

4.1 Kayanuma District Old Channel Restoration Program (Kushiro Development and Construction Department (MLIT), 2006)

The project area is the Kayanuma district of Shibecha Town, approx. 32 km from the mouth of the Kushiro River. In conjunction with the demands of growth and development in the region, the river channel was straightened in 1980 in the Kayanuma district (Fig. 10). The land surrounding the old channel was used for pasture due to its aridification. This is where the main channel of the Kushiro River flows into Kushiro Wetland. The amount of sediment discharge carried into the center of the wetland through the main channel of Kushiro river is the greatest among all rivers in Kushiro Wetland (Fig. 11).

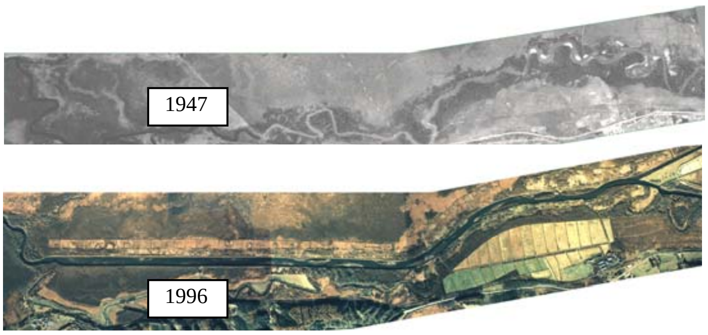


Fig.10: Photos of the Kayanuma district (1947 and 1996)

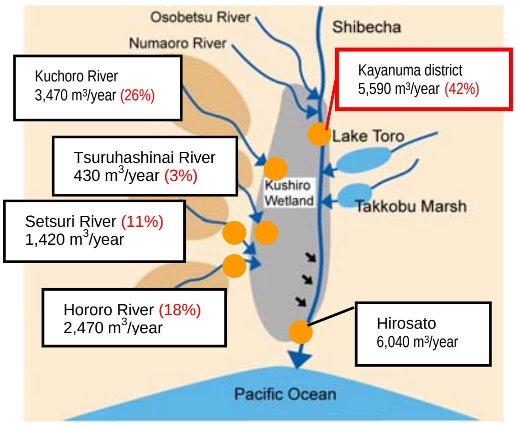


Fig.11: Balance of inflow and outflow of suspended sediment estimated from observation

Straightening of the river channel to facilitate land use in neighboring areas caused the following issues:

① Increase in sediment discharge into the wetland (Fig. 12)

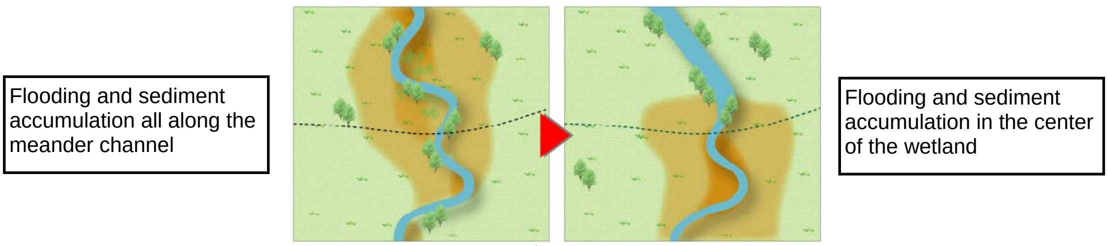


Fig. 12

② Decrease in wetland area from aridification (change in vegetation) (Fig. 13)

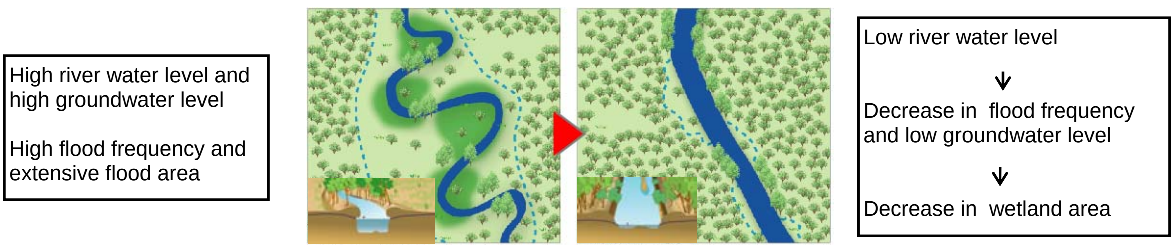


Fig.13

③ Loss of the physical characteristics of the wetland river channel and wetland landscape (Fig. 14)

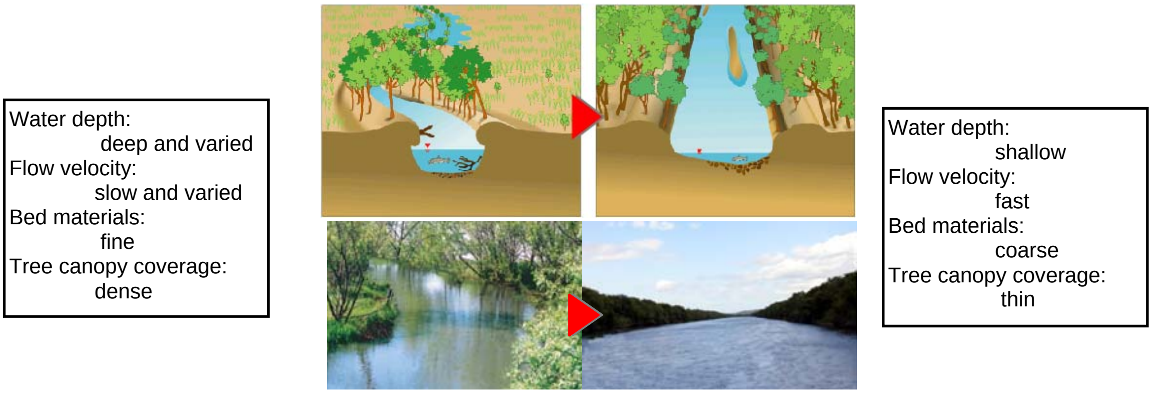


Fig. 14

In order to mitigate qualitative and quantitative changes in the wetland, the Kayanuma District Old Channel Restoration Program was formulated by MLIT in 2006. This program corresponds to "Conservation and restoration of river environments" and is also related to "Restoration of hydrologic and material cycles" and "Sediment control in wetlands, rivers and lakes" in the measures of the Comprehensive Concept. The details of the implementation are as follows (Fig. 15):

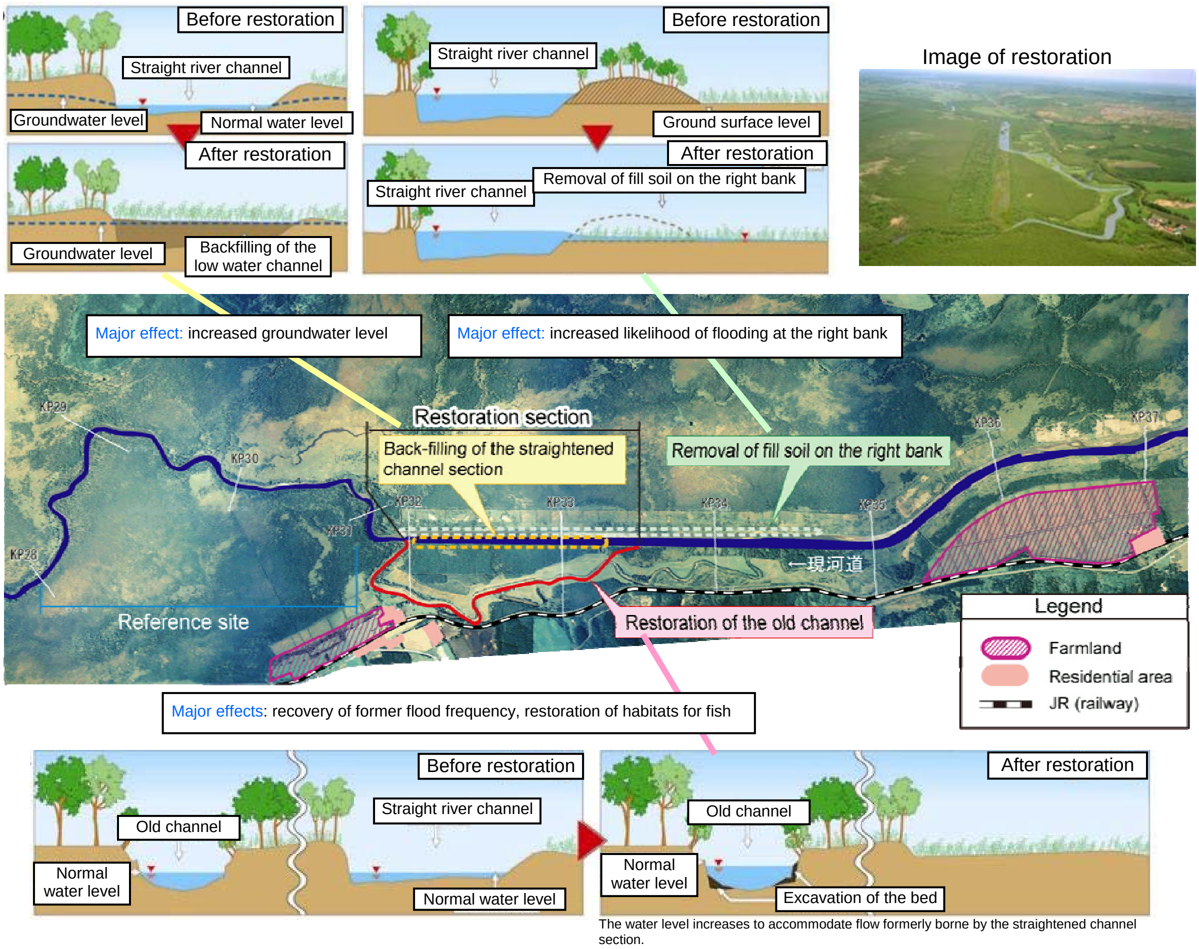


Fig. 15: Details of implementation

The anticipated effects of this project are as follows (Fig. 16):

① Sediment discharge into the center of the wetland through the main channel of the Kushiro River is expected to decrease by approx. 30%.

② Approx. 100 ha of wetland vegetation is expected to recover through increases in river water and groundwater level as well as the increase in flood frequency.

③ The physical conditions, biological environment and landscape are expected to become closer those of the original wetland.

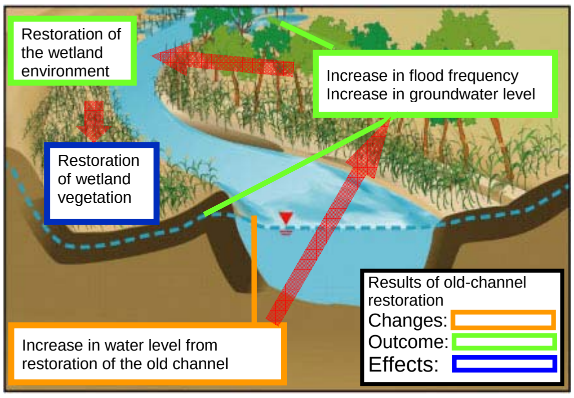


Fig. 16: Anticipated effects

4.2 Sediment Control Program (Kuchoro River)
(Kushiro Development and Construction Department (MLIT), Kushiro District Public Works Management Office (Hokkaido Pref.), Tsurui Village, etc., 2006)

The Kuchoro River is a tributary of the Kushiro River (Fig. 16). The amount of sediment discharge flowing into the center of the wetland from this river is the second highest after the main channel of the Kushiro River (Fig. 17), and the amount per unit area is the highest among those of the Kushiro river and its tributaries.

Fig. 16: Location of the Kuchoro River

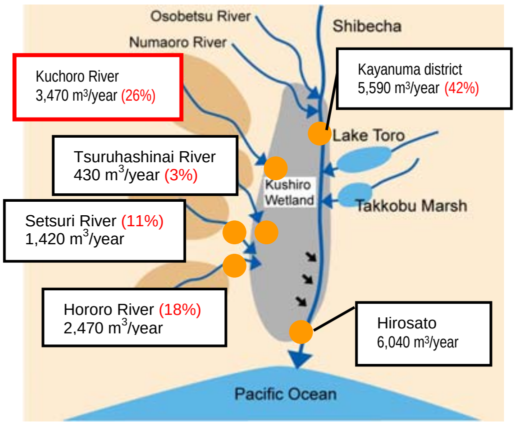


Fig. 17: Balance of inflow and outflow of suspended sediment estimated from observation

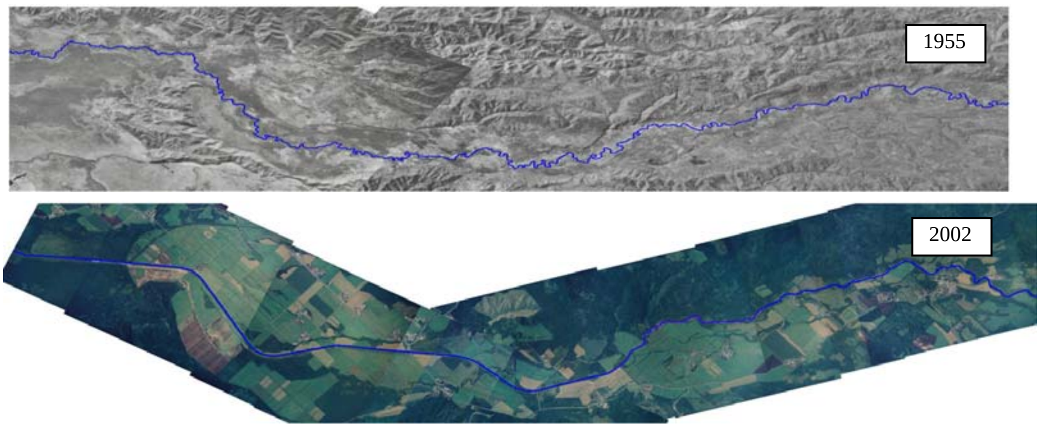


Fig. 18: Photos of the Kuchoro River (1955 and 2002)

In 1955, the river channel was meandering and the basin was hardly developed at all. By 2002, it had been developed under an open ditch drainage project, and farming activities had progressed in the basin (Fig. 18). And, riverbed degradation is observed in its middle reaches.

Land use and groundcover changed in conjunction with the development of the basin. This caused issues of the increase in sediment discharge into the wetland, the increase in sediment accumulation in the wetland and changes in wetland vegetation.

In order to mitigate qualitative changes in the wetland, the Sediment Control (Kuchoro River) Program was formulated by MLIT, MAFF, Hokkaido Prefecture, Tsurui Village, local residents, etc. in 2006. The target area of the project is the Kuchoro River basin. This program corresponds to "Sediment control in wetlands, rivers and lakes" in the measures of the Comprehensive Concept. The details of the implementation are as follows (Fig. 19):

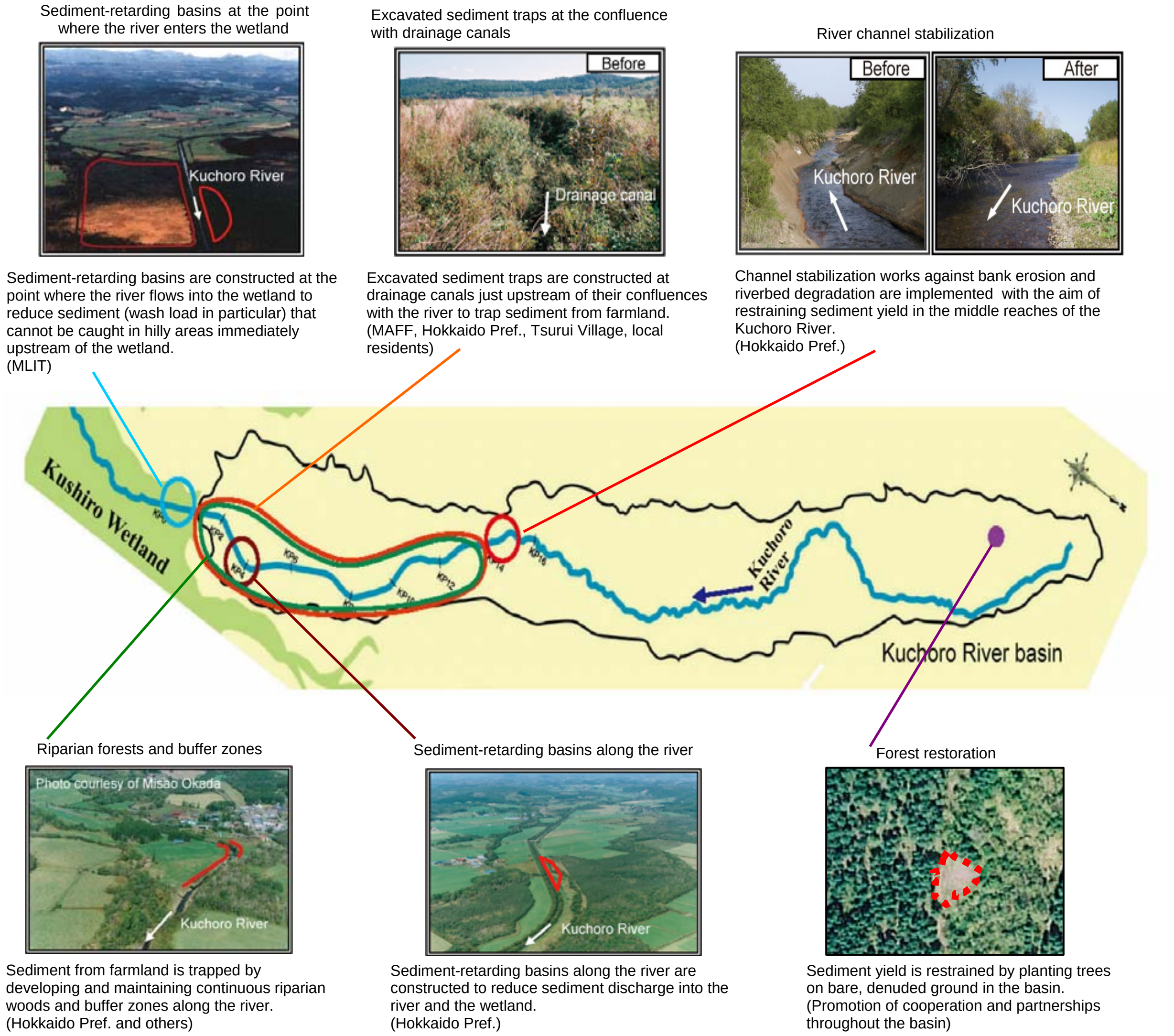


Fig. 19: Details of implementation

The anticipated effect of the project as a whole is a reduction of sediment discharge into the wetland by approx. 40% from the present level.

5. CONCLUSION

The area of Kushiro Wetland – the first Ramsar site and the largest wetland in Japan – has decreased dramatically, and wetland vegetation has also changed significantly in the last 60 years.

The Kushiro Wetland Restoration Committee was established by local residents, NPOs, experts and the national and local governments in 2003 in order to promote Kushiro Wetland restoration projects through cooperative efforts.

By 2009, six implementation programs had been formulated, and many organizations and residents, including MLIT, remain active though the Kushiro Wetland Restoration Committee in efforts to conserve and restore the wetland.

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CLIMATE CHANGE THREAT AND THE LOW INCOME POPULATIONS OF COASTAL ZONES – A STUDY OF THE NORTHEASTERN REGION OF PENINSULAR MALAYSIA

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ABSTRACT

Low Income Economies would continue to predominate and plays a significant role for many of Malaysia's coastal and island regions. These systems are usually managed by the household family unit with additional labour been utilized on a semi-permanent basis in the daily activities. In Peninsular Malaysia the Low Income Economies are often associated with small scale rural industries that are dependent on manual labour and the limited use of capital. These rural activities are very structured, and a certain level of skill and experience to operate the routine activities, and follow a predetermined cycle of operations which in most cases are subjected to the conditions of the environment. The population communities who are involved in the activities are barely sufficient to meet the daily expenses of the family unit and in most cases hovers just above the poverty threshold value for rural regions in Malaysia. This paper discusses part of an ongoing research findings of a study carried on the Low Income Economies of the coastal region of the Northeastern part of Peninsular Malaysia. The study identifies a number of low income economies in this coastal region that are associated with fishing, agriculture and rural cottage activities and examines the socio-demographic profiles of the operators, the cycle of activities pertaining to each Low Income Economies, and how the activities are being dictated to conditions of the environment. Low Income Economies play a very important role in maintaining the wellbeing of the rural populace of the Northeast region of Peninsular Malaysia and a disruption to these economic systems could have serious repercussions on the poverty alleviation efforts of Malaysia. Changing environmental conditions as dictated by a changing climate will affect the cycle of operations of the Low Income Economies and would have strong implications on the wellbeing of the coastal rural family unit. The study shows that the Low Income Economies are indeed very vulnerable systems with limited ability to adapt and thus would easily succumbs to changing environmental conditions, which could become much worst with the impending threat of global warming and climate change which could / or have influence the behavioural patterns of the Northeast Monsoons and Low Oceanic Pressure Cells of the South China Seas. In anticipation of these increasing threats from changing environmental conditions the Low Income Economies need to reinforce their ability to adapt to the changing conditions. The study also proposes a number of strategies on how to increase the resilience of the Low Income Economies to changing environmental conditions.

Keywords: rural coastal populations, climate change threat, low income economies, vulnerability, adaptability

1. INTRODUCTION

Global warming would affect the behavioral patterns of regional atmospheric, oceanic and hydrological process response systems and in the long term the regional climate of Southeast Asia. Recent studies have shown that there are marked changes in the behavioral patterns of Southeast Asia's Monsoons and its adjoining Oceanic Circulation Systems (such as the effects on the behavioral patterns Indian Dipole and El Nino Southern Oscillation Cycle (IDO and ENSO). These changes would affect regional and local weather patterns, river basin hydro-meteorological and geomorphological processes and with an impending threat of sea level rise, and associated effects of coastal degradation, saltwater intrusion and ground water contamination, flooding, and the destruction of habitats and ecosystems would pose serious threats on local population welfare and their livelihood activities. Southeast Asia's coastal regions are especially vulnerable as most of the coastal population livelihoods are dependent on coastal resources exploitation. The rural coastal populations of countries such as the Philippines, Vietnam, Thailand, Indonesia, Myanmar, Brunei and Malaysia are still very much involved with inshore and offshore fishing and rural – cottage industries that utilizes the fish products. Other than fishing, small – scale agricultural cultivation which is usually a family enterprise also dominates most of Southeast Asia coastal zones till today. Any change to the onset, duration, frequency and intensity of weather events and local and regional climate would severely affects these activities as they are not only climate driven but also climate dependent. Most Southeast Asian countries coastal populations could be categorized belonging to the low income group and many are near or below the poverty threshold. Regional climate change would severely affect the rural coastal population livelihood thus pushing them towards poverty or below the poverty threshold. Their vulnerability to climate change is a function of their physical exposure and the ability to adapt to changing weather and climate conditions. Thus, vulnerability recognizes the role of societal systems in adjusting to and moderating the impacts of climate change and emphasizes the degree to which the risks of disaster can be cushioned or ameliorated by adaptive actions that can be brought within the reach of populations at risk. The significance of climate variation or change depends on the change itself and the characteristics of society exposed to it .These characteristics determine its adaptive capacity and its adaptability. Adaptive capacity refers to the ability to prepare for hazards and opportunities in advance (as in anticipatory action) and to respond or cope with the effects (as in reactive adaptation). This paper discusses the findings of a study that was conducted on the rural coastal populations of the coastal regions of Northeastern Peninsular Malaysia. The study region was chosen as it is categorized as one of the most vulnerable regions in Malaysia because of the existence of predominantly low income populations and potential threats from changing regimes of the Northeast Monsoon and Low Oceanic Pressure Cells of the South China Seas. Vulnerability analysis shows that the coastal populations are exposed to potential threats of climate change induced stresses. The populations too are dependent on livelihood activities which are mainly environment driven where income generated hovers about the national poverty threshold/line. These makes the coastal populations to be at low resilience and high vulnerability with very limited inherent coping mechanisms to manage the impending threats of climate change induced stresses.

The last half decade has shown that our society and livelihood systems are becoming more exposed and vulnerable to the threat of climate extremes, variability and anomalies and our ability to adjust and adapt to these imposing conditions are becoming more demanding and would continue to do so in the near future. Vulnerability can be defined in many ways, and it is not the intention here to review them all. For a summary of definitions of and approaches to vulnerability and adaptive capacities the reader should consult Adger (1999) , Downing et al. (2001), Kasperson et al. (2002), Adger et al. (2004) and the IPCC's Third and Fourth Assessment reports on Impacts, Adaptation and Vulnerability (IPCC 2001; 2007). Vulnerability of a community and system to a threat describes its susceptibility to be harmed by that threat. Social scientists and climate scientists have different interpretations of the term "vulnerability". Social scientists views vulnerability as representing the set of socio-cultural, economic, population and demographic factors that determine people's ability to cope with stress or change (Allen, 2003), whereas, climate scientists views vulnerability as the likelihood of impacts and stresses of weather and climate events or climate induced hazards on society and systems (Nicholls et al., 1999). Weather and climate induced hazards or events that describe changing behavioral trends of values or departures from the mean of values of variables such as rainfall, temperature, wind speed, water level, or a combination of parameters that could include factors such as speed of onset, duration, intensity, frequency, magnitude and spatial extent. A vulnerable system that is exposed and threatened by a hazard may be a region, population groups, community, ecosystem, country, economic sector, household, business or individual. Vulnerability in climate change studies falls into two categories, (1) the potential damage caused to a system by a particular climate induced hazard (Jones and Boer, 2003), for example what would be the impact of a 10 mm increase in sea level on the surrounding coastal ecosystems?, (2) the state of a system before it encounters a hazard event (Allen, 2003), for example the existence of early warning systems within a particular region which is been threatened by a low pressure systems. Climate change impacts studies have typically examined vulnerability of a human system as determined by the nature (behavioral patterns) of the physical events or hazard characteristics to which it is exposed, the likelihood or frequency of occurrence of the hazard(s), the extent of human exposure to hazard, and the system's sensitivity (inherent vulnerability and resilience of the system stress and changes) to the impacts of the hazard(s) threat. This view is apparent in the principal definition of vulnerability in the IPCC Third Assessment Report (TAR) and the Fourth Assessment Report (FAR (IPCC, 2001 and 2007) that describes vulnerability as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of thee character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity". Adaptive capacity is "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences". This combined vulnerability, a function of hazard, exposure and sensitivity, is sometimes referred to as physical or biophysical vulnerability (O'Brien et al., 2003). The term "biophysical" will be used here, as it suggests both a physical component associated with the nature of the hazard and its first-order physical impacts, and a biological or social component associated with the properties of the affected system that act to amplify or reduce the damage resulting from these first-order impacts. Biophysical vulnerability is concerned with the ultimate impacts of a hazard event, and is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard. Conversely, the view of vulnerability as a state (i.e. as a variable describing the internal state of a system prior to the occurrence of a hazard event) has arisen from studies of the structural factors that make human societies and communities susceptible to damage from external hazards (Allen, 2003). In this formulation, vulnerability is something that exists within systems independently of external hazards. For many human systems (social and physical systems), vulnerability is viewed as an inherent property of that system arising from its internal characteristics. Inherent vulnerability is determined by factors such as poverty and inequality, marginalization, food entitlements, access to insurance and housing quality, presence or absence and the state of infrastructures and mitigation measures. In this formulation, it is the interaction of hazard with inherent vulnerability that produces an outcome, generally measured in terms of physical or economic damage or human mortality and morbidity (Brooks and Adger, 2003). The nature of a system's inherent vulnerability will depend on the nature of the hazard to which the system is exposed; certain properties of a system will make it more vulnerable to certain types of hazard than to others. For example, quality of housing will be an important determinant of a community's vulnerability to a flood or heat wave threat, but is less likely to influence its vulnerability to drought threat. In general human systems vulnerability can be differentiated based on their "generic" determinants and their "specific" determinants to particular hazards threats. The state of vulnerability for a particular system describes the risk of that system to harm by induced stresses. Low vulnerability – high resilience systems are associated with low risks to change and harm whereas high vulnerability – low resilience systems are associated with high risks to change and harm to induce stresses. Risk can be defined as a function of hazard and the inherent vulnerability of a particular system and is compatible with risk defined as probability x consequence, and also with risk defined in terms of outcome. The probability of an outcome will depend on the probability of occurrence of a hazard and on the inherent vulnerability of the exposed system, which will determine the consequence of the hazard. The ambiguity as to whether it is the probability of occurrence of a hazard, or the probability of a particular outcome that is being referred to be addressed by Sarewitz et al. (2003). They define event risk as the "risk of occurrence of any particular hazard or extreme event" and outcome risk as "the risk of a particular outcome". They state that outcome risk "integrates both the characteristics of a system and the chance of the occurrence of an event that jointly results in losses." The principal difference between the natural hazards risk-based approach and the IPCC biophysical vulnerability approach is that risk is generally described in terms of probability, whereas the IPCC and the climate change community in general tend to describe (biophysical) vulnerability simply as a function of certain variables. Nonetheless, the determinants of both biophysical vulnerability and risk are essentially the same - hazard and vulnerability. The natural hazards community, which emphasizes risk, and the climate change community, which emphasizes vulnerability, is essentially examining the same processes. However, this has not always been immediately apparent, due to differences in terminology. Both are ultimately interested in the physical hazards that threaten human systems, and in the outcomes of such hazards as mediated by the properties of those systems, described variously in terms of vulnerability, sensitivity, resilience, coping ability and so on. The integration of the risk-based and vulnerability-based approaches is desirable if we are to address the numerous threats that human systems will face in the future as a result of climate variability and change, and also from non-climate hazards. As stated by Kasperson et al. (2001), "What is essential is to assess vulnerability as an integral part of the causal chain of risk and to appreciate that altering vulnerability is one effective risk management strategy."

The literature on the vulnerability have grown enormously over the past few years. Key articles include and Chambers (1989), Blaikie et al. (1994),Clark et al. (1998), and Adger and Kelly (1999), Bohle et al.(1994;2001), Downing et al. (2001), Kasperson et al. (2002), and the IPCC's Third and Fourth Assessment reports on Impacts, Adaptation and Vulnerability (IPCC 2001; 2007). The literature on risk, hazards, poverty and development is concerned with underdevelopment and exposure to climatic variability – among other perturbations and threats.

Vulnerability has no universally accepted definition (Downing and Patwardhan 2007). This is because it has been used in a wide variety of contexts and in many different fields. Some of the various definitions of vulnerability are those by Bohle, Hans-Georg and R. Kasperson (2001), Langeweg, Fred, and Roger Kasperson, Pamela A. Matson et al (2003), Vogel, Coleen (1998), Blaikie, Piers. Et al (1994) .Common to all these definitions is that vulnerability generally has a human or society-centered perspective. The Intergovernmental Panel on Climate Change (IPCC) tuned its definition of vulnerability specifically to climate change. Using this lens, vulnerability is seen as the residual impacts of climate change after adaptation measures have been implemented. Tol, Richard S J et al (1998) for example defines vulnerability to climate change as a function of both the sensitivity of a system to changes in climate and the ability to adapt to such changes.

Investigating the potential effects of changing climate has occurred for different ecosystems and sectors in various locations on a case study basis, for example coasts (Adger,W.Neil 1999; rivers/water resources forests wetlands, agricultural productivity and the carbon sink. Essentially such studies are predicated upon a simple linear relationship between hazard and impact, and vulnerability is referring to the sensitivity of natural environments to projected changes in climate, or their biophysical vulnerability. Through influencing resource availability, such impacts might in turn filter through to impact human populations, particularly those that are geographically proximate to the exposure. Other studies have explicitly investigated the impacts of climate change on human lives through such parameters as malaria incidence, water availability and coastal flooding. This trend of assessing impacts based on biophysical vulnerability is also enshrined in the IPCC process. However, the approach has attracted criticism through assuming humans are passive recipients of global environmental change, and thus failing to capture their dynamic ability to mediate such hazards, either through resisting an event or coping once it occurs.

The potential threat of climate change induced hazards in Malaysia should not be taken lightly. Although the IPCC 2007 report on the "Science of Climate Change" shows a small increase in temperature for the Southeast Asia Region in the last 50 years or so, there is general agreement amongst scientists that the changing behavioural patterns of the el-Nino ENSO , Monsoons and to a certain extent the Indian Dipole

Oscillation circulation systems are triggering weather extremes and variability to influence changing behaviour patterns of hydro-meteorological and geomorphological events (floods, haze pollution and slope failures) in the region. To this date the impact of these changes can still be absorbed by the strong foundations of Malaysia's environmental management programmes and backed by her stringent economic policies. This scenario can change if the gradual increase in global warming is left unchecked and unabated because increasing global temperatures could lead to thresholds been breached where habitats and ecosystems could not recover to existing equilibrium and stable conditions.

Generally, vulnerability, resilience and the ability to cope and adapt to impending climate induced hazards would be more challenging to the lower income groups. These components of society are involved with simple - low income economic systems derived and dictated by the vagaries of man – environment relationships. Malaysia's economic development programmes and urban – rural transformations have improved substantially the quality of life of these people and by 2007 most of the country low income populations has move out of the poverty line threshold, though there are still many that hovers around these threshold boundaries. There are many ways to classify these groups of low income populations which could be based on their economic activities or as used by the author based on their geographical distributions. In Malaysia (based on an on- going study of Peninsular Malaysia), three major regions are distinguished, based on the nature of how climate change can induced changes to economic systems practices based on man-environment relationships in the regions. These low income economic systems are found in, (1) the urban regions, where the most critical groups are the urban poor whose income activities are mostly associated with informal activities, (2) highland regions, where the low economic systems are associated with traditional practices of agriculture cultivation and the harvesting of forest products, and (3) the coastal and island regions, the low income populations here are generally associated with the traditional fishing and agricultural practices. Though these three regions shows a general picture of the existence of low income economic systems, the economic performance of these systems do fluctuate as dictated by the nature of man – environment relationships. As an example, the economic performance of the fishing communities of North Eastern Region of Peninsular Malaysia is very much dictated by weather conditions in the South China Seas. Also, it should be noted here that there are other components of society such as that which belongs to the lower hierarchy of government and private sector employment though not belonging to below the poverty threshold but are within distance of it and are also postulated to belong to that part of the population which have high vulnerability, low resilience and poor coping and adaptive mechanisms to any forms of environmental stresses.

The paper examines the vulnerability, adaptability and resilience of the traditional economic system in the coastal region of Peninsular Malaysia. Most of the coastal communities are fishing communities with fishing as the main activity often also supported by fishing related activities, mainly the manufacturing of fish products. In some of these areas, activities related with traditional crafts industries as well as tourism related activities are also predominant. The economic activities are mainly small-scaled in nature, usually involving family or local labour and produced for own consumption or for local markets. Based on the climate change vulnerability model by Kasperson (2001), the study identifies the environmental and social perturbations and stress, the socio-and environmental conditions of the exposed as well as the coping/response mechanisms put in place. Finally, the study also postulates questions related to the resilience and survival of these communities.

2. CLIMATE CHANGE THREAT AND THE VULNERABILITY MODEL: THE CASE OF COASTAL AREAS OF PENINSULAR MALAYSIA

The Peninsular Malaysia's coastline extends over 2031 km and most of the coastal districts are fishing areas of the peninsular. These coastal areas are also form major tourism areas based on their long stretches of beaches. In recent years the areas have been subjected to tremendous development to support the tourism industry.

The coastal areas of the country have been experiencing environmental degradation- mainly the result of natural processes but greatly induced by the development taking place in these areas. The most prevalent environmental stress is seen in the form of beach erosion, pollution, sea- level rise and salt water intrusion.

The study focuses on the coastal areas of a northeastern state of the peninsula; Kelantan.In the study area, the environmental stress is very much related to the North-east monsoon, which resulted in floods, coastal erosion, strong winds and turbulence and in recent years concrete evidences of sea level rise, beach retreat and salt water intrusion.

Based on the monitoring report of the Drainage and Irrigation Department, there are three categories of beach erosion in the coastal areas of Malaysia. These categories and their characteristics are shown in table 1. All the beach areas in the state of Kelantan are in the category 1.

Table 1. Categories of Beach erosion in Peninsular Malaysia

Category	**Definition**	**Total area**	**Total beach length (km)**
1 (Critical)	Areas where social and economic threat and impact is at the dangerous stage	74	232.7
2 (Evident)	Beach areas shall be under threat in between 5-10 years if no action taken	64	221.1
3 (Acceptable)	Beach areas are not seriously eroded	77	946.5

The climate change vulnerability model is adopted at a very local scale, involving a coastal community in the north-eastern part of Peninsular Malaysia.

The study attempts to identify the environmental/ecological stresses and the vulnerability indicators of these areas. The data and information related to environmental stressors are obtained from records of government agencies and also interviews with the authorities at the village levels. The data on vulnerability indicators are obtained from questionnaire surveys, carried out at the household levels. The selection of vulnerability indicators are guided by the Social Vulnerability Model postulated by Dwyer, A. Zoppou,C. et al (2004). The indicators used are shown in table 2. Based on the indicators selected a questionnaire survey is carried out at two levels: the community and the household. The community level involved interviews with mukim heads, involving 6 mukims in the districts of Tumpat. The second level involves questionnaire surveys involving the head of households in the villages in each of the mukims. This survey is still on-going. The paper presented the preliminary findings of the first survey

3. HAZARDS, VULNERABILITY AND COPING STRATEGIES OF COMMUNITIES AT RISKS

As mentioned above, the scenario of climate change as can be seen in the gradual increase in global warming if left unchecked and unabated has led to increasing global temperatures and could lead to thresholds been breached where habitats and ecosystems could not recover to existing equilibrium and stable conditions.

In the study area, incidences of sea level rise, extreme weathers and storms, coastal and riverbank erosion, floods and salt water intrusion had occurred over a long period. In recent years, the occurrence of these hazards in the area has seen severe impacts on the exposed communities, the ecosystem and physical infrastructures of the area. For example, in 2003, 48 houses and a mosque had been destroyed, as a result of coastal erosion, followed by another 28 houses in December 2004 and January 2005. At the same time, livelihood activities are being hampered by strong winds and floods. Some evidences are shown below:

Table 2: Vulnerability Factor and Indicators

Factors	**Factor Components**	**Indicators**
Hazard	Floods Erosion Others (strong winds, drought, salt water intrusion)	Frequency of flood Last flood experiences Coverage and intensiveness eroded
Exposure	Physical Infrastructure	Number of dwellings Number of Fishing boats
	Population exposure	Population
	Economic System exposure	Household Income Livelihood Activities
Vulnerability	Physical infrastructure	House Structure Distance from Sea Distance from river Piped and Electricity supply
	Population Vulnerability	Age, Sex, Income, Education level, level of awareness
Coping Mechanisms/Adaptability	Resource	Savings, insurance, alternative livelihood strategies
	Mobility and Access	Distance from nearest town Distance from Mosque Distance from community Centre
	Formal	Government aids and mitigation efforts

Some of the vulnerability characteristics of the coastal community in the district of Tumpat, one of the study areas in the northeastern state of Kelantan is summarized in table 3. The preliminary findings reveal that the mukims under study are typical coastal areas vulnerable to hazards related to climate induced incidences. The major hazards are floods, coastal erosion and strong winds. It is clear that these hazards have an impact on their main economic activities thus livelihood strategies and their income level. Most of the populations are involved with fishing as their main economic activity supported by farming of small food or handicraft business to support the tourism industry. There al also fishing related activities which involved the production of fish produce into goods. These activities involved the drying of fish as well as the cooking of fish into fish products. These activities are small scale in nature carried out using family labours and local women folks who supplement the income from the fishing activities. It should be noted that the income level of these population is about RM 500 per month which is considered to be low-income population in the rural area.

Similar preliminary surveys have also been carried out in other districts of the state of Kelantan, namely Bachok, Kota Bahru and Pasir Putih. Generally, the communities in these areas identified the strong monsoonal winds and the floods as the major hazards affecting their livelihood activities. Similar surveys are also carried out in other states of Johor, Kedah and Selangor.

Generally, in Malaysia, the vulnerability of the people associated with low income economic systems could be the function of many factors. These factors describes, (1) the population and demographic structure of the household members, (2) their economic livelihood activities, (3) the physical characteristic of the household unit (4) the immediate living environment, (5) the exposure to climate induced hazards, (6) inherent coping mechanisms and (7) the existence of infrastructure and support systems. In addition it could be added that (8) the nature of awareness (apathy, sympathy or empathy) to the climate change threat. Limited knowledge and awareness of climate change threat could hinder their immediate response) actions) to any form of climate change induced hazards which could be costly or fatal in the future. The failure and success of implementing early warning systems for climate change induced hazards (floods, droughts, outbreak of vector borne diseases, heat waves etc.) would be dependent on the level of the system's awareness on the nature of the threat that they are exposed to.

Table 3: Vulnerability Indicators of Mukims in Tumpat

Mukim	**No of Villages**	**Population**	**Main Livelihood strategies**	**Supplementary Livelihood Strategies**	**Monthly Income**	**Water Supply**	**Hazards**	**Impact of hazards**
Mukim Tujuh	4	2000	Fisherman & Agriculture	Trading	500-550	70% - self	Flood- Dec 2007	Crop Fishing Fish rearing
Mukim Geting	12	5000	Fishermen	Farming	600-700	70% - self	None	None
Mukim Bandar Tumpat	3	3000	Fishermen	Trading	450-500	70% - self	Monsoon Winds/	Fishing and Crops
Mukim Dalam Rhu Pantai	1	2000	Fisher men Farming	Trading	450-500	70% - self	Flood- Dec 2007	Fishing and Crops
Mukim Ketil	5	3000	Fishing	Trading	450-500	70% - self	Flood	Fishing and Crops
Mukim Tebing	2	2000	Farming & Fishing Industry	Self-employment	450-550	70% - self	Monsoon Winds	Fishing

There are generic as well as specific characteristics of the low income economic systems of the coastal and island regions that describe their vulnerability. The main generic vulnerability indicator is their income. Income here is defined by the total remuneration a family received in a day, which could then be translated to monthly or yearly earnings (this is because in general the source of income is not fixed and consistent). However, for low income economic systems, daily income is much more important as the daily activities of the household unit are defined and governed by its daily income, with limited savings available. Whatever limited savings that are available would be used for other social obligations inherent in the culture systems of the society which includes providing for their children education, religious obligations and needs associated with increasing the performance of their economic activities such as investing in better machineries and technologies and others. The more specific indicators of vulnerability are associated with the nature / behavior of the prevalent / impendent local environmental stress, the socio-demographic profile of the communities at risk, their external and living environment and inherent cultural practices. To add to these indicators are the communities level of awareness, whether they perceived environmental stress as part of the normal cycle of man-environment relationships or whether the effect of environmental stress is actually changing and would influence their future relationships with the environment.

4. CONCLUSIONS – POLICY IMPLICATIONS

People develop coping strategies to deal with climate variability as with other shocks or stresses. These include building social networks as forms of insurance, traditional forecasting in order to be prepared for climatic changes and ingenious means of protecting assets such as the use, in Asia, of floating seed beds in times of floods. However, the poor's range of coping strategies is naturally more restricted by their lack of assets and by the other stresses on their livelihoods.

Adaptation is very important in poor countries because they are more vulnerable to the impacts of climate change. Broadly speaking, there are two reasons for this vulnerability. One is low adaptive capacity — high levels of poverty and a relative lack of the financial capability, institutional strength, skills, infrastructure, technology and other elements needed to cope with the effects of climatic shifts. The other is geographic location: large numbers of poor people live in areas such as drought-prone sub-Saharan Africa or flood-prone Bangladesh.

In terms of livelihood and employment vulnerability, there is not much effort in adaptation. There is very little evidences of alternative livelihood and employment strategies taken by the population themselves as well as by the authorities. As far as infrastructure and physical adaptation, in terms of their houses and properties, the population seems to be taking small, ad hoc strategies, very much inhibited by their low income. However, the state government through the department of Irrigation and Drainage has taken various Curative and Preventive Actions, which includes:

Construction of erosion control structures, including: Groin, Offshore Breakwater Revetment - rock revetment and Labuan Block revetment, beach nourishment and beach management system. Coastal Zone Land use Planning and Development Management with priority to natural coastal processes. Various instruments towards such planning efforts includes: a general Guidelines for development of coastal areas by the department of Irrigation and drainage, preparation of the Integrated Beach Management Plan-involving various adjoining states. However these efforts are more focus on the mitigation of vulnerability of the environmental/ecological, not the social vulnerability which covers the community. This is especially true in terms of education and awareness towards the hazards and threats of environmental degradation especially the impending threats as a result of climate change.

The climate is becoming more variable and creating additional risks so that the poor are becoming more vulnerable. As climate extremes are 'covariant risks' (i.e. simultaneously affecting a wide range of people), current safety nets are likely to be overwhelmed. This includes both formal systems (e.g. social assistance), and informal systems (e.g. social networks). Whatever the response, it should be an integral part of development planning. Responding to climate variability requires development agencies and governments to work on the development of strategic planning systems, which take account of current and projected climate patterns. There are two types of responses to the threat of climate change. The first, mitigation, involves reducing emissions of greenhouse gases as a way of slowing or stopping climate change . The second, adaptation, is learning to cope with temperature increases, floods and the higher sea level associated with climate change. Adaptive responses can be technological (such as sea defense construction), behavioral (such as altered food and recreational choices), managerial (such as altered farm Adaptation to climate change needs to be mainstreamed into development policy and practice at national, international and regional levels. Particular attention needs to be paid to supporting community-based approaches to adaptation. Building on the considerable body of knowledge already possessed by poor people is essential. Governments can, however, attempt to increase the resilience of their growth strategies to the impacts of increasing climate variability and climate change. Unfortunately there is, as yet, little experience of best practice of adaptation to climate change on which to draw, but experience of more general adaptive economic policies offers some pointers.

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EFFECTS OF WINDS ON NIGERIAN PORTS AND HARBOURS

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ABSTRACT

This work aims at identifying the pattern of wind in Nigerian coast and its effects on ports and harbour operations. The wind speed, wind direction and wind duration were graphically analyzed. Their effects on near – shore ocean whose driven mechanism is mainly the local wind conditions were discussed and the associated weather phenomena highlighted.

Statistical analysis was used to investigate the nature and characteristics of the coastal winds for the period of ten years, 1997 – 2006. This was carried out on monthly basis, using data from Victoria Island, Lagos. The analysis revealed that winds were predominantly from WSW and WNW directions. Winds from fetch area (lat. 10ºS – 20ºS and long 10ºE - 20ºW) generally increase from East to West with their strength lying between 6-20kts. This agrees with previous works carried out by other scientist e.g. Afiesimama et al (2001). For the period of study, the weakest winds were observed between Oct – Jan while the strongest winds were mostly observed during summer period especially in the month of August which coincides with the period of little dry season.

There were no major interruptions in operations of ports and harbours as a result of direct adverse wind flow. Ports and harbour installations, engineering works, shipping operations, etc however face the risk of being interrupted and some facilities damaged during summer period, if not well protected. Some wind related meteorological factors such as storm surges, fog, thunderstorms etc generally disrupt coastal activities including those of ports and harbours.

1. INTRODUCTION

Nigeria coastline is about 853km of the Atlantic Ocean. It is bounded in the west by the republic of Benin and in the east by the Republic of Cameroun. It lies generally between latitudes 4º10` and 6º 20`N, and longitude 2º45' and 8º 35`E adjacent to the gulf of guinea. The elevation of the coastal region lies between 3 - 4 meters above mean sea level. The region geomorphic zones from west to east are; the barrier – lagoon coast, the transgressive mahin mud coast, the Niger – Delta and the strand coast (Fig.1). Victoria Island beach is known to be part of the barrier- lagoon coast of the Nigerian coastline. This is located east of the eastern breakwater (east mole) on the down drafts side of the inlet into the Lagos harbor. To the east of this island are the Kuramo waters and the Igbosere creek and stretches approximately 80km (Ibe 1988). It is bounded on the north by the five cowries and to the south by the Atlantic ocean (Ibe, 1988) where Tin can and Apapa Ports were located (Fig 2). There are busy ferry and barge operations and a growing population engaged in recreational sailing and other water sports.

Wind, earthquake, the volcanic eruption and landslide generates wave while tides are as a result of gravitational attraction of the moon and sun. Winds are by far the most common causes of observed ocean waves (lyons1994). Two air streams affect the weather over the coast of Nigeria especially in the southwest. These are the southwest monsoons, from South Atlantic Ocean, in summer, and the dry and dusty northeast trade from the Sahara anticyclone, in winter. In both northern summer and winter, the dominant air stream is the southwest monsoon. The winds associated with southwest monsoon are the southwesterly wind Winds over most oceans are classified into light, moderate and strong depending on strength of the wind. The wind stress is more than the wind itself, it determines the exchange of momentum between the Earth and the atmosphere and exerts a strong influence on the typical variation of wind through the lowest kilometer of the atmosphere. Significant stresses arise within the lower atmosphere because of the strong shear of the wind between the slowly moving air near the ground and the more rapidly moving air a kilometer above and because of the turbulent nature of the airflow in this region. Details of the behavior of wind stress in the marine atmospheric boundary layer can be seen in Yelland and Taylor (1995) and chen et al (2000)

In this paper, the focus is on the nature and behavior of the winds speed, direction and duration as they affect port and harbour with emphasis over Nigerian coast. Coastal winds especially over the Nigerian coast have mean velocities between 5- 10knots but more consistent and strong during the rainy season especially when there are squall lines lying over the coast.

There is substantial agreement that the drag of the wind on the sea is small relative to that of a fixed soil surface with the same geometry. It is largely independent of the fetch and so seems to depend less on the larger waves than on the short waves and ripples. Plunging wave at breaking tends to marginally dominate the beach Ibe (1998). Surface – active agents, that affect the shortest waves, may therefore be important.

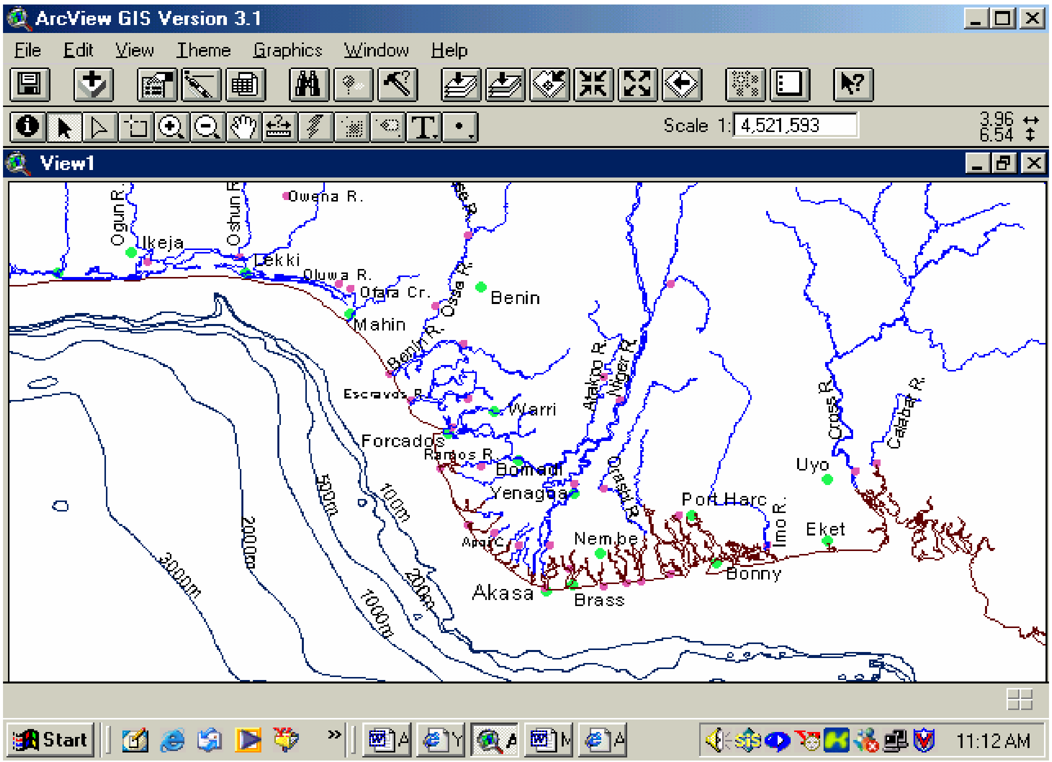


Figure 1: Map of Nigerian Coastal Areas

1.1 Geomorphology of the coast

- The Barrier/Lagoon Coast **-** Characterized by fringes of mangrove ecosystem along the banks of the Lagos and Epe lagoons and extensive wetlands. Large irregular shaped Lagos and Lekki Lagoons.

- Mahin Transgressive Mud Coast **-** The inter-tidal zone typically has a slope of 1:50, while beach elevation averages 3m above mean low water level.

- The Niger Delta **-** The largest delta in Africa and is characterized by approximately 20 km2 of mangrove swamps at or very close to present sea level.
- The Strand Coast **-** It is characterized by moderately wide (75 m) gently sloping (1:20) beach face that changes into beach ridge behind, with a few small swamps systems that extend to the shore.

1.2 Characteristics of Nigeria coastal wind

(1) Two air streams affect the weather over the coast of Nigeria namely:
The southwest monsoons, from South Atlantic Ocean, in summer, and the dry and dusty northeast trade from the Sahara anticyclone in winter.
In both northern summer and winter, the dominant air stream is the Southwest Monsoon.
(2)The wind associated with southwest monsoon are the southwesterly winds
(3)Winds over most oceans are classified into light, moderate and strong which are respectively influenced by trade wind, average cyclone and hurricane weather system (Lyons 1994). The classification is according to the strength
(a) Light 1 - 9kts
(b) Moderate 10 – 19 kts
(c) Strong 20kts and above.

1.3 Area of study

The Nigeria coastline is about 853km of the Atlantic Ocean. It is bounded in the west by the Republic of Benin and in the east by the Republic of Cameroon. It lies generally between latitudes 40 10’ and 6020’N, and longitude 2045’ and 8035’E, adjacent to the Gulf of Guinea. A common feature of this coastline is its low-lying nature.

2. WIND RELATED METEOROLOGICAL PHENOMENA AFFECTING PORTS AND HARBOUR OPERATIONS

Real time information on the nature and characteristic of wind and how they affect the ships could assist the captain / sailors in maneuvering and reducing the risk associated with berthing ships at the ports under adverse meteorological conditions. The wind related phenomena were highlighted below:

2.1 Adverse weather at the coast

Adverse weather at coast includes Thunderstorm, Rainfall, fog, dust haze etc.

2.1.1 THUNDERSTORM is a typical meteorological phenomenon affecting port and harbor operations.
Cold wind blowing over warm surface of the sea results in formation of convective clouds from which showers and thunderstorm often develops.

Effects

(1) It reduces visibility and could be dangerous to operations and cargoes that are not well protected.
(2) Lightning associated with strong wind disrupt power supplies / radar and electronic installation at the port.

2.1.2 FOG / MIST the interaction of the sea surface and nature of air mass (wind) over it affect the coastal weather.
When warm air flows over cold water, it is cooled from below resulting in cold layer which is nearly saturated, forming mist or fog.

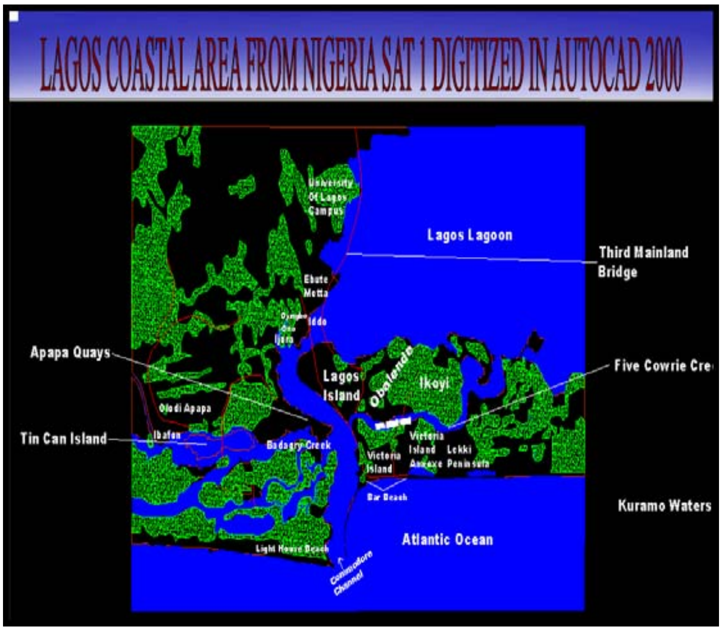
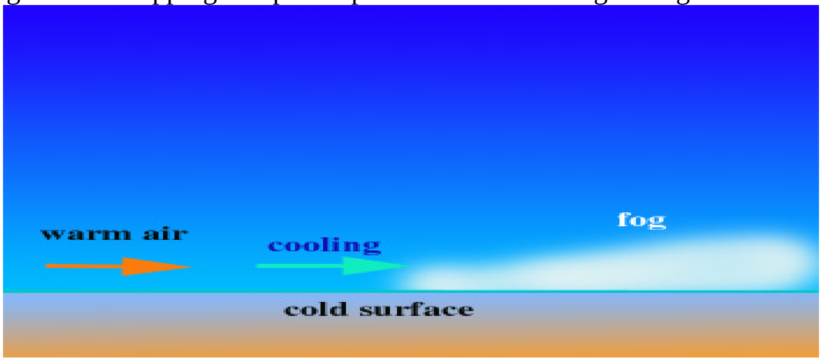


Figure 2: Area of study

Effects

(1) It is often dangerous to shipping and ports operations like berthing of large vessels.



(2) Fog poses serious problems to coastal engineering work, port and harbour operations especially cargo handling, ship coming in and leaving the ports.

2.1.3 <u>WAVES</u>; Wind wave or Sea waves are waves raised by wind blowing over a stretch of water. Swell are waves that travelled a distance from where they are generated. The waves affecting the Nigerian continental shelf are wind generated with intensities generally determined by the wind velocity, duration and fetch. Plunging waves are dominant in the Barrier-Lagoon coastline in the southwest and the Niger Delta of Nigeria.

2.1.4 STORM SURGES are changes in water level generated by storms passing over the sea. They are generated by wind stress acting over the sea surface and by variation of atmospheric pressure. It is the rise and fall of the sea level caused by a meteorological disturbance. High waves often result in Ocean Surges. Winds play a huge role in the occurrence of a surge.

2.2 EFFECTS OF WAVES & SURGES ON PORTS/HARBOUR

a) Surges can be very dangerous depending on the severity. Severe waves caused by strong wind could be very notorious to the mariners, coastal dwellers, Ports & harbour as they often result in flooding, coastal erosion, loss of recreational facilities, decreased water quality, damage to infrastructures, interruption of power and communication network, human injuries and loss of lives and property at ports.
b) With the Atlantic Ocean overflowing its bank, the resulting flooding has become an annual occurrence, adversely affecting Nigerian coast line, ports and harbour activities etc.
c) Increasing water level during some ocean surges in Nigeria to about 5m (Awosika et al 1995)
d) Upsetting the ocean mix by creating large wave action. Not only will this upset the bio-diversity in the region but it threatens sea-going vessels and crew, also small fishing trawlers are highly affected during strong wind.
e) (Adverse effects on oil and gas transportation.
f) Shipping of goods, commercial fish trawling and economic growth of Nigeria is not only retarded, but takes downward spiral thereby increasing poverty and unemployment in the country.
g) Causing serious flooding when an extreme storm surge event occurs.
h) Decimation of coastal vegetation especially the mangroves.
i) Uprooting of coastal settlements, and destabilizing coastal infrastructures along the entire coast.

2.3 Coastal flooding

Affected areas

(1) The low lying densely populated areas
(2) Ports and Harbour Area
(3) Poorly defended coastal areas like the Lagos beach and
(4) The Niger delta areas.

The adverse effects of flooding are more apparent when stormy weather coincides with high tides.
Also high rate of erosion at the bar-beach has been linked to the construction of the moles built to stop the silting up of the entrance to Lagos harbour.

2.4 Coastal erosion

Result of flooding has led to the decimation of coastal vegetation especially the mangroves. All along the entire coast, erosion is uprooting settlements, and destabilizing infrastructure. Coastal erosion is very prevalent along the Nigeria coastline. The Bar beach in Lagos is the fastest eroding beach in Nigeria with average erosion rates of 20-30m annually. Between 1900 and 1959, the Bar beach retreated by over 1km near the eastern mole, decreasing to about 400m some 3km eastwards in the area of the Kuramo waters. However, the Lighthouse beach near the western breakwater accreted by over 500m within the same period. This high rate of erosion has been linked to the construction of the moles built to stop the silting up of the entrance to Lagos harbour. Erosion of ground surfaces and the production of waves on water are manifestations of wind stress. Studies carried out by Awosika et al (1993) revealed that Victoria Island and lekki could lose well over 584 and 602 square kilometers of land from erosion while inundation could completely submerge the entire lekki barrier system. According to Asangwe (1993), more than 50 erosion sites have been identified along the 853 km coastline, consequently erosion poses great threats to coastal communities and their economic activities. Identified areas of major erosion along the Nigerian Coastal Zone are: Victoria beach, Awoye/Molume, Escravos, Ugborodo, Forcados, Brass, Bonny, Ibeno-Eket, Ikot-Abasi.

Projected total land loss km^2 due to erosion and inundation (Awosika et al 1992).

	LOW ESTIMATE				HIGH ESTIMATE			
SLR	0.2m	0.5m	1.0m	2.0m	0.2m	0.5.m	1.0m	2.0m
Barrier	177	284	584	1167	118	289	602	1204
Mud	403	1008	2016	3456	403	1008	2016	3456
Delta	2846	7453	15125	18398	2865	7500	15332	18803
Strand	79	197	395	575	85	212	446	677
Total	3445	8942	18120	23596	3471	9009	18396	24140

3. ANALYTICAL METHODS

3.1 Data Collection. Daily Wind speed & direction data at 0900z were obtained for a period of 10 years 1997 -2006, from Marine Met station at Victoria Island near Lagos harbour. The same meteorological phenomenon at east mole marine station is applicable to Apapa and Tin can Island ports. This station is meant to service these ports.

3.2 Data Analysis.

- Daily wind speed and direction at 0900z were graphically analyzed on monthly basis using the mean values and Relative frequency of occurrence analysis (empirical approach) in determining the proportion of times that a particular wind strength and direction occurs for the period considered.
- Analysis of speed, direction and duration of the wind were also carried out to determine the pattern of flow and strength of the wind in the coastal area.
- Statistical speed- duration analysis of the wind data was also carried out to determine the average duration that the wind of a specific speed blew from a certain direction.

WIND SPEED/DURATION ANALYSIS

(Table2)

	DURATION OF WIND SPEED/DAY							
SPEED	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW
< 5kts	4	5	5	7	15	25	23	12
5-10kts	2	2	1	2	5	9	9	3
>10kt	0	0	0	0	4	8	2	0

4. RESULT

4.1 WIND SPEED/DIRECTION ANALYSIS: The analysis for the period is shown in table 1 and reveal some key features. Fig.(a-j) and Fig.k show the mean monthly analysis and the frequency of occurrence for the period respectively. Winds blew predominantly from WSW and WNW direction (Fig l) during the period considered and there were no cases of wind speeds greater than 19kts on the average. Within the period under study, the weakest winds speed were observed between Oct – Jan. while the strongest winds were mostly observed in the month of August.

4.2 **DURATION ANALYSIS:** average duration for the wind from various directions are shown in table 2. The longest average duration of 34% was found in the WSW direction, this was for wind speeds lower than 10kt (light wind). An average duration of 8 % and 4% was found for wind speeds of above 10kts but less than 20kts in the WSW and WNW direction respectively. For wind speeds greater than 10kts have longest average duration of 8 % and it is in the WSW direction. The results indicated that the wind blew more frequently in the WSW direction (Fig m).

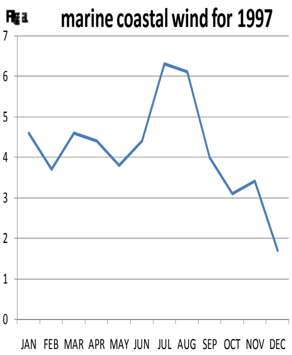


Fig a
marine coastal wind for 1997
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

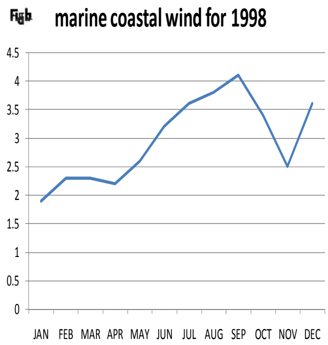


Fig b
marine coastal wind for 1998
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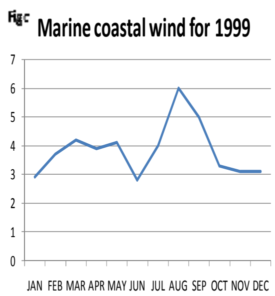


Fig c
Marine coastal wind for 1999
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

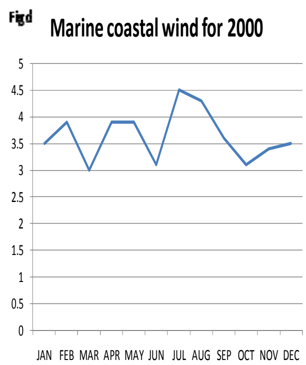
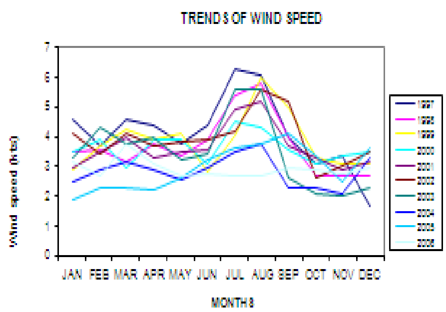


Fig d
Marine coastal wind for 2000
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


TRENDS OF WIND SPEED
Wind speed (kts)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS

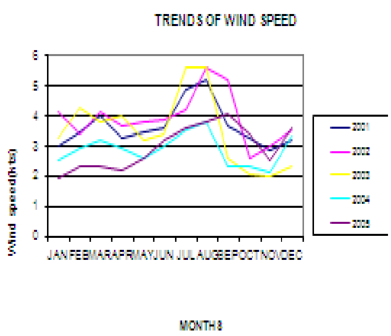

TRENDS OF WIND SPEED
Wind speed(kts)
JANFEBMARAPRMAYJUN JULAUGSEPOCTNOVDEC
2001
2002
2003
2004
2005
MONTHS

Fig e

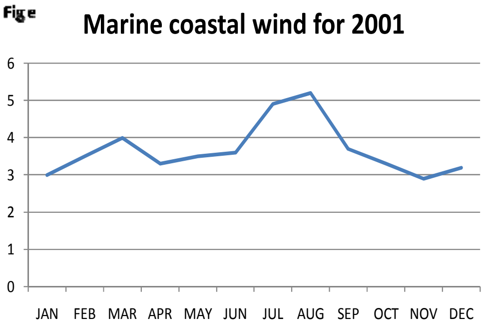


Fig f

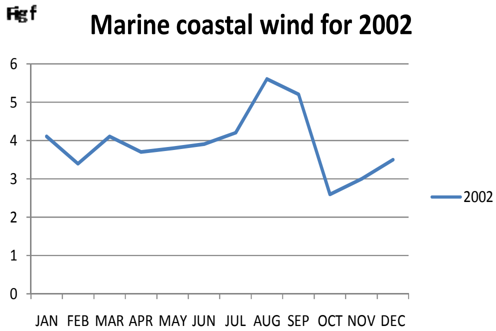


Fig g

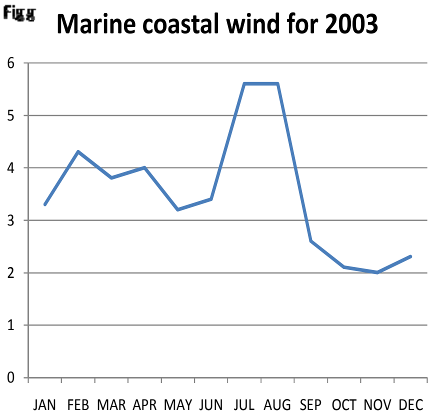


Fig h

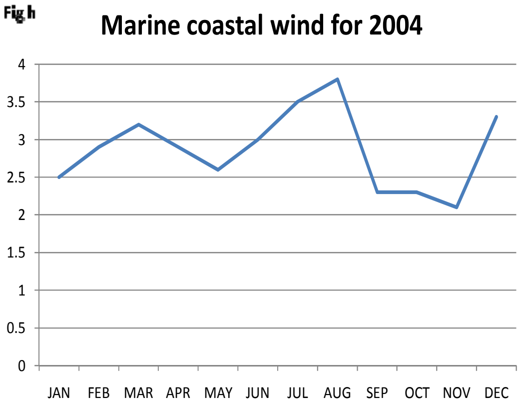


Fig i

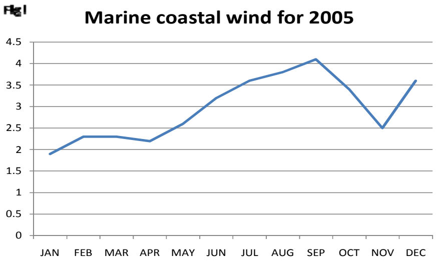


Fig j

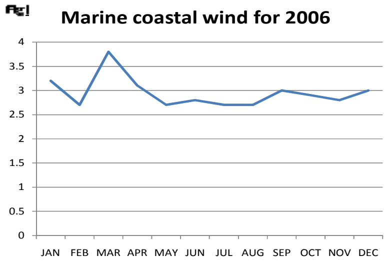


Fig a-j : shows mean wind speed for the period under study (1997-2005).

FREQUENCY OF DIRECTIONAL OCCURENCE OF COASTAL WIND

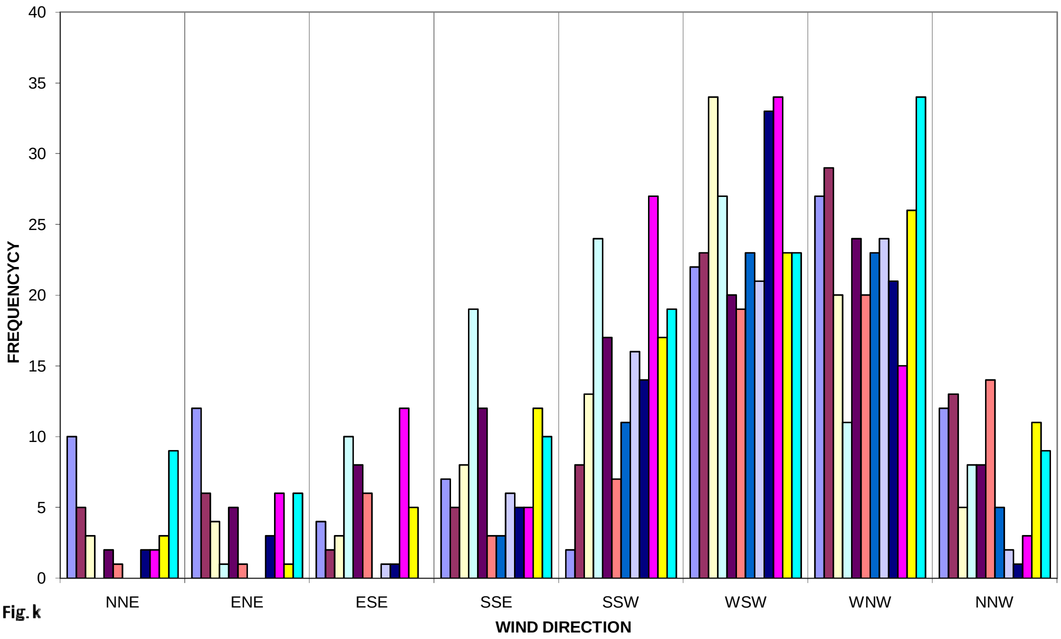


Fig. k

DISTRIBUTION OF WIND DIRECTION OCCURRENCES

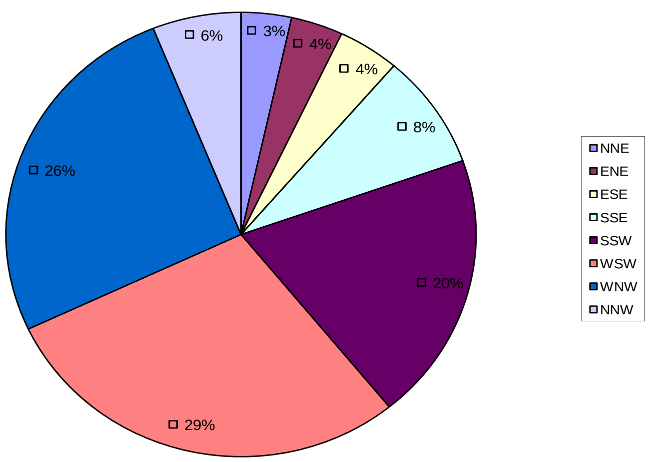


Fig. l

5. CONCLUSION / RECOMMENDATION

The effects wind has over the ports and harbor areas have been investigated. The analysis has revealed the pattern of the wind speed, direction and duration at the near – shore ocean. The wind blew predominantly from WSW and WNW direction. Generally, Nigerian coastal area experiences mainly the south westerlies which are onshore and confined to azimuths of 215º - 266º with velocities of 2-5m/s.

The result indicated that coastal wind during the summer months could cause damages to port operations if not well protected. Also the weather condition resulting from coastal wind could affect everything from shipping, the operation of offshore structures, the breaking up of oil spill and coastal users etc. Uncontrolled felling of mangroves renders the coastal environment very susceptible to erosion and flooding since mangrove trees tend to reduce the impact of waves, tides and long shore currents along the coast. Mangrove trees also trap sediments brought in by tidal currents.

Further research into the nature and characteristic of wind speed, wind direction and duration along the entire coastal area of Nigeria as it affect ports operations will enable more quantitative results to determine the socio economic impact this could have on ports operations in other to help in policy making and for proper functioning. Technical, Engineering and Structural Adaptation Strategies at the port that could be applied for optimal coastal protection and operation includes the use of protective devices or responses, which emphasizes the defence of vulnerable areas such as population centers, economic activities and natural resources. They include dikes, levees, flood walls, sea walls, revetments, and bulkheads, groins, detached breakwaters, floodgates and tidal barriers.

Also the funding of appropriate meteorological and oceanography activities will provide relevant advice that will ensure efficient management and utilization of coastal resource for sustainable development.

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A GEO-MORPHOLOGICAL STATUS OF TUTICORIN COAST THOROUGH GEOSPATIAL TECHNIQUES

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ABSTRACT

The Tuticorin Coast has well-developed geomorphological landforms on the land and sea side and is dominated by a variety of coastal landforms, reaching elevations of 2-28m. Tuticorin Coast, the area for the present study is located in the south eastern coastal zone of Tamil Nadu State in India. It lies between 8o4'49" N - 9o22'20" N latitudes and 78o3'56" E-79o26'6" E longitudes, covering an area of 1437.20Sq.km. Much of the study area is undeveloped and retains a wide array of coastal land forms in near natural condition. However, there are a number of residential communities, primarily on the very near to the coast, that have altered the landscape and geomorphological processes. The controlled inlets at either end of the coast are a type of interactive feature that have particular roles in the passage of land along the shore. Thus, the geomorphological characteristics and configuration of the coast are products of a suite of natural processes, complemented by human actions. This paper describes the geomorphic units were drawn from remotely sensed data and checked the doubtful areas in the field. Tuticoirn coastal zone has been classified into major landforms like Fluvial,(deep buried pediment, natural levee, river, alluvial plain, flood plain, deltaic plain and delta), Fluvio-Marine identified in the study area are estuary and shoal and Marine origin (sandy plain, coastal plain, beach ridge-swale complex, stabilized dune, coastal dune, sandy beach, marine terrace, spit, cliff, sand bar, creek, salt flat, mud flat, tidal flat/tidal inlet, tombolo, island, lagoon/paleo lagoon, and coral reef) based on theoretical explanations and image interpretation elements. The features were checked with existing literatures, topographical sheets and field checks. The observed geomorphic features identification, description and distribution are explained.

1. INTRODUCTION

Coastal environment plays a vital role in nation's economy by virtue of the resources, productive habitats and rich biodiversity. India has a coastline of about 7,500 kms. The coastline of Tamil Nadu has a length of about 1076 kms constitutes about 15% of the total coastal length of India and stretches along the Bay of Bengal, Indian Ocean and Arabian Sea. Tamil Nadu is endowed with one of the largest and richest fisheries in India. The consequences of accelerated urbanisation are many and various pressure on the natural spaces and landscape, impermeabilisation of soil, multiplication of infrastructures, increase in water consumption, wastewater and refuse, atmospheric and noise pollution. In this perspective, the Tuticorin coast has launched a study which consists in selecting and applying relevant criteria for dividing up and qualifying the littoral. The State has 1.9 lakh sq. m of EEZ covering the three coastal zones already described, besides 21 coral islands in the Gulf of Mannar, with rich habitats of corals, coastal lagoons (Pulicat Lake and Muthupet swamp) and estuaries. The unique topography of Tamil Nadu with the Gulf of Mannar and Kaniyakumari in the south, and Pulicat Lake, which is the second largest lagoon in the country, in the north, has resulted in an abundance of endemic species and a large number of high value potential resources. They include spiny lobsters, crabs, flower shrimps, coral fish, sea bass, groupers, sea breams, mullets, gastropods (abalones, chunks) pearl oysters, etc. Nearly one-third of the seaweed resources of the Indian Ocean are found along the coast of Tamil Nadu, particularly the Gulf of Mannar (CASI, 2000). The present study is perhaps a description of broad factual sources and facts themselves from earlier literature. The context of the study area has however been described very briefly and so this chapter concerns itself with providing a detailed profile of the Tuticorin Coastal Zone, which is the Tuticorin Coast with all of its physical, social and economic characteristics. The physical and human environments of the Tuticorin Coastal Zone are described using both the primary and secondary sources of information.

2. TUTICORIN COASTAL ZONE – AN OVERVIEW

The Tuticorin Coastal Zone has been demarcated by ten kilometers off set distance towards landward side from the coast line (above the high water line). To carry out the phase of spatialisation, the littoral environment considered as an individual territory which comprises in the coastal zone. Subsequently, it has been segmented, taking essentially the geomorphology of the coast into account. By dividing up the coastal zone it has been possible to qualify these units (sometimes also referred as littoral regions), it is the most comprehensive scale. In the present study area the Tuticorin coast runs for 193km including Rameswaram Island. Thus, the littoral villages (facets of human habitants) have an average density of 136 persons per sq.km regarding census of India 2001.

This division has led to the definition of 20 homogeneous zones within which territorial land management may be implemented taking into account the range of coastal eco-systems.

The present study area is a part of the Gulf of Mannar Marine Biosphere Reserve. It is the first marine reserve not only in India but also in the entire south and south East Asia. It was established jointly by the Government of India and the Government of Tamil Nadu with effect from 18 Feb 1989. The Indian part of Gulf of Mannar lies between India and Sri Lanka and has an area approximately 10,500sq.km. There are 21 uninhabited islands lying off the coast in Ramanathapuram and Tuticorin districts. Most of the islands are of coral origin. The 21 islands altogether have an area of 623ha. This area is the last refuge of any significance off Indian coast of the highly endangered sea-mammal, the Dugong. The reserve is one of the richest areas of marine biodiversity in India. It encompasses diverse ecosystems like coral, mangrove, sea grass, and Island ecosystems. It is sea-algal resources, ornamental reef fishes, shell and fin fish resources, marine mammals and marine turtles. More than 50, 000 fisherman living on the coast of the Gulf of Mannar depend upon the fisheries resources of the reserve for their livelihood (GoM Marine National Park, 1999). The Reserve is comprised of a 560 sq.km core area of coral islands and shallow marine habitat, surrounded by a 10 km wide, 160 km long buffer zone. The Gulf of Mannar Marine National Park (hereafter referred to as the Park) comprises the core area of the Reserve and is made-up of 21 uninhabited islands ranging in size from 0.25 ha to 130 ha and lying between one and four km offshore, surrounded by shallow waters. The buffer zone is comprised of Gulf waters to the south and an inhabited coastline to the north.

Seventeen different mangrove species occur within the Reserve and act as important nursery habitats. A species namely, Pemphis acidula is endemic to the Reserve; five other mangrove species occur here and nowhere else in India. The shallow waters of the Park have the highest concentration of seagrass species along the Indian coastline for about 7500km. All six genera and 11 species of seagrass recorded in India occur in the Reserve. Six of the world’s twelve seagrass genera and eleven of the world’s fifty species occur here. A species of seagrass, Enhalus acoroides, a monospecific genus of seagrass is endemic to the Reserve. These same shallow waters are also known to have at least 147 species of marine algae (seaweed). These seagrass and algal beds support complex ecological communities and provide feeding grounds for many animals, including the globally endangered marine mammal dugong (Dugong dugong-sea cow).

Productive fringing and patchy coral reef surrounding the Park’s islands are comprised of at least 91 species of coral belonging to 37 genera. The islands are used by 168 migratory bird species. The sandy shores of most of the islands provide nesting habitat for sea turtles and all five species of marine turtles have been recorded nesting on the islands. Of the 2,200 fish species in Indian waters, 450 species (20%) are found in this Gulf, making it the single richest coastal area in the Indian sub-continent in terms of fish diversity. Over 79 species of crustaceans, 108 species of sponges, 260 species of molluscs, and 100 species of echinoderms occur in the Gulf.

According to the experts (MSSRF: 1999) the threat of irreversible damage to some components of the marine ecosystem, e.g., dugongs, coral reefs and sea grasses, is very real. An international authority on coral reefs recorded that the current effort at strengthening the management of Gulf of Mannar Biosphere Reserve (BR) “is almost certainly the last hope that such species will survive in the Gulf”. (Kelleher: 1998)

The Marine-based livelihoods of people in the coastal buffer zone partly depend on coastal and marine resources. However, agriculture and allied activities still play a major role in providing livelihoods for the poor. The activities of coastal-based people include fishing, salt making, seaweed collection or other marine-based activities are gaining importance. Ninety percent of these fisherfolk are artisanal (using wind or small engine powered craft) and 10% are mechanized trawler fishermen. (Source: Paragraph 8 of GEF project brief).

The agriculture-based livelihoods in the buffer zone area, agriculture also plays an important role in the life of the people. The major part of agriculture thrives based on the irrigation available through the village tanks. These tanks are traditional water harvesting structures and provide ample scope for enhancing their existing livelihoods if rehabilitated and maintained properly. As per the recent statistics (1994) there are 71 tanks in this coastal zone region irrigating 3,750 ha. This constitutes around 21 % of the tankfed area. As the region is devoid of any other form of agriculture, tanks irrigate around 80% of the lands under cultivation. Almost all the tanks in the reserve area are in need of rehabilitation.

Financial services for poor in the Existing livelihood related programmes in the buffer zone continue to ignore the development of sustainable alternatives. In a majority of the cases, people would continue to be forced to seek credit from the moneylenders at prohibitively high rates of interest, resulting in more pressure on the resource to repay the interest.

There are efforts by a few NGOs and Research Institutions working in the area on the socio- economic development of the area. There are also community-based organizations working on banking programmes in the region. But the present study deserved mention for the purpose of the proposed study on sustainable management for Tuticorin Coastal Zone.

Location

Tuticorin Coast, the area for the present study is located in the south eastern coastal zone of Tamil Nadu State in India. It lies between 8o41’49” N-9o22’20” N latitudes and 78o3’56” E-79o26’6” E longitudes (Fig. 2.1), covering an area of 1437.20Sq.km. Apart from the mainland, the study area also includes the Rameswaram and twenty one other tiny reef islands. In the mainland, the study area stretches curvilinear in a NE-SW direction between Mandapam in the north and Madikettan Odai (Odai-ephemeral stream in vernacular) in the south with a width of ten kilometer stretching parallel to the coastline. It is bounded on the east by the Gulf of Mannar and Palk Bay. In fact the coastline of the study area forms part of the Marine Biosphere Reserve, the first of its kind in the country. The western part on the mainland is bounded by the villages of Tuticorin and Ramanathapuram Districts, while the southern part is by Tirunelveli District. Rameswaram and other fringe Island, located in the eastern part of the study area. The Rameswaram Island is stretching from Pamban in the west to Dhanuskodi in the east, is the largest, which separates the Palk Bay and the Gulf of Mannar. The other 21 islands are smaller in their areal extent lie parallel to the coast line.

Review of Literature

International Scenario: Coastal geomorphology, by definition, is the study of the morphological development and evolution of the coast as it acts under the influence of winds, waves, currents, and sea-level changes. This study of physical processes and responses in the coastal zone is often applied in nature, but it also involves basic research to provide the fundamental understanding necessary to address the pertinent questions. A principal coastal concern today and in the foreseeable future is beach erosion. It is estimated that 70 percent of the world's sandy shorelines are eroding (Bird, 1985). In the United States the percentage may approach 90 percent (Leatherman, 1988). Thus, the geomorphological characteristics and configuration of the island are products of a suite of natural processes, complemented by human actions are (Norbert, Michele Grace, and Jeffrey P. Pace, 2005) describes the landforms (beaches, dunes, inlets, and barrier island gaps) and basic controls on these landforms.

National reviews: The adjoining sea portion, the Gulf of Mannar, houses in a variety of rich faunal and floral species. According to Pillai (1986) about 96 species of corals belonging to 36 genera are found to occur in the study area. Apart from algae the reefs are also found to shrimps, fishes (Krishnamurthy, 1987) besides the extensive sea grass beds on which the green turtles, Olive ridley turtles and dugongs of the study area are depended upon. John Joseph (1991) has studied the coastal forestry resources of Tamil Nadu concluded that it is continuously subjected to intensive escalation of biotic and industrial pressures which lead to consequent degradation. The Gulf of Mannar Biosphere Reserve was described by Krishnamoorthy (1991) and pointed out the lacunae in the management strategy and emphasised the need for cooperation among various agencies. The study of coastal process physiography, ecology, and its conservation of Tamil Nadu and special care gave to his studies in the Gulf of Mannar biosphere reserve areas using different tools were illustrated by Natarajan, Dwivedi and Ramachandran (1991). A number of other studies which provide an account on the status of coral reefs of the study area have been carried out by Shepard and Wells (1988), Allan white and Arjan Rajasuria (1995) and Pillai (1996). All these, studies provide a comprehensive picture not only on the status of the coral reefs but also of the government policy towards their conservation and management.WWF (1992) since the last decade, remote sensing- the techniques capability of which has been amply demonstrated in various parts of the world, has been used in India by Bahuguna and Nayak (1994) and by the Indian Governments Departments of Ocean Development (DOD) and space Application Centre (SAC), 1997. Their mapping has revealed the existence of various reef forms such as shore platform, patch, coral pinnacles and atoll. The total area occupied by the reef and its associated features is 94.3sq.km. Reef flat and reef vegetation including algae is found to occupy 64.9 and 13.7 sq.km respectively. Balakrishna (1991) has studied coastal industries along Tamil Nadu and pointed out places for different industries. Prakash (1991), in his detailed study on sea water salt production, discussed about different issues that affect salt production. Similar study has been undertaken by Bahuguna and Nayak (1998), issues relating to coastal zone management with reference to India along with the role of remote sensing have been dealt in detailed by Nayak (2000). Balraj (1991) has studied the major ports and harbours and summarised that the state Government should initiate critical studies on erosion and accretion and accretion problems. Sivasubramanian et al (1991) has written about the coastal soils of entire Tamil Nadu, based on the electrical conductivity, pH and sodium absorption of soils taken from 30cm to 1m depth during field traverse. Balaraman (1991) has studied the coastal population of entire Tamil Nadu and brought out the population density of studied the coastal population density, growth rate and sex ratio. Franklin et al. (1991) brought out the three levels in classification system for coastal mapping using remote sensing. Agarwal (1988b) has studied the geomorphology of Gulf of Mannar off Manapad to Vaippar and reported the northward movement of sediments along the coast and the presence of saltation in Tuticorin harbour and the utility of marine geomorphology in developing the concept of sub-marine terrain evaluation in harbour engineering. Aruchamy et al. (1991) has brought out the stages in the Manimuttar delta, by tracing the meander belts and coastlines and evolution and morphological changes in the Vaigai delta, these observations from IRS – 1A data indicate the dispositioning of different landforms like ancient channels. Bojan et al (1991) have identified the potential areas available for development of brackish water prawn farming along the Coromandal coast of Tamil Nadu and also pointed out the non-availability of natural seed resources.

3. AIM AND OBJECTIVES

The study aims to drawing up geomorphology of the Coastal Zone for Tuticorin coast so as to be able to manage and develop its coastal zone in a sustainable manner by having the following objectives:

1. To demarcate coastal land by their influences between land and sea (probably 10km distance from the coast line)
2. Within the coastal land to identify the different coastal goemorphology, relatively self-contained units composed of a natural community along with its physical environment.
3. To calculate all the geomorphological units were calculated and interpreted.

4. DATA & TECHNIQUES

The study on Geomorphology has been dealt by many researchers by using different remotely sensed data products. For all mapping of the study area has been prepared from the topographic sheets (58K/4, 8, 11, 12, 15, and 16; and 58O/3, 4, 7 and 8; and 58L/1and5), published by the Survey of India (SOI) on 1:50,000 scales. The present study also used remotely sensed data of IRS-1D (LISS III) obtained in two different seasons (Kharif & Rabi) 2003 FCC images (Used Geo-coded IRS-1D product P101-R067 (Vaippar portion), P101-R068 (Tuticorin portion), P102/R067(Rameswaram portion)) By using Arc GIS linear referencing tool, the geometric measurements of lengths and aerial units were calculated with WGS 84 UTM 44 grid polyconic projected coordinate system. After having set up the objectives of the study, primary and secondary base line data have been collected from the published and unpublished reports/data of different departments and analysed in order to understand the existing condition of the study area (profile) in detail on various physical, economic and social attributes.

Administrative Units

The administrative units are drawn and complied based upon the survey of India map with the permission of surveyor general of India, 1996. The Tuticorin coastal zone forms part of the two districts viz. Ramanathapuram in the north and Tuticorin in the south (Fig 2). About 61.5 per cent of the study area falls under Ramanathapuram District comprising Rameswaram, part of Ramanathapuram and Kadaladi Taluks and they altogether covers 70 villages. The Tuticorin District covers the rest of the 38.5% of the study area comprising 50 villages belong to Vilathikulam, Ottapidaram and Tuticorin Taluks. There are 21 islands in the study area which 14 (*Shingle Tivu, Kurasad Tivu, Kovi Tivu, Pumarichan Tivu, Manalipatti Tivu, Manali Tivu ,Musal Tivu, Mulli Tivu, Valai Tivu, Talari Tivu, Appa Tivu, Puvarasampatti Tivu, Palliyarumma Tivu and Anaipari Tivu*) belongs to Ramanathapuram Taluk, 3 (*NallaTanni Tivu Shalli Tivu and Uppu Tanni Tivu*) under Kadaladi Taluk and the rest of four belongs to Kovilpatti Taluk (*Kariya Shuli Tivu, Vilangu shuli Tivu, Kosuvaritivu and Van Tivu*). The mainland of Kovilpatti Taluk exists away from the study area.

Relief

The relief of the study area was deduced from the Survey of India topographic sheets of 1:50,000 scale and by the field survey by using GPS (*GARMIAN Palm tap*). The contour at two meters intervals were generated (Fig. 2.3) to understand the topography. Accordingly, two small pockets of high grounds found near near K. Shanmugapuram of Ottapidaram Taluk and the other near Thathaneri Village of Vilathikulam Taluk. The rest of the study area is relatively plain. The maximum elevation of 28.7m above MSL is found near K.Shanmukapuram. The Rameswaram Island also is a plain with the maximum elevation of 21.5m above MSL found Gadhamanaparvatham. In general gradually decreases towards the east from highlands. No one island has perceptible relief variation except their central parts having a slight higher elevation.

Geology

The study area comprises of rocks and unconsolidated sediments ranging in age from Archaean to Recent, unconsolidated sediments deposited during Recent to late Pleistocene epochs to occur over most part of the study area. About 83.5 percent unconsoliodated sediments are formed. They have been classified as fluvial, fluvio-marine and marine and they areal extent for 275km *(19.3 per cent)*, 763sq.km *(53.5 per cent)* and 153sq.km *(10.7 per cent)* respectively. Marine sediments occupy the entire Rameswaram Island and the region from Mandapam to Killakarai. The width of these marine sediments narrows known in the southern part, ranging from 8km (in the south, near Tuticorin) to less than a kilometer near Killakarai. The fluvio-marine sediments on the other hand are confined only to the southern and central part of the study area. They lie along a narrow stretch between Kuliyankarisal in Tuticorin Taluk to Gundar River and parallel to the marine sediments on the island side. Fluvial sediments that lie along the western margin adjacent to the fluvio-marine sediment on the island side continuously from the area near Kottagudi Ar in the northeast up to the area just north of K.Thangamalpuram in the south. These sediments have been deposited by the rivers such as Gundar, Palar and Kottgudiar. Apart from these unconsolidated sediments, laterites of Quaternary period are also found along a narrow stretch between the Kottagudi Ar in the northeast and Palar in the southwest and the northeast of Kadugusandai. Further down southwest between the villages S.Tharaikudi and Narippaiyur of Kadaladi Taluk. Calcareous gritty sand stone and clay are *(5.34 sq.kms, 0.31 per cent)* confined to the northern rim of Rameswaram Island. Hornblende-biotite gneiss rock is *(136sqkms, 9.54 per cent)* restricted to the southwestern part towards the west lying on either side of the Vaippar River.

The important minerals which are exploited at present are clay minerals, Gypsum, Limestone, shell lime stone, salt, Illumite and Garnet. Most of the Garmet and Illumite deposits are confined to the eastern halves of the study area especially near Mandapam, Periyapattinam and Kanjirangudi of Ramanathapuram Taluk. Garnet deposits are predominant near Taruvaikulam and Terku Kalamedu villages of the Ottapidaram Taluk. Gypsum deposits are encounted near Tuticorin, Kalamedu, mouth of Pal Ar River and near Kilakkarai of Ramanathapuram Taluk. Large deposits of salts are found to occur near Tuticorin and Valinokkam (Kadaladi Taluk). Limestone deposits are also found near Valinokkam. Shell limestone deposits are restricted to the areas, are near the northern tip of Rameswaram Island and the the Vaippar river mouth.

Drainage

The Tuticorin coastal zone is drained by a number of rivers (Fig.2.6) of which the Vaigai Ar, Pal Ar, Gundar and Vaippar are the major rivers. The other drainage rivers of the study area include Kottagudi Ar, Korrampallam Odai and Madikettan Odai. Which debouch their surplus water into the Gulf of Mannar. Apart from these, a number of minor rivers draining the study area debouch into the tanks and these they form the major source for irrigation. The major rivers of the study have their catchments at the Western Ghats and they flow from the west to the east and empty their surplus water, if any, during the monsoon seasons. In general, streams and rivers of the Tuticorin Coast are ephemeral.

Geomorphology

The geomorphic units were drawn (Fig. 2.7) from remotely sensed data and checked the doubtful areas in the field. Tuticoirn coastal zone has been classified into major landforms like Fluvial, Fluvio-Marine and Marine origin based on theoretical explanations and image interpretation elements. The features were checked with existing literatures, topographical sheets and field checks. The observed geomorphic features identification, description and distribution are explained in the following paragraphs.

Fluvial Origin

It refers to those landforms formed due to the action of running water. Like many denudational agencies, running water also develops certain characteristic landforms. The study area has a number of landforms such as *deep buried pediment, natural levee, river, alluvial plain, flood plain, deltaic plain and delta.*

Deep Buried Pediment: It is an area of flat and smooth with weathered material of varying lithology and normally has good ground water condition. In the study area occupies 16717ha which account for 10.91 total of area of Tuticorin coast zone.

River: It refers to a large natural flow of water traveling along a channel to the sea or a lake. All rivers of the study area are ephemeral, and they debouch their excess water into the Gulf of Mannar or Palk Bay. Among the rivers of the study area, the Vaigai River flows in the northeastern part of the Ramanathapuram Taluk through the villages Valantaruvai, Alagankulam, Perungulam and Attangarai before debouching into the adjoining Palk Bay. The Gundar which flows in the central part of the study area in an almost southerly direction, through the villages Archanipagam Usilangulam, Sayalkudi, Kadaladi, Kadugusandai, Kuthiraimozhi, Periyakulam, and Mookkaiyur before empties into the Gulf of Mannar. The other important river of the study area, the Vaippar river, which flows in a south easterly direction by connecting Vedapatti, Puliyankulam, Kulathur and Vaippar villages of Villathikulam Taluk. The water flow, even though restricted only to a few months, replenishes ground water aquifers facilitating irrigation besides other uses. It occupies an area about 1211ha which account for 0.81percent.

Natural Levee: They are natural embankments or a ridge of sediments deposited along the side of a river. Natural Levees bordering in the river channels and backed by lowering swamp or flooded depression in the lower parts of the river valleys (Bird, 1984). Levees are ridges sloping away from the channel and are most conspicuous on the concave erosional banks of meanders (Aruchamy et al 1992). A portion (916ha or 0.61 per cent of the coast) in the Vaigai river estuary has levees.

Alluvial Plain: The term alluvial plain represent those landforms which are essentially plain and are predominantly built by the periodic deposition of sediments by the rivers. In general these areas are very fertile, owing to the periodic replenishment groundwater and soil, and hence intensive agricultural activities are being carried out. A linear stretch of fluvial plains parallel to the coast bordering the middle portion of western and south west of Vaippar are very conspicuous. It covers an area about 24335ha or 16.3percent of the total area of the Tuticorin coastal zone.

Flood Plain: They are seen along the banks of the rivers of the study area. These plains are formed due to deposition of sediments during the flood seasons. The periodic floods for several thousand years resulted in the piling of huge volume of sediments, spreading laterally for long distances. These flood plain area have ideal conditions for carrying out agricultural activities. It covers an area of 2931ha or 2.3per cent of the total study area.

Deltaic Plain: Flat to gently sloping plain of large areal extent of thick sediments with fan shape formed at the end of river cycle. It consists of material from river borne sediments mostly alluvium. This area has very good ground water potential. Deltaic plain of Tuticorin coastal zone is distributed for 7867 or 5.28 percent of the coastal zone.

Delta: In the old stage of a river, the low velocity of the water flow and the low gradient results in the branching out of the main river into a number of distributaries. Such branching out of rivers and sediments deposits in between them, when viewed over a large area provides a triangular shape, which is varying characteristics of a delta. In the study area such deltas are found seen in the tail-end areas of the river Vaigai, Pal Ar, Gundar and Vaippar and occupies an area extent of 2402 or 1.61per cent of the total study area.

Fluvio-Marine Origin

The fluvio-marine landforms are the landforms which are made by the combined action both by fluvial and marine process. Such landforms identified in the study area are estuary and shoal. They are described as follows:

Estuary: The term estuary, derived from the Latin ‘aestus’ meaning tide, refers to a tongue of the sea reaching inland. A definition that is widely used describes an estuary as ‘a semi-enclosed coastal body of water having a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage’ (Cameron and Pritchard, 1963). The upstream limit of an estuary can be defined in terms of the limit of saline water penetration, or the uppermost point at which tidal oscillation of water level is discernible. The term ‘ria’, which is Spanish for estuary, was used by Von Richthofen (1886) to refer to mountainous sided estuaries. Estuaries have been observed in Karampallam, Vaigai, Vembar, Gundar Pal Ar, Kottagudi Ar and Vaigai river mouths. They cover an area of 874ha or 0.58percent of the total study area.

Shoal: The term shoal refers to an area of shallow water in the coastal area especially to a submerged sand bank that is visible only during the low tide. In the study area shoals occur at the river mouths of Kottagudi ar, Pal Ar, Gundar, Vaippar and Korampallam Odai which covers an area of 265ha or 0.18 per cent.

Marine Origin

The marine landforms are those which have been formed predominantly due to the action of sea waves. They are 18 marine landforms in the study area. They are *sandy plain, coastal plain, beach ridge-swale complex, stabilized dune, coastal dune, sandy beach, marine terrace, spit, cliff, sand bar, creek, salt flat, mud flat, tidal flat/tidal inlet, tombolo, island, lagoon/paleo lagoon, and coral reef*. The following section described them detail.

Sandy Plain: Coastal sandy plains are generally appeared an extensive area of lowland, with a level or sloping. They formed due to the marine deposition. It occupies an area of 17832ha which accounts for 11.88 per cent of the total area of the Tuticorin coastal zone. They are distributed for larger extent in the western portion of Rameswaram Island followed by the coastal margin of the northern part, Kilakarai-Nochiyurani coastal margin of Tirupullani Taluk, Tuticorin coast, south east of Karampallam Odai and adjacent to on either siding of Vaippar Estuary.

Coastal Plain: Coastal plains are generally an extensive area of lowland, with a level or gently undulating surface. These formed due to the marine deposition. The Tuticorin Coastal zone occupies and area about 14614ha or 11.88per cent. The major coastal plains are seen the southwest of Tirupullani, the northeast and along the northeastern part of the coastline, the north and south of Tuticorin.

Beach Ridges & Swale Complex: Beach ridges are moderately undulating terrain features of marine depositional type. They formed during Pleistocene to Recent age. The areas between Sikkal and west of Tiruppulani are covered by well-developed beach ridges. There are nine major beach ridges observed in the coastal zone, which are the ancient shore line. Almost all beach ridges in the coastal zone are parallel to each other and trend from east to west and northeast to southwest direction. The complex swales are seen to be a part of the coastal plains of Attangari, Raghunathapuram, and Tiruppulani of Vaigai river delta. They are branched and arranged in linear patterns. They lie almost parallel to the present coastline. The swale complexes are predominant between Kottangudi Ar and Pal Ar. Swales are depressions, located normally between beach ridges. Swales are comprised of silt, clay and sand. During monsoon periods, Swales are flooded with the water and water stagnation persists for some time. It covers an area of 27,453ha which accounts for 18.42 per cent of the total area of the Tuticorin coastal zone.

Stabilised Dune: Stabilised dune along the present shoreline are well developed and vary in elevation from 2 to 5 metres and are found near Ervadi, Mandapam, Attangarai, and Rameswaram. The width of the dune varies from 50 to 70 metres. The dunes run almost parallel and sub parallel to the coastline. About 4680ha of the land is under stabilised dunes which shares 3.23 per cent of the total area of the study area.

Coastal sand dune: A dune consisting of loose sands filled up by the wind action, commonly found along the low lying seashores above high tide level. They occur for an area about 681ha or 0.44 per cent and these are found in Millavittan, Ayyanadippu, Kanjirangudi, Tiruppulanni, Pamban and Rameswaram of the study area.

Beach: Beach is a temporary or short lived deposit on the shore and it consists partly of unconsolidated materials. Beaches are extensively developed all along the coast, except at edge rock areas. All along the shore the beach is observed to be gently sloping and marked with altered crusts and troughs that are formed due to wave action. It covers an area about 726ha or 0.38 per cent of the study area.

Marine Terrace: It is a known fact that the marine terraces are one of the indicators of sea level variations. Some of the marine terraces are observed at places such as the Vembar to Killakarai coastal tract. The vertical sequence of marine terrace is formed 6 metres below the level. It also indirectly indicates hard rock regions. About 6718ha of land is under the terrace which accounts for 4.65 percent of the total area of the study area.

Spit: Schwartz (1972) states that the spits are depositional sand bodies formed above the high tide. Chapman (1964), Hepburn (1952) and Tansely (1939) have indicated that the spits are a shingle or sandy structure. Thornbury (1984) has suggested that the spits can be attributed commonly to movement and deposition of materials by longshore currents. As the Gulf of Mannar is on the lee of the northeast monsoon, there is no long shore drift from the northeast that might be the cause for the inward curving of this spit (Ahmad 1972). The Tamil Nadu spits have been studied by workers notably Prassa (1978) Loveson and Victor Rajamanickam (1988), Aruchamy et al (1992), and Anbarasu (1995). The present study were found there are 5 spits namely, Valinokkam, Chinna Ervadi on Kadaldi Taluk, Kanjirankudi on Madapam Taluk and Pamban South, and Pamban and altogether covers an area of 1919ha or 1.29 per cent of the study area. And altogether covers an area of 1919ha or 1.29 per cent of the study area. The southwestern shore of Rameswaram has a tongue shaped spit. Hence it may be assumed that these spits are recently formed. It can be explained that the Rameswaram spit may have been the result of littoral current from Palk Bay to Gulf of Mannar during northeast monsoon period.

Cliff: The details of cliff formation depend on the nature of the rocks, their stratification and jointing, their resistance to erosion, their homogeneity or heterogeneity, and the presence of bands of weakness such as shatter-belts along the faults (Monhouse 1967). This kind is conspicuous along the coastal tract of Narippaiyur to Mookaiyur of Kadaladi Taluk and Sattakovanvalasai and near Tannimutti in the Rameswaram Taluk. It covers of an area about 111ha or 0.08 per cent.

Sand Bar: A diversity of coastal features is produced by the growth of bars of sand or shingle, either offshore or parallel to it, or across the mouth of a bay or estuary, or at the point at which the direction of the coastline abruptly changes, or between the mainland and an island (Monhouse, 1967). The main conditions necessary for their growth is an ample longshore drift material, together with an irregular coastline which the sea is smoothing off by building up these lines of sediment. They were drawn from satellite imageries. Accordingly, found at Tuticorin, Mullakadu, the Mandapam Taluk it found Uchchipuli East-Vedalai North and Rameswaram Taluk sand bar extended from Ramakrishanapuram East to Rettialai kovil North, Dhanuskodi-Arichamunai, Kondodarasami kovil Southeast-Dhanuskodi Northwest, Rettaialaikovil-Kondodarasami kovil South) four in each. All these stretches occupy and area of 420ha or 0.30 percent of the total area of the study area.

Creek: This type of coastal marshy land sheltered estuaries and bays and include extensive areas in Vembar to Gundar river estuary in the Kadaladi Taluk area occupied in 1152ha or 0.77 percent of the total coastal zone. The basis for the formation of coastal mud-flats and marshes is the deposition of fine silt by the tides in a sheltered area, helped in some cases by alluvium brought down by rivers. Then vegetation begins to spread and help the process. The tidal water flow between them and is more restricted in the creek. It occupies 30km length of central part of the coastal zone.

Salt Flat: A salt covered the surface that is formed when a lake in an area of internal drainage in an arid area dried up. In the present study area a major salt flat lie in and around the Tuticorin and Valinokkam and distributed for 6902ha or 4.63per cent of the total area under salt production.

Mud Flat: The land which consists predominantly of mud comes in this category. It is generally found in the water logged and low lying areas near the coast. In the study area about 440ha (0.3%) lands are under mud flats which are extending from north of Karampallam Odai and upto south of Kallar odai and the Vaigai estuary.

Tidal flat/Tidal inlet: Tidal flats are wide expanse of fine grained soft mud along the shore. They generally, consist of deposits of clay silt, ooze etc (King 1972). They are further classified into high tide or supra tidal flats, inter tidal slopes and sub tidal zones. High tide flats are more or less flat and near high water line. Deposition is provided by the very highest tides. Intertidal slopes are the area of instability and it's affected by daily tides. The sub tidal zone is normally exposed during very low tides. In the study area it found in Valinokkam and head of the Rameswaram Island. It covers an area about 1793ha or 1.21 per cent.

Tombolo: A form of coastal spit comprising a ridge of shingle or sand that joins an Island to the mainland. The tombolo has been found along the Tuticorin coast formed due the erosion, indicating tide less seas. It covers an area about 69ha which accounts of 0.05percent of the total area of the study area.

Islands: There are 21 emerged islands in the Gulf of Mannar near the coast between Tuticorin and Dhanuskodi. These islands named in vernacular such as, Van Tivu, Koswari Tivu, Vilangu shuli Tivu, Kariya shuli Tivu, Uppu Tanni Tivu, shalli Tivu, Nalla Tanni Tivu, Anaipari Tivu, Plliyarmunai Tivu, Puvaransan putti Tivu, Appa Tivu, Talairi Tivu, Valai Tivu, Muli Tivu, Musal Tivu, Manali Tivu, Manali Putti Tivu, Pumurichan Tivu, Kurusad Tivu, Kovi Tivu and Shingle Tivu. These islands are sedimentary rock types of landforms. It noticed that fringing reef along the windward side of the islands protects the islands from direct wave action. Morphology of sandy islands are very dynamic. The morphological variations of islands are due to natural and anthropogenic agents. The natural agents include erosion, accretion, wave, current, sea level variation etc. Anthropogenic impacts are construction of breakwaters, discharging of effluents, mining of coral reef etc. The Islands erosion and accretion are caused mainly by the action of wave and wave-induced current and longshore current along the shores of islands. In the study area the waves are in the northeast and southwest direction and wind direction is similar to that of wave direction. According to Chandrasekar (1996), coral reefs are destroyed by siltation, logging and illegal mining in Tuticorin group of islands. During the last 50 to 60 years, mining of stony corals from the reef area, especially from the Kadaladi groups of islands and mining activities are more towards south on islands. The erosion has been identified along the northern side of the islands (*landward side*). Evidences of submerged trees and sharp edged coasts are found along the northern shores of these islands. This is because of the long shore current and tidal current flows towards the south, along the northern shore of islands erode the coast and these eroded materials are transported and deposited on seaward side of the coast. While high velocity waves are moving towards northern shores of islands with the littoral sediments and coming across the coral reefs, these sediments are dropped on the coral reefs; wave speed reduces and turns into a wave-induced current. By repeated action of such processes the area between Islands and reef edge get shallow and reefs submerged. Evidence of submerged reefs is identified along the southeast of Kursad Tivu. These islands area vary from 1to 10 ha each. Altogether, they occupy an area 767.31ha or 0.52 per cent.

Lagoons/ Paleo Lagoons: These geomorphic features are usually a form low lying flats and are made up of alluvial deposits with predominantly clay and silt. Two major lagoons were observed in the coastal zone. One in the northern part called Periyataruvai near Raghunathapuram village (Ramanathapuram Taluk) and it extended near Pudumadam (Mandapam Taluk) and another in the central part of the study area near Valinokkam village (Kadaladi Taluk), these lagoons cover an area of 4134ha, which accounts of 2.8per cent.

Coral Reef: Coral reefs tend to occur in warm, tropical, shallow waters. Coral reefs form natural offshore, backwater and so play an important role in the coast from waves and reefs are particularly susceptible to environmental impacts. Many problems relating to the reefs are due to the impacts of tourism (Middleten, 1995). Coral belongs to the *phylam coelenterate* and classes of Anthozoa are the major species of the study area. A total 137 such coral species are found in this area (Tamil Nadu Forest Department, 2002). Some general characteristics of the coral reefs are follows;

- Coral is a colony of tiny sea *anemone* like *Polyps* living together in thousands and secreting calcareous skeleton of calcium corbonate ($CaCO_3$), they have different colours and shapes.
- Coral reef provides an ideal habitat and feeding ground for various marine animals.
- Coral reef protects the islands from coastal erosion.

Pillai (1975) has drawn attention to the large scale destruction of the coral reef at Manoli Tivu. The study observed that most of the corals, especially the massive forms such as *Porities, Favia, Favities, Goniastrea and symphyllia* were totally removed, and there were no signs of any reef frame work, the area being now covered with sand, where once reef existed. The reefs are well growing in all islands of the Gulf of Mannar especially, Kurusadi Tivu, Valai Tivu, Talairi Tivu and Valai Tivu in the warm conditions to face off the coast lines. The grouping Islands are Muli Tivu, Musal Tivu, and Manali Tivu, much more concentrated in the coral reefs. The coral reefs are distributed 935ha, which accounts for 0.63percent to the total study area under this study.

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ASSESSMENT OF RAINFALL WATER POTENTIAL FOR RAIN-FED CROP PRODUCTION IN THE CENTRAL HIGHLANDS OF ETHIOPIA: CASE OF "YERER" WATERSHED, OROMIA REGION

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ABSTRACT

This study was conducted to assess the rainfall potential of 'Yerer' watershed in the central highlands of Ethiopia, Oromia Regional State. Different models like FAO(1978), Reddy (1990),) and the Markov Chain were used to analyze and explain the thirty three years of weather record (1975-2007) and subsequently determine and estimate the onset and end of the growing season, the length of the growing period and the dry/wet spell lengths and distributions in the study area. The mean onset of the main growing season was found to occur during the second meteorological decade and ended during the end of September. Similarly, though unreliable and only few occurred during the entire study period, the mean onset of the shorter (Belg) season was found to occur during the beginning of the first decade of April. The length of the growing season during the main rainy season,(Kiremt,) ranged from 112 to 144 days with a standard deviation of 9.6 days and coefficient of variation of 7.5%. However, the mean growing length during the Belg season was found to be 22.4 days with a standard deviation of 27 days and coefficient of variation of 122%. The results of analysis obtained both from the Markov Chain model and Reddy indicated higher probabilities of dry spell occurrences during the shorter season (Belg) but the occurrences of the same in the main rainy season (Kiremt) was very minimal. Like wise, the SPI model detected some drought events ranging from mild to severe classes in both seasons based on one and three-month time scale analysis.

1. INTRODUCTION

Rain fed agriculture, on which the Ethiopian economy rests, has been the dominant sources of food production. Recent studies reported that this sector is still contributing more than 50% to GDP and about 60% to foreign exchange earnings and provides livelihood to more than 85% of the population (Goodswill etal., 2007). However, yields from rainfed agriculture are often very low.

Some studies conducted in sub-Saharan Africa indicated that there is a potential opportunities for increasing crop yields in the region. An assessment made by Baron (2004) showed that the cereal crop yields could reach as high as 3.5 t ha-1 against the existing yield 1 t ha-1 yield estimated by Rockstrom (2003). This wide gap suggests that there is an enormous opportunity to raise crop yield from rainfed agriculture. This is entirely linked to focusing attention on maximizing yield per unit of water. However, the agricultural economy is highly fragile due to repeated failure of crop yield associated with irregularity in onset, temporal and spatial distribution of rain in most parts of the region during the growing season. According to Meinke (2003), rainfall water potential assessment work determined through possible estimation of rainfall onset date, end date, duration and seasonal totals and dry spell length, which together make up the overall rain feature, can provide deep insight into the rainfall variability and into the field management options through proactive responses.

In line with this, few studies have been conducted in Ethiopia mainly focusing on rainfall potential assessment based on the analysis of growing periods. Some researchers tried to inventorize the agro-climatic resources of Ethiopia for land use planning. However, certain limitations have been observed in the model they used in that it assumes an optimal matching between the length of the climatic growing period and the crop growth cycle to the extent that they are often used interchangeably (Mersha, 2005).

However, the main limitations of these works are also that they used aggregated climatic data that do not enable assessment of dry spells on crop yields and the model did not also account for the conserved soil moisture in determining the growing period (Mersha, 2000). Moreover, one month time step was used in the analysis of the growing period, which is so long for the proper characterization of the moisture status and planning of agricultural operations in the growing season. Besides, little efforts were made, if any, in characterization, quantification and assessment of climatic resources such as dry-wet spell and drought events on a watershed scale for decision making purposes. Recently many more researchers are becoming interested in the analysis of the dry-wet spell lengths using the Markov Chains model (Reddy etal., 2008). McKee et al. (1993) also developed the Standardized Precipitation Index (SPI) for the purpose of defining and monitoring drought. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location in the world that has a precipitation cord.

Therefore, if the rain fed-based farming is to be productive, detailed rainfall resources assessment and quantifications should be undertaken at the farm level and/or at watershed scale.

This study was, therefore, aimed at assessing the rainfall water potential in the central highlands of Ethiopia, ‘Yerere' watershed, with the following specific objectives:

- to determine the onset and end of growing periods in Belg and Kiremt seasons in the watershed, assess their probability of occurrences and asses the variability of growing period over years,
- to analyze the distribution of dry and wet spells during the two seasons and quantify the drought magnitude and intensity in the watershed

2. METHODOLGY AND DATA ANNALYSIS

2.1 Location

The study was conducted in “Yerer” watershed, 40 km south east of Addis Ababa, Ethiopia. The watershed is situated between 38051’43.63” to 39004’58”E and 8046’16.20” to 8059’16.38”N, in the Western margin of the great East African Rift Valley. The area of the watershed is estimated to be 12, 074 Km with an altitude range of 1910-2600 meters above sea level having rugged topography and a mountain at its peak. But as there is only one meteorological station around the watershed the data taken for analysis and results are only made to represent the down stream part of the watershed with a range of altitude 1930-2000 meters above sea level. This can fairly be represented by the meteorological data taken from an altitude of 1950 meters above seal level (Merhsa, 200, 2003, and 2005)

2.2. Data summary

Meteorological data of more than thirty years record has been obtained from the nearby station located at eight kilometers from the center of the watershed. Decadal (ten days) rainfall amounts were computed from the daily data set of 33 years (1975-2007) using standard meteorological decades. The standard or meteorological dekades (SMDs) were constructed in such a way that each month of a given year was divided in to three dekades and subsequently the first two ten days were considered as the first and second dekade for each month, respectively. The rest of days in each month again summed up to form the last or third dekade (Messay, 2006). The monthly ETo data retrieved from the

CropWat model was adjusted to daily values and again re-adjusted to the dekadal values for the appropriate analysis.

2.3. Determination of beginning and end of the growing seasons and length of growing period

The beginning or the start of the rainy season both for Kiremt(the main growing season and Belg(the shortest) was identified based on FAO (1978) simple soil water balance model which suggested that a growing period starts when a dekadal rainfall amount is equal to or greater than the corresponding reference evapotrainspiration(ETo). Accordingly the end of the rainy seasons was set when the dekadal rainfall of amount during the end of season is again less than the corresponding values of the reference evapotranspiration. Finally, the length of the growing period (LGP) was defined by counting the number of days between the start and the end of the growing period plus the period required to evapotranspire the 100 mm moisture stored in the soil reserve during the rainy season.

2.4. Dry-wet spell and drought analysis

2.4.1. *Dry and wet spell analysis*

Reddy (1990) has already stated that a 3 mm rainfall depth per day is the minimum threshold valued for crops to satisfy their crop water requirement. Accordingly, in this study, a 30 mm per dekad of precipitation depth was taken as a threshold value for evaluating whether a dekade is in a dry or wet spell. A dekade with a depth of precipitation below this value was considered as dry and vice-versa for a dekade with precipitation value of above the threshold level and a Markov chain model was used to explain the dry-wet spell during the two rainy seasons.

2.4.2. *Standardized precipitation index*

The time series of monthly rainfall data of 33 years (1975-2007) was made to fit the gamma distribution function to define the relationship of probability to precipitation. Once the relationship of probability to precipitation is established from the historic records, the probability of any observed precipitation data point is calculated and used along with an estimate of the inverse normal to calculate the precipitation deviation for a normally distributed probability density with a mean of zero and standard deviation of unity and this value is the SPI for the particular precipitation data point (Drought Net work news, 1999). The same time step (decadal) can not be used to obtain SPI values in this study as there has not been any practice of similar case so far in the world.

3. RESULTS AND DISCUSIONS

3.1. Onset, end and length of the growing period

The FAO (1978) simple soil water balance model based on the mean statistical analysis of the 29 years data revealed that the main rainy season (Kiremt) starts during the second meteorological decade of June (decade 17/ second dekade of June) and the rainy season ends during the last decade of September ,decade 27 (Table 1). The mean starting decade of the main growing season, Kiremt, had low standard deviation amounting to 6 days (Table 1) and hence the onset date of the season is promisingly stable (Reddy, 1990). The lower standard deviation of the onset date of the season implies that patterns could be easily understood and consequently decisions pertaining to crop planting and related activities could be made more easily and with less risk.

The summarized statistics of occurrences of the onsets of the growing periods in the main seasons in different dekades and the general characteristics of the identified growing period is presented in the figure 2.

Table 1: Summary of the onset date of the main growing season

	Mean onset decade No	SD (in decade)	CV (%)	Frequency (%)	Stability of the onset
	17	0.62	3.6	58.6	Very high

Table 2: Characteristics of the Kiremt growing period in the watershed

Characteristic	Decade no
Earliest onset	16
Mean onset	17
Delayed onset	18
Earliest recession of the rainy season	26
Mean recession of the rainy season	27
Delayed recession of the rainy season	28

The length of growing period (LGP) in the main rainy season in the watershed ranges from 112 to 144 days with a mean of 129 days and with CV and SD of 7.5% and 9.6 days, respectively (Figure 1.).The period includes the duration of the time that 100mm of soil moisture reserve has already been evapotranspired after the end of the rainy season (FAO, 1978 and Mersha, 2005). The deviation magnitude of the LGP obtained in the watershed could not be regarded as high because the length of growing period even with minimum length is fairly enough to support the cereal crops (Teff and Wheat) which are commonly grown in the areas of the watershed that require not far more than 100 days of growing period to their maturity.

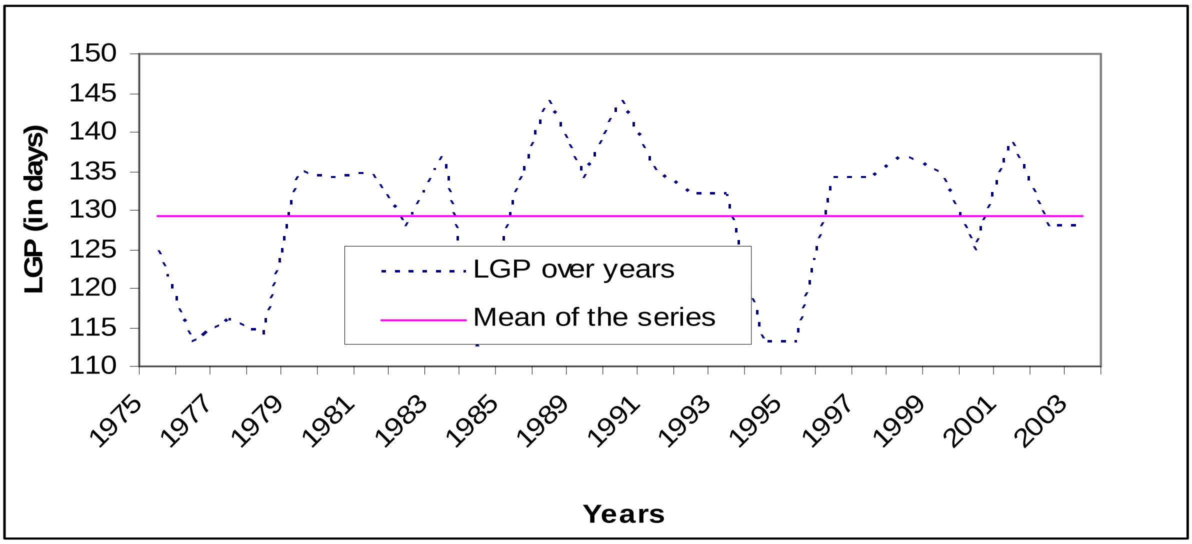

Figure 1: Length of the growing season in the watershed across years (Mean 129 SD 6.2 CV 7.5%)

Like wise, the occurrence of the Belg growing season as a whole is less frequent. The mean onset decade of this particular season (decade no 9) had a standard deviation of 1.5 dekades i.e., 15 days on average (Table 3).

Table 3: The occurrence distribution of the onset of belg season

Dekade No	**7**	**8**	**9**	**10**	**11**	**12**	**With no occurrence of Belg**	
Number of occurrences	5	3	6	2	2	1	10	
Percentage of occurrences	15.15	9.09	18.18	6.06	6.06	3.03	30.30	

This implies that the available rainfall in most of the years is not sufficient to satisfy the water requirement of an ideal crop. Reddy (1990) reported that crop physiology is severely affected when the moisture amount is critically less than that half of the potential evapotranspiration of a given crop growing area. Therefore, one can infer that rainfall availability is the limiting factor for crop production in this particular area during Belg season.

3.2. Dry and Wet Spell analysis and drought assessment

The probability of a decade being wet in the Kiremt was found to be greater than 40% throughout the meteorological dekades with the exception of decade number 16 and 17, which gave a corresponding probability, value of 21% each (Table 4). The probability of getting a wet decade after wet in the study watershed during the main rainy season was also found to be in the range of 14 – 100% with most of the meteorological dekades skewed to the maximum. In general, the Kiremt season is having well above the threshold limit for most of the years during the study period. Therefore, crop harvesting during the same season is less likely affected by moisture stress.

Table 4: Dry/wet spell probability distribution through the kiremt (Main) rainy seasons (1975-2007)

Decade No	**Pw**	**PD**	**Pww**	**PDD**	**PWD**	**PDW**
16	21	79	14	92	8	86
17	21	79	57	88	12	43
18	42	58	29	89	11	71
19	64	36	52	75	25	48
20	88	12	69	25	75	31
21	88	12	66	0	100	34
22	91	9	87	0	100	13
23	94	6	90	0	100	10
24	94	6	100	0	100	0
25	88	12	100	0	100	0
26	61	39	90	8	92	10
27	52	48	53	56	44	47

Where: PD is the probability of a dekade being dry.
FD is the number of dry decades.
PW is the probability of a dekade being wet.
FW is the number of wet decades.
PWW is the probability of wet dekade followed by another wet dekade .
FWW is he number of wet dekades followed by other wet decades.
PDD is the probability of a dry decade followed by another dry one.
FDD is the number of dry decade followed by another dry one.
PWD is the probability of a wet decade followed by another dry dekade
PDW is the probability of a dry decade followed by a wet one.

But the probability of getting a wet decade during this season was found to be in the range of 15 to 30 % (Table 14) throughout the meteorological decade. The same table also showed that high probability of occurrence of dry spells was observed in the season throughout the meteorological dekades (greater than 70% in all dekades), as expected. Consequently, one can infer from these figures that the particular season is getting below the threshold minimum requirement of rainfall and hence planting during Belg season is less likely.

Based on a one month time scale of SPI analysis, no extreme drought events were detected in the months of the main growing season (Tables 5). But two sever drought events were experienced each in June and August while one was observed in July. Overall, the watershed experienced more occurrences of drought events with equal magnitude in August and September (17) followed by July (13) and the least was in June, amounting 12.

Table 5: Frequency of occurrences of drought events during Kiremt

		Months		
Drought Category	**June**	**July**	**August**	**September**
Extremely dry	0	0	0	0
Severely dry	2	1	2	0
Moderately dry	3	4	3	5
Mildly dry	7	8	12	12
Total	12	13	17	17

Results of this analysis indicated that there was only one extreme drought event (in March, 1998) during the short rainy season (Belg) based on one-month time scale. Three dry events were recorded each for March and May and two were in April. Mild drought events were experienced in about 23% of all months of March and April during the 30 years of record. Maximum mild drought events of 26.7% were experienced in the month of May. . In general drought events are uncommon during the months of this particular season. Drought events ranging from mild to extreme and or severe categories (SPI < 0) were experienced in about 43.3% of the months of March and April while the same category of drought events were detected in about 46.7 % of the months of May (Table 6).

Table 6: Frequency of drought severity during the Belg growing season

	Months		
Drought class	**March**	**April**	**May**
Extremely dry	1	0	0
Severely dry	3	2	3
Moderately dry	2	4	3
Mild	7	7	8
Total	13	13	14

4. CONCLUSION

It can be noted from this study that planning of agricultural activities is fairly simple and involves less risks in and around the study area during the main rainy season because of the stability of the onset dates of the main rainy season. However, it was found that the variability of length of growing period in Belg (the shorter rainy season) season is extremely high (CV = 121%) implying difficulties associated with its prediction and frequent occurrences of dry spells and drought events. In general the shorter rainy season, Belg is liable to drought and its impacts. Hence crop production during this particular period needs a due attention and monitoring of planted crops. In general a kind of analysis work is extremely helpful for decision making in agricultural operation and related activities especially at a watershed scale. Therefore this work needs to be promoted in a similar fashion across the country.

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ASSESSING VICTORIA'S COASTAL VULNERABILITY

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ABSTRACT

The Victorian Government's Future Coasts Program will advance the management of, and planning for, the impacts of climate change on the Victorian coastline by providing data and information to improve decision-making processes.

Future Coasts is working to better understand the physical vulnerability of the entire Victorian coastline through the investment of $13.5 million in the capture of bathymetric and topographic elevation modelling and the modelling of coastal processes such as extreme sea levels. These data sets have been amalgamated with coastal landform and geomorphology data to provide an indicative, state-wide assessment of the sensitivity of the Victorian coastline over a range of sea-level rise scenarios and timeframes. This assessment will be available to coastal land managers and decision-makers. The state-wide assessment will assist in the selection of high risk locations where Future Coasts, in collaboration with local government and project partners, will undertake detailed, site-specific vulnerability assessments.

In addition to assessing physical vulnerability, Future Coasts also acts as a platform on which the complex social issues associated with adaptation along the coast can be explored and discussed. To this end, Future Coasts has conducted a series of workshops along the coastline which have contributed to the development of a Coastal Climate Change Impacts and Responses Paper to enable coastal communities to contemplate the challenges, opportunities and potential responses. The submissions received in response to the Paper will then be used to inform the Victorian Government's long-term adaptation responses.

Future Coasts is working to develop guidance material for the improved and consistent consideration of coastal hazards, such as coastal erosion and flooding, in decision-making processes through standard approaches to vulnerability and risk assessment. The guidance material will provide a framework to ensure that sea-level rise is factored in to land-use planning and land management decisions.

Managing and planning for the effects of climate change on the coast requires a coordinated response from all levels and arms of government and partnerships with industry and communities. Future Coasts will continue to work closely with its project partners to produce information and guidance to allow decision-makers make well informed decisions.

1. INTRODUCTION

In Victoria, Australia, climate change is projected to result in sea level rise and changes to storm frequency and intensity. The effects of climate change on the coast will be exacerbated by existing pressures associated with population growth and increasing levels of tourism in coastal areas which are already placing pressure on Victoria's coastline.

Coastal land managers and decision-makers along the coast must continue to make decisions amid a level of uncertainty and whilst the information base is continually being updated. Due to the life expectancy of structures such as roads and public facilities, land-use planning decisions which are made now will have long-term implications.

2. VICTORIA'S FUTURE COASTS PROGRAM

The Future Coasts Program is a major investment by the Victorian Government to help Victorians better understand and plan for the risks associated with sea level rise and extreme storm events on the coast resulting from changing climate conditions.

Future Coasts will produce data and information products, including an assessment of the Victorian coast's physical vulnerability to impacts from rising seas and extreme storm events. This is complemented by policy recommendations and the development of tools to assist decision-makers incorporate data and information about sea level rise when making decisions about coastal land use and management.

Future Coasts delivers on the Victorian Coastal Strategy (VCS), 2008. The VCS requires that planning account for a sea level rise of not less that 0.8m by 2100, which corresponds to the upper limit of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report projections on sea level rise. The VCS also notes that, as new scientific data becomes available, the policy will be reviewed.

The work of Future Coasts complements other Victorian Government initiatives in relation to addressing the impacts of climate change on the coast, including the Victorian Coastal Climate Change Advisory Committee (VCCCAC). The VCCCAC was established to advise the Victorian Minister for Planning on how Victoria's land-use planning and development controls can best support the management of coastal climate change impacts.

The VCCCAC and Future Coasts are part of the broader Victorian Government response to address climate change, which includes the development of a Climate Change White Paper, Climate Change Legislative Bill and the Victorian Land and Biodiversity White Paper.

3. VICTORIAN COASTAL VULNERABILITY ASSESSMENT

The Future Coasts Program is a major investment by the Victorian Government to help Victorians better understand and plan for the risks associated with sea level rise and other climate-induced coastal hazards. The program will produce data and information products, including an assessment of the Victorian coast's physical vulnerability to impacts from rising seas and extreme storm events.

Figure 1 conceptually illustrates the nature of coastal vulnerability information and tools, which can be applied in different circumstances.

The Future Coasts high resolution DEM provides an accurate base layer for modelling the potential impacts. The coastal landform and geomorphology classification was developed as part of the national first pass coastal vulnerability assessment, to generate the Smartline[1]. The Smartline is a geographic information system (GIS) tool that provides data on multiple attributes of different coastal

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[1] GeoScience Australia, OzCoasts: Australian On line Coastal Information, Canberra, Australia http://www.ozcoasts.org.au/

landform types and has been used as an input into both the national first pass coastal vulnerability assessment, and Victoria's second pass coastal vulnerability assessment.

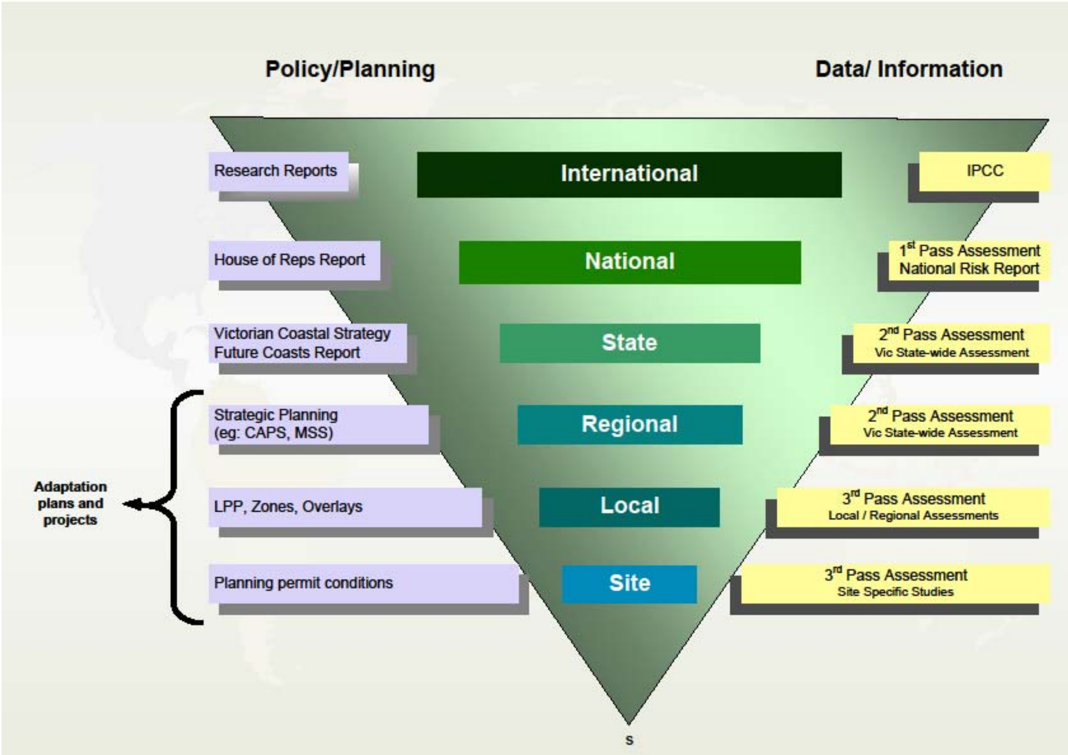

Figure 1: A conceptual diagram of the 3-pass assessment approach, applied as part of the Future Coasts Program

Figure 2 outlines the components of the Victorian second pass coastal vulnerability assessment. This state-wide assessment provides data and information on the physical vulnerability of Victoria's coast to inundation and coastal instability due to sea level rise and extreme storm events. The state-wide assessment is a second pass assessment, which will then guide the selection of local or regional areas that required more localised third pass assessments (or coastal hazard assessments). These third pass assessments may occur at the municipal or settlement scale, or at a scale that is defined by dominant coastal processes and hazards (for example, beach or bay scale).

The sea level rise scenarios and the storm tide modelling used in Victoria's second pass coastal vulnerability assessment were undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). In this study a hydrodynamic model was used to estimate the storm tide heights for the entire Victorian coast under a range of climate change scenarios over different timeframes. For more information on the results of the study please refer to the report by McInnes et al. (2009), "The Effect of Climate Change on Extreme Sea Levels along Victoria's Coast."

Victoria's second pass coastal vulnerability assessment is a strategic tool used to identify areas of coast potentially at risk and to prioritise areas for further investment and more detailed, location-based assessments. As suggested by Sharples et al. (2008), it is appropriate that the second pass coastal vulnerability assessment for Victoria is developed by the Victorian Government so as to ensure methodologies are consistent products are accessible.

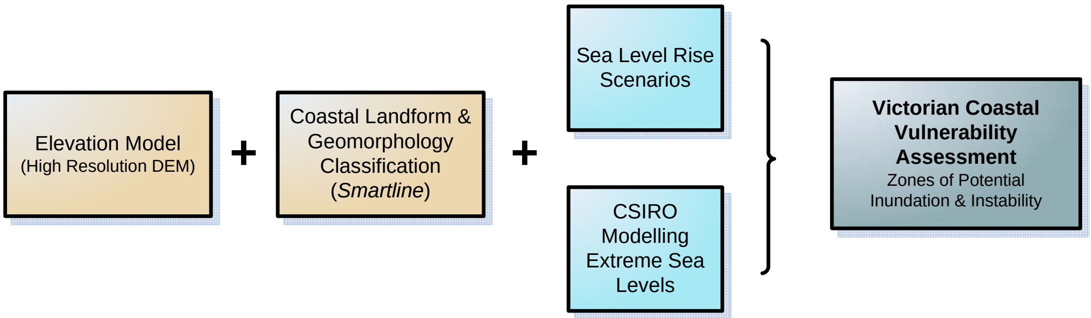

Figure 2: Components of the Victoria's 'Second Pass' Coastal Vulnerability Assessment

It is not appropriate that the second pass coastal vulnerability assessment be used as a location-based assessment. A more refined, site-specific level of vulnerability assessment, known as a third pass assessment (Sharples et al. 2008) is necessary. This will take into account site-specific factors such as geology, coastal planform, bathymetry and wave dynamics, tidal influences, river mouths, local sediment transport regime, existing hazard mitigation structures (e.g. sea walls, levies), hydrology and inundation connectivity. Doing so will provide a sound basis for decisions regarding necessary mitigation works, evaluation of adaptation responses and defensible land-use planning decisions.

In preparation for the next phase in the program, Future Coasts is forming partnerships with Local Government to undertake third pass local vulnerability assessments for a number of locations along the Victorian coastline. These local partnership projects will provide a basis to pilot methodologies and to learn as the work progresses. With this process, Future Coasts intends to employ an adaptive management approach.

4. PORT FAIRY: A CASE STUDY

Port Fairy, on Victoria's west coast is one of a number of locations along the Victorian coastline that are sensitive to coastal hazards, which will be exacerbated by sea level rise and extreme storm events.

The inundation extents for Port Fairy have been mapped using the second pass coastal vulnerability assessment for Victoria and shown in Figure 3. In this figure the blue area shows the current 1 in 100 year storm tide inundation extent against the levels projected for 2030, 2070 and 2100.

Port Fairy's is a culturally and economically important coastal township that supports a vibrant and regionally significant tourism industry and a working commercial port. Port Fairy's population of approximately 3000 has remained steady due to an increase in tourist visits, holiday homes and people seeking a rural/coastal lifestyle.

Port Fairy is located around the mouth and floodplain of the Moyne River. The town is historically sensitive to inundation from the Moyne River catchment, the coast, and erosive coastal processes. Port Fairy has experienced major flood events in 1870, 1894 and most notably in March 1946 when approximately 200mm of rain was recorded over three days (Bishop and Womersley, 2009). This flood event, associated with an 'East Coast Low', caused significant flood damage and social disruption.

Low lying coastal fringes to the west of Port Fairy town centre are also at risk of inundation from the open coast, independent to estuarine processes. In May 2009, south-eastern Australia was subjected to the combined effects of a low-pressure system, combined with a high-tide, causing a storm tide event which temporarily inundated private land, lifted rocks onto roads and generated localised erosion of sand dune systems.

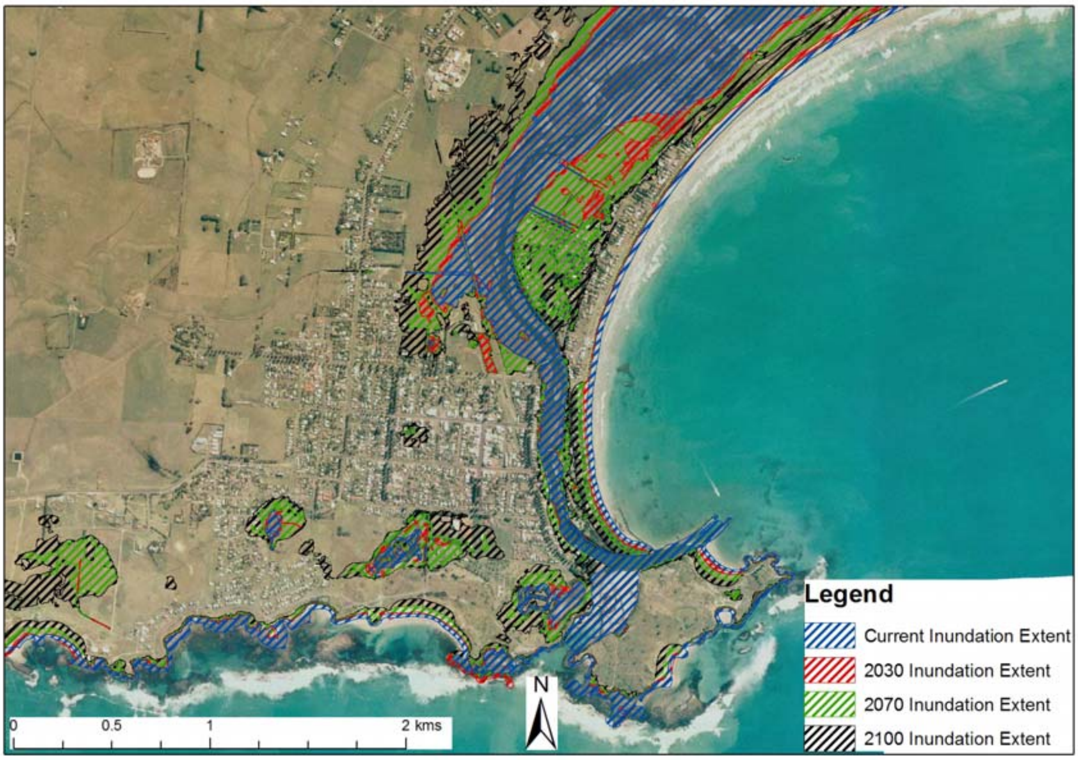

Figure 3: Inundation Extent in Port Fairy. The inundation extent is based on modelling of storm tides using IPCC's high emissions scenario (A1F1 scenario) and projected increases in wind speed.

Figure 4: Images Showing Storm Tide Event, Port Fairy, May 2009

Port Fairy's coastline is part of a high energy and dynamic coastal system that is subject to natural coastal processes and sand movement. Significant engineering works, associated with the protection of the Port of Port Fairy during the last 150 years has significantly altered the natural coastline and sediment transport. WBM Oceanics concluded that the natural easterly longshore flow of sediment is altered by works at the port entrance, and as a consequence the East Beach dune system, immediately to the east of the port, is gradually receding (WBM, 1996).

East Beach is highly-valued by the community for its recreational opportunities. The fore dune also supports a large amount of public reserve, existing private and public (surf life saving club) development, a golf course and a former council land fill. The existing residential development, is protected by an ineffective rock wall which is now structurally inadequate and generally unstable.

The dune system at East Beach is strategically important as it acts as a natural barrier between the ocean and the Moyne River floodplain which abuts the landward face of the dune system. At certain points, the fore dune is structurally compromised, presenting a potential for the ocean to breakthrough to the floodplain and, given the right circumstances, create a new coastline.

A third pass local vulnerability assessment is required at Port Fairy to ensure that suitable long-term response options to managing the risks are developed. The assessment should acknowledge all sources of risk relating to Port Fairy and its community from inundation and erosion, under various climate change scenarios and over a series of planning horizons.

Some of this work has already been completed. The Port Fairy Regional Flood Study undertaken by the Glenelg-Hopkins Catchment Management Authority in 2008 quantified the flood risk to Port Fairy and surrounds and included an assessment of flood risk due to climate change. The Study mapped flood risk under three climate change scenarios, allowing for a component of sea level rise, storm surge and increased rainfall (Bishop and Womersley, 2009).

The challenge before us is to integrate the existing robust modelling stemming from the Regional Flood Study with coastal erosion modelling still to be undertaken. To consider appropriate risk management responses and build adaptive capacity a risk assessment approach should be adopted. Such an approach will also provide for consistency over a selection of climate change scenarios and planning horizons. As in any third pass assessment, the degree of uncertainty associated with the assessment of each coastal hazard should be explained.

5. CONCLUSION

To achieve its objectives the Future Coasts Program relies on strong partnerships and integration across all levels of government, industry and community. These linkages will become increasingly relevant as the Future Coasts progresses to understanding risk and vulnerability at the local scale, such as at settlements like Port Fairy. It is at this point the data and information being produced by Future Coasts will be instrumental in building local capacity by informing risk management and adaptation response planning.

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CLIMATE CHANGE AND MANAGEMENT OF COASTAL LAGOONS IN THE WESTLAND REGION, NEW ZEALAND

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ABSTRACT

Coastal lagoons are dynamic and diverse systems, which respond rapidly to sea-level, tectonic, meteorological, anthropogenic and other synergistic drivers. The impact of climate change on coastal environments is a function of the balance and interaction between changes in sea level, wave energy, river flow and sediment supply. The Westland region experiences a high energy wave climate and high precipitation levels, and climate change has been predicted to result in increased storminess in the area. This paper examines the potential impact of climate change on two choked coastal lagoons (Totara Lagoon and the Shearer Swamp-Waikoriri Lagoon complex) in Westland, New Zealand and investigates the potential changes in these systems under different dominant forcing factors and management regimes. This is achieved by documenting their current geomorphology and recent outlet migration, in order to predict how these lagoons may change in the future under varying sea level, catchment dynamics, and management regimes. Geographical Navigation Satellite Systems (GNSS) surveys and GIS analysis using ArcGIS software were used to map the current features and elevation of representative sections of each study site, producing a baseline for predictions of future morphodynamic change. Analysis of aerial photographs from 1948 to present shows changes in the position of the lagoon openings over time, of up to 2500 m in the case of Waikoriri Lagoon, and up to 5800 m for Totara Lagoon. These systems have been artificially managed at times. Dramatic changes in land-use and management in the areas surrounding these sites and their catchment zones have occurred over the past 150 years, resulting in changes in the hydrology and sediment supply to the systems. Coastal erosion is already causing problems in the Westland region including loss of land and infrastructure. Sea level rise associated with climate change would exacerbate this problem, and in the case of these lagoons, would likely result in barrier rollback and lagoon system migration if natural processes prevail. If management strategies attempt to halt such natural processes to preserve farmland behind, then loss of the lagoons or significant changes in morphology are likely to result. However, if increased storminess was to lead to an increase in fluvial input and sediment supply, this may offset the erosional effect of sea level rise. These findings are applicable to other dynamic lagoon and estuarine environments in a management context, especially as concerns of climate change grow.

1. INTRODUCTION

Coastal river mouth lagoons and wetlands are dynamic, active environments that exhibit rapid changes in response to sea-level, tectonic, meteorological and anthropogenic drivers (Cooper, 1994; Woodroffe, 2003). These drivers interact in a complex network of feedback loops, making it difficult to predict the magnitude and direction of changes that may occur in response. This is particularly apparent in Westland, New Zealand, where the coastal environment is characterised by a high energy coastal marine boundary, frequent intense weather patterns, and high sediment loads derived from the nearby Southern Alps (Neale *et al.*, 2007). Climate change has been predicted to exacerbate these intense meteorological and marine conditions in the Westland Region (MfE, 2008a). This paper reports findings of an investigation into the current topography and decadal-scale dynamics of two Westland coastal rivermouth systems: Totara Lagoon and the Shearer Swamp-Waikoriri Lagoon Complex, and predicts their future under differing climate and management scenarios.

The type of system existing at a given river mouth is a result of the relative strengths and interactions between fluvial and marine processes. Deltas form in fluvially dominated systems, whereas estuaries form in tidally dominated settings (Carter and Woodroffe, 1994; Hart, *et al.*, 2008). Coastal lagoons frequently form on wave-dominated coasts with a microtidal marine regime, and are most often classified according to the degree of water exchange between the lagoon and the ocean (Cooper, 1994; Kjerfve, 1994). The systems studied here are classified as 'choked' lagoons, as they generally possess a single, semi-stable outlet and experience only a limited exchange of water with the ocean.

Similar systems to Totara and Waikoriri Lagoons have been studied extensively on the East Coast of New Zealand, where they are referred to by the Maori name 'hapua' (Kirk, 1991). These lagoons possess a long, narrow, shore-parallel waterbody, which is separated from the ocean by a narrow barrier that forms as a result of strong longshore drift (Kirk and Lauder, 2000). This barrier growth leads to offsetting of the river mouth; a cyclic process which occurs repeatedly throughout the life of the lagoon (Todd, 1992). Flood events may lead to breaching of the barrier opposite the river mouth, bypassing the lagoon, until longshore drift once again offsets the outlet (Kirk, 1991; Todd, 1992).

In comparison to other regions in New Zealand, very little coastal process and management research has been undertaken in Westland (Hesp *et al.*, 1999; Kench *et al.*, 2008), and consequently the coastal history and processes of the region are not currently understood to the level required for effective coastal management decisions and strategies.

2. STUDY AREA

The physical environment and climate of the West Coast region is heavily influenced by the location and orientation of the New Zealand landmass (Sturman, 2001). The coastline extends 600 km, is aligned northeast to southwest, and is situated at approximately 45° latitude. As a result, the coastline is exposed to the predominant westerly weather systems of the 'Roaring Forties' and experiences very high energy wave action (Salinger, 1980). Waves primarily approach sub-parallel to the coast due to the northeast-southwest orientation of the coastline, and their energy is further enhanced by the close proximity of the continental shelf to the coastline (Stanton, 1980). Littoral drift is predominantly in a northward direction, and the oceanic environment of the region is heavily influenced by the convergence of sub-tropical waters with the colder waters of the sub-Antarctic, which occurs at this latitude.

The climate of the Westland region is temperate and mild, and experiences extremely high levels of precipitation. This averages 2500 mm yr^{-1} on the coastal plain, reaching over 12 000 mm yr^{-1} in the Southern Alps (Moar and McKellar, 2001). The frequency and intensity of precipitation events combined with the steepness and geology of the mountains results in high levels of erosion and sediment transport to the coast. The distance between the mountains and the coast is very short and consequently, so are sediment transport and river response times, with floods arriving at the coast within four hours of precipitation in the upper catchment. These conditions are expected to intensify over the next century in response to climate change (MfE, 2008a).

Totara Lagoon and the Shearer Swamp-Waikoriri Lagoon Complex share the same coastal plain, and were chosen due to their proximity to each other, value as a natural resource, and low levels of constraint by hard-engineering. Mean fluvial inputs are small to moderate in both systems, with base flows of less than 50 $m^3 s^{-1}$.

Totara Lagoon is a large and relatively stable lagoon system (Table 1)(Figure 1) and is fed predominantly by the Totara River, although a number of smaller creeks enter the lagoon north of the lagoon-river confluence. The waterbody is long and narrow, and significant northward outlet offset has occurred at times. Under the current outlet configuration the lagoon experiences a significant degree of tidal influence, which extends several kilometres up the channel. A narrow, sandy barrier beach separates the lagoon from the sea, along the length of which evidence of dune blowouts and wave overtopping is visible.

The Shearer Swamp-Waikoriri Lagoon Complex is a large composite freshwater wetland-lagoon system which occupies 140 ha south of the Ross township (Figure 1). The wetland is bounded by well several small streams flowing into two main creeks; Granite Creek and Waikoriri Creek, which come together at the southwest corner of Shearer Swamp and are joined by a third major stream (Black Creek), before discharging to the sea via Waikoriri Lagoon. This lagoon waterbody is significantly smaller than Totara Lagoon (Table 1) and occupies a swale behind the beach and the foredune. A series of low-lying relic dune ridges separate the lagoon from the western edge of Shearer Swamp. Waikoriri Lagoon is very dynamic, exhibiting frequent outlet migration and dramatic variation in waterbody extent. This variability is a result of both natural processes, such as storm and flood events, and anthropogenic influences, including catchment modification and artificial outlet breaching.

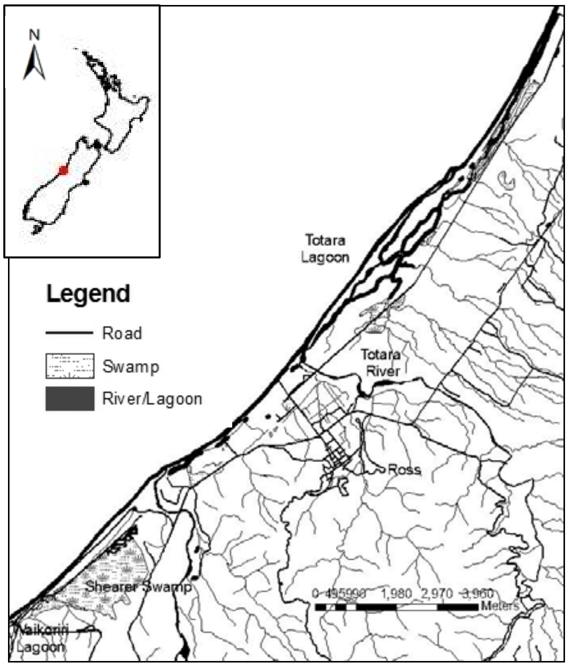

Figure 1. Location map showing Totara Lagoon and the Shearer Swamp-Waikoriri Lagoon Complex, Westland, New Zealand.

Table 1. Boundary descriptions of Totara and Waikoriri Lagoons

	Surface area (ha)	**Current extent (km)**	**Maximum extent (km)**	**Current discharge point**
Totara Lagoon	100	10	10	Rivermouth
Waikoriri Lagoon	6	0 (water absent)	4	Rivermouth

3. METHODS

Four site visits were undertaken from September 2008 to March 2009 at intervals of two weeks to three months. Fieldwork included visual observations and photographs of outlet position and structure in addition to detailed topographic surveying and hydrological records.

Representative sections of the sites' topography was surveyed using a Trimble R8 Geographical Navigational Satellite System (GNSS), which was used in tracking mode and recorded position and elevation at 5 s intervals. Surveyed areas included the Totara Lagoon mouth, central and northern reaches, the entire Waikoriri Lagoon area, and sample elevation points west to east across Shearer Swamp. Transects were taken across the lagoon channel and adjacent dunes at several locations within each site. From this data digital elevation models (DEMs) of each surveyed area were created using the ESRI *ArcGIS* software programme. From these DEMs, cross-sectional profiles were created spanning the channel and adjacent areas.

Outlet dynamics on a decadal scale were investigated through analysis of aerial photographs, taken in the following years: 1948, 1963, 1972, 1976, 1981, 1986, 2002, 2005 and 2006. Images were in digital format, and were georeferenced and orthorectified using *ENVI* software. For Totara Lagoon, this was performed using control points from orthorectified images produced by Land Information New Zealand (LINZ). Waikoriri Lagoon images were referenced to a GIS file of roads in the area, sourced from the NZ 1:50 000 topographic survey, which introduced a degree of inaccuracy. Images from each site were then compared visually for changes in structure and vegetation patterns, and quantitative spatial analysis of temporal changes was performed using *ENVI* and *ArcGIS*. Digitisations of Totara and Waikoriri Lagoons were created for each survey period, which mapped channel configuration and from which outlet offset was measured and rates of outlet migration calculated for periods where photographs were available at 5 year intervals. Due to its dynamic nature, this was not possible for Waikoriri Lagoon.

4. RESULTS

4.1. Existing topography and structure

The geomorphology of Totara Lagoon varies considerably between the northern and southern ends of the system. In the south, dunes are sparsely vegetated, low and rounded with crest heights of between 6 and 7.5 m above sea level (ASL), becoming steeper and progressively more vegetated towards the north. Crest heights in the north are between 10 and 13 m ASL (Figure 2). The channel is bounded by an equally high dune ridge to the landward side at the northern end.

The lagoon channel also changes substantially northwards along its 10 km length. It is wide, shallow and well flushed in the south, becoming narrower, muddier and deeper in the north. The southernmost 2 km is a single channel, beyond which the lagoon bifurcates, with islands of established vegetation separating two large channels. The northern third of the lagoon returns to a single channel, which is narrow and choked by rushes growing across the channel at several points. This limits water and sediment exchange within the water column, causing it to stagnate.

Waikoriri Lagoon is much smaller than Totara Lagoon, and exhibits much less variation along the channel. The lagoon channel is located between two series of dunes, which are low and rounded on the seaward side and essentially free of vegetation (Figure 2). The landward margin of the lagoon consists of a series of shore-parallel Holocene dune ridges, which are well vegetated and extend 200 m inland to the edge of Shearer Swamp.

4.2. Outlet dynamics and channel configuration

4.2.1. *Short-term dynamics*

The configuration and extent of Totara Lagoon changed little over the study period. Significant changes were observed solely around the Totara River-Lagoon confluence and opening to the sea. The lagoon opening remained at the southern (rivermouth) extremity for the duration of the observation period. Over the months of September to December 2008, the outlet was very open to oceanic influence, experiencing significant tidal inflows. Minor sediment redistribution occurred in this area in response to a large sea storm and river flood event. By March 2009 a sediment wedge had accreted at the Totara River mouth and the outlet channel had become narrower and oriented at a northward-trending diagonal through the barrier. This did not inhibit the ability of the river to discharge at this point and was not sufficient to cause a complete migration of the outlet.

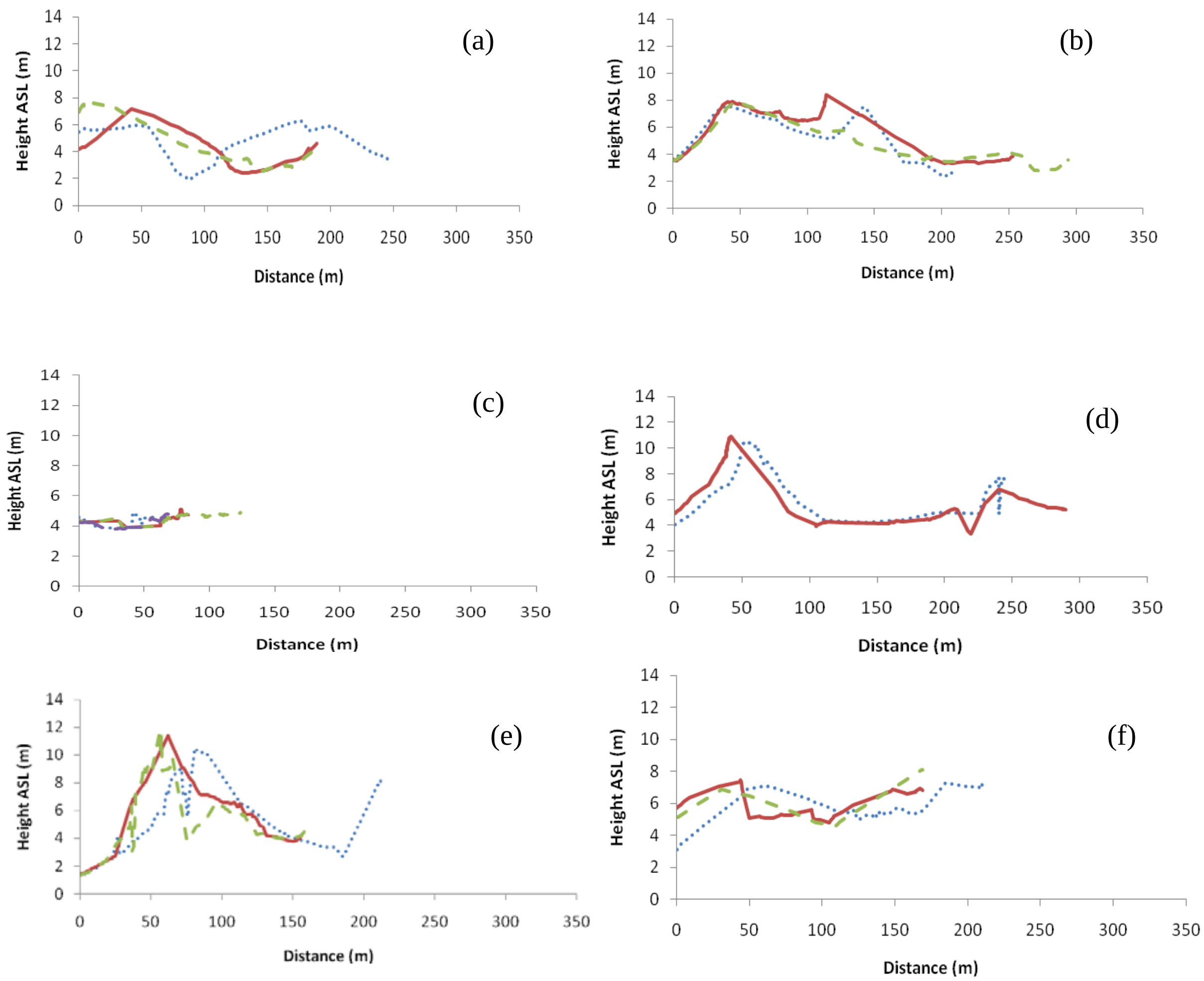

Figure 2. Representative cross-sectional dune profiles from the two field sites. (a) Totara River-Lagoon confluence, seaward dune ridge and channel. (b) 2 km north of river mouth, seaward and landward banks (c) 5 km north of river mouth, seaward and landward dune ridge, with water surface elevation between. (d) 8 km north of river mouth, seaward dune ridge. (e) Northern extremity of Totara Lagoon, 10.5 km from river mouth, seaward dune ridge.(f) Waikoriri Lagoon, including seaward dune ridge, across the channel, and landward dune ridge.

In contrast, Waikoriri Lagoon exhibited a large degree of variation over the six month observation period, which also affected the hydrology of Shearer Swamp. In September 2008 the lagoon outlet was situated 2.5 km north from the point where the feeder stream reaches the coast and the waterbody extended a further 1 km beyond the outlet position. Water levels in the wetland behind were high at this time. Several weeks later, the barrier was breached at the southern extremity of the lagoon (where the stream meets the coast), which caused the existing outlet to be abandoned and the lagoon to drain entirely. The cause of this breach was a combination of a storm induced flood event, and artificial destruction of the barrier using a digger. The effect on the wetland was of a significant decrease in water storage in the marginal creeks, causing significant impact to the wetland habitat.

In December 2008 this outlet configuration remained unchanged and the lagoon channel was still empty. However, by March 2009 a sediment wedge had accreted across the outlet, causing it to migrate 20 m northwards and become diagonally oriented through the barrier. Discharge through the outlet had become comparatively inhibited, leading to an increase in water levels in the creek and wetland behind. The capacity of the outlet to migrate up to 10 m per day (either north or south) was observed on several occasions.

4.2.2. *Decadal-scale dynamics*

The position of the Totara Lagoon outlet varied significantly over the entire survey period, fluctuating between 0 and 5800 m from the river mouth (Table 2, Figure 3). It remained within the first 5 km of the channel for the majority of the study period. It was common for the lagoon to discharge at its current location, which occurred in 1972, 2002 and 2005, and in 1948 the outlet was a mere 560 m north of this position. Net rates of northward (upstream) migration reduced with distance of outlet offset, decreasing from 575 m yr^{-1} between 1972 and 1976 (outlet offset = 2300 m) to 280 m yr^{-1} between 1981 and 1988 (outlet offset = 1950 m). The position of the lagoon's northern extremity did not change throughout the period photographed.

Basic channel structure remained constant throughout the photographed period, but the distribution of water within the channels varied significantly in the central reaches, depending on outlet position (Figure 3). Channels landward of the central islands were abandoned or experienced low flows in the following years: 1963, 1976, 1981 and 1988. These corresponded with outlet offsets of between 2500 and 5800 m. Periods of high water content and full channel occupation coincided with a river mouth outlet position. No change in structure or visible changes in surface area of the waterbody occurred in the northern third of the lagoon. Only minor changes in response to shifting sandbars were observed in the southern 2 km of the lagoon over these decades.

In Waikoriri Lagoon, the outlet position fluctuated from a river mouth position or close to it (1948, 1972, 1976, 1981 and 1988) and a maximum offset of 2500 m, reached in 2002 (Table 2, Figure 3). Between 1948 and 1972 the outlet varied between an offset of 120 m and 560 m, before increasing five times in length in the five year period of 1976 and 1981. Evidence for the retreat of the outlet down-channel was present in 1972 and 2006, where remnant water was still present in the abandoned channel north of the outlet. Outlet position in 1981, 1986 and 2006 is approximately the same. Beach width appears to vary throughout the photographed period, appearing greatest between 1963 and 1988, and decreasing in later images. A wedge of sediment accreting around the outlet position is clearly visible in many of the photographs.

Table 2. Offset of the lagoon outlets, measured north from the point at which the feeder river reaches the coast.

<table>
<tr><th colspan="4">Totara Lagoon</th><th colspan="3">Waikoriri Lagoon</th></tr>
<tr><th>Survey Date</th><th>Outlet offset (m)</th><th>Net Difference (m)</th><th>Net Rate (m yr⁻¹)</th><th>Survey Date</th><th>Outlet offset (m)</th><th>Net Difference (m)</th></tr>
<tr><td>Apr 1948</td><td>560</td><td>-</td><td>-</td><td>Apr 1949</td><td>325</td><td>-</td></tr>
<tr><td>Feb 1963</td><td>2590</td><td>+ 2030</td><td>-</td><td>Feb 1963</td><td>560</td><td>+235</td></tr>
<tr><td>Feb 1972</td><td>-125</td><td>-2710</td><td rowspan="4">+575
+335
+280</td><td>Feb 1972</td><td>120</td><td>-440</td></tr>
<tr><td>Oct 1976</td><td>2175</td><td>+2300</td><td>Oct 1976</td><td>205</td><td>+85</td></tr>
<tr><td>Oct 1981</td><td>3850</td><td>+1675</td><td>Oct 1981</td><td>1050</td><td>+845</td></tr>
<tr><td>Jan 1988</td><td>5800</td><td>+1950</td><td>Jan 1986</td><td>1250</td><td>+200</td></tr>
<tr><td>Feb 2002</td><td>0</td><td>-5800</td><td>-</td><td>Jan 1988</td><td>150</td><td>-1100</td></tr>
<tr><td>Aug 2005</td><td>0</td><td>0</td><td>0</td><td>Feb 2002</td><td>2500</td><td>+2350</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Aug 2006</td><td>900</td><td>-1600</td></tr>
</table>

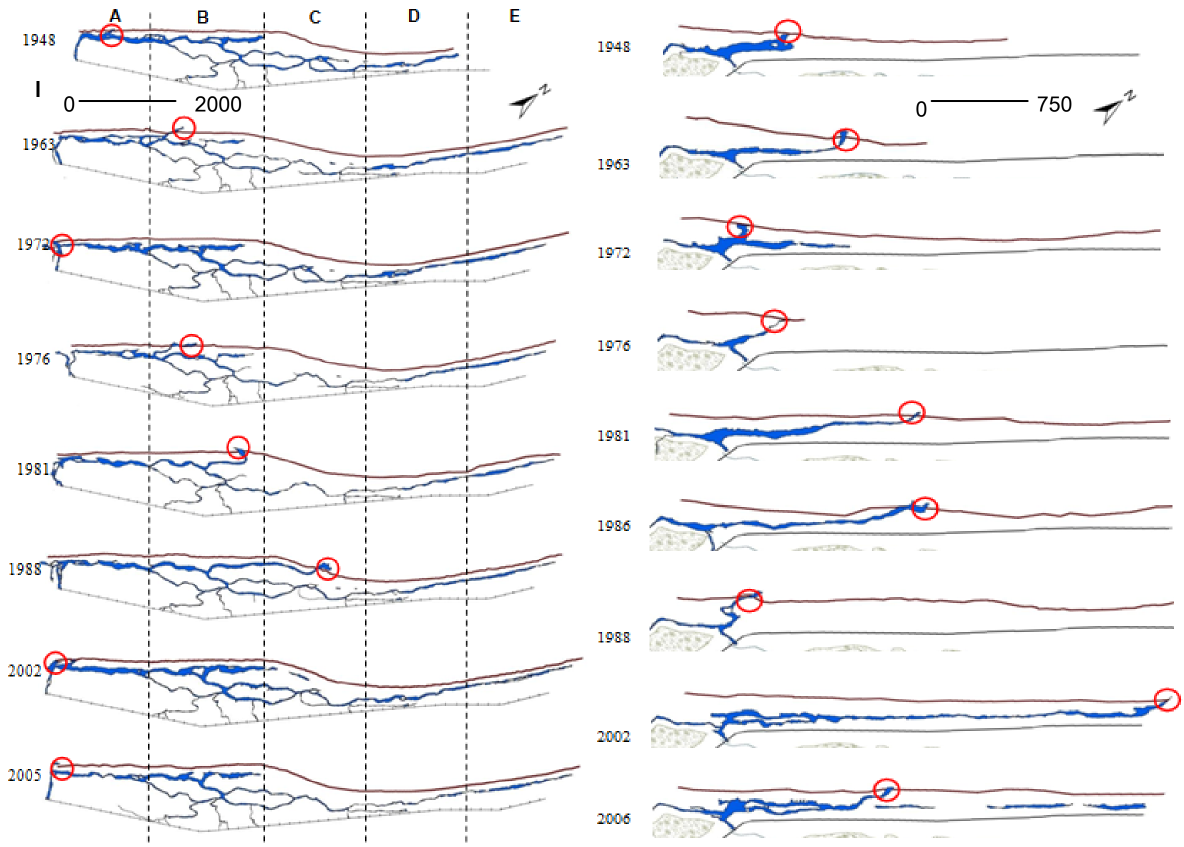

Figure 3. Digitisations of Totara Lagoon (left) and Waikoriri Lagoon (right) showing changes in outlet position and channel utilisation over time. Outlet position is circled in red.

5. DISCUSSION

Important differences exist in size and structure between Totara Lagoon and Waikoriri Lagoon. Results show that these differences cause variations in dynamics and stability that are apparent on both short and long-term timescales. Totara Lagoon is much more stable than Waikoriri Lagoon, which is a consequence of the disparity in spatial scale between the two systems, as well as differences in their topography and fluvial inputs. The implication of this is that the two systems have very different response times and capacities to absorb changes in coastal and catchment processes.

5.1. Climate change and Westland lagoons

As such dynamic systems controlled by a complex network of interacting factors, the response of these lagoons to changes in climate conditions, catchment dynamics and management pressures is difficult to predict. Ultimately, it is the balance between these multidirectional pressures that determines the morphological and hydrological state of the system and determines what, if any, transformations will take place.

Sea level rise alone leads to a long term erosional trend at the affected coastline, provided this is not counterbalanced by increased sediment supply (Pethick, 2001). This is already a chronic problem along much of the Westland coast (Neale *et al.*, 2007; Ishikawa, 2008), although a few small sections have been recently accreting. No sea level data was available in the Westland region, but a New Zealand average sea level change of +1.6 mm yr^{-1} has been calculated (Hannah, 2004). This amounts to a total of approximately 100 mm sea level rise over the 62 year study period. Climate change is expected to result in an increase in frequency and intensity of westerly weather systems in the

Westland region (MfE, 2008a). A consequence of this increase in weather intensity is that more sediment will be transported to the coast from the upper catchment. However, this will not be distributed evenly along the coastline of the Westland region, further adding to spatial disparities in erosion and accretion trends.

Totara Lagoon and the Shearer Swamp-Waikoriri Lagoon Complex are highly likely to be affected by continuing sea level rise and erosion of the seaward barrier over the next century. In a natural, unconstrained lagoon system, this would result in rollback of the barrier and landward migration of the entire lagoon system, while maintaining essentially the same morphological form (Pethick, 2001). There is evidence of this already occurring in the southern half of Totara Lagoon, with a low, wide seaward barrier and heavily eroded farmland on the landward margin of the lagoon channel. This pattern of morphological change is currently restricted to the southern reaches of Totara Lagoon, which is unsurprising as it is the most active section of the lagoon and thus has a faster response time. Results show the central reaches of Totara Lagoon exhibit a large degree of variation in channel utilisation, which would likely absorb any such changes occurring in this section of the lagoon and prevent large scale changes at the landward margin. In addition, the landward margin of the central reaches is wetland, which is much more able to deal with such dynamic changes than the rigid, eroding farmland in the south. The northern section of the lagoon will respond last to any large scale changes in morphology in the southern and central reaches. Both seaward and landward barriers are much more stable here, and are unlikely to change significantly over the next century. Sea level rise and increased storminess will likely be manifested in increased wave overtopping and dune blowouts along the entire system, including in the northern reaches.

Hydrologically, the Totara Lagoon waterbody could become increasingly influenced by marine processes. In the absence of an increase in sediment supply to counterbalance sea level rise, there will be increased incidence of wave overtopping of the barrier and marine incursion at the outlet, increasing the salinity of the lagoon waterbody. In addition, percolation of water through the barrier is a function of hydraulic head between the lagoon and the ocean (Todd, 1983), which will be lessened if sea level rises. This could result in increased water levels within the lagoon.

This process of landward lagoon migration is not currently occurring at Waikoriri Lagoon, and anthropogenically driven changes in outlet morphology and sediment supply are currently the dominant drivers of change in this system. The effect of climate change on Shearer Swamp in the geological short term (timescale of decades to centuries) will be relatively small. Sea level rise will not affect the swamp itself in terms of saltwater intrusion, as the western margin is situated 200 m from the coast, behind Waikoriri Lagoon and a set of relic dune ridges. However, it could affect it indirectly through alteration of the level and character of the water table. Moreover, the effect of increased weather intensity would take the form of increased water storage and sedimentation rates in the swamp, thus a faster rate of infilling.

5.2. Management implications

The management response to observed morphological change is central to the preservation or degradation of these lagoon systems under continuing pressure from external factors. Existing coastal management schemes are often spatially and temporally restrictive, often constrained to short term solutions (less than 50 years) and pertaining only to a narrow part of the coastal zone, rather than taking a holistic view that includes marine factors and catchment dynamics. The findings of this research support the idea of an integrated coastal and catchment management plan, an idea which was raised in a New Zealand context by Hart (2009). The landward margins of Totara Lagoon and Waikoriri Lagoon are not currently heavily constrained by infrastructure or engineering works. Although the land is farmed, the future development of the lagoon depends on the management regime.

The immediate physical response to events of morphological change is of major importance to the future of these lagoon systems. In the case of barrier rollback and lagoon migration, several measures can be considered. The most natural of these is the concept of ‘managed retreat’, whereby loss of adjacent land is accepted as a consequence of coastal migration and the system is allowed to naturally migrate (Emmerson *et al.*, 1997; Pethick, 2001). In the case of Westland lagoons, this is the most desirable solution from the perspectives of lagoon preservation and hazard management, due to the low population density of the area, small funding base and lack of structural development along lagoon margins (MfE, 2008b). The loss of adjacent land could be significant for those affected, but cheap compared to the cost of protecting that land, in terms of both dollar amount and in degradation of the lagoon environment.

Other management strategies for mitigating the effects of erosion range in extent of interference with natural processes and result in varying degrees of change in lagoon morphology. Hard structures such as rock walls and revetments have commonly been used on the West Coast to combat erosion (Ishikawa, 2008), but these are currently absent from the eroding channel in Totara Lagoon. These measures are totally impractical in this situation due to the length of affected area, financial cost and most of all because of cost to the lagoon environment. If they were to be used in such a system, the result would be eventual loss of the lagoon system, with the seaward barrier becoming eroded from both sides and unable to migrate landwards. This behaviour of morphological change and loss of the natural coastal sequence in response to hard engineering has been termed 'coastal squeeze' by Pethick (2001). Soft measures of erosion mitigation involving the artificial redistribution of sediment (e.g. beach nourishment) could be considered, but the benefit of this in such an isolated, natural and unconstrained area as Westland is not great. In addition, it is not viable on the West Coast due to budgetary constraints and the large quantities of sediment and coastline involved.

6. CONCLUSIONS

Two coastal lagoon systems were investigated in Westland, New Zealand, to document their current topography and both spatial and temporal scales of outlet dynamics in order to predict their response under changing climate and management pressures. Totara Lagoon, a large relatively stable coastal lagoon, was found to experience outlet migration on a scale of months to years. In contrast, Waikoriri Lagoon, a small and very dynamic system, was found to exhibit outlet migration on scales of days to months. Barrier morphology varied significantly between sites, with the Totara Lagoon barrier being much higher than that of Waikoriri Lagoon. Along the length of Totara Lagoon, the barrier became more stable to the north, suggesting a northward decrease in dynamics within the system.

The implication of the differences in spatial scale and stability found between the two field sites is that these systems will respond to changes in climatic forcing factors on different temporal scales, with Totara Lagoon able to absorb a greater degree of pressure before exhibiting a large-scale morphological response.

Over the next century, these systems are likely to experience pressure from a variety of factors, both climate induced and anthropogenic, which interact in a complex network of feedback loops. Climate change is likely to result in an increase in sea level, which will result in landward migration of the entire system unless barrier erosion is counteracted by increased sediment supply. In addition, increased frequency and intensity of westerly weather systems could result in changes to the catchment dynamics and river flow patterns. This research suggests that the preferable management strategy to deal with these changes is to maintain the system as naturally as possible, avoiding all hard measures to prevent erosion.

This research highlights the scope that remains for investigating the potential effects of climate change on coastal systems, particularly the investigation of relationships between interacting processes. There is a need for long term studies of coastal environments and their dynamics to aid in understanding and predicting the potential effects of climate change in this sensitive, and very important, environment. This would be particularly beneficial in the Westland region, where funding is limited, yet science could benefit greatly from the study of a rich coastal environment that is relatively unconstrained by engineering and infrastructure.

ACKNOWLEDGEMENTS

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CHANGES IN COPEPOD COMMUNITY IN A TROPICAL MANGROVE ESTUARY: AN APPROACH TO CLIMATE CHANGE

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ABSTRACT

A decadal change of copepod community in Indian Sundarban mangrove regions at the estuarine phase of the River Ganges was recorded. On a regular one month interval basis, zooplankton samples were collected using a Ring Trawl Net (Hydro-Bios No. 438 700, Germany), mouth area 0.78 sq. m, mesh size 200 µm. The volume of water filtered was measured by a calibrated Flow-meter (Hydro-Bios No. 438 110, Germany) mounted in the mouth of the net. The net was trawled on water surface for 10 minutes for each sampling. The zooplankton was fixed with 4% buffered formaldehyde solution and taken to the laboratory for further analyses. Simultaneously, surface water samples were collected for the analyses of dissolved oxygen, biological oxygen demand (BOD), chemical oxygen demand (COD), inorganic nutrients (nitrate, phosphate and silicate), water temperature, pH, salinity, turbidity, transparency and chlorophyll pigments (a, b, c) by standard methods. Six copepod species (Saphirella indica, Pontella andersoni, Pseudodiaptomus binghami, P. hickmani, Cladorostrata brevipoda and Laophonete setosa) which were abundant during 1980s are absent in recent samples which make them sensitive beacons of climate-induced biological changes. In contrast, four copepod species, namely, Bestiolina similis, Acartia tortaniformis, Parvocalanus dubia and Canthocalanus pauper dominated recent times suggesting a shift in the functioning of the pelagic ecosystem. A peculiar element of regularity in the structure of copepod assemblage was represented by temporal succession of species within the genera Oithona and Paracalanus suggesting ecological differentiation among the congeners. The positive correlation between any two pairs among the families Paracalanidae, Pontellidae, Eucalanidae, Oithonidae, Temoridae and Corycaedae provides evidence that these families combine to form a group by themselves while the family Pseudodiaptomidae showed negative correlation with other families. Sharp decline in the copepod diversity was observed during profuse bloom of a centric diatom Hyalodiscus sp., coinciding with exponential increase of chlorophyll a and chlorophyll c. High diversity index was associated with evenness reflecting the multi-dominance pattern in diversity. The multiple regression analyses show that the density of total copepods was controlled by water temperature and salinity. The data indicate the extreme flexibility of copepods in adapting to a fluctuating and hostile environment and thus acting as causal link between climate change and alteration in biodiversity in the Ganga River Basin (GRB).

1. INTRODUCTION

Copepods, the dominant mesozooplankton component, comprise 60 to 80% of the total zooplankton biomass (LópezIbarra and PalomaresGarcía 2006) of the pelagic food webs worldwide (Froneman, 2004; Magalhaes et al., 2009). They also play an important role as prey for many juvenile and adult zooplanktivore fish (Schipp et al. 1999, Sommer et al. 2002) thus it can be termed as a key factor in the control of fish stock sizes (Payne and Rippingale 2001, Evjemo et al. 2003). Hydrological parameters are directly influenced by climatic variations which might be useful in explaining zooplankton distribution and abundance (Kimmerer, 2002). Indian Sundarban is highly vulnerable to natural disasters and there is increasing frequency and intensity of cyclones (such as 'Aila' on 25th May 2009), storm surges, flooding and coastal inundations which are linked to climate change. Hence an attempt has been made to describe the influence of hydrological parameters on the community structure of copepods inhabiting in the coastal regions of Sundarban considering the observation of 1980s and 2007 – 2009.

2. **MATERIALS AND METHODS**

2. 1. Area investigated

The Indian Sundarban, the low lying, meso-macrotidal, humid and tropical mangrove belt, is located on the southern fringe of West Bengal, on the northeast coast of India. Four stations were chosen, namely, Jambu Island (S_1) (21°36'10″ N - 88°11'09″ E), Gosaba (S_2) (22°11'02″ N - 88°49'07″ E), Canning (S_3) (22°12'13″ N - 88°40'01″ E) and Dhamakhali (S_4) (22°20'26″ N - 88°53'18″ E) (Fig. 1) as they belong to different hydrodynamic set up, wave energy fluxes and distances from the sea (Bay of Bengal).

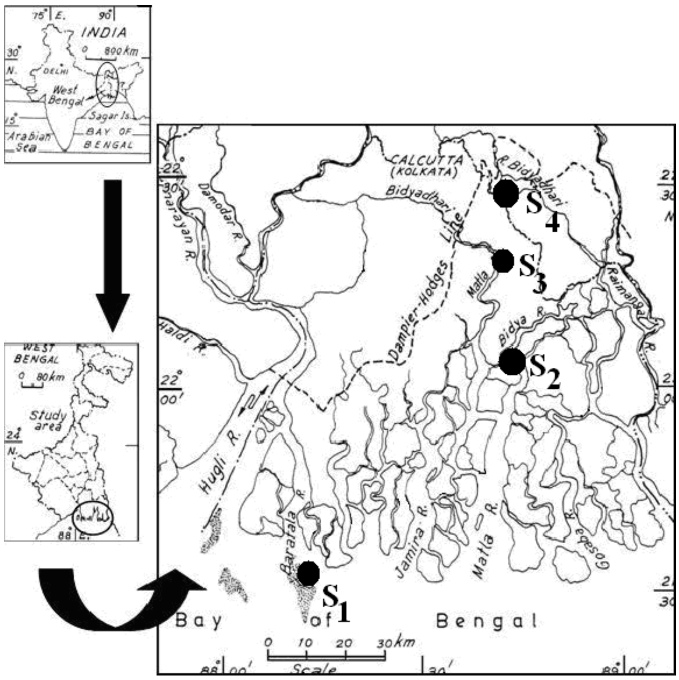


Figure 1: Map showing the location of sampling stations in Indian Sundarban

2. 2. Collection and analyses of zooplankton samples

Zooplankton samples were collected monthly in the coastal regions of Sundarban wetland from March 2007 to September 2009, during high tide. Samples were collected by horizontal subsurface tows (Hydro-Bios No. 438 700, Germany, mouth area 0.78 sq. m, mesh size 200 µm), equipped with a Hydro-Bios flow meter (Hydro-Bios No. 438 110, Germany) and preserved in a 4% buffered formaldehyde seawater solution. Zooplankton samples were brought to the laboratory, copepod samples were sorted and identified with the help of a binocular microscope and split into random subsamples for counting in a Sedgewick-Rafter counting cell (ind. m^{-3}). The biomass values were determined using the methods described by (Margalef, 1967). Feeding habit of the individual copepods has been considered on the basis of the findings by the previous workers (Nakamura and Turner 1997; Islam *et. al.*, 2005; Turner, 2004; Stoecker and Sanders. 1985).

For comparison, the previous published reports published by Sarkar et. al., (1985a, b; 1986a, b) were taken into account in which the collection of zooplankton sample from the same coastal regions was done by filtering the measured amount of surface water through a conical net (0.25 m diameter and 0.0695 mm aperture). The water quality parameters were worked out by standard methods as referred above.

2. 3. Water Sample collection and analyses

Simultaneously, surface water samples were collected in acid-washed polythene bottles to estimate the water quality parameters (salinity, pH, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, nitrate, phosphate, silicate, chlorophyll a, b, and c). All the parameters were estimated by methods described by Strickland and Parsons, (1972) and Parsons et. al., (1984).

2. 4. Statistical Analyses

Statistical analysis was performed using statistical softwares, MINITAB 14, STATISTICA 6 and S-Plus. Data were transformed using the $\log_{10}(x+1)$ function to allow the less abundant species to exert same influence on the calculation of similarities (Clarke and Warwick, 1994). For comparison of the dynamic values of copepod species of this study area, index of dominance and seasonal replacement rate were calculated using the formula described by Yang et al. (1999).

3. RESULTS

3.1. Changes in the environmental parameters

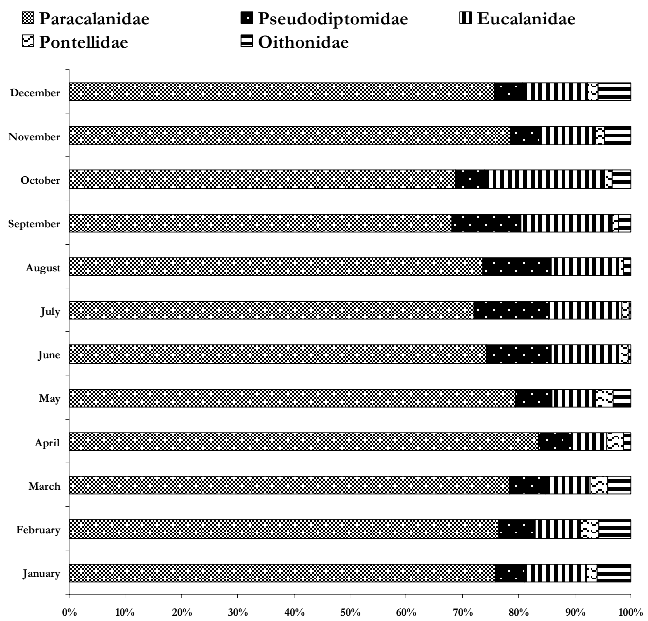
A distinct spatial and temporal heterogeneity in distribution of different water quality parameters were observed in the studied regions. Average surface water temperature recorded during the study period was 28.79 ± 5.44^{0}C whereas, during 1980s the average temperature was recorded 28.22 ± 2.83 (table 1). Decadal increment in the surface water temperature was also endorsed recently by Mitra et. al., (2009) from this coastal region. The correlation coefficient (r) between turbidity and temperature showed a positive value (r = 0.502, p = 0.01) in the present study. A sharp increment in the dissolved oxygen level has also been observed in the surface water from 3.12 ± 0.40 to 6.12 ± 0.58 mg L^{-1} which is indication increment in the biological activities (Sawant et. al., 2007). Biochemical oxygen demand (BOD) values were moderate low ranging from 0.86 – 1.36 mg L^{-1}. The surface water pH during present study ranged from 7.1 – 8.8. The high COD values (101.28 – 111.31 mg L^{-1}) were found at Jambu Island (S_1). The concentration of nutrients found to be increasing during the monsoon season. Phosphate levels were observed to be maximum (2.25 µgm. atom L^{-1}) during late-monsoon period. Values for phytopigments ranged between 5.86 – 1.24 mg l^{-1}, 3.26 – 0.02 mg l^{-1} and 5.28 – 0.97 mg l^{-1} for chlorophyll a, b and c respectively.

Table 1. Comparative table of water quality parameters and total zooplankton and total copepod in Sundarban coastal waters during 1980s and present study

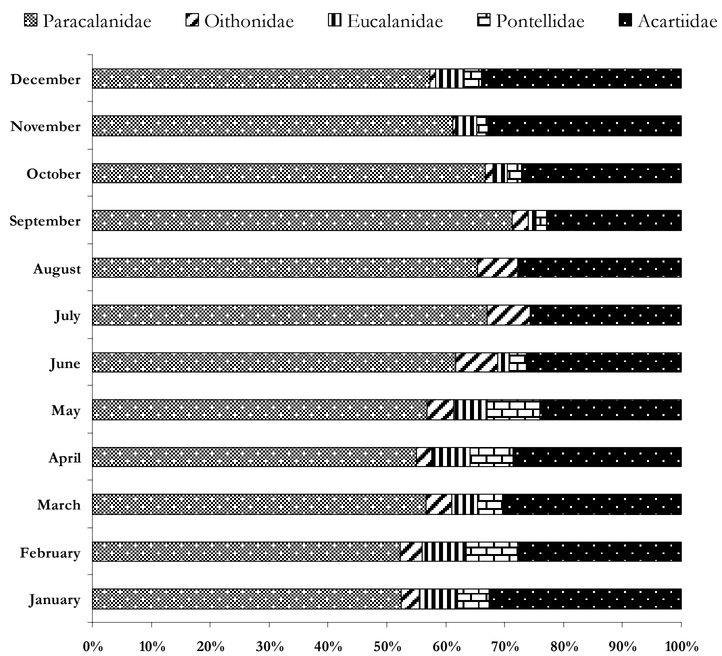
Physicochemical Parameters and related biomass	**Previous study durng 1980 - 1982**	**Present study during 2007-2009**
Water Temp (ºC)	28.22 ± 2.83	28.79 ± 5.44
Salinity (0/00)	12.65 ± 6.29	15.29 ± 5.13
DO (ml l-1)	3.12 ± 0.40	6.12 ± 0.58
pH	8.08 ± 0.18	8.13 ± 0.44
Turbidity (NTU)	10.11 ± 2.81	13.04 ± 8.73
Total Zooplankton (ind. m-3)	23256 ± 10217.41	1458.67 ± 718.77
Total Copepod (ind. m-3)	16369.38 ± 9543.64	972.17 ± 125.82
Diversity Index (H´)	5.87 ± 2.74	4.79 ± 1.21

3. 2 Changes in copepod composition and their distribution

Sharp decrease in the numerical density of total zooplankton was observed while comparing the data during 1980s and recent one (Table 1). Numerical density of total zooplankton dropped from 23256 ± 10217.41 ind. m^{-3} to 1458.67 ± 718.77 ind. m^{-3} (Table 1). Zooplankton abundance was higher during the dry season (> 1000 no m^{-3}) than the wet season (<500 no m^{-3}) for both the cases. Copepods constituted the single largest taxon and comprised 61.20% to 97.0% of the total zooplankton counts in the Indian Sundarban estuary for 1980s whereas 57% - 96.70% at present time. Numerically, 54 species of 32 genera and 41 species of 14 genera copepod were recorded during 1980s and 2008 respectively and respective diversity indices values were also dropped from 5.87 (during 1980s) to 4.79 (during 2008) (as shown in Table 1. Family Paracalanidae dominated the copepod community in pre- and post-monsoon periods whereas the families Acartiidae, Pseudodiaptomidae and Cyclopoidae were dominant during monsoon (Fig 2a).In contrast, the most dominant copepod families of the present time are the Paracalanidae and Acartiidae followed by Pontellidae, Eucalanidae and Oithonidae (Fig 2b).



(a)



(b)

Figure 2. Graph showing contribution of major copepod families as percentage (a) during 1980s and (b) present study from Sundarban coastal waters (annual mean of all the stations have been taken)

On 21st May, 2009 a severe tropical storm 'Aila' was originated within the northeastern India Ocean and had left prodigious impact on the coastal regions of West Bengal especially on the Indian Sundarban wetland which not only caused stupendous changes in the physicochemical characteristics of the water but also left direct impact on the Mesozooplankton as well as copepod biomass. An abrupt site specific decrease of biomass, numerical density and species diversity of copepods was very pronounced during post-aila period. The average numerical density of total copepod was 1097 ind. m^{-3} and 521.50 ind. m^{-3} during pre- and post-aila period respectively. About 50 % reductions in the numerical density of zooplankton were also observed by the previous workers by Reddy et. al., (2005) while observing the after-effects of the tsunami. Surprisingly, there was extreme dominance of two copepods namely, *Bestiolina similis* and *Oithona brevicornis* . The perusal of literature has shown that these two species are organic pollutant-tolerant in nature (Uye, 1994; Anakubo and Murano, 1991; Nair, 2007) which might favor their dominance when the COD value was as high as 109 mg l^{-1}. Their dominance might be further stimulated due to the presence of large amount of organic debris (e.g., mangrove litter, carcasses etc.) in the estuarine waters brought due to severe cyclone in the aquatic system.

3. 3. Changes in Food and feeding habits of the copepods

During 1980s, herbivore copepods were found to be dominant throughout the year constituting about 66 – 82% of the total copepods while omnivores contributed a substantial part only during the monsoon and post-monsoon. In contrast, traces of the carnivores were occasionally found. In contrast, herbivores and omnivores contributed 55.47 – 79.48% and 26.20 – 59.30% respectively during recent times. The overall dominance of the carnivore copepods was found at Canning (S_3), where the major part of the copepod biomass is mainly comprised by the representatives of the family Oithonidae. Their dominance may have large impact on zooplankton biomass, potentially masking the changes in secondary production. Among the omnivores, *A. tortaniformis* was the most abundant species. During June-July, omnivore copepods dominate over herbivores. Detritivores were found only in the station Jambu Island (S_1). Two omnivore species (*A. spinicauda* and *A. tortanifromis*) showed very significant positive association (Index of association I = 1), whereas, one solitary carnivore species (*O. brevicornis*) and herbivore species (*P. parvus*) showed negative significant associations (I = -0.69).

4. DISCUSSION

The observed decadal changes in hydrology (water temperature, dissolved oxygen and salinity) and abundance and community structure of mesozooplankton might be considered as regional impact which link between long-term climate forcing and marine ecosystem processes. The Sundarban coastal regions underwent natural disasters such as flooding, storms and cyclones for the last few decades mainly due to its tropical setup, low-lying position coupled with the immense impact of southeast monsoon. As a result, changes in water mass properties, such as increment of water temperature, dissolved oxygen and salinity were marked over the decades. Similar changes were also established recently by Mitra et. al., (2009) from this coastal regions which might have direct or indirect impact on biological activity (Sawant et. al., 2007) including growth sustainability and community structure of zooplanktons (Puells et. al., 2004; Campbell et. al., 2001). The increment of water temperature is reflected in the perennial occurrence of two calanoid copepods (B. similis and P. parvus) during recent times in Sundarban coastal regions, which are considered as warm water species (Stephen, 1984; Wong et al., 2000). During 1980s, six autochthonous key copepod species, namely, Saphirella indica, Pontella andersoni, Pseudodiaptomus hickmani, Cladostrata brevipoda, Laophonte setosa and Centropages dorsispinatus were present almost throughout the year in Sundarban coastal regions (Sarkar et. al., 1985a, b; 1986a, b) but totally absent during recent time. These sharp changes in appearance might be related to several factors, like biological interactions in the form of predation and competition, changes in feeding habit of the copepod species as well as due to climate change. In contrast, copepod species like B. similis, A. tortaniformis, P. parvus and C. pauper which form the dominant species during the recent time, were either absent or present in few number duirng 1980s. This also suggests a shift in the functioning of the pelagic ecosystem (Molinero et. al., 2008) revealing that changes in community structure reflect adjustments of pelagic ecosystems to large-scale climate-driven modifications (Beaugrand et. al., 2002; Hoof and Peterson, 2006). Hence the observed changes in copepod community over decades could be considered as biologial indicator to climate change related stressors on biodiversity. It is worthwhile to mention that the reorganization of plankton communities might also have dramatic socioeconomic impacts through effects on commercial fisheries. Further analyses of the developmental stages and size composition of the major copepod species is required to strengthen the decadal changes of copepod.

5. CONCLUSION

As concern over the impacts of climate change intensifies, a clear picture of major changes in plankton ecosystems over recent decades is emerging (Drinkwater, et al. 2004). The present study provides an overview of the changes in abundance and community structure of copepods and strengthens the role of copepod as an indicator of hydrographical changes over the decades in Sundarban mangrove coastal waters. A conceivable 'site-specific' heterogeneity of the copepods was observed which may be due to the effect of the local hydrographic conditions. For instance, unique assemblage and dominance of the representatives of the family Oithonidae were marked exclusively at the site Canning (S_3), infested with mangroves. Like in many other tropical and subtropical estuaries in world, an overall dominance of the small-sized (<1mm) copepods was pronounced as they connect the link between the classical and microbial food-web. An extensive monitoring program related to copepod biomass and production is required for generating much longer data series. This would help for a deeper understanding of zooplankton variability and the impact of climate change in this fragile coastal environment which had been completely devastated very recently due to a severe tropical cyclonic storm 'Aila' (25^{th} May 2009). Ongoing plankton monitoring programmes around the world will act as sentinels to identify future changes in marine ecosystems.

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ANALYSIS OF SHORELINE CHANGE OF SENGGARANG COASTLINE USING GENESIS

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ABSTRACT

Study of Malaysian coast erosion in 1986 has observed that about 29% of 4,809 km of Malaysian coastline are facing critical erosion. One of worst areas affected by erosion is coastline of sub district of Senggarang in the State of Johor, Malaysia which may disappear from the face of earth very soon. About 30,000 residents who lived in 20 villages along the coastal area are terrified to lose their land and houses as they will be flooded by sea water due to gradual coastal erosion process. A study to identify the problem of coastline erosion and predicting the future condition has been carried out. The occurrence of coastline erosion was due to the soil that formed the beach is very soft which cannot withstand the powerful surge of wave energy especially during stormy seasons. The existence of mangrove along the coastline did absorb some of the energy but erosion still occurs because power of the wave. Results from simulation using Genesis of the current condition of eroded area shows that the coastline of Senggarang area will be eroded as much as 5.0 to 7.5 m a year by the sea water.

Keywords: coastline erosion, coastal modeling, Genesis

1. INTRODUCTION

National Coastal Erosion Study of Malaysia from November 1984 to January 1986 concluded that about 29% of 4,809 km of Malaysian coastline are facing critical erosion. It has received amounts of attention because the coastal erosion impinges directly on many aspects of life such as industry, transportation, residential and recreational. Related with Malaysian coastline that is facing critical erosion, sub district of Senggarang, Batu Pahat, Johor, Malaysia could be disappeared from the earth soon. About 30,000 residents which stay in 20 villages along the coastal area between Rengit and Semerah will lose their land and houses as it will be flooded by the sea water due to gradual coastal erosion process. Some areas such as Parit Botak, Pantai Sungai Punggor, Kampung Sri Pantai, Kampung Sungai Lurus, Kampung Parit Balak, Teluk Wawasan and Parit Simin are specified to have been facing serious problem since many years ago. Larger portion of the coastal area is expected to be flooded by sea water due to constant and gradual erosion process which eventually eats up the land. Thousands of people that make use of the wealth of the coastal area for fulfilling their daily needs and livelihood will lose benefit for millions of Dollar.

This phenomenon has drawn the attention of the nearest university (Universiti Tun Hussein Onn Malaysia) to take away the problem into a research study with a proposal to conduct a research concerning the coastal erosion problem and its impacts in the years to come, with the hope that the results of the study could be adopted as a scientific document for supporting the Government decision makers.

Hence, referring to that study, simulating the coastal line changes due to erosion using GENESIS is an essential to predict the shoreline changes of Senggarang if no prevention was taken.

2. LOCATION AND AREA OF STUDY

The area of study is located in Senggarang coastline of Batu Pahat, Johor State, Malaysia. This lies between the coordinates of (108° 53' 30" to 108° 59' 30" East Longitude and 07° 22' 30" – 07° 37' 00" South Latitude). Figure 1 shows the location of area of study at Senggarang that is between Tanjung Labuh and Sungai Punggur.

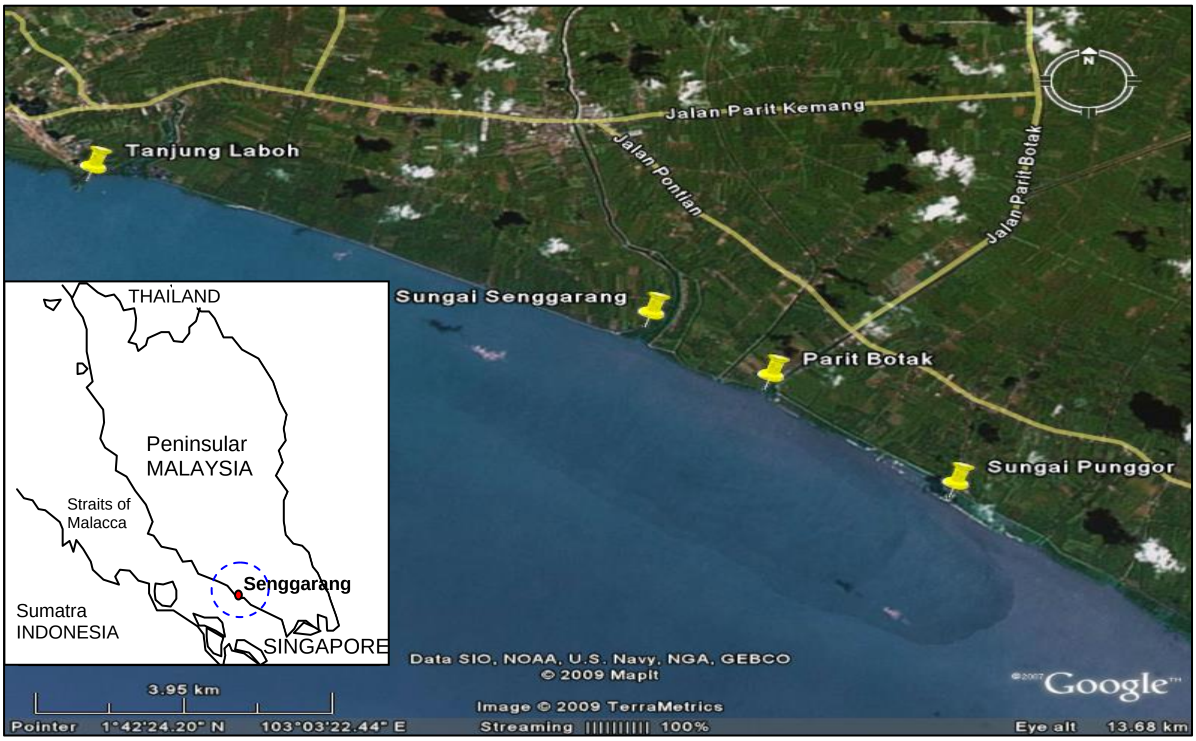

Figure 1: Map showing the study area

From the site visit, problem identification and data collection, it is known that the dominant wave direction is from south west. The occurred wave always increases from 1.5 m to 2.5 m, while tide is varied and has tendency increasing. This phenomenon may be caused by the global warming has influenced the weather that is able to change the condition of sea water to make the height of wave and tide is higher than the previous one.

Change of sea water condition is proved by the existing beach structure (breakwater) has been over flown by sea water, so then the structure cannot break the wave or not function optimally to make the shoreline has tendency to move to the land. Based on the map survey, information from the surrounding people and spot observation, it is concluded that within around 40 years the shoreline has moved to the land until 200 m to 300 m away or averaging about 5 m to 7.5 m a year.

Seashore erosion in the Senggarang coast is a process of shoreline moving to the land which is caused by: a) the tendency of increasing of sea water level which can be seen by overtopping on the existing breakwater structure; b) the material that forms the coast is soft soil where this kind material is not able to detain force of wave even though mangrove trees are available to protect the beach; c) the amount of formed sediment transport is not balance where inflow of sediment is less than outflow; and d) the equilibrium in the coastal is disturbed by the existing structure that sticks out into the sea, for example in Punggur beach there are two jetties nearby the drain where the direction of wave is from south west, then at left side of jetty got accretion while at the right side of jetty got erosion.

3. ANALYSIS OF WAVE

One of most important data for system analysis of a coastal area is wave where wind and fetch data will cause the wave of sea to occur. Hence data of wind is required to calculate or forecast the height and direction of wave at the area of study. Wave forecasting is depending on the wind data as the principal wave generator and also the fetch. The wind data with the direction used is from the year 1999 to 2009 for Batu Pahat Senggarang data, while the fetch area for Senggarang is referred to Sumatra Island, Indonesia.

Table 1: Repetitive Period Recapitulation Wave Extreme

Repeat Period (Years)	High Wave Extreme Value (m)	Period Wave Extreme Value (second)
1	0.20	2.00
2	1.13	4.84
3	1.47	5.54
5	1.87	6.27
10	2.38	7.09
25	3.03	8.02
50	3.51	8.65
100	**3.98**	**9.23**
200	4.46	9.87

The scheduled wave used according to the extreme price analysis from the biggest yearly wave data yielded from wave forecasting. The method used in extreme price analysis is the Pearson Method. The height of wave for Senggarang waterways is presented in Table 1.

For Sea Shore Senggarang case, the low tide data was done at site within 15 days. However, low tide analysis has been done as well by taking the already component data low tide in book of Table Low Tide Dishidros 2009. It mentiones the prediction within 20 years to identify the important elevations of low tide as given in Figure 2.

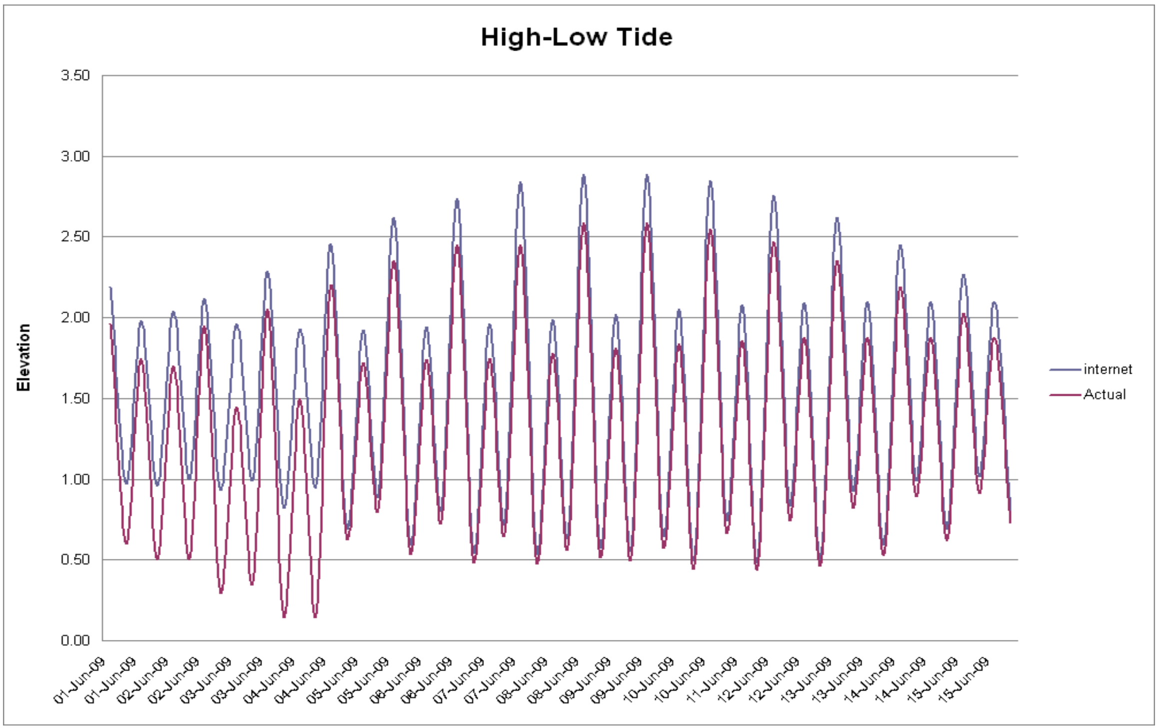

Figure 2: Low Tide Graphic Outcome from Actual Data within 15 days and Prediction Data

4. ANALYSIS OF SHORELINE

To analyze the change of shoreline it is necessary to model the system of shoretline. The model is about determination of sediment transport model or shoreline change model that has happened and future happening in a certain period using GENESIS (Generalized Model for Simulating Shoreline Change) from US Army Corps of Engineers (ASCE). The Methodology analysis of simulation program of GENESIS is as detailed below.

Long-shore transport rate (Q), or level of sediment transport is parallel with shoreline, it is common to have unit cubic meter per year. Due to the movement is parallel with the coast, then there are two possibilities of movement, it is to right and left direction relative to a researcher that is standing on the coast to see the ocean. The movement from right to left is given notation of Q_{lt}, and the movement from left to right is given notation of Q_{rt}, so then it obtains sediment transport level 'rough' (gross),

$$Q_{gross} = Q_g = Q_{lt} + Q_{rt} \tag{1}$$

And level of transport 'clean' (net),

$$Q_{net} = Q_n = Q_{lt} - Q_{rt} \tag{2}$$

Value of Q_g is used for predicting level of drying on an open water path, Q_n for designing the protected path and coast erosion estimation, and Q_{lt} with Q_{rt} for designing sedimentation at behind of a beach structure that detains the movement of sediment.

This GENESIS program, with input data above can give estimation of value of long-shore transport rate and change of shoreline caused by sediment transport with the existing structures at the beach for certain time period.

5. RESULT AND DISCUSSION

In the modeling of Senggarang coastline, simulation was made for 1, 3, 5 and 10 years later. It is shown that for grids of 5 -25 and grids of 50 -70 are risky areas to get erosion as shown in Figure 3. While in the estuary areas have tendency opposite by sedimentation at the mouth of river. Sedimentation at the estuary is an unfortunate condition because it can handicap the flow of river from upstream which can cause over flow when the flow is high.

According to the result of simulation for 10 years later, most of shoreline moves to the land about 60 m or 6 m/year. This shoreline change is about similar with the study on the map survey, information from the surrounding people and spot observation that is between 5 to 7.5 m a year. It can be concluded that the change of shoreline will be worse in the future and it should be taken over to make sure the surrounding people are saved.

6. CONCLUSIONS

Based on the result of analysis can be concluded as follows:

1) Analysis of wave prediction with return period of 100 years yielded that height of wave $(H)_{100}$ = 3.98 m, wave period (T) = 9.23 second. Dominant wind direction is from south east or south west for months of January - April. But for months of May – August the dominant direction is south and in September – December the dominant direction is from west.
2) The movement of shoreline to the land is about 5 to 7.5 m a year. It means that the land is eroded by sea water as much as 5 to 7.5 m a year due to the type of soil is very soft which cannot stand to the wave attach and the existing mangrove is not effective to absorb the energy of wave.

3) Tide prediction with Admiralty method, the tide is categorized semi diurnal type with time of 24 hours and 24 minutes. Mean High Water Level (MHWL) = 1.864 m, Mean Sea Level (MSL) = 0.0 m and Mean Low Water Level (MLWL) = -1.003 m.

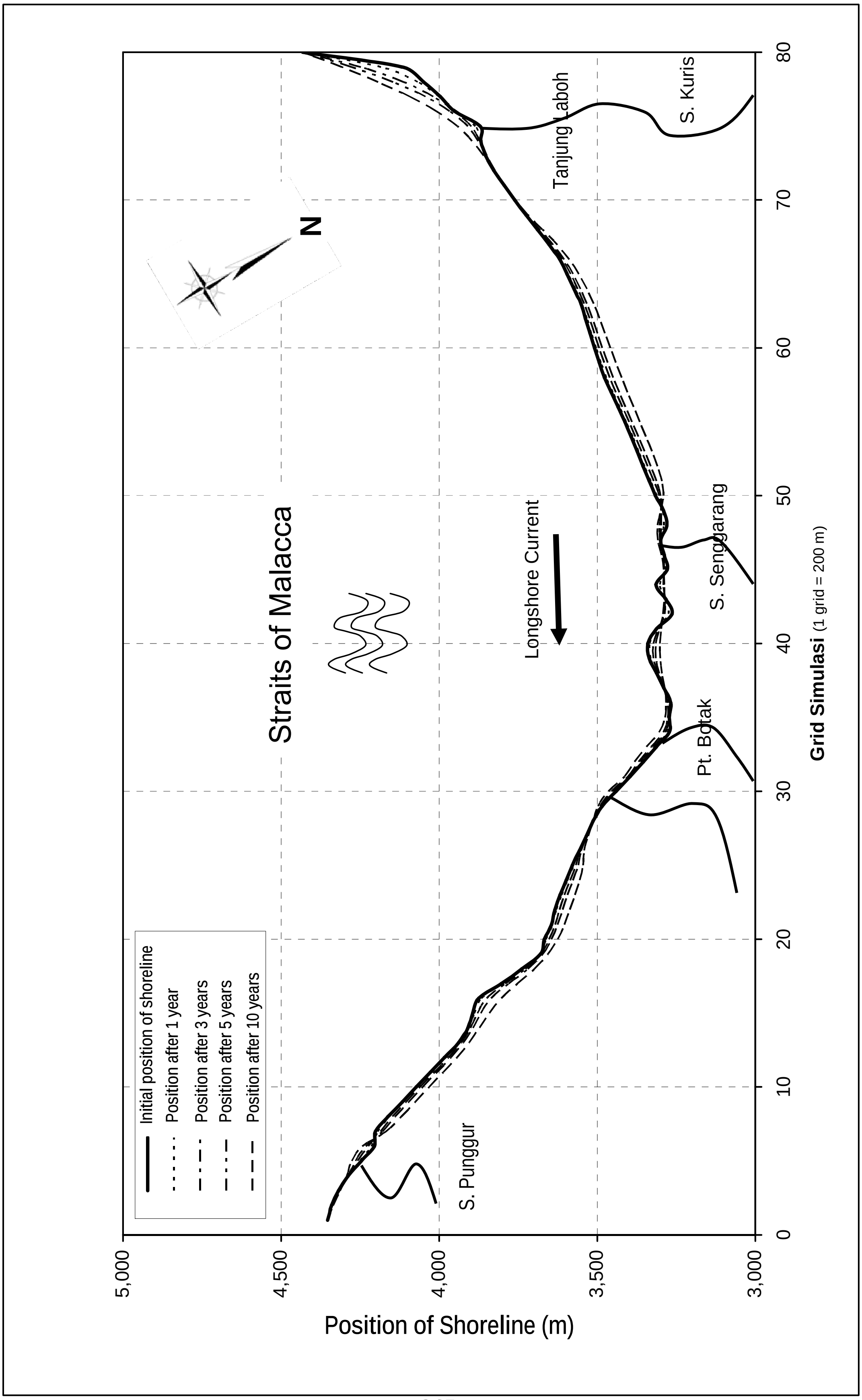

Figure 3: Changes of Shoreline without Prevention

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CLIMATE CHANGE: ASSESSING THE IMPACTS AND DEVELOPING ADAPTATION STRATEGIES USING APPLICATION OF ELECTRONIC GOVERNANCE AND ICTs FOR RURAL REGION IN INDIA

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ABSTRACT

The Information and Communication Technologies plays an important role in rural development. The Empowerment of Rural communities is crucial for the development of the rural region. Brining the rural people along the coastal region in to the mainstream of the digital technologies for the assessing the impacts of climate change and mitigation is a major concern now. Rural Development implies both, the economic development of the people and greater social transformation using electronic governance. In order to provide the rural people along coastal region with better prospects and opportunities for economic development, agriculture development and management, marketing management ; increased participation of rural people along coastal region in electronic governance through information and communication technologies are envisaged .This paper aims to explore the nature, role and relevance of the Electronic/Digital Governance using ICTs and wireless technologies for assessing the impacts of climate change and mitigation for agriculture and rural development along coastal region and its impacts to highlight approaches and methods for improving local environmental governance, having particular regarding to the range of interests and actors involved in e-governance, ICTs. The paper will examine the current status of electronic governance in India in different coastal regions and different technologies involved in e-governance process for the assessment of impacts of climate change and natural disasters along coastal regions. The paper will focus on development of the model for the e-governance using ICTs /wireless technologies for agriculture development in rural coastal region with respect to climate change and its impacts.

1. INTRODUCTION

The Empowerment of coastal communities is crucial for the development of the Rural India. Brining the rural people along the coastal zones in to the mainstream of the digital technologies is a major concern now. Rural Development implies both, the economic development of the people and greater social transformation using electronic governance. In order to provide the rural people in coastal regions with better prospects and opportunities for economic development increased participation of rural people in electronic governance through information and communication technologies are envisaged .Over the next generation of greatest increase in population, in production and in poverty will occurs in rural part of India causing the social, economic and environmental problems. Due to this the problems of management to different services, natural resources management and financial resources mobilization in coastal and rural areas, it would be necessary to study the application of Electronic Governance using Information and communication Technologies (ICTs) / wireless technologies for the economic development of the rural region. The Government of India has started the implementation of National Electronic Governance Plan in rural region using the wireless technologies, Local Area Networks (LAN), Internet and online systems. India is largely rural with more than 70 percent of our population dependent on agriculture and allied activities. Ecologically sound agriculture is knowledge intensive. Farm women and men need dynamic information relating to coastal zone management, climate change, meteorological, management and marketing factors as related to crops and animal husbandry, fisheries, agro-forestry and agro-processing. The new approach to productivity improvement and employment generation is also information and knowledge intensive. In the context of globalization of trade, there is need for launching a genetic (i.e. relating to genetically modified farm products), legal (i.e. IPR and Farmers' and Breeders' Rights), quality (i.e. sanitary and phytosanitary measures and codex alimentarius standards), and trade (i.e. prices in home and external markets) literacy movement. There is presently a disconnect between what farm families need by way of generic and dynamic information and what the conventional extension agencies are able to provide. It is also important to address the need for demand driven and value added information, which is time and location specific. There is also need for new technology enablers on local agro-ecological and socio-cultural conditions of each coastal village, and also relating to various farming methods and techniques. Apart from information related to farming, rural women and men urgently need access to healthcare information. Increased health expenditure is an important cause of farmers' indebtedness, leading occasionally to suicides. Information on the health status of livestock and poultry, on-farm and off farm livelihoods and market-led entrepreneurship opportunities for the poor and the marginalised in rural India need attention. There is also need for promoting functional literacy among the adult illiterate and making learning joyful for the young through interactive pedagogic methodologies. All this can be effectively done through E Governance project across the coastal region of the country that focus on skill building at the local level and information empowerment with the help of contemporary Information and Communication Technology (ICT) tools.

2. OBJECTIVES

a) To identify the critical parameters in Electronic Governance for rural development with reference to different services.

b) To disseminate the information required for Electronic Governance for planning, development and management of different rural services,

c) To develop the E-Governance plan/ model using ICTs and wireless Technologies for different services.

Studies on Application of Electronic Governance Using Information and Communication Technologies For Rural Development involve the following consideration**:**

i. **Selection of Location :** Rural areas, coastal regions, disaster prone region.

ii. **Selection of Target group/beneficiaries:** Economically disadvantaged sections of the society, self help groups, coastal communities, Farmers, Fishermen.

iii. **Selection of Stake holders:** Central /state Government, NGO, District Administration, Village Panchayats, Local Communities.

3. CITIZEN CENTRIC E-GOVERNANCE IN RURAL AND COATAL REGIONS OF INDIA:

E-governance is defined by Kanungo Vikas as "the application of information & communication technologies to transform the efficiency, effectiveness, transparency and accountability of informational & transactional exchanges with in government, between govt. & govt. agencies of National, State, Municipal & Local levels, citizen & businesses, and to empower citizens through access & use of information."

Kanungo Vikas assessed the present status of e-governance in Indian states in 1996 for the benefit of citizens. As per his assessment the concept of "e-governance" is termed as "E-citizenship". Global shifts towards increased deployment of IT by governments emerged in the nineties, with the advent of the World Wide Web. The technology as well as E-Governance initiatives have come a long way since then. With the increase in Internet and mobile connections, the citizens are learning to exploit their new mode of access in wide ranging ways. They have started expecting more and more information and services online from governments and corporate organizations to further their civic, professional and personal lives, thus creating abundant evidence that the new "E-citizenship" is taking hold. The concept of E-Governance has its origins in India during the seventies with a focus on development of in- house government applications in the areas of defence, economic monitoring, planning and the deployment of IT to manage data intensive functions related to natural resources management, disaster management, climate change, coastal zone management, elections, census, tax administration etc. The efforts of the National Informatics Centre (NIC) to connect all the district headquarters during the eighties was a very significant development. From the early nineties, IT technologies were supplemented by ICT technologies to extend its use for wider sectored applications with policy emphasis on reaching out to rural areas and taking in greater inputs from NGOs and private sector as well. There has been an increasing involvement of international donor agencies under the framework of E-Governance for development to catalyze the development of E-Governance laws and technologies in developing countries. While the emphasis has been primarily on automation and computerization, state governments have also endeavoured to use ICT tools into connectivity, networking, setting up systems for processing information and delivering services. At a micro level, this has ranged from IT automation in individual departments, electronic file handling and workflow systems, access to entitlements, public grievance systems, service delivery for high volume routine transactions such as payment of bills, tax dues to meeting poverty alleviation goals through the promotion of entrepreneurial models and provision of market information. The thrust has varied across initiatives, with some focusing on enabling the citizen-state interface for various government services, and others focusing on bettering livelihoods. Every state govt. has taken the initiative to form an IT task force to outline IT policy document for the state and the citizen charters have started appearing on govt. websites.

4. E- GOVERNANCE AND DEVELOPING COUNTRIES RESEARCH :

Michiel Backus said that *E-democracy* refers to the processes and structures that encompass all forms of electronic interaction between the Government (elected) and the citizen (electorate). *E-government* is a form of e-business in governance and refers to the processes and structures needed to deliver electronic services to the public (citizens and businesses), collaborate with business partners and to conduct electronic transactions within an organisational entity. E-governance is defined as the application of *electronic means* in (1) the *interaction* between *government* and citizens and government and businesses, as well as(2) in internal *government operations* to simplify and improve democratic, government and business aspects of Governance.

The term *interaction* stands for the delivery of government products and services, exchange of information, communication, transactions and system integration. *Government* consists of levels and branches. Government levels include central, national, regional, provincial, departmental and local government institutions. Examples of government branches are Administration, Civil Service, Parliament and Judiciary functions. *Government operations* are all back-office processes and inter-governmental interactions within the total government body. Examples of *electronic means* are Internet and other ICT applications.

5. COMMUNICATION AND EXISTING WIRELESS TECHNOLOGIES :

The term communication means sending, processing and receiving information by electrical means .Communication is the process where by the meaningful information is transferred from one point to called source in the space to other point called destination and Wireless communication is the communication in free space,there is no need of wires, cable of optical fibers to communicate from one to each other. The wireless communication is also called as radio communication The communication term is nothing but transmission between transmitter and receiver and mentioned The types of communication system which are given below

- Analog input- Analog transmission
- Analog input- Digital transmission

- Digital input -Digital transmission
- Digital input -Analog transmission

The existing wireless technology and applications are given in Table no.1. Some of the wireless technologies mentioned in the Table No.1 are found effective for assessing and mitigating the impacts of the climate change and natural disaster management along the coastal region in India .

Table 1 :Existing wireless technology and application.

Application	Existing standard/technology
Mobile telephony (digital cellular telephony)	GSM,CDMA (IS-95 TO CDMA 2000), WCDMA-UMTS
Wireless LAN/MAN/WAN	IEEE802.11(Wi-Fi),802.16(WiMAX)
Personal area communication	Bluetooth
Digital audio broad cast, HD radio,DRM	DAB
Digital video broadcast,DTH through satellite	DVB
Mobile satellite communication Global communication	Iridium, UMTS,GPS
Mobile internet access	GPRS, Mobile IPV6,WAP
Wireless local loops	DECT, CorDECT, CDMA,GSM
Mobile adhoc networks	ALL WLAN/WAN standards AND Bluetooth,sensor N/W

6. E- GOVERNANCE MODEL USED IN COASTAL INDIA :

M.S. Swami Nathan Research Foundation [SN-RKC] with support from Tata trust has established J.N.Tata virtual academy for rural prosperity. The Academy in association with alliance partners has identified a million grassroots knowledge workers in coastal region in coastal region who are enlisted as Fellows of the Academy. They are the torch bearers of the Knowledge Revolution in our 600,000 villages. The Knowledge Centres are set up and managed by ICT Self-help Groups comprising both women and men. This ensured the demand-driven nature of the information provided. Obviously the goal of taking the benefits of ICT to every village in the country can be accomplished only by providing a platform for partnership among the numerous agencies and individuals who are currently working in different parts of the country in setting up information kiosks and other methods of empowering rural women and men with the technologies associated with the digital age. In several parts of the country farm families are facing deep distress due to meteorological, marketing, institutional and social factors. MSSRF is doing everything to empower the rural communities with relevant and timely information on weather, management, marketing and entitlements. Education and health for all are the other major goals of the Academy. Swami Nathan M .S. Research foundation (MSSRF) developed the Hub and Spokes Model for rural community in Chennai In this model, pioneered by MSSRF, RKCs have both connectivity and content. The local population contributed towards the expenses of the RKC, so that the long-term economic sustainability of the programme is ensured. Contributions in cash or kind generate a sense of ownership and pride and create an economic stake in the operation of the centre. The local able to run the centres when the implementing agency moves to other regions. The hub centre and RKCs acted as a rural library and much more. Each hub centre cover 25 to 30 villages within a radius of 60 km. Each hub centre consist of at least three networked computers, one scanner, two web cameras, internet facility, one printer, one digital camera, solar backup facility, etc. The RKCs located in a public place and not associated with one group or caste; and allowed everyone to take part. Each RKCs have two-way communication with hub. RKC consist of two to three computers [depending on village population / needs], a web camera, phone, a printer, notice board, etc Regarding Connectivity they said that New technologies, especially wireless, are becoming increasingly important because they are easier to deploy and cost less than conventional technologies. What already exists often determines what options you actually have and the options are often limited. Telephony is still very relevant for rural access. Adequate technical skills are required for ensuring/maintaining a robust connectivity infrastructure. Internet technologies offer new options to provide cheaper and more flexible services The most feasible and cost-effective system used. Connectivity and Content received concurrent attention of RKCs.

7. OBSERVATIONS

During the South Asian Tsunami disaster along the south Indian coast in 2004, this rural knowledge centres in Pondicherry state were found beneficial to the coastal population for e- communications for giving the disaster warnings to the coastal communities. The Tsunami warning was issued to the various rural knowledge centres immediately. Due to the efficient use of e-governance and wireless technologies thousands of the lives were saved as the people moved towards landwards side from the coastal region after the warning .However in TamilNadu it is observed that there were more death recorded in coastal region as the disaster warning was not given to the public. Also lack of e-governance facility increased the human loss along the coastal region of Cuddalore and Nagapattinum districts in south India .The involvement of coastal communities through Information and Communication Technologies, wireless technologies and E-governance is essential for mitigating the impacts of the coastal disaster along the coastal zones

8. CONCLUSION

The coastal areas are disaster prone region .The assessing and mitigating of impacts of coastal disasters is crucial for the rehabilitation of the coastal communities. The Information and Communication Technologies, Wireless Technologies and E-governance plays an important role in coastal zone management and climate change information e3livery system in coastal region. The use of e-governance is very effective for the management of the coastal disasters .In order to provide better information and communication to the people in rural and remote places in coastal zones wireless technology can be effectively used during the coastal disasters .The fishermen communities can get the updated weather information and the fishery date through use of the e-governance and wireless technologies .During the cyclone along the coastal region the information and communication technologies with application of e-governance and wireless communication found suitable and most effective technology to save the coastal region from human life and economic loss. For the involvement of the coastal communities in E-governance process, extensive capacity building is required for enhancing the skills and knowledge through use of Information and Communication Technologies .

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COST EFFECTIVE ADAPTATION STRATEGY FOR THE DISASTER PRONE AREAS OF COASTAL AREAS OF BANGLADESH

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ABSTRACT

Bangladesh is a disaster-prone country that is affected almost every year by some form of tropical cyclone. Among the 508 cyclones that have originated in the Bay of Bengal in the last 100 years, 17 percent have hit Bangladesh, amounting to a severe cyclone almost once every three years. Of these, nearly fifty three percent have claimed more than five thousand lives. As a low lying country, most of the southern regions of Bangladesh go under water during surge and face an uncountable amount of damage by destructive wind speeds. Agricultural fields lose their fertility due to erosion, sedimentation, sea-spray and saline water intrusion. These also affect the availability of water and soil for all kinds of human activities. Damage of crops and vegetations affects national food production and security. Loss of lives, livestock, damage of crops, contamination of water sources, destruction of houses, transportation systems, embankment and other development structures not only stop the flow of livelihood, these infirm the long term social, health care, economic development and policy of the country. Every year, government needs to allocate huge amount of budget for the relief, medication, subsidy and post-disaster phase of socio-economic recovery, reconstruction and maintenance works in coastal area. Adaptation capacity of people in this region is noticeable.

During the disaster, there is shortage of water supply and food apart from the loss of homestead, crop and livestock. Lack of infrastructure for suitable sanitation leads even to worse health conditions of the victims. Loss of the rural roads leads to a missing link for the supply of relief and rehabilitation facilities at the quickest possible time. This paper aims at a conceptual adaptation strategy for the coastal population of Bangladesh at an affordable manner. The recommended strategy involves minimum intervention to the existing locality and thus a minimum of cost being involved with the maximum possible facilities to available at the end of the victims especially during and immediately after the disaster. The main theme of the adaptation strategy is the modification of the landscape to the smallest extent in order to facilitate the shelter for human beings and livestock, storage of harvested crops, water supplies, sanitation and the transportation network. This paper also proposes the saline water tolerant crops be considered for those areas. The paper proposes the minimum coastal zone that should be brought under the adaptation strategy at the initial pilot stage. The ecological balance of the affected locality is also considered in the adaptation strategy as well.

1. INTRODUCTION

Bangladesh is a deltaic low land country located at 20°34′-26°38′N and 88°01′-92°41′E in South Asia with territorial area, 147,570 sq. km and population, about 162 million (Wikipedia, 2009). About one-fifth of the population lives within 19 coastal districts. Since the geographical, natural and social characteristics of this country, people have suffered repeated disasters of floods and storm surges including huge 1970, 1991 and 2007 cyclone disasters. The devastative impacts of those disasters not only concentrated on the coastal residents and resources, it stopped all kinds of progressive activities instantly throughout the country at that time. Government, public private organizations and communities from different sectors had to take extra challenge to save the affected people and to overcome the extensive losses and damages. Large numbers of people became a burden having no way to earn. Putting excessive pressure on the national economy. In most cases, it is seen that another severe cyclone attacks before initial recovery.

To improve the overall situation, comprehensive long-term disaster management is necessary. Cyclone shelters and embankments have insignificant roles to mitigate the impacts of disaster. The best way is to introduce natural protective barriers with proper planning and design. In this paper the role of several components of nature in disaster mitigation has been described and a combined design and strategy have been mentioned. The design will be easy to implement and affordable in cost and people will get opportunities to be involved in alternate income generating activities; improvement of overall production and health situations. In the initial stage, this strategy can be experienced in a coastal island to evaluate its grade of sustainability.

2. CYCLONE DISASTER IN BANGLADESH

Due to unique geographic location, Bangladesh suffers from devastating tropical cyclones frequently. The funnel-shaped northern portion of the Bay of Bengal causes tidal bores when cyclones make landfall and thousands of people living in the coastal areas are affected. Of the 508 cyclones that have originated in the Bay of Bengal in the last 100 years, 17 percent have hit Bangladesh, amounting to a severe cyclone almost once every three years (GoB, 2008). To understand the frequency and intensity, it is necessary to provide some background of the top cyclones hit Bangladesh. The description of some severe cyclones hit Bangladesh (since 1960) including their causalities and damages according to the wikipedia (2009) are given below.

October 30- 31, 1960: A severe cyclonic storm hit Chittagong, Noakhali, Bakerganj, Faridpur, Patuakhali and eastern Meghna estuary, with winds speed up to 210 km/h. The storm surge reached a height of 4.5-6.1 m. About 10,000 people, 27,793 cattle were dead and 568,161 houses destroyed.

May 28- 29 May, 1963: A severe cyclonic storm devastated Chittagong, Noakhali, Cox's Bazar and coastal islands of Sandwip, Kutubdia, Hatiya and Maheshkhali. The storm surge reached 4.3-5.2 m in Chittagong. Maximum wind speed was up to 203 km/h and at Cox's Bazar 164 km/h. Casualty- 11,520 people, 32,617 cattle. 376,332 houses, 4,787 boats, and standing crops were completely destroyed.

November 12, 1970: The 1970 Bhola cyclone hit the entire coast of Bangladesh. The official death toll was 500,000 but the number is likely to be higher. Damages include destruction of approximately 20,000 fishing boats, and also property and crops. Total loss of cattle reached more than one million. More than 400,000 houses and 3,500 educational institutions were destroyed. Maximum wind speed reached about 222 km/h. Maximum storm surge was about 10.6 m.

May 24 -25, 1985: A severe cyclone hit Chittagong, Cox's Bazar, Noakhali and coastal islands. Maximum wind speed at Chittagong was 154 km/h, at Sandwip was 140 km/h, and at Cox's Bazar was 100 km/h. The storm surge reached a height of 3.0-4.6 m. Casualty-11,069 people, 135,033 cattle. 94,379 houses and 74 km of road, and embankments were destroyed.

April 29 -30, 1991: The 1991 Bangladesh cyclone hit Bangladesh late 29 April night. The storm originated in the Indian Ocean and reached the Bay of Bengal coast after 20 days. The diameter of the storm was close to 600 km. The maximum wind speed (observed at Sandwip) reached 225 km/h (The NOAA-11 satellite estimated the maximum wind speed to be about 240 km/h at 1.38 pm on 29 April). The maximum storm surge height reached about 5 to 8 m. About 150,000 people was dead, 70,000 cattle lost and damage of property was estimated at about Tk 60 billion.

September 25 -27, 1997: Another severe cyclonic storm hit the coastal islands and chars (Shoal) near Chittagong, Cox's Bazar, Noakhali and Bhola districts. The maximum wind speed was 225 km/hour, and the storm surge reached 3.05 meters.

November 15, 2007: Cyclone Sidr is the fourth named storm of the 2007 North Indian Ocean cyclone season. The storm formed in the central Bay of Bengal, and quickly strengthened to reach peak sustained winds of 215 km/h (135 m/h). The storm eventually made landfall near Bangladesh on November 15. As it intensified to a Category 4-equivalent cyclone on November 15, thousands of emergency officials were put on standby in Bangladesh in advance of the storm's arrival. Massive evacuations of low-lying coastal areas also took place; a total of 650,000 people evacuated to emergency shelters. Approximately 3,447 deaths were blamed on the storm according to governmental sources. Agencies like Save the Children or Red Crescent Society claimed the number of deaths to be within 5,000 to 10,000 in Sidr. Overall damage and losses due to this cyclone is US$1674.9 Million (GoB, 2008).

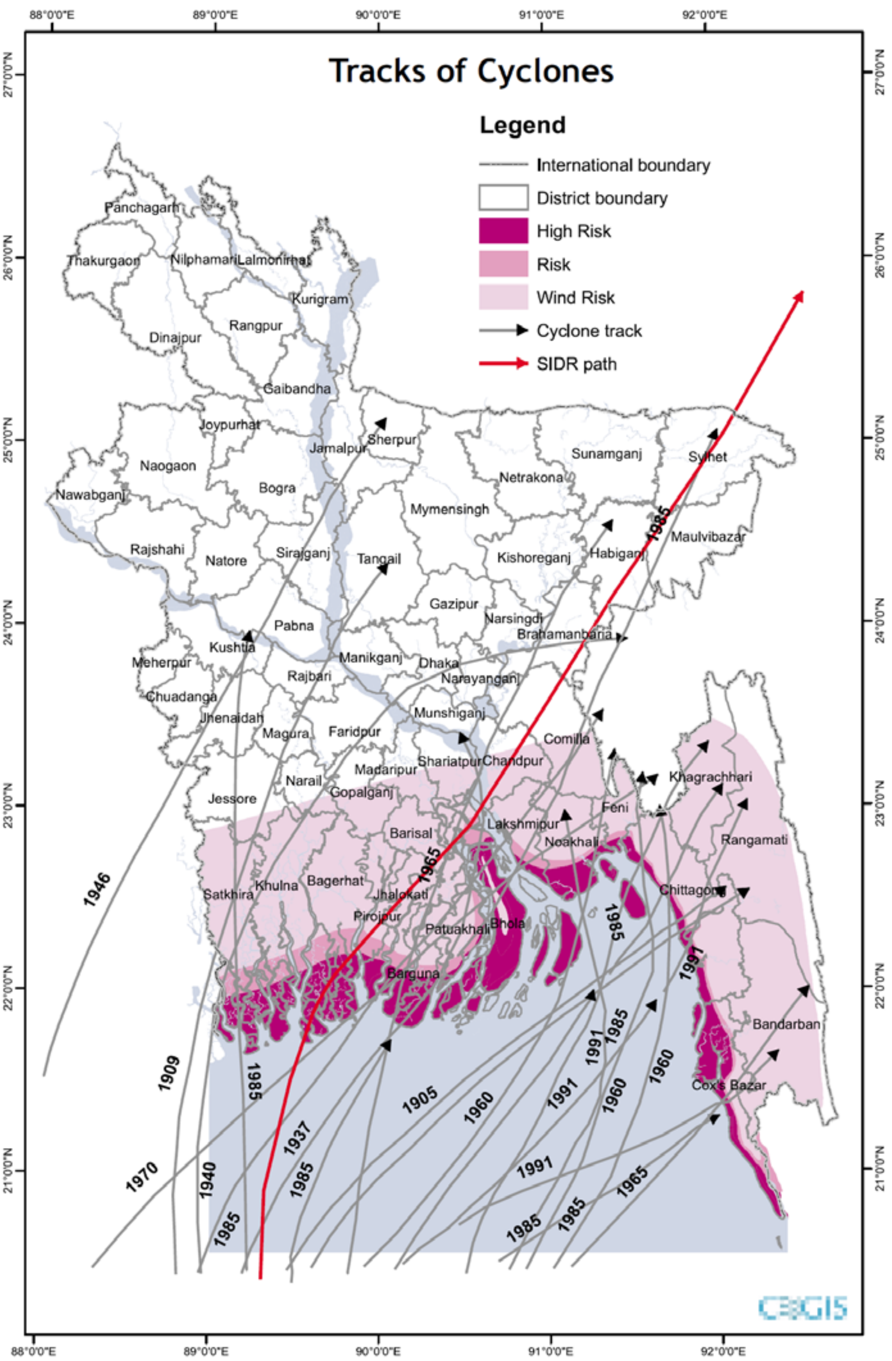

Figure 1: Tracks of major cyclones hit Bangladesh (MoEF, 2008)

May 25, 2009: Tropical Cyclone Aila hit Bangladesh. More than 400,000 people were reportedly isolated by severe flooding in coastal regions. An estimated 58,950 animals were killed by the storm with up to 50,000 deer missing, more than 6,600 people were injured by the storm and 3.3 million were affected. Maximum average wind speed was 110 km/h. Damages to water embankments throughout the country were estimated at US$14.4 million.

From the statistical analysis of the recorded cyclones over the last 200 years, it has been found that number of occurrences of major cyclones has drastically increased in the recent decades. While the number of cyclones was 3 during the period of 1795-1845 and 1846-1896 respectively, the number increased to 13 during 1897-1947 and 51 during the period of 1848-1998. The tracks of major cyclones hit Bangladesh at different times are shown in figure 1. The main reason identified for this increase of frequency of cyclone landfall Bangladesh is global warming and climate change. In fact, only the major cyclone disasters have been mentioned here. Lots of storm forms in Bay of Bengal. Heavy rainfall, devastative wind, surge, saline water intrusion, sea-spray are common during cyclone and the impacts are loss of lives, livestock, crops and belongings associated with land erosion, soil fertility reduction, water and environment pollution, destruction of potable water supply and sanitation system etc in coastal Bangladesh.

3. COST EFFECTIVE ADAPTATION STRATEGY

The coastal land of Bangladesh (around 710 km long) is of recent origin formed out of the process of sedimentation. Most parts of the area are, therefore, low lying which can be subject to inundation even under ordinary circumstances of tides. A tidal surge accompanied by a cyclone storm makes the situation alarming, which is further exacerbated by the triangular shape of the Bay of Bengal. The wide shallow continental shelf is conducive to amplification of surges causing wide spread flooding. The human settlements in the coastal areas are mostly developed in an unorganized and isolated manner, primarily due to population pressure. In such a situation, community efforts to cope with disasters become extremely difficult. There are certain environmental conditions, which lead to the development of cyclones making the coastal human settlements vulnerable to destruction. The whole coastal zone of Bangladesh is almost flat and land elevation is not high from the sea level. On the other hand except the mangrove sundarban in southeast region the whole coastal area has no significant barrier to minimize the energy of cyclone or tsunami. A typical view of the coastal area of Bangladesh is shown in figure 2.

From the previous experience it is found that in any types of moderate cyclone, the situations happens are, i) destruction due to wind force and surge, ii) loss of lives, livestock and crop by tidal bore, iii) loss of soil fertility from the spread of sea-spray, saline water intrusion and sedimentation, iv) water source contamination v) extensive environmental pollution, vi) spread of diseases and vii) unemployment and starvation. Embankments and cyclone shelters have very little protective capacity. However, to resist the devastative impacts of cyclone it is necessary to develop natural protective barrier in a planned way changing coastal landscape considering all kind aspects as much as possible. In this context the following combined design of landscape from seashore to several kilometer inner lands may provide significant assistance to overcome almost all kinds of impacts of cyclone and tsunami disaster.

3.1 Zone of storm wave-sediment interaction

A range of seashore goes under water during high tide everyday and leaves it as bare land during ebb. If a 500-800 meter width of land area including the tidal area of interference can be kept as bare land it will act as “Zone of storm wave-sediment interaction”. It can slow hurricanes, reduce their wave energy and protect the interior wetland. This land has the capacity to absorb incoming wave energy. It is the one side benefit and the other side is this extended bare land can be effectively used for the improvement of tourism industry in the country. The coastal people will get alternate source of employment facilities reducing the dependence on risky job of fishing in the ocean.

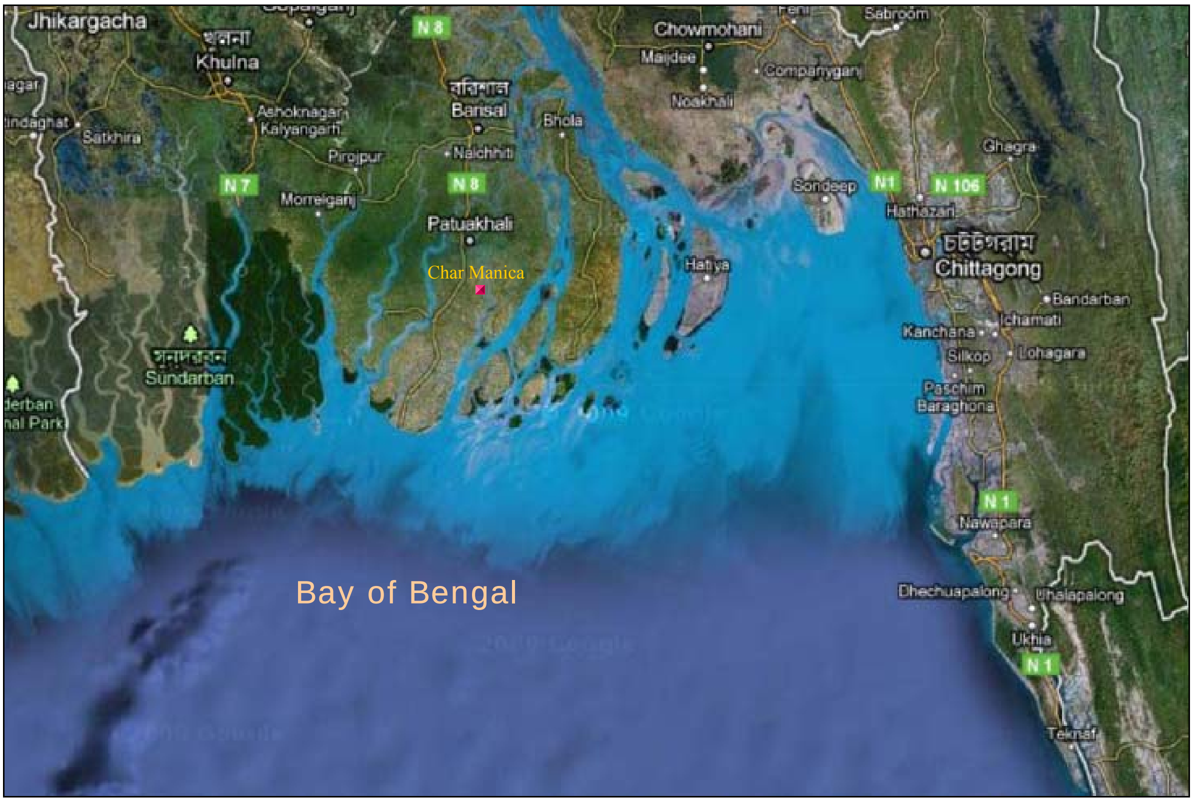

Figure 2: Coastal area of Bangladesh

3.2 Wetlands

Wetlands act as sponges to soak up excess water. Coastal marshes serve as storm surge protectors and help to reduce storm damage when hurricanes or tropical storms come ashore. Inland wetlands function like natural tubs, storing flood waters that over-flood riverbanks, surface areas and protecting adjacent and downstream property. According to EPA (2001), a one-acre wetland can typically store about three-acre feet of water, or one million gallons. An acre-foot is one acre of land, about three-quarters the size of a football field, covered one foot deep in water.

In the seaward side wetland, several water and salinity resistive plants and crops can be cultivated to yield more food production. But the main challenge is to identify the level of salinity and types of species, which can grow in that level and have high food or market value. Local name of some oryza species, Jamainaru, Lakshmikajal, Patnai Balam, Horkuch, Morichshail, Ashfal, Raniselute, Kajalshail, Pokkali, Nona Bokra and salt tolerant modern varieties (SMVs) IR29, BRRI dhan 29 etc have high potential in saline environment (Laisa et al., 2004).

The interior wetland has also some capacity to impart strength to the total protective system dissipating cyclone energy. Water enters into the interior low land during surge remain longer period getting no way to drain away. Proper management of this wetland may provide diverse benefit in normal time as well as in time of emergency. In normal seasons water and saline tolerant crops or mix cropping system can be exercised. New invented paddy, Swarna Sub1, BR11 Sub1, IR64 Sub1 and Sambamasuri Sub1 are highly recommended at this zone. The attractive features of these species are the sustainability in flood water or inundated condition more than 15days and short time period of harvest. In case of 12 months inundation this zone can be utilized for fish culture. After cyclone disaster, interior wetland can act as waterway of transport. It will make possible to send relief goods using waterways immediately after disaster to the affected groups.

3.3 Forest

Forests and tree roots provide a protective cover for vegetation that anchors soils, slows and soaks up water runoff. Deforestation worsens the impacts of hurricanes and other storms, increasing the likelihood of mudslides and flooding. Studies show that coastal forests like mangroves and cypress stands shield the coastlines by reducing wave height and energy. Areas buffered by mangroves were less damaged by the 2004 tsunami than areas without tree vegetation. Mangroves trap and stabilize sediment and reduce the risk of shoreline erosion because they dissipate surface wave energy. It is this attribute that makes mangroves a potential natural solution for particular coastal protection problems.

Surface waves propagating within a mangrove forest are subject to substantial energy loss due to two main energy dissipation mechanisms: (1) multiple interactions of wave motion with mangrove trunks and roots; and (2) bottom friction. The resulting rate of wave energy attenuation depended strongly on the density of the mangrove forest, the diameter of the mangrove roots and trunks and on the spectral characteristics of the incident waves. Typically, wave energy is attenuated by a factor of 2 within 50 meters of the front of the mangrove forest. Hence, the wave heights are typically attenuated by a factor of square root 2 given that the wave energy is related to the square of the wave height (Braatz et al., 2007). The role of mangroves in reducing the sea-waves has been scientifically proved. For instance, a six-year-old mangrove forest of 1.5 km width will reduce 1 m high waves at the open sea and 0.05 m at the coast (Mazda et al., 1997). Energy dissipation is not only the main protective activity of forest against cyclone. Sea-spray enters and spread in the coastal area and inland with wind. Mangroves reduce the wind speed and capture sea-spray. It increases the turbulent flow of sea-spray, provides rough surface and easily capture the sediment and sea-spray.

But position, height, width, continuity and density of plants and trees are very important to consider for the reduction of wind speed, strength and direction. Plants with loosely dense and low height should be in the front position seaward side. The medium dense and moderate height plants should be in the middle position and finally most dense and tallest trees should be planned after the medium height mangrove row.

3.4 Stabilized elevated bank

An elevated land with sufficient stability is necessary to build up after the end of mangrove belt. Alignment, elevation, width, layer by layer compaction and slope should be designed properly. To impart more stability in affordable expanse, mat made of jute or scrap cloth can be used. In most vulnerable areas or where more protection is needed, concrete sea-wall with proper design need to be constructed.

The elevated bank creates wave reflections and promotes sediment transport offshore. It should be constructed along the whole coastline; if not, erosion will occur on the adjacent coastline. From the previous study it is found that only sea-wall, embankment or elevated land easily get eroded and damaged. But mangroves before sea-wall or embankment stabilize those structures and protect from wind speed and tidal wave.

3.5 Human habitat

Human settlement in Most of the coastal areas is isolated and unprotected. Devastating wind force and surge easily attack the unsupported houses and other structures with full energy. For this, though the recent developed warning system providing decent role in evacuation but the resource damage is not decreasing substantially. To improve this conditions some specific areas should be taken under development plan. Housing and other structures should be built on elevated land which will remain beyond the normal flood level. This developed land should have stable slope and soil protective vegetations. Housing and other structures will be supported by tall and dense trees. People will live there in community based and there should have adequate facilities of potable water supply and sanitation.

3.6 Emergency response

It becomes the main task to shift people of vulnerable areas to cyclone shelter or other safe area before the landfall of cyclone. Most of the cases, the time available for evacuation are far less than the time required. If the time of approach of disaster is possible to extend, more life will be saved and large margin of resources can be restored from damage. There are some species like *Sonneratia*, *Kandelia candel* etc. can increase the arrival time of tsunami a lot and save lives and livestock by giving enough time to shift them to shelter. It was predicted with empirical evidence that *Sonneratia* and *Kandelia candel* forest of 1 m width can defer the time of Tsunami attack by 727 and 343 seconds respectively (Braatz et al., 2007).

Post disaster relief distribution activity and to reach adequate food, water and medication are very important to support the affected peoples. Damage of roads, embankment and other infrastructure make this very difficult. But if there are alternate provisions to transfer goods and emergency facilities to the affected areas, significant number of post disaster causalities and spread of diseases can be prevented.

Considering all kinds of aspects, affects of disaster, land characteristics, human behavior and action plan of Bangladesh government disaster management, an improved coastal design and strategy has been developed that is presented in figure 3.

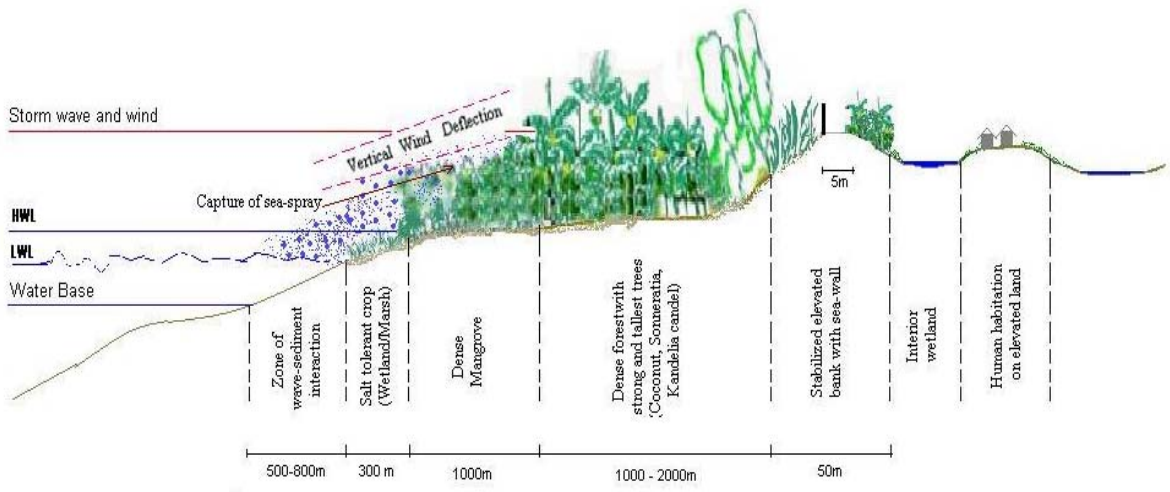

Figure 3: Cross section of the proposed design of coastal area.

4. FEATURES OF THE PROPOSED DESIGN AND STRATEGY

The main feature of the proposed design and strategy is to assure more involvement of natural barrier in a planned way. Other characteristics are as follows

- 500-800 m zone of wave sediment interaction
- At least 1km wide marsh and mangrove belt after previous zone
- Cultivation of Salt and water tolerant crops in seaward side before mangrove, which will act as marsh.
- Trees with loosely dense and low height in the front position seaward side, the medium dense and moderate height trees in the middle position and finally most dense and tallest trees will be planted after the medium height mangrove row.
- Build up 25m wide and 4m high elevated land with 5m wide crest. Proper compaction, slope stability, mangrove and vegetation before embankment must be assured. Construction of concrete sea-wall where necessary.
- Reforestation as long as possible in interior side from embankment.

- Preservation of low land and flood plain
- Fish culture or cultivation of submerged crops in floodplains and low lands
- Human settlement on stabilized elevated lands having proper communication system.

Implementation of the proposed design and strategy will provide benefits in four ways. All parts of the design have specific role in disaster mitigation, protection of lives and resources, improvement of living standard and preservation of coastal environment as a whole. These are separately described in table 1. Except in suburban areas, the proposed design can be implemented in almost all parts in coastal area since major development has not yet been done here and these areas remain in unprotected condition. To evaluate the effectiveness and sustainability of the proposed design, “Char Manica” (22°08′N and 90°41′E) shown in figure 2, can be a suitable area to implement it as a pilot project.

Table 1: Beneficial role of different components of the proposed design and strategy in coastal area.

Component	**Beneficial role**			
	Disaster mitigation	**Protection of lives and resources**	**Living standard and resource development**	**Preservation of environment**
Zone of storm wave-sediment interaction	Absorb tidal energy and protect sea-ward wetland	Reduce cyclonic power	Improvement of tourism, employment facilities	Coastal biodiversity conservation
Wetland/Marsh land	soak up excess water, increase of friction force	Surge height reduction	Cultivation of salt tolerant crops, food production, alternate income generation activity, less dependence on fishing in ocean	Absorption of polluted matter, improvement of coastal ecology
Forest/Mangrove	Reduction of wave energy, wind force, runoff, surge height, sea-spray, sediment transport, land erosion, increase of bank stability, tsunami approach time and change of wind direction	Decrease of sudden shock of disaster, death toll, loss of soil fertility, damage of house, embankment, infrastructures, crops and vegetations.	Collection of fruits, flowers and leaves with high medicinal, honey, wood and other materials. Improvement of tourism, employment facilities	Improvement of wildlife, ecosystem and coastal stability. Minimization of post disaster environmental pollution.
Elevated bank	Strong protective barrier to lessen impact of disaster	Act as protective land to facilitate transport and stay of lives temporarily	Serve as way of transport to carry products to growth center	Protection of interior lands and water bodies from contamination, salinity and sedimentation.
Interior mangrove and low land	soak up more water and impart more protection	Preservation and stabilization of land for human habitation.	Vegetation, crop cultivation and fish culture	Salinity reduction and ecological balance.
Protected human settlement	Act as island during flood and inundation	Protection of lives and livestock from tidal wave	Stable habitation, decrease of migration rate.	Minimization of pollution from causalities.

5. SUPPORT TO GOVERNMENT STRATEGY

The Government of Bangladesh (GoB) is committed to increase the resilience to coastal disaster; reduce the risks coastal disaster poses to national development; and rapidly develop the country. GoB has the Climate Change Action Plan which is a 10-year programme (2009-2018) to build the capacity and resilience of the country for meeting the challenge of climate change. The needs of the poor and vulnerable, including women and children, will be mainstreamed in all activities under the action plan. In the first five year period (2009-13), the programme will comprise six themes with sub programmes of each theme (MoEF, 2008). It is required to mention that the proposed design and strategy in this paper for coastal areas in Bangladesh directly or indirectly supports almost all the themes selected by GoB. More specifically the supported themes (T) and sub programs (P) are as follows-

- Food Security, Social Protection and Health (T1)
- Improvement of cyclone and storm surge warning (T2P2)
- Risk management against loss on income and property (T2P4)
- Repair and maintenance of existing coastal polders (T3P3)
- Adaptation against tropical cyclones and storm surges (T3P6)
- Preparatory studies for adaptation against sea level rise (T4P3)
- Monitoring of ecosystem and biodiversity changes and their impacts (T4P4)
- A forestation and reforestation programme (T5P7)
- Revision of sectoral policies for climate resilience (T6P1)
- Strengthening human resource capacity (T6P3)
- Strengthening institutional capacity for climate change management (T6P4)

6. CONCLUSION

Coastal disaster management is one of the major concerns of coastal countries throughout the world. Every year GoB need to allocate a large amount of budget for cyclone disaster management, coastal development, repair and maintenance. Large number of cyclone shelter has already been made and warning system is modernized. These are contributing to minimize death toll a lot. But integrated management for preservation of land, embankment, infrastructure, water sources and overall environment from severe cyclone are not been seen yet. The dispatch of food, goods, medication and after disaster relief distribution system are still facing great difficulties for lack of proper planning and damage of routes. It is found that the overall damage and losses due cyclone Sidr was US$1674.9 Million. But if the Sidr effect could be minimized 20%, around 335 million dollar would be saved from instant losing and this could be used for more development works. The main feature of the proposed coastal design and strategy in this paper is to mitigate the affects of disaster by introduction of natural protection systems as much as possible and simultaneously, development of adaptation capacity of the local community with maximum utilization of existing environment. In one side, protective barrier will minimize the disaster effects; preserve the land fertility, potable water sources, infrastructures and resources. In other side, salt tolerant submerged crops, wetland and forest will give people more opportunities to yield more, improving living standard and adding additional in national income. Conservation of bio-diversity and ecosystem balance is also a crucial part of the proposed strategy.

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RESILIENCE PLANNING FOR COASTAL ZONE MANAGEMENT

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ABSTRACT

According to the Human Impact Report on Climate Change (Global Humanitarian Forum, 2009), the impacts of climate change are happening right now. Events like weather-related disasters and rising sea levels, affect individuals and communities around the world, especially those living in coastal areas where the human pressure over resources (land, water, food) is increasing. Coastal zone management is focusing on adaptive strategies in order to prepare those socio-ecological systems to deal with higher levels of disturbances, with planning processes moving towards resilience keeping.

Resilience has been described as the capacity of a system to absorb disturbance and re-organize while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al. 2004). Resilient coastal areas are more adaptable to change, are more able to learn and are less vulnerable to disturbance and external shocks (e.g. natural phenomena, human hazards). Planning for resilience is not to be seated waiting for disturbances to happen, in order to cope with their impacts. Planning for resilience is all about being pro-active, focusing on adaptation and learning processes (individual, organizational and social), being less dependent on laws, regulations, strategic goals and bureaucratic procedures, which can bring order and orientation but also inflexibility, inefficiency and conflict. The paper will explore the potentialities of the resilience theories for planning and management of coastal areas. The key idea is that resilience can be enhanced through planning processes in order to prepare the coastal systems to adapt to challenges like the climate change and others.

1. INTRODUCTION

One third of the world's population live in the coastal zone, which comprises an area of only 4% of the total land surface (Nellemann and Corcoran 2006). The increased vulnerability of coastal communities to potential hazards is partly due to the constantly increasing coastal population (Adger et al. 2005). Currently, an estimated 23 percent of the world's population (1.2 billion people) lives within 100 kilometres of a shoreline and 100 meters of sea level (Small and Nicholls 2003). By the year 2030, an estimated 50 percent of the world's population will live in the coastal zone. Coastal development is increasing rapidly and is projected to impact 91% of all inhabited coasts by 2050 and will contribute to more than 80% of all marine pollution (Nellemann et al. 2008).

The Inter-Governmental Panel for Climate Change (IPCC 2007) has estimated that by 2100 the global average surface warming (surface air temperature change), will increase by 1.1 - 6.4 °C; the sea level will rise between 18 and 59 cm; the oceans will become more acidic; it is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent; it is very likely that there will be more precipitation at higher latitudes and it is likely that there will be less precipitation in most subtropical land areas; it is likely that tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures.

According to the Human Impact Report on Climate Change (Global Humanitarian Forum 2009), the impacts of climate change are happening right now. Events like weather-related disasters,

desertification and rising sea levels, affect individuals and communities around the world. They bring hunger, disease, poverty, and lost livelihoods — reducing economic growth and posing a threat to social and, even, political stability. Many people are not resilient to extreme weather patterns and climate variability and they are unable to protect their families, livelihoods and food supply from negative impacts of seasonal rainfall leading to floods or water scarcity during extended droughts.
The world faces a compounding series of crises spawned in part by human activity, which are outpacing the capacity of governments and institutions to deal with them. Energy, food and water crises, climate disruption, declining fisheries, ocean acidification, emerging diseases and increasing antibiotic resistance are examples of serious, intertwined global-scale challenges spawned by the accelerating scale of human activity. And there are few institutional structures to achieve cooperation globally on the sort of scales now essential to avoid very serious consequences (Walker et al. 2009a; Rockström et al. 2009). If resilience continues to decrease in social-ecological systems as we strive to increase production efficiencies, the frequency of regional catastrophes will escalate. The ongoing climatic and ecological changes, together with population growth, rapid urbanisation, land-use change and globalisation, are key drivers of human vulnerability to natural disasters, especially in coastal areas where large populations are concentrated.

Nevertheless moments of crisis provide a much-needed breathing space to rethink patterns of growth, ways of measuring progress, and the means to build more resilient systems. We may not be able to protect people from stresses, shocks and catastrophic events, but we can help them withstand disasters, recover and adapt (IIED 2009). Handmer and Dovers (1996) link resilience to planning for adaptation to hazards, referring that responses to environmental change are shaped by what is perceived to be politically and economically palatable in the near term rather than by the nature and scale of the threat itself.

Disturbances and crisis will become more frequent and intense in the coming future, due to the aggravation of global problems like the climate change but also to other realities like the environmental degradation, the energy demand or the socio-economic inequities that are thriving, in a highly interdependent and interconnected world. Resilience is more than ever a critical property that reflects the system's capacity (e.g. nations, regions, communities, enterprises, families, etc.) to adapt and to resist to disturbances without collapsing.

2. RESILIENCE AS A FRAMEWORK

The resilience framework is becoming increasingly relevant and revolutionary, bringing a more pro-active and less resign way of dealing with problems that affect socio-ecological systems. The resilience theories are focusing on understanding, managing, and governing complex linked systems of people and nature (Folke 2006), bringing new perspectives and helping to strength the sustainability science frameworks. Resilience as a framework is a broad, multifaceted, and loosely organized cluster of concepts, each one related to some aspect of the interplay of transformation and persistence (Carpenter and Brock 2008).

Strengthening the capacity of societies to manage resilience is critical to effectively pursue sustainable development (Lebel et al. 2006). Sustainability involves maintaining the functionality of a system when it is disturbed, or maintaining the elements needed to renew or reorganize if a large disturbance radically alters structure and function. Managing complex, coevolving social-ecological systems for sustainability therefore requires resilience as the ability to cope with, adapt to and shape change without losing options for future development (Folke et al. 2002). Building adaptive capacity is a prerequisite for sustainability in a world of rapid transformations (Gunderson and Holling 2002) and resilience can be seen as an issue of environmental, social and economic security (Germany Advisory Council on Global Change 2000).

Resilience has been described as the capacity of a system to absorb disturbance and re-organize while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks

(Walker et al. 2004). According to Carpenter et al. (2001) resilience is the amount of disturbance a socio-ecological system can absorb and still remain within the same state. It can also be seen as the degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors), or even the degree to which the system can build and increase the capacity for learning and adaptation. The main objective of managing resilience is thus to prevent the system from moving to undesired configurations in the face of external stresses and disturbance (Walker et al. 2002).

Understanding the loss, creation, and maintenance of resilience through the process of co-discovery (by scientists, policy makers, practitioners, stakeholders, and citizens) is at the heart of sustainability (Gunderson and Holling 2002), especially when the systems are facing so much turbulence and when people tend towards resignation in face of overwhelming problems. The bottom line is that resilience can be taken as an opportunity to fight resignation, enhancing the capacities and the wills that are needed to face the threats of the future ahead.

The loss of resilience means an increase of vulnerability which can be defined as a measure of the extent to which a community, structure, service or geographical area is likely to be damaged or disrupted, by the impact of a particular disaster hazard (OECD 1997) or the state of susceptibility to harm and stress, associated with environmental and social change, resulting from the absence of capacity to adapt (Adger 2000). Vulnerability is the flip side of resilience: when a social or ecological system loses resilience it becomes vulnerable to a change that could previously be absorbed (Kasperson and Kasperson 2001).

3. ADAPTIVE CAPACITY AS A CRITICAL FEATURE

Adaptability in a resilience framework does not only imply adaptive capacity to respond within the social domain, but also to respond to, and shape, ecosystem dynamics and change it in an informed manner (Berkes et al. 2003). Adaptive capacity can also be defined as the ability to plan, prepare for, facilitate, and implement adaptation options (Klein et al. 2003). Adaptive capacity reflects learning (individual, organizational, social), flexibility to experiment and adopt new solutions, and the development of generalized responses to broad classes of challenges (Walker et al. 2002). The adaptability of the socio-ecological system is mainly considered a function of the social component due to the importance of human actions —individuals or groups - which actions influence resilience, either intentionally or unintentionally.

Adaptive capacity is a prerequisite for sustainability in a context of rapid transformations (Gunderson and Holling 2002), helping to keep resilience as the capacity to absorb disturbance and re-organize, without collapsing or changing considerably to a worse condition. For example resilient coastal communities with high adaptive capacity are more able to re-configure themselves without significant declines in crucial functions in relation to social relations or economic prosperity (Folke et al. 2002). In high adaptable systems, the actors can reorganize and shape a desirable state in reaction to changing conditions and disturbances. To Luers et al. (2003) adaptive capacity is also the extent to which a system can modify its circumstances to move to a less vulnerable condition. Adaptive capacity is a key property based on the capacity of people, individually and collectively, to manage resilience by building social capital and trust and thereby reducing vulnerabilities in face of disturbances and changes (Folke et al. 2003).

Adaptation is defined by the IPCC (2007) as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Examples of adaptation include preparing risk assessments, protecting ecosystems, improving agricultural methods, managing water resources, building settlements in safe zones, developing early warning systems, instituting better building designs, improving insurance coverage and developing social safety nets. These measures are intrinsically linked to sustainable development, as they reduce the risk to lives and livelihoods and increase the resilience of communities to all hazards (UN ISDR 2008).

For example the California Climate Adaptation Strategy (California Natural Resources Agency 2009) takes into account the long-term, complex, and uncertain nature of climate change and establishes a foundation for an ongoing adaptation process defining a set of objectives. It aims to identify sector-specific, and to the extent possible, cross-sectoral adaptation strategies that help reduce vulnerabilities and build climate resilience. California's ability to manage its climate risks through adaptation depends on a number of critical factors including its baseline and projected economic resources, technologies, infrastructure, institutional support and effective governance, public awareness, access to the best available scientific information, sustainably-managed natural resources, and equity in access to these resources.

Adaptation and disaster risk reduction, previously academic topics of interest only to specialist groups, are now common currency in policy debates, the media and public dialogue (Moench and Dixit 2007). Disaster risk reduction can be defined as action taken to reduce the risk of disasters and the adverse impacts of natural hazards, through systematic efforts to analyse and manage the causes of disasters, including through avoidance of hazards, reduced social and economic vulnerability to hazards, and improved preparedness for adverse events.

Resilience is being widely discussed and applied in many different contexts, under different disciplines and themes, therefore with different focus and specifications, but always maintaining common elements. For example resilience in the context of disasters reduction is defined as the capacity of a system, community or society to resist or to adapt to change, and to achieve acceptable function and structure (UN/ISDR 2002). For Tobin (1999), comprehensive planning for sustainability requires changes in the structure of society, and in its culture of thinking, to accommodate hazards within the framework of day-to-day affairs.

Society depends on a range of infrastructures and services, preventing their interruption and restoring their operations becomes an important concern for public policies. From that perspective resilience can be defined (with variants) as the capacity of infra-structure, service and social systems potentially exposed to hazards from events to adapt either by resisting system degradation or by readily restoring and maintaining acceptable levels of functioning, structure and service following an event (Bruneau et al. 2003). Today the economy is highly dependent on a complex system of production and distribution of resources and services, including the electric grid, water supply, telecommunications, emergency services, and transportation network, which are critical infrastructures. Klein et al. (2003) note that from an economic perspective, sustainability is a function of the degree to which key hazard impacts are anticipated.

Adaptive strategies involve mechanisms to encourage groups to learn from each other through social learning and to help policy reflect a range of different values and viewpoints (Stringer et al. 2006). Adaptation in the context of climate change refers to the process of adjustment that takes place in natural or human systems in response to the actual or expected impacts of climate change, aimed at moderating harm or exploiting beneficial opportunities. The world is changing quickly and in order to grow and survive, organizations and communities must learn to adapt faster (Schein 1993). More than of planning to adapt to a given impact, planning for resilience lays a foundation for ongoing adaptation efforts that can adjust and improve as new information, techniques, or conditions are encountered. What kinds of processes are needed? Processes for learning as we go; processes for checking and correcting for maladaptation as we learn; processes for making trade-offs that reflect public values; and processes for sharing information to support the trade-offs (Mcgray et al. 2007). Planning as a learning and adaptation process is therefore fundamental to generate trust, awareness and knowledge, to align ideas and goals, to shape leaderships, to produce consensus and co-accountability, to mobilize collective action and to prepare people for managing change.

4. PLANNING FOR RESILIENCE IN COASTAL ZONES

Resilience is a relatively new way of thinking about how to comprehensively manage coastal areas to reduce vulnerability. Resilience is being actively promoted as a management strategy by organizations and agencies, suggesting that planning for resilience can proactively reduce vulnerability by recognizing and accounting for the complex ecological, social, engineering, and economic links that exist in communities (Collini 2008). Resilience of coastal communities is inherently complex, consisting of numerous linked ecological, social, engineered, and economic systems occurring at various temporal and spatial scales, which are vulnerable to a range of natural and man made disturbances.

For example the combined cumulative effects of coastal over-fishing, marine pollution and coastal development are impacting the long-term productivity of the coastal zone. The clearing of coastal forests increases suspended sediments and nutrients in terrestrial run-off, causing direct and indirect effects on algal and oral growth and competition and coral reef resilience (Nystrom et al. 2000). Those situations and others may lower the capacity of these systems to support human livelihoods in the long-term, requiring effective integrated land use planning including fisheries, tourism and costal infrastructure development (Nellemann and Corcoran 2006).

Another relevant example can be found in tourism in coastal and island destinations which is highly vulnerable to direct and indirect impacts of climate change (such as storms and extreme climatic events, coastal erosion, physical damage to infrastructure, sea level rise, flooding, water shortages and water contamination), given that most infrastructures is located within short distance of the shoreline. This high vulnerability often couples with a low adaptive capacity, especially in coastal destinations of developing countries, leading to disasters and stressful events (WTO and UNEP 2008). Coastlines are economically of outstanding importance not only for tourism, but also for a large share of coastal fisheries, providing a large range of ecological goods and services, from which coastal communities depend (Moberg and Folke 1999).

Coastal communities around the world are experiencing an unprecedented rate of change due to population growth in coastal areas, human-induced vulnerability, and global climate change. The effects of this change are placing communities at increasing risk from coastal hazards such as tsunamis, severe storms, and shoreline erosion. It also has become evident that even without a major catastrophe such as a large tsunami, most coastal communities are not resilient to normally recurring hazards (US IOTWSP 2007). Policymakers, developers, and property owners are not fully aware of the present and future risks associated with coastal development. Priority must be placed on providing local governments with the capacities and tools they need to adapt land use and infrastructure for an uncertain future (The Heinz Center and Ceres 2009).

Community resilience can be defined as the community's ability to withstand and recover from disturbances. Even in the case of a widespread emergency, residents can meet their basic needs including food, water, energy, transportation, housing, and economic and social services (Bay Localize 2009). The Community and Regional Research Initiative on Resilient Communities (CARRI) defines resilience as a community or region's capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to public safety and health, the economy, and national security (Colten 2008). Enhancing community's resilience is to improve its capacity to anticipate significant multi-hazard threats, to reduce overall the community's vulnerability to hazard events, and to respond to and recover from specific hazard events when they occur. Coastal resilience as a planning approach is highly cross cutting because it incorporates elements of land use, hazards mitigation, resource protection, community cohesiveness, cultural preservation, etc.

Coastal community resilience can be strengthened by decreasing the probability that a hazardous event will become a disaster, avoiding or mitigating the potential effects of a disturbance, and/or facilitating recovery after a disturbance has occurred (McCarthy et al. 2001). Prospective disaster risk management should be integrated into planning and management of coastal zones. For example the rise of sea levels will place great strain on coastal communities (UNDP 2004). Most coastal communities are highly dependent on natural resources, which make them particularly vulnerable to changes in resource conditions.

Coastal resilience is also a place specific. For example in more populated central and southern Asia, sea level surges and increased intensity of tropical cyclones could result in the displacement of tens of millions of people from low-lying coastal areas (UNDP 2004). One of the main lessons in the aftermath of the tsunami of 2004 in Southeast Asia - and seen in other coastal hazards stemming from poorly planned development - is that single-sector development planning cannot solve the complexity of problems posed by natural hazards nor build resilience to them. Resilience requires the spreading of risk and the development of integrated and holistic prevention and management programs (US IOTWSP 2007).

The harm associated with climate change falls disproportionately on poorer nations and communities: whereas the wealthy may lose some wealth, the poor risk losing their livelihoods and lives. Poor people often tend to live in fragile or degraded environments and have livelihoods that are more dependent on ecosystem services. With fewer resources from which to draw during periods of stress or crisis, they are more vulnerable to increasing frequency and intensity of weather extremes, seasonal shifts in precipitation, sea level rise, and other observed or predicted effects of climate change. Supporting adaptation measures in poor communities is an urgent priority (Mcgray et al. 2007).

Adapting to coastal impacts will require adapting to more frequent or more severe short-term problems such as increasing episodic coastal flooding and storm damage while also taking into account the long-term problem of increasing mean sea level, which threatens to permanently inundate low-lying areas. Adaptation to climate change can take three forms. Accommodation involves altering current uses of the coastline in response to changes in coastal oceans and environment, such as by raising the height of piers and placing shoreline buildings on pilings. Protection involves fending off the impacts by building structures like seawalls and dikes that keep the sea from intruding on coastal structures. Retreat involves avoiding the harmful effects of rising sea level by abandoning coastal sites and moving to higher ground (Binder et al. 2009). Building more permanent and robust housing and infrastructure may enhance the resilience of coastal communities while fitting a broader set of development needs—placing it more centrally along the continuum (Mcgray et al. 2007).

A common characteristic of resilient communities is that they accept that disaster events will occur and they take necessary steps to plan for them. Land use management and structural design are excellent examples of planning activities communities can use to minimize potential impacts of tsunami and other coastal hazards. In order to contribute to a community's overall resilience, both land use management and structural design practices must consider the community's vulnerability to all coastal hazards while minimizing impacts to natural resources. When used in combination, these related risk reduction strategies are very effective mechanisms for enhancing community resilience (US IOTWSP 2007).

5. FINAL CONSIDERATIONS

Coastal resilience is a new way of thinking about how to better protect coastal communities from a range of natural hazards. Resilience incorporates elements of coastal management, emergency response, and community development. Resilient communities understand the hazards they face, take specific and coordinated actions to reduce their vulnerability, and develop response and recovery plans to facilitate a quick response and effective long term recovery should a disaster occur (Collini 2008).

Sea level rise, temperature increases, changes in precipitation patterns and other climate-related changes are expected to occur and to become increasingly more severe over the coming decades. The need to adapt to these climate-driven changes and to better manage existing coastal risks is obvious and immediate (The Heinz Center and Ceres 2009). The resilience perspective shifts policies from those that aspire to control change in systems assumed to be stable, to managing the capacity of social–ecological systems to cope with, adapt to, and shape change (Berkes et al. 2003; Smit and Wandel 2006). Resilience is an approach to managing systems that takes into account social, ecological, and economic influences at multiple scales, accepts continuous change, and acknowledges the level of uncertainty (The Resilience Alliance 2007).

Even though climate change affects countries differently, all countries will need to perform many of the same adaptation functions, such as climate information management and public engagement in adaptation planning (WRI, 2009). Emerging consensus is driving the recognition that any effective development planning process will need to take climate change into account—and, more particularly, will need to facilitate adaptation to the effects of climate change (Mcgray et al. 2007).

The stake of sustainable development depends more and more on the capacity of social and ecological systems to support disturbances and persist in the long term, meaning that resilience is a critical property for sustainability. Sustainable development challenges societies, organizations and individuals to learn to deal with high levels of uncertainty, long time horizons and the interaction of ecological, social and economic systems as well as multi-level thinking to link local, regional and global perspectives (Siebenhüner 2005). The resilience lens accept a world where multiple scales and stakeholders interact along the time and space, where many pathways can be found and shaped, where change can be incremental or irregular, where several points of equilibrium might occur, regardless its human desirability.

Planning for resilience is not to be seated waiting for disturbances to happen, in order to cope with their impacts. Planning for resilience is all about being pro-active, focusing on learning processes (individual, organizational and social), being less dependent on laws, regulations, strategic goals and bureaucratic procedures, which can bring order and orientation but also inflexibility, inefficiency and conflict, instead of adaptive capacity, anticipation and motivation. Resilience can be enhanced through planning processes in order to prepare the coastal areas to adapt and to cope with disturbances and crises. The resilience framework is emerging as an alternative path for dealing with sustainable development issues, in a more interconnected world under greater pressure and turbulence. And that is why resilience is a crucial property for coastal zone management and planning has a crucial role in sparking learning and adaptation.

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DEVELOPING ADAPTATION STRATEGIES DUE TO CLIMATE CHANGE : WITH SPECIAL REFERENCE TO THE VULNERABLE SMALL SCALE FISHERIES SECTOR IN CENTRAL JAVA-INDONESIA)

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ABSTRACT

One of the densily populated province in Indonesia is Central Java. Propulation of this province is about 34 million persons. It shared for significant role in man-powering fisheries sector in Indonesia. The situation of vulnerable fisheries resource somehow made fishers and other parties (who engaged in fish production-chained) uneasy and uncomfortable. As of now, many parties might not prepared sufficiently for climate change. In Northcoast part of Central Java, there are several important landing places. From several landing places signaling affected by climate change.Therefore, indeed need to outline the strategy on mitigation and adaptation for the climate change in fisheries sector.

The main objective of the study is to outline the strategy on mitigation and adaptation for the fisheries sector due to climate change shock. Primary data are collected from fishers in the study area with suitable sample frame. In addition, discussion with key-persons and other competence persons also be carried out, while secondary data are used to enrich the analysis. The study employed a GIS in marine meteorology (Hartoko and W. Sulistya, 2009) and socio-ecnomics approaches (Susilowati et al., 2004, 2005; 2007; 2009) with necessary modification.

Several salient findings of the study, among others are: (1) evidence of climate change in some extents of small scale fisheries in Java, Indonesia; (2) evidence of the impact on vulnerable fisheries in the selected pilot projects; and (3) a short term prescription on mitigation and adaptation strategy to cope the climate change in small scale fisheries sector in the study area.

1. INTRODUCTION

Indonesia covers a vast archipelagic area consisting of more than 17,000 islands stretching about 5,000 km from East to West and about 2,000 km from North to South with a coastline of 80,000 km. The Indonesian archipelago and territorial sea covers an area of about 3.1 million sq.km, excluding 2.7 million sq.km area of marine waters which is under the Exclusive Economic Zone (EEZ) (Anon, 1983). Therefore, Indonesia has large marine resources with various stocks of fish and other marine animals. The total area of Indonesia is about 1,919,317 sq. km with a total population of about 210 Million in 2009 with a growth rate is 2.34% per annum (BPS, 2009).

The climate of Indonesia is similar to the other countries of Southeast Asia like Malaysia, Singapore, Thailand, and the Philippines in the past decades The surface current for Indonesian waters is strongly influenced by currents from the Pacific Ocean and the Indian Ocean (Bailey et. al., 1987). In addition, the surface currents are also greatly influenced by the winds of the prevailing monsoons. North of the equator during November through March, the monsoon winds come out of the Northeast. From June to September, the Southeast monsoon dominates, marked by currents flowing in a north-westerly direction around Australia and the island of New Guinea. During this period, the circulation of surface waters is reversed through the Banda, Flores, Java and South China seas. The Southeast monsoon is relatively milder than the Northwest monsoon as described by several authors (Wyrtki, 1961; Soegiarto and Birowo, 1975; Salm and Halim, 1984 and Bailey et. al., 1987). But nowadays this conditions might changed due to global warming and/ or climate change.

Global Climate changed is happening in all over the world and gave a significant impact on to the fisheries sector. In fact, this sector in Central Java province plays an important role due to become as the economic grassroot's driver. Involvement of fishers are dominant. However their production is relatively inelastic. They are powerless in accessing information on economic, politic and social aspects (Susilowati et al., 2004; 2005; 2009). Thereby, the micro- and small-scalers in fisheries sector are less adaptive towards the climate shocked.

The past 25 years since 1980 to 2008, a significant impact of climate change in terms of ecological or oceanographical variables had been detected. This is such as the Sea Surface Temperature (SST) positive anomaly, the seasonal extreme changes of ocean wind , wave height, etc. Which is in turn had also influence to the change of nutrient cycles, microbial, planktonic and larval community, fish behaviour such as spawning cycles, and ultimately to the marine fish production. More specific are to the most vulnerable demersal and small pelagic fishery in Java sea. Also the effect of climate change to the change of fish seasonal and spatial distribution. Based on the fact that the sea surface temperature (SST) is one of the limiting factor for some small fish communities, and some other species is known as seawater temperature conformer. SST data then was processed into a spatial distribution pattern, where so far one can not be able 'to see' the actual state of the sea surface temperature or other ecosystem parameters spatial distribution.

2. MATERIALS AND METHOD

The main objective of the study is to find out the evidence due to climate change shock toward the fisheries sector (with special reference to small-scalers) in Central Java, Indonesia. The specific objectives are: (1) to identify the climate change evidence in fisheries sector; (2) to analyse the vulnerability of fisheries sector; (3) to explore the impact of climate change on fisheries sector in the selected pilot projects; (4) to formulate a strategy on mitigation and adaptation for the fisheries sector. The main data used in the study are marine meteorology indicators such as wind speed and direction, sea surface temperature (SST) for 30 years, 1971–2000 which were collected from National Center for Environmental Prediction (NCEP). The primary data were collected from fishers in the study area with suitable sample frame. Discussion with key-persons and other competence persons also done accordingly. The study employed a GIS in marine meteorology (Hartoko and W. Sulistya, 2009) and socio-ecnomics approaches (Susilowati et al., 2004, 2005; 2009) with necessary modification.

The study area are located along the North coast of Java sea with 22 stations. Marine meteorological data from NCEP was sampled on a monthly- and yearly-basis for a series of 1971 to 2000. The phenomena of climate change and vulnerability of the fisheries resource are estimated using the digital layer for the ecosystem model was transferring 'geodetic/ position data' (degree; minute; second / D˚ M' S") of latitude and longitude data into a single-numerical value with the following formula.

Numeric Value (Lat; Long) = Degree + {minute + (second/60)}/60

Then the Y (latitude), X (longitude) and Z data (ecological parameters) was grided using Er_Mapper ver 6.4 software. The world geodetic system (WGS84) for geodetic datum and Geodetic for map projection was used in the digital mapping processes. Grided layer of SST was then displayed in a standard spatial data presentation. The necessary indicators of GIS in marine meteorology which may affected by the climate change then will be socialized to the competence persons including the fishers. Empowerment strategy (Susilowati et al., 2004; 2005; 2009) was applied to disseminate and to educate the fishers in their activities in anticipating the climate change in the pilot study.

3. RESULTS AND DISCUSSION

3.1. Seasonal Pattern and Climate Zonation of Java Sea.

North coast of Java from Jakarta, Losari (Brebes) upto Margoyoso (Pati) in general has D3 climate type, with four wet month and 3– 6 dry months. From Juwana (Pati), Rembang to the East of Java has type E3 climate with only one wet month and 6 dry month and E4 type with only one wet month and 7–8 dry months. Based on geographic distribution several areas such as Pati (it is located just near of Muria mountain) during the west (wet) wind or Leeward Side has a smaller possibility for rain compared with other area along the North coast of Java (B Tjasyono,1993). Other coastal area which located just next to a mountainous area such as Batang, Kendal dan Semarang have a more possibility to have a longer rain period in a year, about 6 months. North coast and Java sea in general has a longer dry season than the wet season. During wet and dry season Bulukumba, Pemalang, Petarukan, Batang, Tulis, Grinsing, Kaliwungu, Tugu, Tanjung Emas have more than about 7 months in a year.

3.2. Wind Variability in Java Sea

Wind pattern in Java sea is basically dominated with Eastern wind during the dry season from April to Oktober, and west wind during Nopember to March. The highest East wind speed recorded during August and the highest west wind was in Januari (see Figure 1). While the first seasonal transition during March and April, transition 2 was in Oktober and Nopember. In general central of Java sea has a higher wind comparred to the west or the east part of Java sea. Based on the the monthly wind analysis then the peak of the west wind was recorded in January is in line with the winter in Asia and the peak of the east wind in August. This is similar to the winter in Australia. The transition of those two seasons were recorded during March-April and October-November. The wind pattern in Java sea in general was influenced by the seasonal pattern in Asia and Australia. During the winter in Asia in Indonesia would by dominated by Asian wind which is called the South East Monsoon or the west wind, and in the same time most of Indonesian region has the rainy season, including the Java sea. When Australia has a winter, in Indonesia was dominated with the South East Monsoon or the East wind. When most of Indonesia has a dry season including the Java sea would be influenced by the Asia – Australia monsoon as in Fig 2 and 3.

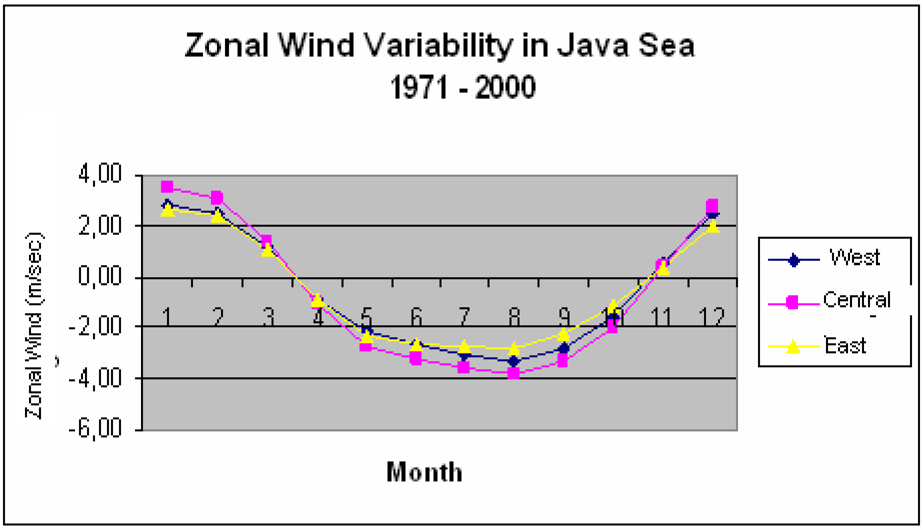

Figure 1 : Monthly Wind Pattern in Java Sea year 1971 -2000

The seasonal wind and wave pattern in Java sea is influenced by West monsoon (Dec–March) in Figure 2 and East Monsoon (April – November) in Figure 3. West monsoon or known as wet season usually identical with strong winds and followed by high waves. Impact of climate change to seasonal wind changes is mainly changes in terms of day to day strong wind periodes espescialy during the West Monsoon, and make difficult for fisherman to access for such real time information. Based on average of 30 years data is remain the same. The East part of Java sea as indicated in the black zone in Figure 2 in average has a stronger wind speed, about 3–4.5 m/second during the West Monsoon, thus will have higher waves.

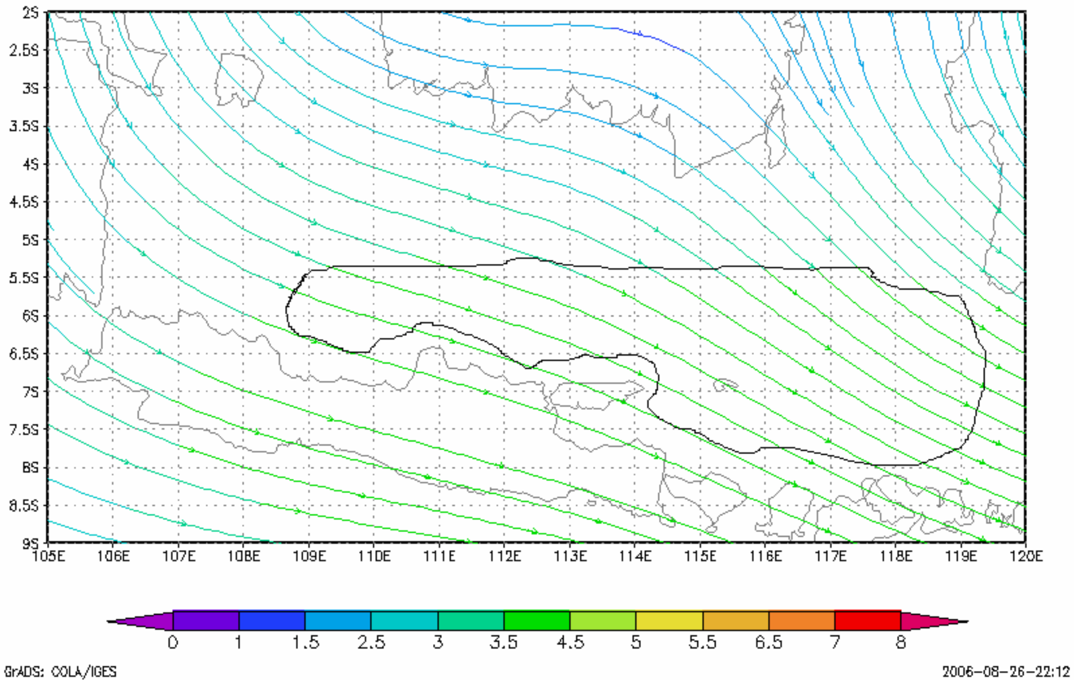

Figure 2 : Average wind pattern/ direction during December - February
Year 1971 -2000.

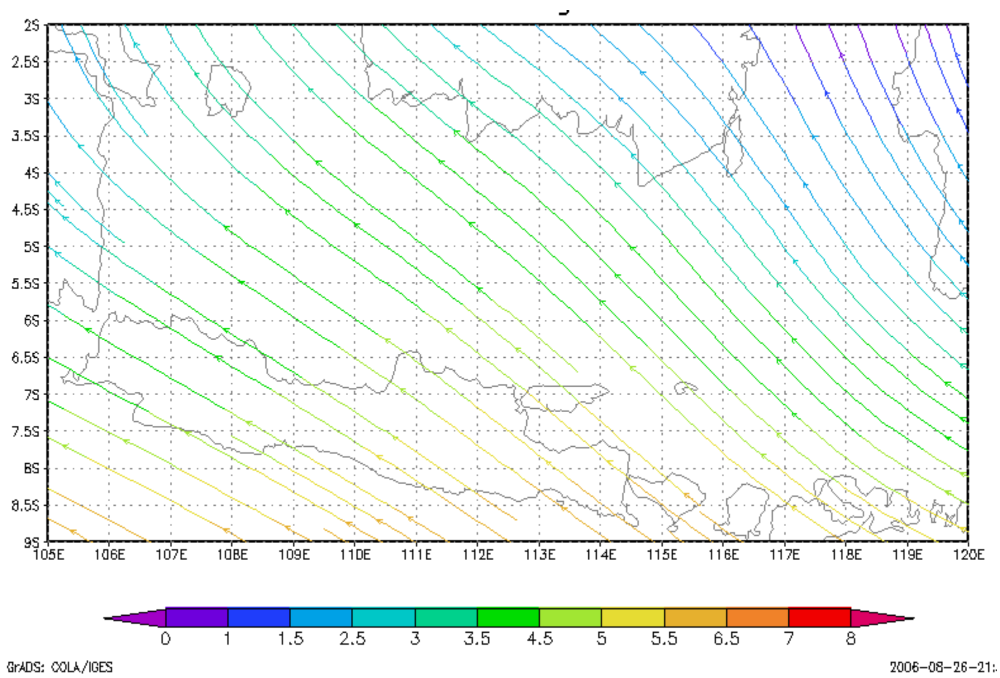

Figure 3 : Average wind speed direction during East Monsoon : Juni - August
Year 1971 -2000.

3.3. Variability of Sea Surface Temperature of the Java Sea

The role of of sea surface temperature (SST) is important since it is the interface from the atmospheric to the oceanographic environment. Based on three coordinate (represent the west, central and east region) data recorded from 1971 to 2000, then the range of SST in Java sea is 27,48 ^{0}C to 29,66^{0} C as in Figure 4. The highest SST in the west region was recorded in May and the lowest in February. While highest SST in central region in May and the lowest in August, and highest SST was in April and lowest in August for the East region. In general there were two peak and two crest for SST in a year periode. The first peak was during April – May and the second in, with the first low SST in February and the second in August. There were two cycles of low (February and August) and high (May and November) SST in avearage for 30 years (1971 -2000) as in Figure 4.

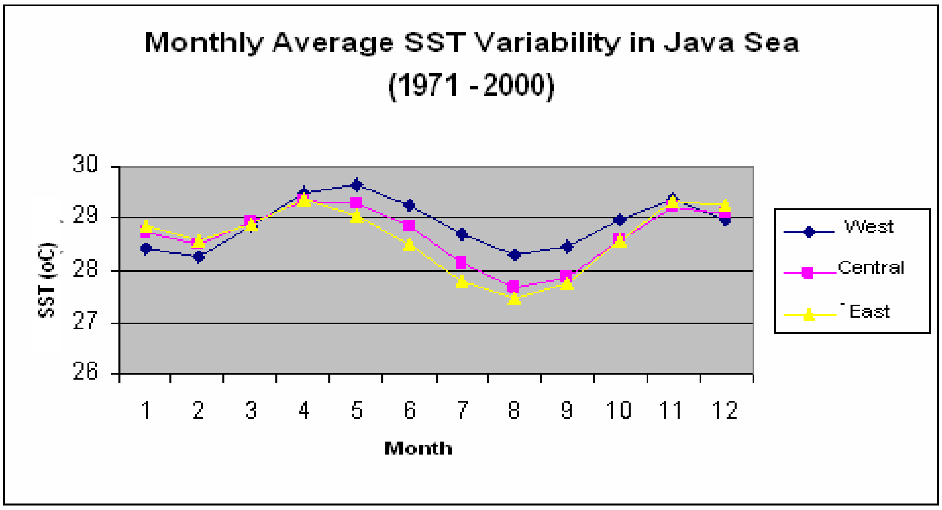

Figure 4. Average monthly SST in Java Sea year 1971–2000.

This SST cycles is an indication of reflection of the seawater oscilation in coincidence with the sun position. The sun will be on the equator during March and September; and on January the position of the sun would be in the *Southern Hemisphere* then in the *Northern Hemisphere* is on July. The maximum SST in May and November when the sun leaving the equator and the minimum SST in February and August when the sun in the far distance. The two cycles of SST (maximum and minimum) each has a six month periode. Other than in coincidence with the position of the sun, the SST variability of the Java sea was also influenced by the monsoonal changes. Basically the monsoonal pattern can be classified into the South East monsoon (April – October) with the wind blows from Australia bringing cooler seawater mass, and during November – March wind blows from Asia.

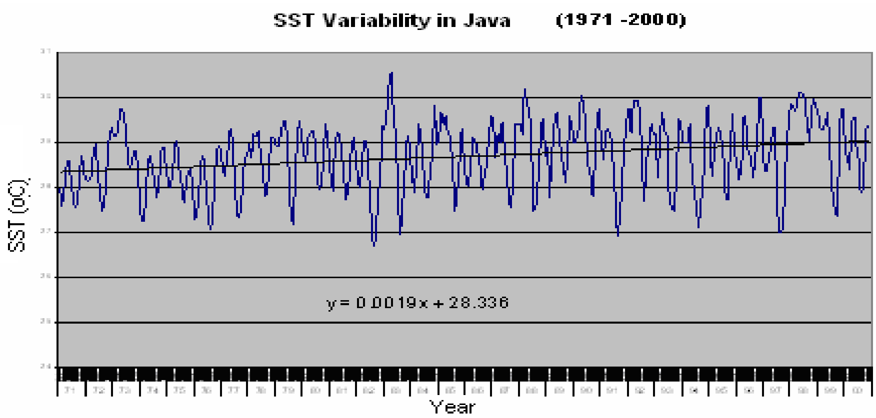

Figure 5. Variability and increasing trends of SST in Java Sea Year 1971 -2000.

The most important analysis on SST variability has been done that is the yearly SST variability for 30 years based on data from 1971 to 2000. During the periode before 1980, the anomaly of SST was in below normal, or cooler than its average value. In fact, after 1980 indicates an SST anomaly is above normal (above its average) as shown in Figure 5 and 6. This means that the SST of the Java sea was tends to increase after 1980.

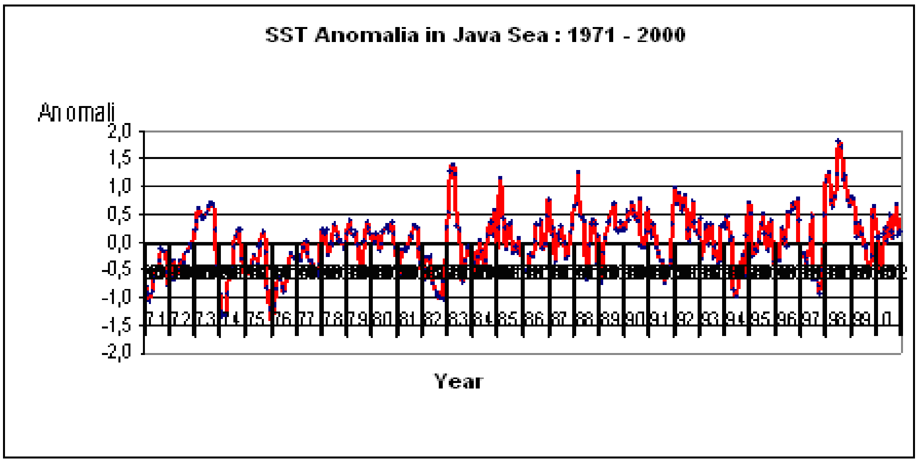

Figure 6 : Monthly SST anomaly in the Java Sea Year 1971–2000.

The global ocean phenomena of that is *global warming* effect. On the basis of small scale fishery resources point of view, SST anomaly of 0.5 ^{0}C (positive and negative) is still tolerable, which is happened until 1980. But SST anomaly up to 2.0 ^{0}C and could be more for the future as in Figure 6 is regarded would be harmfull for small scale fishery resources. That is related to the temperatuare tolerance of microbial, planktonic, larvae, and fish biomass, and the extreme SST anomaly is regarded since 1980.

3.4. Java Sea SST and Sea Water Spatial Distribution

During the winter periode in Asia, a warm seawater inflow from South China sea towards Java sea. The effect of this water mass spread over to the strait of Makassar also in the north of Lombok island in February (Figure 7). This means one month delay after the peak monsoon domination in January. But other perspective there is also a seawater input flows into strati of Makasar from Pacific ocean which is called *Indonesia Through Flow* (Susanto, D and J Marra, 2005).

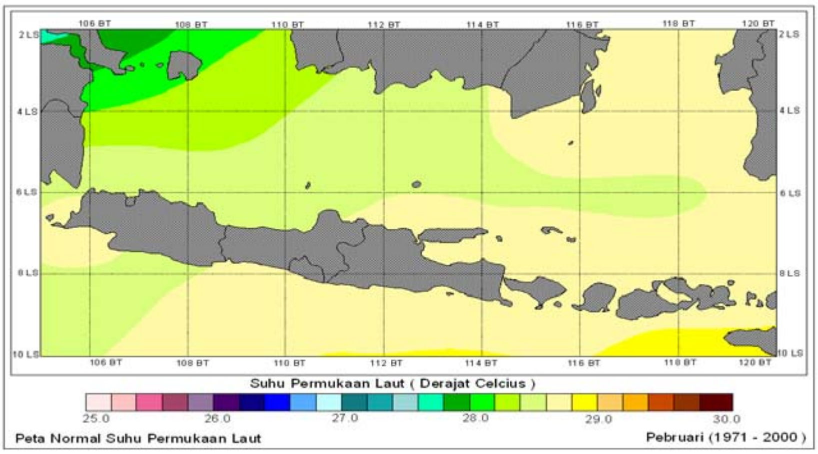

Figure 7: SST (^{O}C) and Sea Water Spatial Distribution during West oonsoon (February), year 1971-2000.

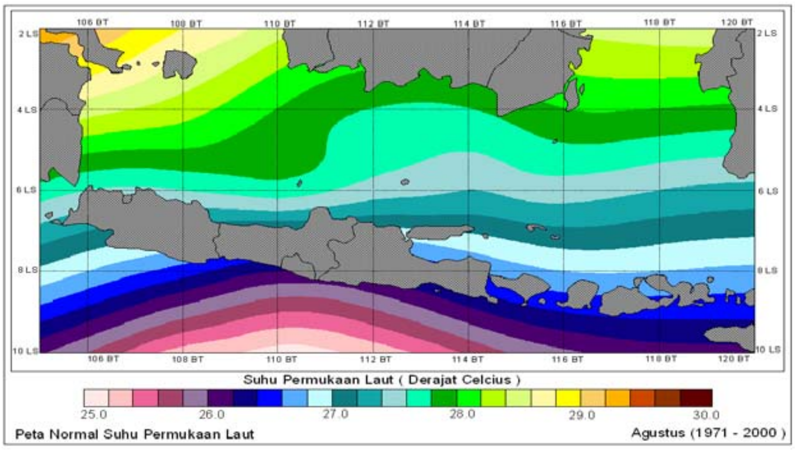

Figure 8. Spatial distribution of SST (^{O}C) East Monsoon (August) in Java sea, Year 1971-2000.

During the east monsoon a cooler seawater mass flows from the north of Australia and Indian Ocean into the Java sea (Figure 8), espescially during Agustus. This cool seawater mass flows into Java sea through Lombok and Bali strait and spread over to the north in Karimata strait. The phenomena was also reflected with the surface water current during the west and east monsoon (Wyrtky, 1961 and 2005). Susanto D and J Marra, (2005) postulated that interannual variation of SST in Indonesia was also affected by ENSO. This was reflected in the periodic cycles of SST in the Java sea, beside a seasonal, but also yearly and 8 years variation. But up to this date there were less interaction *Dipole Mode* phenomena originated from Indian Ocean to the El Nino/La Nina from SST variation in Pacific ocean (Sulistya W., A.Hartoko, S.B.Prayitno. 2007a).

3.5. Vulnerable Fisheries

The more vulnerable demersal small scale fisheries, such as shrimp and mollusc fishery (Hartoko, inpress 2010c) comparred to small scale pelagic fishery (anchovies, Rastrelliges sp, Euthynus.sp; sardine, etc (Hartoko et al, 2000b) and its long term annual catch variation (Hendiarti, 2005). The long term effect is the need for a more specific and detail research in the effect of seawater temperature increase to the spawning rate, cycles, seasonal breeding cycles. Such as to the flying fish community in the south of Sulawesi. The phenomena of vulnerable fisheries in Java sea is shown in Figure 9.

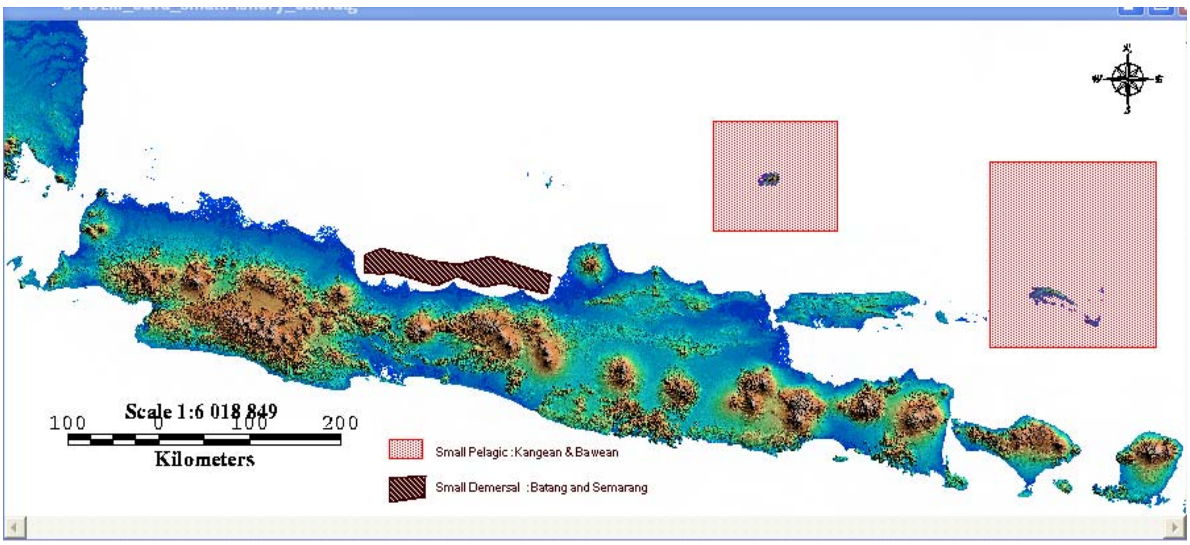

Figure 9. Small Pelagic and Demersal Fishery in Java Sea

The vulnerable small scale fishery resources based on the above spatial distribution pattern can be divided in two parts, the first is small scale demersal shrimp fishery espescialy in Semarang coastal area. The second is small scale pelagic Rastrelliger.sp fishery around Kangean and Bawean islands (Figure 9). To this case, one of approach can be prepared for those two kind of fishery is the development of Fish Aggregating Device (FAD), in order for protection, adaptation and rehabilitation against extreme seawater temperature anomalies.

3.6. Adaptation Strategy

The fisheries stock in Java sea is found to be declining (Squires et al., 2003; Susilowati et al., 2004b), particularly in the densily populated area. This is due to a heavy fishing efforts have been put on by fishers with multi-gears in all the time. In addition, the impact on vulnerable fisheries in fish stock and environment quality toward the economic gain of micro-and small-fish processors in the pilot study (Pekalongan, Central Java) was significant. The performance of fish processing industry were estimated by several indicators such as costs and returns, productivity and intensity of empowerment (Susilowati et al., 2008; 2009).

In general the economic gained by fishers (micro- and small-scalers of hunter and processor) in the pilot project were marginalising and tend to be dissipated particularly due to a fragile of the stock supplied to sustain the food security due to climate change. Mostly fishers observed in the pilot project were not able to predict their production activities successfully due to they are powerless (Susilowati et al., 2004; 2005). On the other hand, the behavior of fisheries resource has changed vulnerably inline with the global change. Therefore, it is indeed need to provide a sufficient prescription to waken the micro- and small-scale of fishers in adjusting their behavior and habits towards the vulnerable changes in fisheries resource behavior through an empowerment strategy (Susilowati et al., 2008; 2009; Waridin and Susilowati, 2009). This study proposes that the salient indicators of marine meteorology and geophysics (among others are seasonal pattern and climate zonation, wind variability, variability of sea surface temperature, sea water spatial distribution, etc) should be disseminated to the fishers and the competent parties as a public information. Thereafter, fishers will be well informed about the current of vulnerability of fisheries resource. Moreover, the fast action on the campaign program (by all means), necessary training simulation, extensions program, etc need to be designed and launching accordingly by the competent and relevant stakeholders.

4. CONCLUDING REMARKS

It is hardly to convince to the grassroot community (including fishers, farmers, etc in which majority are conventional and/ or traditional) in short terms regarding to the affection of climate change towards the change of behavior of fisheries resources. Nevertheless, this is urgently to be done in the study area with specific prescription and also to the fishers in general in Indonesia.

Small-scale fisheries sector which is mostly composed by fisher with 5–30 GT engine fleets is mainly party who affected by the vulnerable fisheries phenomena in Java. At the moment, the small-scale of fishers (hunter, processor, traders, etc) are powerless. They likely have not aware and neither well informed about the indicators or database of marine or vulnerable fisheries. Therefore, empowerment action to the competent stakeholders (academician/ NGO; business, Government; Community) need to be launched simultaneously and integratedly. With a help of the Department of Fisheries, A Board of Meteorology and Geophisics; Office of Community Empowerment; Department of Agriculture; Department of Industrial and Trade; and the Local Government in the respected regions, thus the powerment action indeed need to be done shortly. Lastly, co-managment approach seems will provide a good promise.

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AN ADAPTATION STRATEGY FOR SEA LEVEL RISE IMPACT ON COASTAL CITIES: A CASE STUDY, SOUTH WESTERN COASTAL REGION OF BANGLADESH

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ABSTRACT

Climate change will possess risk including increased temperature and sea level rise. Coastal zones are particularly vulnerable to climate variability and change. Furthermore, the negative impacts of climate change on coastal zones are increasing. As a result, a number of changes have been observed, including the loss or reduction in productivity of certain forest and agricultural land, increased flooding and salinity intrusion. There is a need to enhance resilience to current climate and to be better prepared to respond and adapt to impacts of climate change. In some cases, though, these changes may occur gradually providing time for adaptation. Adaptation to climate change will therefore have very important social and economic implications. The potential for developing climate change adaptation measures has become a recent focus for research. Moreover, research is needed to establish the scenarios under which the process of mainstreaming can be most effective. Current land use policies can determine whether an area will be developed in the near future hence, officials should begin today to consider options for averting adverse consequences of sea level rise. The most important decision will generally be determining which areas should be protected with dykes and which should be allowed to flood.

The study aims mainstreaming climate adaptation into coastal zone management to facilitate policy development. Here adaptation has been limited to structural adjustment for the existing dykes against sea level rise (SLR). South west coastal region of Bangladesh has been selected as the case study area for the implication of adaptation measures. The topography of the area is flat and gently sloping towards the sea. The river system is very complex and is affected by the downstream tidal fluctuation. Moreover, the severity of the storm surge has increased because of climate change causing failure of existing flood control structures. Salinity intrusion is a major problem in this area and it may increase due to SLR. Most of the area is covered with dykes against river flood.

To evaluate the adaptation measures, hydrodynamic and newly developed river salinity transport model have been simulated with different scenarios for the coastal zone. The hydrodynamic model uses the one dimensional unsteady dynamic wave form of St Venant's equation for river flow simulation and two dimensional unsteady equations for floodplain flow. The river salinity model uses Advection Dispersion equation in the longitudinal case using explicit solution scheme. The scenarios include model simulation with and without existing dykes. Changes due to increased dyke heights have also been simulated as a future scenario. The existing flood scenario shows large area to be inundated from river flood. With sea level rise the flood situation will be worse and the existing dykes are not capable of protecting flood against sea level rise. The future scenario shows relation between the increased dyke height and the reduction in inundation area. The outcome of this study will help policy makers for policy making to adapt with the changed situation.

1. INTRODUCTION

Coastal zones and shallow marine regions are among the most productive systems in the world (Glantz, 1992; Mann, 1988). The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report presents some observational evidences of climate change in the coastal region. Some of the evidences are increased ocean temperatures, changes in precipitation and river flow, land subsidence, sea level rise (SLR), increased flooding and inundation etc.

Flood magnitudes and frequencies will very likely increase in most regions — mainly as a result of increased precipitation intensity and variability — and increasing temperatures are expected to intensify the climate's hydrologic cycle and melt snowpacks more rapidly (IPCC, 2007). Flooding can affect water quality, as large volumes of water can transport contaminants into water bodies and also increase transport through overloaded storm and wastewater systems. The lives of human beings and aquatic life are greatly dependant on the availability of fresh water and sea level rise can change the availability and distribution of fresh water. The water quality is a current problem in the coastal zone which is expected to be exacerbated by climate change and sea level rise. Sea level rise may also affect freshwater quality by increasing the salinity of coastal rivers and bays and causing saltwater intrusion, movement of saline water into fresh ground water resources in coastal regions resulting in decreasing water quality (Bashar and Hossain, 2006). Sea level rise may cause saline intrusion into the land and larger or more frequent storm surges may impact salinity in coastal zone. It would be more acute in the dry season, especially when freshwater flowing from rivers has diminished. Salinity intrusion due to reduction of freshwater flow from upstream, salinisation of groundwater and fluctuation of soil salinity are major factors and concerns. As a low-lying country, Bangladesh is considered as one of the most vulnerable countries in the world to climate change and SLR (IPCC, 2007). The country is experiencing rising sea level along its coast (SMRC, 2003) due to global sea level rise and the subsidence of the Ganges delta (Alam, 1996).

The causes behind flooding, water quality deterioration in coastal areas are: climate change and sea level rise, decrease of upstream flow due to the Farakka Barrage in India, expansion of shrimp farms and Coastal Embankment Project, implemented during the 1960s. This is of great concern, since the location and geography of Bangladesh makes it not only particularly susceptible to the effects of climate change, but also extremely hard to protect. The consequences of climate change lead to an increase in the cyclone-prone area and put a large number of people at risk. The impact is exacerbated by increasing human-induced pressures (Nicholls et al., 2007).

The impacts of salinity are: more land will be salinity-affected and the intensity of the salinity effect will be increased, decreased productivity of agricultural land, increased food insecurity as naturally growing species disappear, serious scarcity of safe drinking water, loss of biodiversity, e.g. decrease in tree species and freshwater fish and socioeconomic problems. There is clear evidence of increased saline intrusion in the coastal zones. For example in Bangladesh, in the coastal city of Khulna the main power station uses fresh water to cool its boilers by sending a barge upstream to get fresh water. Over the last one decade the barge has had to go further and further upstream to get suitable fresh water for the purpose (NAPA, 2005). Increased salinity intrusion due to sea level rise poses a great threat to the Sundarban forest. The Sundarban has already been affected due to reduced freshwater flowing through the Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing various species of plants and animals to be adversely affected. Increased salt water intrusion is considered as one of the causes of top dying of Sundari trees.

The most important decision will generally be determining which areas should be protected with dikes and which should be allowed to flood (Titus, 1990). Computer based mathematical model is now a well recognized tool for simulating these complex problems. Mathematical modeling has been carried out for more than three decades (Dutta, 1999). Growing needs of mathematical model made to improve its quality and technique. Traditional lumped conceptual type models cannot rightfully be claimed to be scientifically sound (Klemes, 1988). The study aims to develop a comprehensive understanding of the sea level rise impact on coastal water quality with the aid of mathematical model. This research aims determining impact of SLR on flooding and salinity and also developing flood maps for different scenarios and find out critical areas to be affected.

2. SEA LEVEL RISE AND SALINITY INTRUSION

IPCC projected 26 – 59 cm global SLR under scenario A1F1 (Meehl et al, 2007). Steffen, W. (2009) outlined that, the climate system is changing faster than it was thought earlier. From the recent observations, it is found that the SLR has increased from 1.6 mm yr^{-1} in the period 1961-2003 to 3.1 mm yr^{-1} in the period 1993 – 2003 (Church and White 2006; Domingues et al, 2008). The meteorological research council of the South Asian Association for Regional Cooperation carried out a study on relative SLR in the Bay of Bengal based on 22 years (year 1977 – 1998) measured sea-level data and observed that sea level at Hiron Point (refer to Fig. 1 for location) has been rising by 4 mm/ year (SMRC, 2003). The result showed that the rate of SLR along the coast of Bangladesh is much higher than the global rate of 1 – 2 mm/year in the last century. However, the relative sea level in the Bay of Bengal is influenced by local factors such as tectonic setting, sediment load and deltaic subsidence (Warrick et al, 1996). As outlined by Alam (1996), the Ganges – Brahmaputra delta is subsiding at a rate of 2 – 4 mm/year. There is no specific regional scenario for coastal SLR in the Bay of Bengal. In an earlier study, predicted SLR in Bangladesh was 30 – 150 cm by 2050 (DOE, 1993). The NAPA for Bangladesh recommended SLRs 14, 32 and 88 cm for the year 2030, 2050 and 2100 respectively (MOEF, 2005). The Bangladesh country study (Agrawala et al, 2003) put the range at 30 – 100 cm by 2100 (Meehl et al, 2007).

Sea level rise would generally enable saltwater to advance inland in both aquifers and estuaries which will bring more coastal area to be inundated. In estuaries, the gradual flow of freshwater toward the oceans is the only factor preventing the estuary from having the same salinity as the ocean. A rise in sea level would increase salinity in open bays because the increased river cross-sectional area would slow the average speed at which freshwater flows to the ocean (Titus, 1990). Moreover, the salinity concentration is increasing in the upper layer of the ocean (Bindoff et al, 2007). This phenomenon when coupled with reduced upstream river flow will accelerate the salinity intrusion and increase in soil salinity will have serious negative impacts on agriculture. Winter crops in the coastal area which depend on ground water for irrigation will suffer a lot. Agriculture, forestry and fisheries sector will be severely affected by increased salinity in river water and soil.

3. SOUTH WEST REGION BANGLADESH

The area is low-lying deltaic plain and is characterized by wide rivers and estuaries that allow sea water to propagate faster and to intrude far inland (Barua, 1991). The study area comprises an area of 32,280 sq. km between latitude 21˚30’ N to 24˚00’ N and longitude 88˚50’ E to 90˚10’ E. The area has four distinct seasons. The monsoon and the dry season are the main seasons. The monsoon lasts approximately from June to September. More than 90% of total annual rainfall occurs during this period where the annual average rainfall is 1,700 mm/year (ADB, 2005). The area is bounded by Ganges River in the north, tributaries from Meghna River in the east, international boundary in the west and the Bay of Bengal in the south (Fig. 1). The topography of the region is rather flat, and gently sloping towards the Bay of Bengal. Most of the area is protected with polders against river flooding. The downstream part of the area is covered with Sundarban forest. The part of Sundarban forest in Bangladesh occupies a land area of 6016 sq.km, of which rivers, streams and channels occupy 1,874 sq. km. About 70% of the Sundarbans is land and 30% is water. In order to prevent cyclonic or storm-surge flooding and to increase crop production by preventing intrusion of saline ocean water, many coastal embankment projects were initiated in the 1960s by the Bangladesh government (Choudhury et al, 2004). In coastal and near-coastal areas polders protect against saline water intrusion and tidal flooding, and to some extent against cyclonic flooding and tidal surges (Thompson & Sultana, 1996).

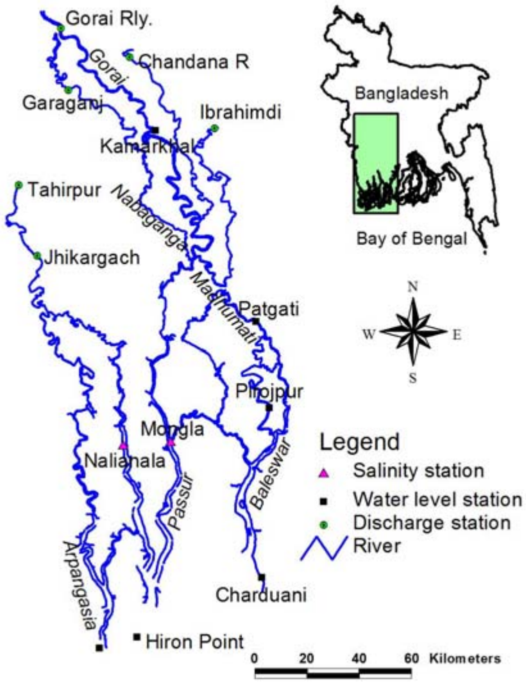


Figure 1: River network in the South West region of Bangladesh

4. INTEGRATED MATHEMATICAL MODEL

4.1. Hydrodynamic Model

The hydrodynamic model was originally developed at the Public Work Research Institute (PWRI) of Japan. The model has two components: river flow and overland flow. The model has been widely applied for flood modelling and risk analysis in many Asian river basins (Bhuiyan et al, 2005; Dutta & Bhuiyan, 2007). For simulating surface flow process, the study area is first discretized into square grids. Unsteady equations are derived from continuity and momentum equations for one dimensional as well as two dimensional flows. For river flow component, the finite difference equation for one dimensional channel flow is solved in every grid of the channel for water level and discharge. The model uses explicit solution scheme for river flow calculation. The form of momentum equation described in Dutta et al, (2004) is as below.

$$A\frac{dQ}{dt} + Q^2\frac{d\beta}{dx} - 2\beta Q\frac{dA}{dt} - \frac{\beta Q^2}{A}\frac{dA}{dx} + gA^2\frac{dH}{dx} + \frac{A}{\rho}T_r = 0 \tag{1}$$

$$T_r = \rho g A \frac{Q^2}{[\sum \frac{A}{n} R^{2/3}]^2} \tag{2}$$

where A = river cross-section, Q = river discharge, T_r = river bottom shear, H = water level, R = hydraulic radius

For overland flow component, fundamental equations of two dimensional unsteady flows are constructed from continuity equation and equation of motion. Equation 3 represents the continuity equation and equations 4 and 5 represent the equation of motion in x and y direction respectively (Dutta et al, 2004).

$$\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \tag{3}$$

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y}+gh\frac{\partial H}{\partial x}+\frac{1}{\rho}\tau_x(b)=0 \tag{4}$$

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y}+gh\frac{\partial H}{\partial y}+\frac{1}{\rho}\tau_y(b)=0 \tag{5}$$

where H = water level from datum, h = depth of water, u = flow velocity in x direction, v = flow velocity in y direction, g = gravitational acceleration, ρ = density of water, M = discharge flux in x direction ($M = uh$), N = discharge flux in y direction ($N = vh$), $\tau_x(b)$ = bottom shear stress in x direction, $\tau_y(b)$ = bottom shear stress in y direction.

The main characteristic of the model is the link between unsteady calculation in river channel and calculation of flood in river basin to reproduce the flood inundation phenomenon in large scale over the whole river system. The relation between stages in river channel and height of levee decides the points and scale of flood levee failure with unsteady calculation in river channel.

4.2. River Salinity Transport Model

A salinity transport model has been developed to investigate transport processes through estimating the advection dispersion coefficients and integrated with the existing hydrodynamic model. Both the models work in FORTRAN environment.

The transport and dispersion of solute in the longitudinal case involves a mathematical representation in the form of the following single dimensional, partial differential equation (see e.g. Fischer et al., 1979; Orlob, 1983; Henderson Sellars et al., 1990; Young and Wallis, 1992), usually known by Fickian Diffusion Equation or Advection Dispersion Equation (ADE),

$$\frac{\partial C(s,t)}{\partial t}+U\frac{\partial C(s,t)}{\partial s}=D\frac{\partial^2 C(s,t)}{\partial s^2} \tag{6}$$

where, $C(s,t)$ is the concentration of the solute at spatial location s and time t; U is the cross-sectional average longitudinal velocity; and D is the longitudinal dispersion coefficient.

The distance-time (x-t) planes for formulating explicit finite difference schemes of advection dispersion equation is shown in figure 2.

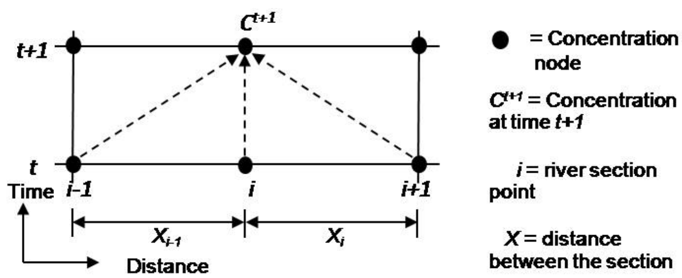


Figure 2: Distance-time plane in the solution scheme of salinity model (Bhuiyan and Dutta, 2009)

4.3. Model Setup, Calibration and Verification

The study area consists of 129,120 square grids of 500 m size. The heights of the existing polders have been added with the topography to represent the river bank protection. For river network, the Gorai river and its tributaries are considered. Three hourly discharges at Gorai Railway Bridge and Tahirpur stations are used as upstream boundary and the three hourly water level data at Charduani and Hironpoint are used as downstream boundary. Daily rainfalls at 24 gauging stations are used as internal runoff. No lateral overland flow is considered. The river network included cross-sections at every 500 m interval between Gorai Railway Bridge and Bay of Bengal. The roughness coefficients for surface were estimated on the basis of the land use types (Dutta & Nakayama, 2009). Upstream discharge, daily rainfall and 3 hourly water levels at different gauging stations have been collected from the Institute of Water Modelling (IWM).

The hydrodynamic model has been calibrated and verified for two events of the year 2002. The month of April-May is used for calibration and November-December for verification. The calibrated parameter is manning's roughness in the river. Calibration and verification were performed using the water level data at some selected stations. The roughness coefficients were adjusted by trial and error. The coefficients were found to be within 0.015-0.035. Figures 3 and 4 show the comparison of simulated and observed water level at Kamarkhali and Patgati where the water levels are measured based on the datum of the Public Works Department (PWD). The PWD datum is 0.46 m lower than the mean sea level (Tinsanchali et al, 2005).

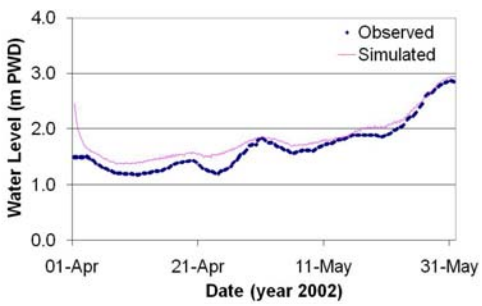


Figure 3 Kamarkhali water levels during calibration

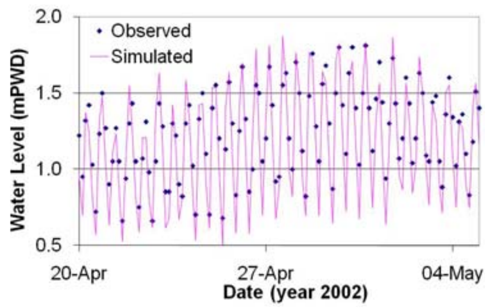


Figure 4 Patgati water levels during calibration

For verification of the model parameter, flow during the month of November and December in the year 2002 has been considered. The simulated water levels show good correlation with the observed data. Figures 5 and 6 show the comparisons of water level at Kamarkhali and Patgati for verification period.

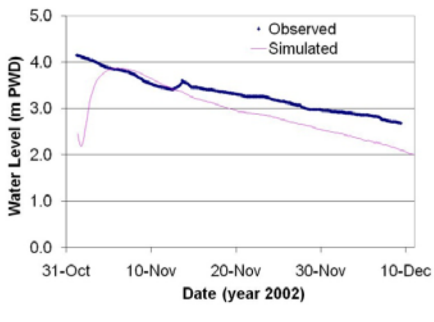


Figure 5 Kamarkhali water levels during verification

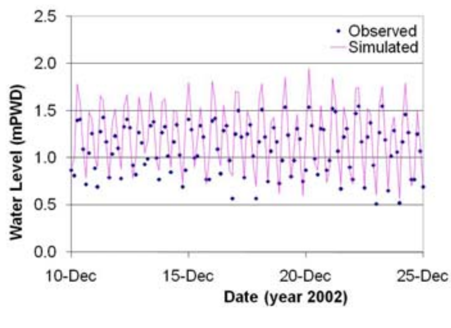
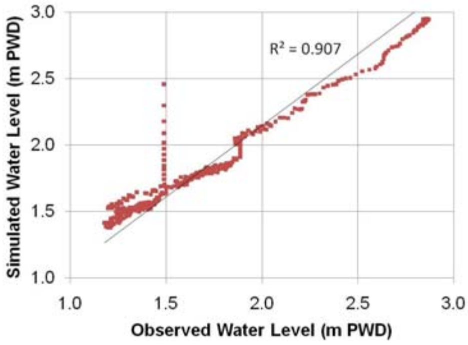


Figure 6 Patgati water levels during verification

The model performance was determined based on mean and coefficient of determination (R^2). The computed mean value at Patgati and Pirojpur were found to be almost the same as the observed mean values, with a variation of + 6% and + 9% respectively. The values of the coefficient of determination (R^2) between the observed and computed hydrograph of water level were found to vary from 0.81 to 0.91, while this value should be 1 for perfect agreement. The scatter plots of water level data for different strategies have been shown in figures 7 and 8.



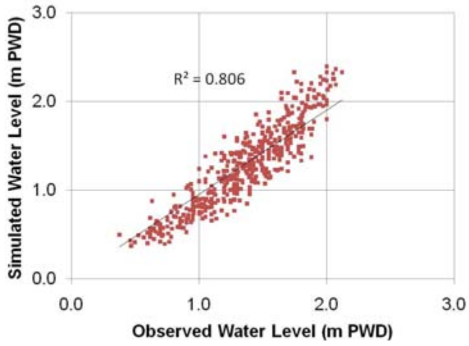


Figure 7: Scatter plot of Kamarkhali water level

Figure 8: Scatter plot of Patgati water level

The salinity model has been calibrated by adjusting values of dispersion coefficient in the river (Gates et al., 2002). Figure 9 shows the comparison of observed and simulated salinity at Mongla station where the unit is parts per thousand (ppt).

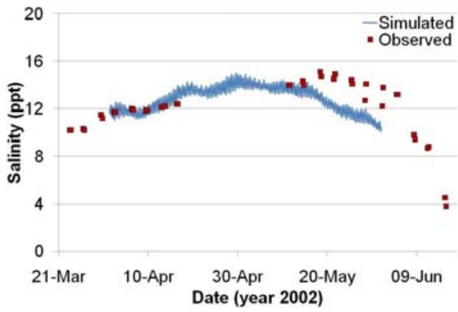


Figure 9: Salinity comparison at Mongla in calibration

5. SEA LEVEL RISE IMPACT

Due to sea level rise and considering same salinity at sea, the changes in maximum salinity at several stations have been summarized in the following table (Table 1).

Table 1: Changes in maximum salinity due to 59 cm SLR

Name of Station	**Without SLR (ppt)**	**With 59 cm SLR (ppt)**	**Salinity Increase (ppt)**
Mongla	14.9	15.7	0.8
Nalianala	16.3	17.0	0.7

The intrusion of salinity which is associated with salinity increase has been determined in the Passur river for different salinity front line and summarized in the following table (Table 2);

Table 2: Salinity intrusion length in Passur river

Salinity front line (ppt)	**Salinity intrusion length (km)**
5	25
10	7

The long profile of maximum salinity along the river length in Passur river with and without SLR has been shown in the following figure (Fig. 10).

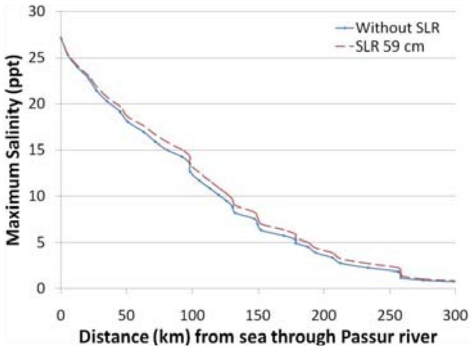


Figure 10: Long profile of salinity along the Passur river

Flood maximum depth for sea level rise condition has been shown in Figure 11. The scenarios used are with and without existing polders.

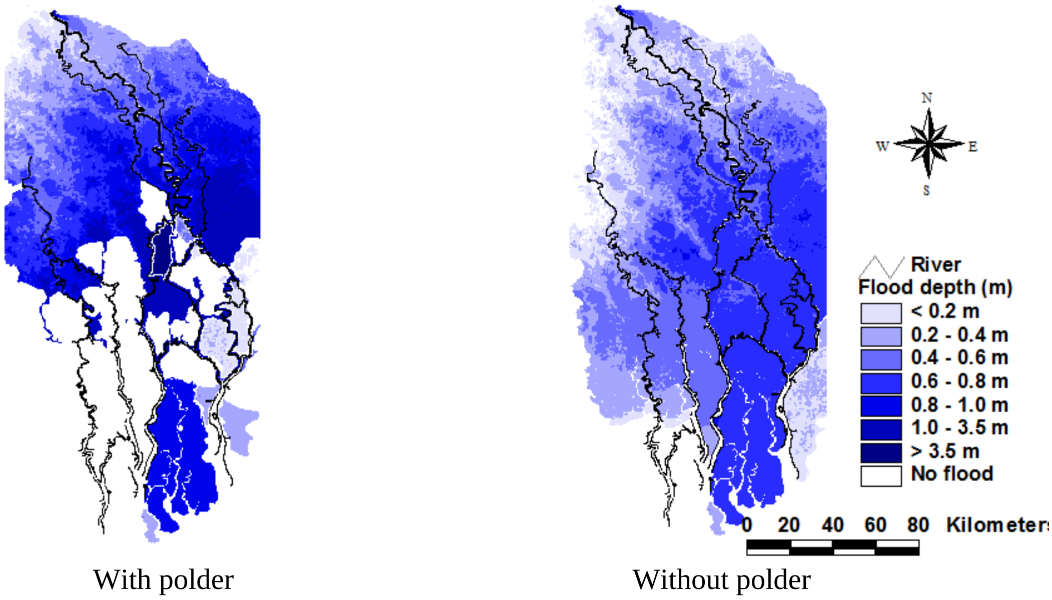


Figure 11: Flood maximum depth for 59 cm SLR with and without existing polders

6. CONCLUSION

The paper has discussed the vulnerability of Bangladesh to sea level rise on the coastal area. The aim of the study was to determine the flood impact and quantification due to sea level rise in the south western region of Bangladesh. The analysis has been both qualitative and quantitative. The results were compared in terms of river water level. The simulated extent of inundation shows significant variation of inundation extent, depth and pattern with change of SLR.

Flood depth and area were the major parameters for the assessment of flood hazard in this study. The hydrodynamic model has been calibrated and verified against the water level data. The model was then applied for flood simulation due to SLR of 59 cm. The resulting flood map shows larger area to be flooded. It indicates that the existing polders at some particular locations are not adequate to protect flood against 59 cm SLR. Breaching of polders at other locations can resulting in floods in adjacent areas.

The assessments may have many shortcomings in terms of procedures, and more research is necessary to arrive at a more reliable assessment so that a better response mechanism can be developed. For comprehensive risk assessment, more elements, such as economic activities, public services, rural growth centers and infrastructures, should be considered. This study will help the responsible authorities to better comprehend the inundation characteristics of floodplains and to protect against inundation which will help risk assessment considering flood hazard and vulnerability. In addition, people can get information about the impact of climate change and corresponding sea level rise before the real event comes. This type of study is an important part of flood protection structure and polder development work in Bangladesh.

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DEVELOPING CLIMATE POLICY IN COASTAL CITIES: LESSONS LEARNT FROM MIAMI-DADE COUNTY IN USA

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ABSTRACT

Coastal cities are particularly vulnerable to global warming effects due to precarious geographic locations and features. Based on archival survey and interviews, this study examines the formulation and evolution of climate program of the Miami-Dade County in the United States, which has initiated its local climate activities since early 1990s. By focusing on the emergence and shaping of local climate mitigation and adaptation actions, the research suggests some lessons that other coastal city governments can learn from, including developing local institutional capacity, promoting community engagement, improving governmental operations, and strengthening inter-governmental cooperation and collaboration, among others.

1. INTRODUCTION

Climate change has risen to dominate environmental and development agendas. Due to the precarious location and unique geographic features, the coastal cities are particularly vulnerable to the effects of global warming, such as the increased flooding in low-lying areas, higher risk from extreme weather events, inundation and shoreline recession, saltwater intrusion into groundwater (Downie, et al. 2009).

Although a consensus has been reached that all levels of government and society should work together to address climate change, however, the critical path from research findings to policy making, and eventually onto practice has been murky and rarely examined, which proves to be challenging for public authorities in the coastal cities (Balstad, 2005). On the one hand, coastal cities need to participate in the global efforts to mitigate greenhouse gas (GHG) emissions; on the other hand, it is imperative for the coastal cities to adapt to future changes. Given the reality of increased but spatially different climate change impacts, as well as the differences in capacity, economic costs and political will, it is of vital importance for the coastal cities to share experience and lessons learnt from the other counterpart cities that have developed and implemented climate change policies in the local area.

There are various types of institutional models influencing or guiding local-national linkage on climate change. Corfee-Morlot, et al. (2009) identify three models: nationally-led “top down” model, locally-motivated “bottom up” model, and hybrid model. In the United States, the lower-level governments are more active than the federal government in developing and implementing climate mitigation policies (Lutsey and Sperling, 2009; Corfee-Morlot, et al., 2009). The merits and weaknesses of this “bottom up” approach are well discussed in the literature. Whereas criticism has been directed at the greater decentralized US climate policy (e.g. Victor et al. 2005; Adler, 2005), some researchers emphasize the importance of the lower-level action in shaping the national climate mitigation policy and in realizing the real, long-term mitigation progress (e.g. Rabe, 2004, Bang et al. 2007; Lutsey and Sperling, 2009). A review of literature also reveals that in local areas, adaptation strategies should be implemented simultaneously and in coordination with mitigation policies (Downie, et al. 2009; Corfee-Morlot, et al., 2009).

Selecting Miami-Dade County as a case, this study analyzes and evaluates the County's climate change policy process in relation to its unique political and institutional context. The purpose is to provide a snapshot of current America's bottom-up climate change policy at the local level. More importantly, it aims to share some knowledge and lessons learnt to date in the formulation and implementation of local climate change policies.

The selection of the Miami-Dade County as a case study area is mainly due to its significance and long-lasting climate action history. Miami-Dade County is one of the most populous counties in the coastal area of the US and the most exposed metropolitan area to coastal flooding in the world (Nicholls, et al. 2003); it is one of the first 12 local governments in the world to initiate a local climate mitigation program since 1993, and since 2006, the County has introduced adaptation activities and integrated with the mitigation programs. The data for case study is based on primary literature of the County documents, journals, and reports; and qualitative, open interviews with key individuals involved in the County climate change policy making and implementation.

2. BACKGROUND

The Miami-Dade County was established in 1836. It is located in the southeastern coastal part of the United States. With over 2.3 million residents and nearly 6000 square kilometers, it is the most populous and second largest county in the State of Florida. The County includes 35 incorporated cities and many unincorporated areas which are heavily urbanized. It has a two-tier government system. The upper tier performs countywide functions for unincorporated areas, as well as certain services for the incorporated cities, such as transportation, environmental management, and solid disposal. The cities make up the lower-tier governments, providing city-type services paid by city taxes and fees. The famous incorporated cities include the Miami City, the Miami Beach City, the Coral Gables City, the North Miami City, etc.

The County's climate change action can be traced back to the early 1990s. In 1990, the International Council for Local Environmental Initiatives (ICLEI), an international association of local governments, was formed, aiming at helping its members to make a commitment to sustainable development. Shortly after the United Nations Framework Convention on Climate Change (UNFCCC) was ratified in 1992, the ICLEI initiated the Cities for Climate Protection (CCP) program[1] with a view to promoting local efforts in reducing GHG emissions and generating multiple environmental and development benefits for their communities. The ICLEI outlines five milestones that have guided the CCP program: compiling baseline GHG emissions inventory and forecast; setting goals over a specific period of time; establishing local action plan; implementing local action plan; measuring/monitoring local action plan (ICLEI, 2010). With the leadership of then County Commissioner Harvey Ruvin, Miami-Dade County became one of the first 12 local jurisdictions in the world to sign on to the ICLEI's CCP program.

A steering committee was subsequently formed to develop a strategic action plan to reduce local carbon emissions. Chaired by the Commissioner Ruvin, the steering committee was composed of 20 professionals from local governmental agencies, environmental groups, universities and business groups. On December 14, 1993, the Board of County Commissioners unanimously approved the "Long Term CO_2 Emission Reduction Plan for Metropolitan Dade County", indicating the formal inception of the County's climate change program. It should be noted that by that time, the participation in the ICLEI's CCP program was completely voluntary without legally binding targets;

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[1] ICLEI's CCP program started in 1993. It offers technical assistance, training, publications and marketing tools to support the local governments to implement voluntary GHG reduction programs, in sectors of buildings, municipal fleets, manufacturing and industrial facilities, waste management, land-use planning, renewable energy applications, transportation, and local government operations. By October 2009, the ICLEI's CCP program has more than 1100 members worldwide. The ICLEI is now officially named as "ICLEI-Local Governments for Sustainability" and headquarters in Bonn, Germany.

therefore, the Miami-Dade County has long been considered a pioneer city in reducing carbon emissions.

The County's involvement in the CCP program was formally ended in 2005. Since 2006, with more evidence indicating the negative climate impacts on the local development, the County government has adjusted its climate strategies and sought to integrate the mitigation and adaptation activities throughout County operations. Next section examines the evolution of the County's climate change program.

3. EVOLUTION OF COUNTY'S CLIMATE CHANGE PROGRAM

Miami-Dade County's climate change program can be generally divided into two phases. In the first phase, from 1993 to 2005, the Long-term CO_2 Emission Reduction Plan was implemented. The focus was on the climate mitigation action countywide. In the second phase, since 2006, more efforts have been undertaken to improve policy coordination and develop local capacities. This section presents the County's climate change policy process by mainly addressing the questions of what the two-phase program aims at, how the County has developed institutions, and how well the local climate program perform.

3.1 The Long Term CO_2 Reduction Plan (1993-2005)

Acting as a pilot project of ICLEI's worldwide CCP program, the 1993 plan set the goal of reducing Miami-Dade County's CO_2 emissions by 20% below 1988 level by 2005 through series of direct and indirect measures. Computer models were developed to estimate the annual GHG emissions based on the consumption of fossil fuels. Year 1988 was set as the baseline year. Calculated by the fuel combustion, the County's carbon emissions in 1988 totaled over 23 million tones, about 12.5 tons per capita. According to the plan, four specific areas were identified to take measures to reduce CO_2 emissions: transportation, electricity generation and consumption, land use, and solid waste management. The County thus recommended about 40 potential CO_2 reduction measures including a number of measures that fall under the state or federal regulations. Some of the measures required urban residents to change their attitudes and behaviors. The intention was to call for wider participation of potential actors, especially the active support from the state and federal governments. Table 1 summarizes the potential carbon reduction measures in the four underlying areas.

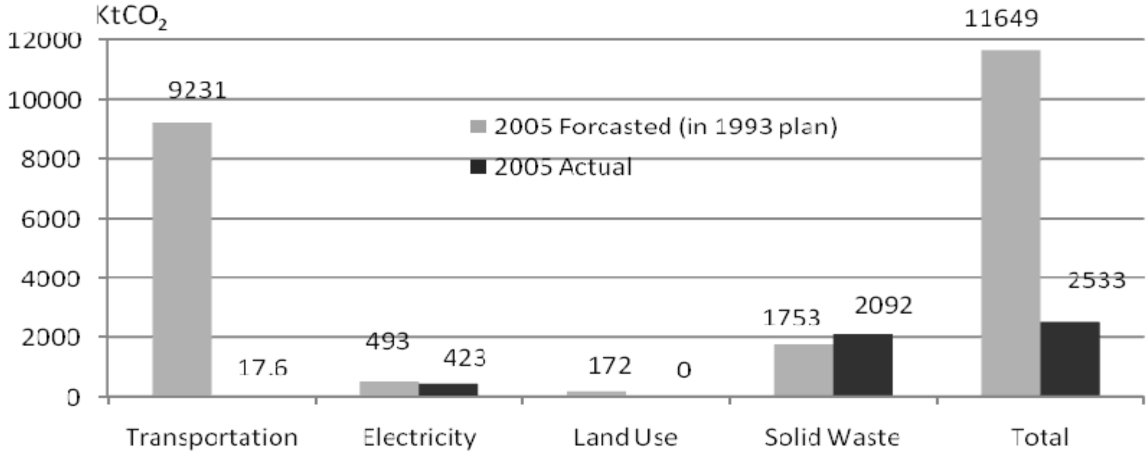
Table 1: Summary of main potential CO_2 reduction measures.

Transportation Sector	**Power Generation Sector**
- Mass transit and road improvement - Traffic demand management - Promote increased use of bicycles - Increase fuel efficiency	- Increase efficiency of facilities/operations - Expand the use of alternative fuels - Promote participation in energy conservation - Decrease residential sector energy
Land Use	**Waste Sector**
- Expand community tree planting program	- Recycle 30-50% of County's waste stream - Recover and utilize landfill methane - Reduce solid waste generated by up to 5%

Source: DERM, 1993; EPA Website

The Department of Environmental Resources Management (DERM) was responsible for administering the program implementation, under the guidance of the steering committee. The DERM was supposed to prepare annual progress report and submit to the Board of County Commissioners. This work performed well in the first few years; however, deeply influenced by the inactiveness of the federal climate change policy, from 1999 till the end of the program, only two reports were developed: one in 2001; the other in 2006. In addition, being closely linked with other programs addressing local air pollution issues and due to the DERM's limited authority in coordinating the CO_2 reduction program countywide, since 2002, the program had been merged with the DERM's Pollution Prevention Program. The goals and staffs were fully integrated.

The final report (DERM, 2006) reveals that Miami-Dade County's CO_2 emissions in 2005 increased by 20.2% compared with the emissions in 1988, which highly exceeded the original target set in 1993. Further, per capita CO_2 emissions increased by 8% over the 1993-2005 period. Figure 1 shows the comparison between the 2005 actual emissions and the original planned reductions from the four sectors.



Source: DERM 1993, 2006

Figure 1: Average CO_2 emission reductions from the four sectors

During the period 1993-2005, the program experienced continuous changes. The final report (DERM, 2006) explains some reasons why the actual annual emission reductions failed in meeting the targets planned in 1993 in the four sectors.

- Transportation: The County had expected 88.5% emission reductions would be realized by enhancing the national Corporate Average Fuel Economy (CAFÉ) standards from 27.5 mpg to 45 mpg. However, this largest improvement has never been adopted by the federal government (though it was hotly discussed in early 1990s), leading to the result that only 1% of actual reductions in 2005 were from fuel efficiency enhancement.

- Electricity production and use: The 1993 plan bypassed setting obligatory targets for the largest utility in the area, namely the Florida Power and Light Company (FPL). The dominant share of the actual reductions (93.6%) came from two unplanned voluntary projects: FPL's Demand Side Management (DSM) program, and the EPA's (Environmental Protection Agency) Climate Wise Program.

- Solid waste: Reducing CO_2 emissions in solid waste proved to be successful. One effective measure was the setup of two landfill gas flaring systems in the County, which converted methane gas into CO_2; the other came from the increase of recycling rate of residential and commercial waste.

- Land use: Several planned measures were taken to reduce emissions from land use. However, the carbon reduction benefits were linked with various regulatory and code changes. The data necessary to calculate emission reductions from these measures had been either unquantifiable or unmonitored.

3.2 Climate Change Activities Since 2006

Although the Long Term CO_2 Reduction Program came to an end in 2005, the County's enthusiasm and efforts in promoting action on climate change have not been weakening. The issues, such as the occurrences of the hurricanes, the vulnerabilities of the coastal ecosystem, and the worries of the energy security in South Florida, have increased the public concerns on the global warming issues. The demands to promote local climate change mitigation and adaptation activities increase. Drawing on the experience of previous CO_2 reduction program, the County's new climate change strategy has transmitted from target-oriented approach toward more process-oriented. The new arrangements have emphasized three tasks: providing market-based incentives to assist entities within the County to reduce emissions; enhancing the engagement of relevant stakeholders in planning and implementing local climate change activities; restructuring the administrative agencies to improve the institutional capacity. These three tasks are briefly described below.

The Miami-Dade County joined the Chicago Climate Exchange (CCX) in 2007. It becomes one of the first local governments in the US to make a voluntary but legally binding commitment to reduce GHG emissions by a set percentage over a specific period of time. The CCX experts provided training service for the County staff to quantify the local GHG emissions. The current agreement specifies a 6% reduction in emissions by 2010 based on 2005 level. Accessing the cap-and-trade mechanism provides an incentive for a variety of public and private actors to cooperate and participate in the mitigation activities.

To promote local climate change activities more effectively, an advisory board, known as the Miami-Dade County Climate Change Advisory Task Force (CCATF) has been established since mid-2006. The mission of the CCATF is to advise the Board of County Commissioners as to strategies and policies with respect to the continued implementation of the adopted plan, as well as adaptation measures to be taken in response to the challenge of climate change (County Document, 2006). The CCATF has 25 members, chaired by Harvey Ruvin, who currently works as the County Clerk of Courts. Of the other 24 members, 13 members are appointed by the 13 County Commissioners; 9 members are from government agencies and educational institutions and recommended by the County Manager; and the other two are appointed by the Mayor. The task force members are not paid by the Board and the term of service is three years. An office responsible for administering CCATF activities was set up in the DERM. Since 2007, six committees have been formed under the CCATF. Table 2 summarizes the missions of these committees.

Table 2: CCATF committees and their missions in the Miami-Dade County.

Committee	Mission
Steering Committee	To set agendas and schedules and provide task guidance and coordination
Scientific and Technical Committee	To provide scientific and technical information and analysis of the climate change impacts on the County
GHG Reduction Committee	To provide recommendations for effectively mitigating climate change through GHG reductions
Natural Adaptation Committee	To provide recommendations for adaptive management of natural systems to predicted climate impacts
Infrastructure Adaptation Committee	To provide recommendations for adaptive management of the existing and future built environment
Economic, Social and Health Committee	To provide analysis and recommendations regarding the economic, social and health impacts of climate change
Intergovernmental Affairs Committee	To provide information and analysis about the climate strategies and actions among other governmental entities

Source: CCATF, 2008

The Committee meetings are open to the public, with a view to encouraging more community engagement. From the participant list, more than 200 volunteers and stakeholders have been actively involved in the various issue discussions. Most of these people are from governmental departments, universities, utilities, and businesses in the County. The meeting records are shared by the committee members and meeting participants. In April 2008, the CCATF finalized a local climate action recommendation report to the County government. The report was the result of 48 meetings of various committees and 7 meetings of the full task force, with over 5,000 person hours involved in discussions and presentations (CCATF, 2008).

The Office of Sustainability has been created by the county government since 2007 to oversee a new program: Sustainable Building Program. Another responsibility of the Office is to coordinate all the sustainability-related initiatives of other County departments and agencies, considering the limited authority of the DERM in administering the climate change program. Currently, the Office solicits suggestions for utilizing the Energy Efficiency and Conservation Block Grant, funded under the American Recovery of Reinvestment Act of 2009. The CCATF subcommittee meetings provide good opportunities for the Office staff to disseminate relevant information and communicate with the community.

In addition, recognizing the importance of coordinated and collective action on the regional development, the Miami-Dade County, together with three other neighboring counties, namely Broward, Palm Beach and Monroe counties, signed Southeast Florida Regional Climate Change Compact in late 2009. The purpose is to develop a joint policy position that secures enhanced levels of federal participation in regional adaptation projects and further policy coordination that facilitates the allocation of federal climate change funding based on the vulnerability to climate change impacts (Broward, 2009).

4. LESSONS LEARNT

Lower-level engagement in the climate change campaign is key to economic and societal transformation toward a low-carbon future. In reviewing the development of Miami-Dade County climate change program, it remains to be seen whether the newly adjusted local climate strategy can bring real, long-term benefits to the County's development. This section summarizes following points as lessons that other local governments can learn from.

- Build upon prior experience and efforts. Although the Miami-Dade County failed in meeting the target set in the 1993 plan, the County has accumulated a lot of firsthand knowledge and experience from the planning, design, and implementation of the Program. Since the climate change capacity development is a long-term and incremental process, it is important to start the work earlier.

- Plan for the future. The climate change mitigation and adaptation strategy should be consistent with the other environmental and economic programs that can generate climate-related benefits and contribute to the sustainable development. The new climate strategy should clearly define a strong vision and be fully incorporated into the comprehensive urban development plan.

- Improve incentives to the local actors. Joining the Chicago Climate Exchange provides an opportunity to realize the emission reductions with lower costs. The County government can provide other types of regulatory incentives to the public agencies and small and medium businesses in the local area. The County government can also encourage large businesses or utilities to develop voluntary programs to reduce their emissions.

- Strengthen scientific support. Climate change policies are driven by scientific evidences. A number of important scientific advances help to resolve economic and political obstacles. The challenges faced in the local climate change policy making and implementation, require sound sciences. The Scientific Committee of the CCATF has convened some professional scientists and researchers to study the possible near-term and long-term impacts of climate change on the County.

- Conduct more public outreach and encourage citizen involvement. Active involvement of public and private actors can greatly enhance the success of climate change mitigation and adaptation program. In addition, the participation should not be limited in the implementation phase, but also in the program planning phase. The CCATF provides a good platform for citizens to discuss policy issues and for governmental agencies to disseminate information and solicit public opinions and suggestions.

- Promote political leadership. Harvey Ruvin, directed the County's effort in ICLEI's CO_2 reduction program during 1993-2005, and has chaired the CCATF since 2006. With his leadership, Miami-Dade County has been highly involved in a number of international and domestic climate change programs, which increase the city's visibility and reputation in fighting against climate change at the local level.

- Improve program evaluation. Program evaluation provides techniques to assess the results achieved and recommend for future improvements. However, to produce rigorous evaluation of program effectiveness, the local government should improve the institutional capacities, train relevant workforces, and introduce quantified approaches to measure performance. In the future, motivated by the requirement of carbon trading, the MRV (measurable, reportable and verifiable) system for accounting emission reductions should be established.

- Integrate adaptation and mitigation activities. Since the coastal areas are more venerable to climate change impacts, the local governments must give significant consideration to adaptation policies to protect city property, municipal infrastructure, and nature resources. The complementary and mutually reinforcing mitigation and adaptation measures should be implemented concurrently, and the climate change policies should be coherent with the sustainable development planning.

- Strengthen inter-governmental cooperation. Promoting climate change activities need concerted efforts from all levels of government. It is important to work with others as partners and allies in order to create more favorable conditions to maximize the local emission reduction benefits. One of the lessons learnt from the County's previous experience is that the local emission goals should not be heavy relied on the uncertain policies out of its own control. Without the supportive national or state policies, the local climate change actions could not go very far. This is the dilemma that has impeded the development of local climate change activities in the US. In this regard, the research on the local-national-international climate policy linkage should be furthered.

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PUBLIC PREPAREDNESS AND PARTICIPATION FOR DISASTER MANAGEMENT PROGRAMMES- A CASE STUDY FROM SOUTH EASTERN COASTAL ZONE, SRI LANKA

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ABSTRACT

South Eastern coastal zone of Sri Lanka is a vast coastal belt and restricted to very narrow land strip (about 1.5km width) between sea and paddy lands. This coastal zone is facing severe socio-economic and environmental problems due to very dense population and it is often affected by natural hazards like surges to tropical storms, monsoon depressions, flash floods and tsunami etc… The tsunami 2004, affected two villages; Akbar village and Maligaikadu in the South Eastern coastal belt of Sri Lanka were selected for implementing of a public participating new disaster management programme to reduce the existing unsustainable management practices.

A baseline survey was conducted to find the benefits of the disaster management and subsequent waste management activities, attitudes and views of the stakeholders and problems of the project activities. Field surveys of the study area were conducted to record the extent of damage due to earlier disasters, identify safe areas and residents preferred evacuation routes. Public preparedness through proper awareness programmes of education and training is one of our main tasks and pre-requisites for the success of a disaster management programmes. Disaster awareness programmes for the community and the school children were successfully conducted. Sharing the knowledge and experiences, sharing resources, communications among the neighbors, community participation in shared voluntary activities have significantly improved with the functioning of awareness programmes.

For the sustainability of the project, Disaster Management Committees at the village level was established with the help of District Disaster Management Center (DMC), Ampara agreed to conduct regular awareness programmes, maintain and to management of the sign boards to protect from corrosion and damaging.

1. INTRODUCTION

Coastal zones, the interface between two distinct environmental domains of the land and the sea, which is inhabited by 75% of the world's population. These eco-systems are subjected to dynamic physical processes like erosion, accretion, and impacts from cyclones and associated storm surges, earthquake, tsunami and sea level changes etc…More than two third of the world's sandy coastline have retreated during the past few decades, only less than 10% have recovered (Bird, 1996 and Papathoma et al, 2003).The development of coast-effective method to asses risk, which allows coastal managers and planners to rapidly determine high-risk area in the coastal zones, is important to manage the coastal zone effectively over the next decades (Hennecke, 2000).

South Eastern coastal zone of Sri Lanka is a vast coastal belt and restricted to very narrow land strip (about 1.5km width) between sea and paddy lands (Fig. 1). The coastal plain is formed mainly by the interaction of marine and fluvial processes. The beach shows a very gentle slope towards the sea. This coastal zone is facing severe socio-economic and environmental problems due to very dense population and it is often affected by natural hazards like surges to tropical storms, monsoon depressions, flash floods and tsunami etc… On Sunday 26th December, 2004, the tsunami occurred as a sudden event, with no antecedent features were found, tsunami event occurred between 8.30 am to 10 am along SE coastal belt. The maximum height of wave observed between 20-30 feet. The time of occurrence of maximum wave height varied between 8.40 am- 9.30 am. Maximum inundation observed in the study area was up to 1.2 km at Akbar village towards Kalmunai- Batticaloa main road. Observations indicate that the total number of waves struck the coast was 4-6 and areas with less vegetation, less elevated, with flat SE coast were badly affected. This resulted in the erosion of huge sand deposits and broadening of channel inlets (Balasooriya et al., 2008).

Based on the government Information**,** Sri Lanka had been seriously impacted by tsunami on 26th Dec.2004. It caused for 30,196 deaths, 21,411 injured and 516,150 displaced and it has been had a severe impact on Economic as well as Environmental. (Fig. 1)

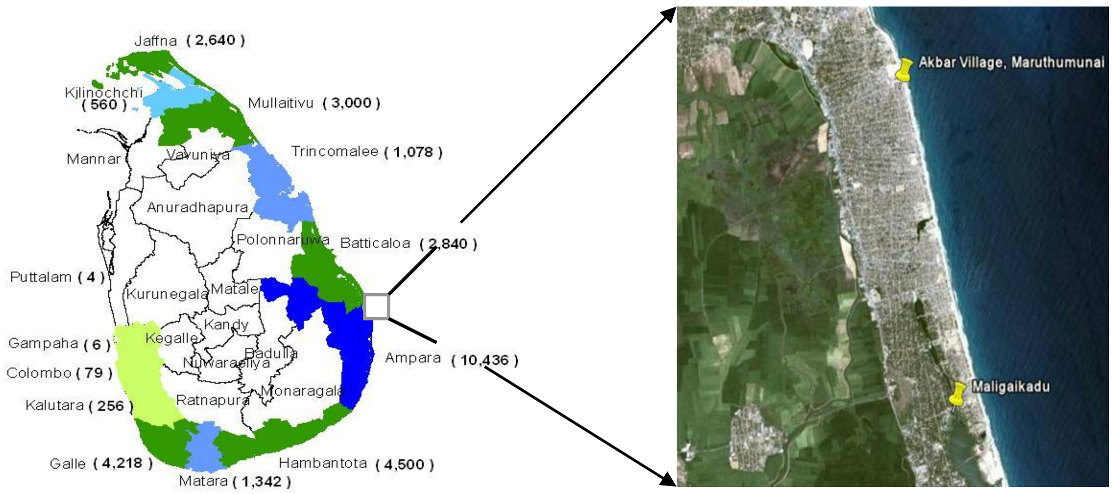

Figure 1: Impact of tsunami in Sri Lanka and study area of South Eastern coastal zone

In the aftermath of tsunami, everybody focused attention on post disaster management issues strictly focused to the disaster management theories and concepts. The post disaster management programmes were aimed for relief, rehabilitation, reconstruction and resettlement (Silva, 2005).

Though the tsunamis are rare among other natural hazards, they are disastrous which can be generated in all the world oceans, inland sea and in any large body of water. The characteristic of tsunami in the world oceans appear to have its own cycle of frequency and pattern in generating tsunami that range in size from small to large and highly destructive events. Most tsunamis frequently occur in the Pacific Ocean and its marginal seas and are least expected surround the Indian subcontinent. (Pacheco et al 1992). Indian Ocean tsunami is more dangerous that the tsunami that are produced in the Pacific and Atlantic Oceans because of the topography of Indian Ocean.

Akbar village (07^o 26’ 22” N & 81^o 49’ 11” E) and Maligaikadu (07^o 23’ 16” N & 81^o 50’ 30” E) village were highly effected by the catastrophic tsunami event and were selected for implementing of a public participating new disaster management programme to reduce the existing unsustainable management practices. These two villages are situated in the South Eastern Coastal Belt of Sri Lanka. Akbar village is located about 2.5 km north of Kalmunai and Maligaikadu village is located about 2 km south of Kalmunai in Ampara district.

It may be understood that tsunami hazards can not be prevented with present technological advances but vulnerability can be reduced by resorting to preparation and execution of a well thought out disaster management programme which was the main objective of this study.

2. METHODOLOGY

The information was collected by using unfocused interviews, focused group discussions, questionnaire and observations. This combination of methods helped to obtain information for different respective.

A baseline questionnaire was prepared to obtain information of hazard identification, past events records and vulnerability assessments (physical, social, motivational, economic and institutional). A sample of the baseline questionnaire is shown in Appendix 1. The baseline survey was conducted about 200 families around the study area to find the benefits of the disaster management and subsequent waste management activities, attitudes and views of the stakeholders and problems of the project activities.

Field surveys of the study area were conducted to identify the locations to establish inundation levels, to determine the flow directions during the tsunami, to record the extent of damage, to identify safe areas and to identify the residents preferred evacuation routes.

Public preparedness through proper awareness programmes of education and training about tsunami and other natural hazards were conducted for the community and school children. Learning materials about disaster management and tsunami were prepared.

Several types of tsunami sign boards were designed: Evacuation Route (L/R), Safe Shelter, Tsunami Zone, Safe Site, Tsunami Water Level (26.12.2004).

3. RESULTS & DISCUSSION

3.1 Preparation of evacuation plan

Locations were identified for both horizontal and vertical evacuation of people to safe places based on the shortest possible distance to move. Roads marks and different types of tsunami sign boards, Evacuation Routes (L/R), Safe Shelters, Tsunami Zone, Safe Sites, and Tsunami Water Level (26.12.2004), were prepared and displayed on the roads in both villages for the people to follow the routs to the evacuation sites (Fig. 2 & 3).

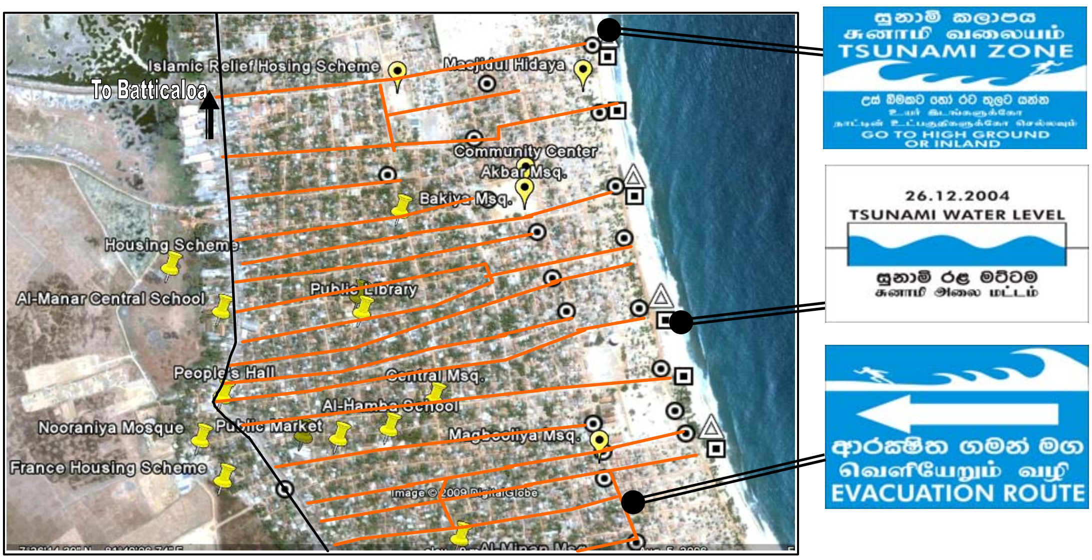

Figure 2: Evacuation plan and displayed sign boards at Akbar Village

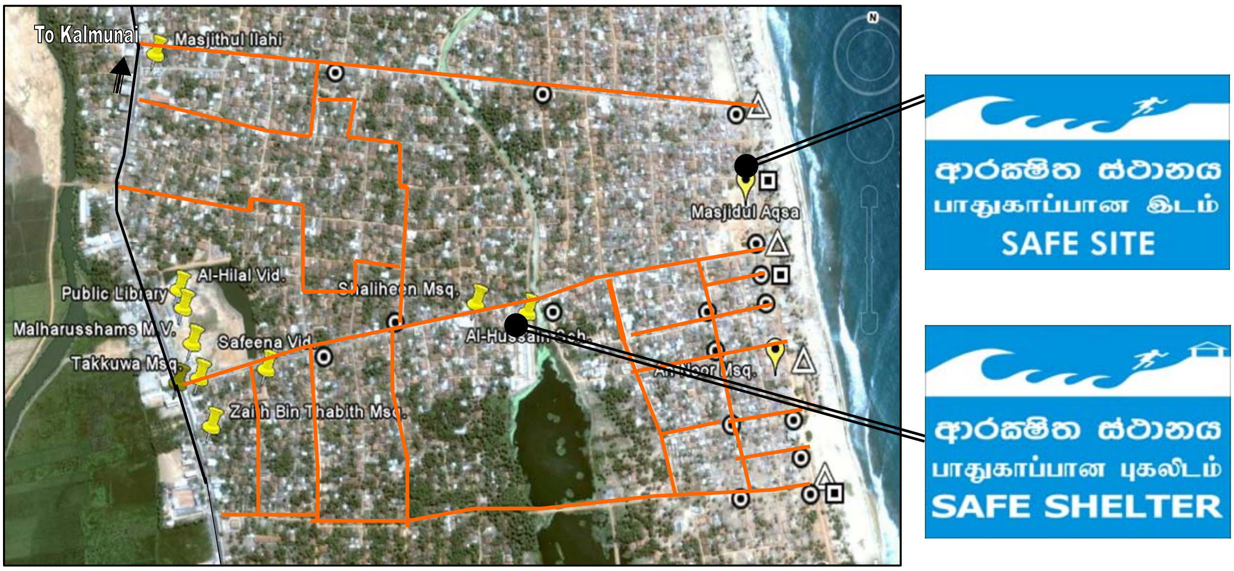

Figure 3: Evacuation plan and displayed sign boards at Maligaikadu Village

Tsunami sign boards were also displayed about 10 km stretch of the SE coastal belt from Akbar village to Maligaikadu. Pandiruppu (07^{o} 25’ 42” N & 81^{o} 49’ 33” E), Kalmunai (07^{o} 25’ 11” N & 81^{o} 49’ 47” E), Kalmunaikudi (07^{o} 24’ 48” N & 81^{o} 50’ 13” E), Islamabath (07^{o} 24’ 35” N & 81^{o} 50’ 19” E), and Sainthamaruthu (07^{o} 23’ 44” N & 81^{o} 50’ 26” E) villages are situated between Akbar village to Maligaikadu and selected for displaying different types of sign boards.

3.2 Awareness programmes

Public preparedness through proper awareness programmes of education and training is one of our main tasks and pre-requisites for the success of a disaster management programmes. Disaster awareness programmes for the community and the school children were successfully conducted.
Disaster management awareness programmes for the community and school children were conducted and are listed as follows (Table 1).

When the announcements for workshops were made for community female members with few male members of fisheries families responded and participated. After participating in first workshop, they promised to get the more male members involved in a training programme. They are fishermen and busy with repairing fishing nets, boats and other equipment so it did not succeed.

The workshops analysis reveal that sharing the knowledge and experiences, sharing resources, communication among the neighbors, community participation in shared voluntary activities have significantly improved with the functioning of awareness programmes.

Necessary forward steps has been taken by the Sri Lanka government to establish few Tsunami and Multi Hazards Warning Centers which will take care of the hazards caused by tropical cyclones, monsoon depressions and tsunami. One of the Tsunami and Multi Hazards Warning Center were situated at Akbar village and it was constructed by Disaster Management Center of Sri Lanka for issuing warning for any natural disaster of the area. Under this study, renovation of the Tsunami and Multi Hazards Warning Center were also conducted.

3.3 Maintenance & management

For the sustainability of the project, Disaster Management Committees at the village level was established with the help of District Disaster Management Center (DMC), Ampara agreed to conduct regular awareness programmes, maintain and to management of the sign boards to protect from corrosion and damaging (Fig. 4).

Top priority should be given for long term mitigation programs to establish a coastal bio-shield moment along the coastal areas, involving the raising of mangroves forest, plantations of *casuaria, salicornia, laucaena, artiplex, palms, bamboo* and other tree species and *halophytes* which can grow near the coast. Bio-shield moment will confirm multiple benefits to local communities as well as to country as a whole.

Table 1: Disaster Management Awareness Programmes

Date	**Location**	**Target Group**	**No. of Participants**		**Remarks**
			Male	**Female**	
22.11.2007	KM/Al- Hussain Vidyalaya, Maligaikadu	School Children (Grade 6,7 and 8)	80	75	Following topics were covered under these programmes: Introduction Disasters Types of Disasters Natural disasters in Sri Lanka Responsibilities to Public, Government officials, and Scientists Response to Early Warning System Evacuation Waste management
18.03.2008	KM/Pulavimani Sharifdeen Vidyalaya, Maruthamunai	School Children (Grade 6,7 and 8)	75	65	
05.04.2008	KM/Pulavimani Sharifdeen Vidyalaya, Maruthamunai	Community	10	60	
26.04.2008	KM/Al- Hussain Vidyalaya, Maligaikadu	Community	05	45	
15.05.2008	KM/Al Manar Central school, Maruthamunai	School Children (A/L students)	80	65	
22.05.2008	KM/Al Manar Central school, Maruthamunai	School Children (O/L students)	85	70	
29.05.2008	KM/Al Sham's Central school, Maruthamunai	School Children (A/L students)	90	60	
05.06.2008	KM/Al Sham's Central school, Maruthamunai	School Children (O/L students)	85	65	
29.10.2008	South Eastern University of Sri Lanka, Oluvil	Community- Police Officers, Government Agents & Officials Researchers	44	6	
30.03.2009	Faculty of Applied Sciences, Sammanthurai	Journalist from Ampara District	48	02	

3.4 Solid waste management

One of the emerging issues in South Eastern coastal region of Sri Lanka is the inefficiency in collection of disposal of sold wastes and consequent widespread scattering and dumping in beaches as well as canals nearby and creating an unpleasant environment.

South Eastern University- CIDA tsunami restoration project cleaned the sea beaches at Akbar village, the sea bed and polluted canal at Maligaikadu village through Sharmadana campaigns and distributed composit bins among the households to produce composite fertilizer using decomposable home wastes.

As there is a great potential for waste management to improve the livelihoods and monitoring are needed for these communities to make the programme sustainability.

3.5 Livelihood activities

Present project was introduced to young males to involve in colleting marine ornamental fish for export purposes in environmental friendly manner. It was designed therefore with a view to restore of the tsunami affected communities in the region and also to find the possibilities of providing alternative livelihoods to those who are involved in environmental destructive activities.

Figure 4: Corrosion and damaging the sign boards

4. CONCLUSION

Public preparedness through proper awareness programmes of education and training is one of our main tasks and pre-requisites for the success of a disaster management programme.

The disaster management progarmme and disaster mitigation should be under the Emergency Action Plan (EAP) to be executed by government and non-government organizations during and after a disaster strikes a particular region. The Emergency Action Plan should include responsibility of all government authorities to build a communication link for reaching the warning to the affected people, activating administrative people for arranging evacuation, mobilizing and relief etc…(Mahanti,2006). Vulnerability and risk aspects of natural hazards to work out the disaster management implications can essentially follow. This can help in designing and implementing any infrastructure development project and making decision for techno- economically feasible land use utilization in such areas with due consideration to avoid future hazards on the specific locations in south eastern coastal belt of sri Lanka.

ACKNOWLEDGEMENT

Financial assistance by CIDA RESTORE PROJECT of South Eastern University is acknowledged.

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Appendix 1

Baseline Survey- Questionnaire

Name of the area:………………….

General Description-Environment				
	Question	**Answer**	**Guidance**	**Remarks**
	Does the area wholly or partly fall within any of the following areas?			
	100m from the boundaries of or within any area declared under the National Heritage Wilderness Act No 4 of 1988	Yes - No	If the answer is Yes to any of these: If the use of this type of area cannot be avoided, then activities to limit or remediate un-avoidable environmental impacts needs to be developed	
	100m from boundaries of or within any area declared under the Forest Ordinance (Chapter 451)	Yes - No		
	Coastal zone as defined in the Coast Conservation Act No 57 of 1981	Yes - No		
	Any erodable area declared under the Soil Conservation Act (Chapter 450)	Yes - No		
	Any Flood Area declared under the Flood Protection Ordinance (Chapter 449)	Yes - No		
	Any flood protection area declared under the Sri Lanka Land Reclamation and Development Corporation Act 15 of 1968 as amended by Act No 52 of 1982	Yes - No		
	60 meters from the bank of a public stream as defined in the Crown Lands Ordinance (Chapter 454) and having width of more than 25 meters at any point of its course	Yes - No		
	Any reservations beyond the full supply level of a reservoir	Yes - No		

	Within 100 meters from the boundaries of, or within, any area declared as a Sanctuary under the Fauna and Flora Protection Ordinance (Chapter 469)	Yes - No		
	100 meters from the high flood level contour of or within, a public lake as defined in the Crown Lands Ordinance (Chapter 454) including those declared under section 71 of the said Ordinance	Yes - No		
	Within a distance of one mile of the boundary of a National Reserve declared under the Fauna and Flora Protection Ordinance	Yes - No		
	Does the area fall within a prescribed project area based on National Environment Act?	Yes - No		
	Disaster Management and Hazard Identification			
	Question	**Answer**	**Guidance**	**Remarks**
	Do you have knowledge in hazard mitigation?	Yes - No	If the answer is yes One or more Mitigatory measures against Tsunami must be mentioned:	
	Was there a possibility to affect tsunami at the area?	Yes - No	If the answer is yes What was the inundation height at your place during the tsunami? According to your experience what is the safest place to move during a tsunami?	
	Is there is any hazards face in the area?	Yes - No	If the answer is yes Please mention:……	
	Is the area subjected to severe erosion?	Yes - No	If the answer is Yes One or more of the following Mitigatory measures against soil erosion must be used a) Paving the ground surface b) Covering the ground surface with a suitable type of vegetation c) Providing the surface drainage to minimize concentrated water flows on exposed ground surface must be avoided	
	Does the area experience high rainfall during the year?	No - Yes	If the answer is Yes: Please indicate the wet months	
	Early warning			
	Have you observed any specific behavior of animals prior to tsunami?	Yes - No	If the answer is yes One or more animal behaviors against Tsunami must be mentioned:	
	Have you heard any specific ability (s) to sense any disaster?	Yes - No	If the answer is yes Please mention the relevant animals. **Disaster** **Animal** Tsunami ………………. Monsoon Depressions……… Floods ………………. Landslides ……………… Cyclones ………………..	
	Have any body from your village rear such animals?	Yes - No	If the answer is yes Please mention:……	

ADAPTATION STRATEGIES AND POLICIES OF LGED IN THE COASTAL AREAS OF BANGLADESH

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ABSTRACT

Bangladesh is one of the most climate vulnerable countries in the world and will become even more vulnerable as a result of climate change. Climate change will severely constrain the country's ability to achieve the high rates of economic growth needed to achieve and sustain these reductions in poverty. Adaptation is the prime need for Bangladesh in the short to medium term and the country is a global leader in adaptation implementation. Local Government Engineering Department as a major public sector infrastructure building department has undertaken Adaptation Strategies and Policies in the coastal area so that the impacts of climate change are tackled, in a routine way, as part of the development process. The strategies and policies include undertaking both structural and non-structural measures. LGED is adopting structured participatory approach involving the local community including the Union Parishad (UP: the lowest tier of local government) in the planning, implementation and evaluation of infrastructural adaptation program. This paper would mainly highlight the Adaptation Strategies and Policies on Climate Change in the coastal areas of Bangladesh with an assessment of the activities undertaken. The salient features of structural measures are to:

1.1 Repair and rehabilitate existing infrastructure (e.g., rural roads, and drainage systems) including raising the Formation Level of the Rural Roads, paths, tracks and plinth level of the Buildings of the above the normal flood level, and ensure, effective operation and maintenance systems.

1.2 Plan, design and construct urgently needed new infrastructure (e.g., cyclone shelters, embankments and water management systems; protection works of the roads, flood shelters, flood proof roads, earthen mounds) to meet the changing conditions expected with climate change.

1.3 Undertake strategic planning of future infrastructure needs, taking into account the likely (a) future patterns of urbanization and socio-economic development; and (b) the changing hydrology of the country, with climate change.

1.4 Undertake small-scale flood management schemes to raise the productivity of low-lying rural areas and protect them from the extremely damaging severe floods; Improve small-scale irrigation schemes to enable farmers to grow a dry season rice crop in areas subject to heavy flooding;

1.5 Carry out Roadside afforestation program in the coastal areas in order to promote Coastal 'greenbelt' projects.

On the other hand, the non-structural measures incorporate carrying out Awareness, Advocacy and Educational campaign focusing on community mobilization, disaster preparedness and imparting training. All these efforts are brining notable success in the area of coping with the adverse impact resulting from climate change in the coastal areas of Bangladesh. LGED’s experience need to be shared with the international community. The resources currently available for adaptation are grossly inadequate to meet the needs of the country. We must scale up this work urgently Any delay will increase the risks associated with climate change, which could be expensive to manage later on but, more importantly, the human costs will be immeasurable.

1. CONTEXT

1.1 Bangladesh consists largely of flat alluvial plains crisscrossed by many rivers and watercourses including some of the world's largest rivers such as the Ganges/Padma, the Brahmaputra/Jamuna and the Meghna; which flow through both India and Bangladesh and create flood problems in the respective basin areas (known as *Ganges-Brahmaputra-Meghna: GBM Basin*) during monsoon months in both the countries almost every year. The area of the country is 147570 square kilometers and the population in 2009 is 160.6 million at a density of nearly 1088 (GoB, 2009) people per square kilometer. Since Bangladesh achieved Independence, in 1971, it has shown sustained growth of economy. This increasing growth has helped to bring down income poverty rates from 60% in 1990 to 40% (upper poverty line) in 2005. It is well recognized both in the scientific and negotiating community that Bangladesh would be one of the most adversely affected country to climate change. Low economic strength, inadequate infrastructure, low level of social development, lack of institutional capacity, and a higher dependency on the natural resource base make the country more vulnerable to climate stimuli (including both variability as well as extreme events). The coast of Bangladesh is known as a zone of vulnerabilities as well as opportunities, which covers one-third area (47,201 km^2) and population (about 53 million people) of the country. The incidence of poverty in this region is relatively high and it is socio-economically far behind the other parts of the country. Several studies indicate that the coastal zone vulnerability would be acute due to the combined effects of climate change, sea level rise, subsidence, and changes of upstream river, discharge, cyclone and coastal embankments. Realizing the fact, GoB has adopted various policies, strategies (including the national strategy for poverty reduction) in this regard and invested over $10 billion (BCCSAP, 2009) to make the country more climates resilient and less vulnerable to natural disasters during the last 38 years.

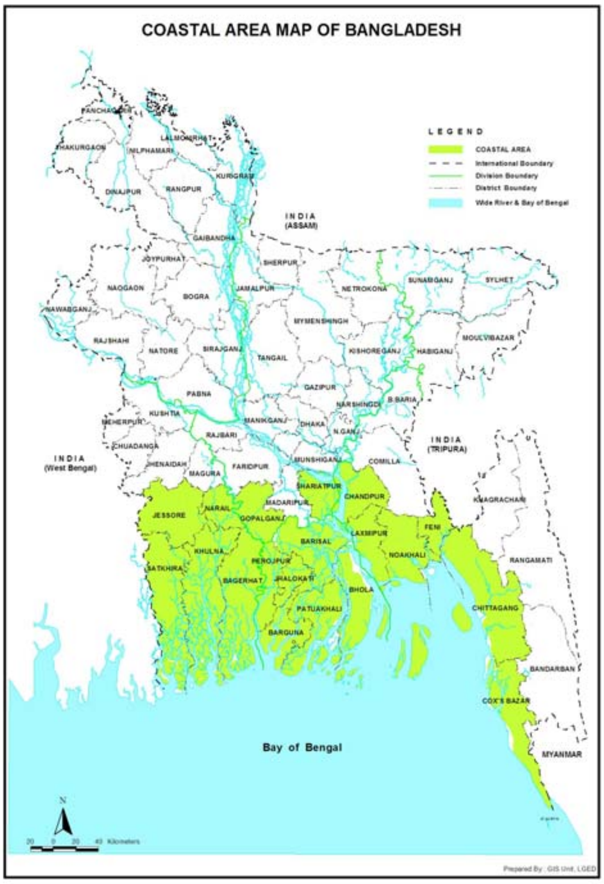

Figure 1: Coastal areas of Bangladesh

1.2 Local Government Engineering Department (LGED), as a major arm of Government of Bangladesh (GoB) under the Ministry of Local Government Rural Development and Co-operatives (MLGRD&C), is responsible to construct and maintain rural as well as urban infrastructures through out the country. The key responsibilities of LGED cover to formulate, implement and evaluate GoB's infrastructure management policies/plans/strategies including tackling climate change issues in the coastal regions.

2. OBJECTIVE

The main objective of this paper is to share the Local Government Engineering Department's Adaptation Strategies and Policies on Climate Change in the coastal areas of Bangladesh with an assessment of the implemented interventions

3. SOCIO-ECONOMIC PROFILE OF THE COASTAL AREA

3.1 The coastal area of Bangladesh (covering 19 districts) and the Bay of Bengal are located at the tip of northern Indian Ocean, which has the shape of an inverted funnel. It is located in the tropical climate zone and the coast line has a length of 710 km along the Bay of Bengal. The discharge of the world's largest river systems drain through the Bangladesh into the Bay of Bengal.

3.2 According to the available data on poverty, the proportion of families below poverty line in this region is about 5~10% percentage points higher in this region than the rest of the country. The coastal region also suffers comparatively more from transport and road bottlenecks. It has extensive river transportation system, which has been clogged and is facing increasing siltation problem.

4. IMPLICATIONS OF CLIMATE CHANGE IN THE COASTAL AREAS OF BANGLADESH

4.1 The global warming will result in sea level rises (BCCSAP, 2009) of between 0.18 and 0.79 meters, which could increase coastal flooding. As about half of the coastal area is less than 1 meter above sea level, this area is more susceptible to river and rainwater flooding as well as tidal flooding during storms. Four key types (NAPA, 2005) of primary physical effects i.e. ***Saline Water Intrusion; Drainage Congestion; Extreme Events; and Changes in Coastal Morphology*** have been identified as key vulnerabilities in the coastal area of Bangladesh. This area was severely affected by two recent cyclones--Sidr in 2007 and Ayla in 2009.

5. KEY ADAPTATION POLIECIES/STRATEGIES OF LGED:

As mentioned earlier, the GoB is incorporating potential response measures for reducing impacts of climate change into overall development planning process. Different Ministries of the Government have announced, over the years, their respective policies/plans/strategies for carrying out the mandates. The following are the major policies / strategies that LGED follow:

5.1 National Adaptation Program of Action for Climate Change (NAPA, 2005):

Ministry of Environment and Forest (MOEF) has prepared the document as a response to the decision of the Seventh Session of the Conference of the Parties (COP7) of the United Nations Framework Convention on Climate Change (UNFCCC). In NAPA, future coping strategies and mechanisms have been suggested based on existing process and practices keeping main essence of adaptation science, which is a process to adjust with adverse situation of climate change.

5.2 Coastal Zone Policy, 2005:

In this policy, a participatory and integrated approach has been framed to reduce conflicts in the utilization of coastal resources and optimum exploitation of opportunities so that the coastal people are able to pursue their life and livelihoods within secure and conducive environment.

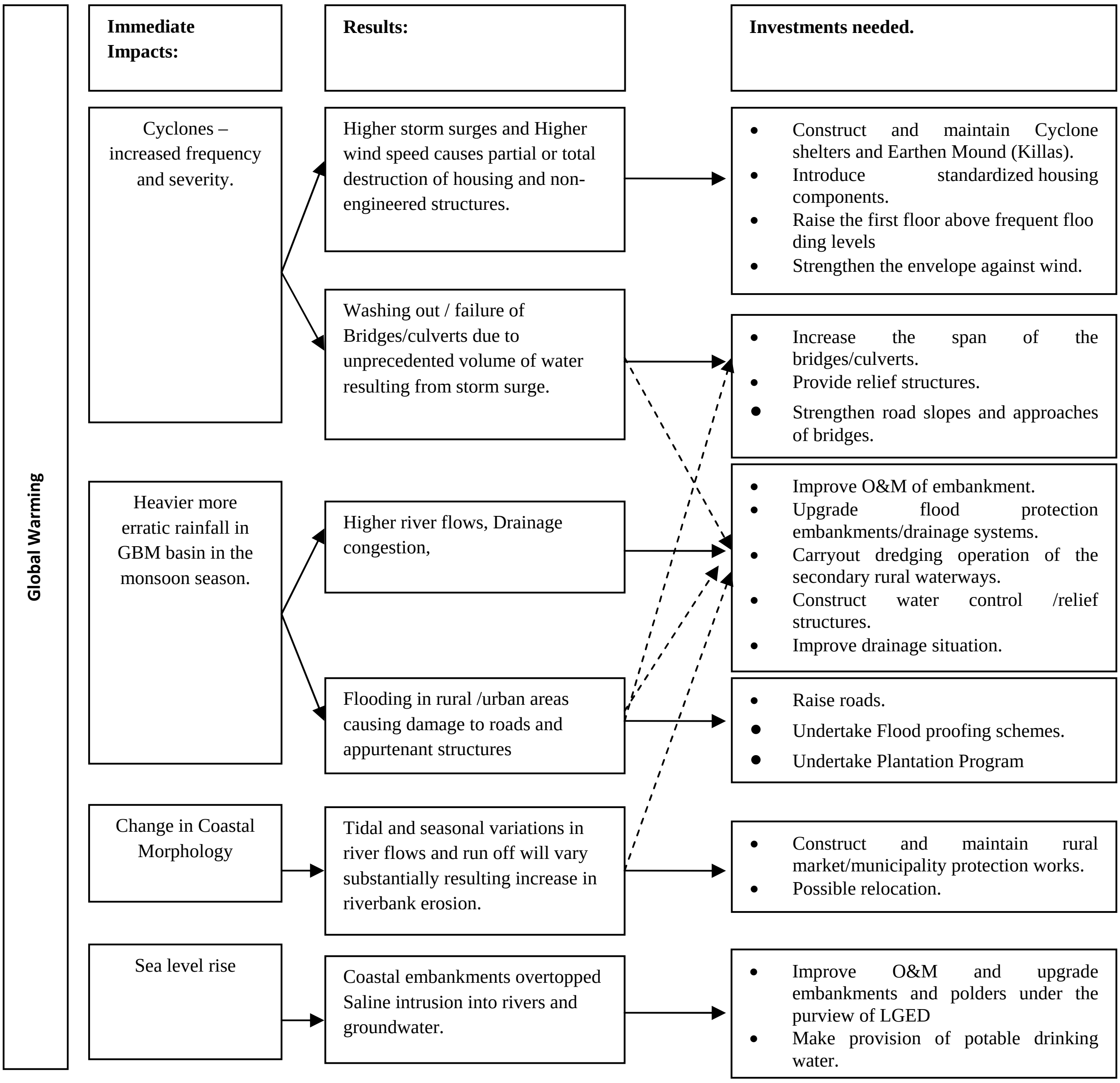

Figure 2: Pathways of physical impacts of climate change and associated structural adaptation

5.3 Coastal Development Strategy, 2006:

The Coastal Development Strategy (CDS) is based on the approved Coastal Zone Policy 2005. The CDS is the linking pin between the Coastal Zone Policy (CZP) and concrete interventions. It prepares for coordinated priority actions and arrangements for their implementation.

5.4 Integrated Coastal Zone Management (ICZM) Plan:

Integrated Coastal Zone Management (ICZM) Plan include : a) Integration through harmonization and coordination; b) adoption of a process approach; c) linkage to national planning mechanisms; d) implementation through respective line agencies; e) co-management and participatory decision; f) gender equality; g) participatory monitoring and evaluation; h) supporting national policy of decentralization and development of the private sector interventions based on the best available knowledge; i) efforts to fill knowledge gaps and j) priority setting on issues of the coastal zone.

5.5 Bangladesh Climate Change Strategy and Action Plan (BCCSAP):

Recently GoB has adopted a climate resilient and low-carbon development strategy, based on the Four pillars of the Bali Action Plan - adaptation to climate change, mitigation, technology transfer and investment, within the framework of food, energy, water and livelihoods security. This will be achieved through the Climate Change Action Plan, which will have six pillars: (1) Food security, poverty and health; (2) Comprehensive Disaster Management; (3) Infrastructural development; (4) Research and knowledge management; (5) Mitigation and low-carbon development; and (6) Capacity building and institutional development. The CCAP will be an integral part of national development policies, plans and programmes.

6. STRUCTURAL INTERVENTIONS:

6.1 Housing / Community Infrastructure:

Most of the houses in the coastal areas of Bangladesh are made of thatches, bamboo, etc., with untreated earth base having minimum or no foundation. Cyclone caused damage in three ways—storm surge, flooding and wind. During floods, rural houses go underwater causing severe damage to their bases. During wind events, the frames of the rural poor houses undergo partial or total collapse as they have little or no lateral load resistance. LGED is undertaking following measures:

6.1.1 Raise the homestead above frequent flooding levels

This is achieved by (Chowdury, 1998): a) Raising the level of ground on which the homestead rests; b) Buildings on stilts and c) Floating house with floor level rising along the flood water. LGED is promoting the traditional approach of building homes on raised mounds. Although in many places it did not seem feasible as it is associated with huge earth work other than RCC pillars lateral stability is difficult to ensure which increase might cost for the second options. The third options appeared to be highly expensive in countries like Bangladesh.

Figure 3 Raised Homestead

6.1.2 Introduce Standardized Housing Components.

It is also assisting the community to develop cost-effective, standardized housing components that raise the first floor above frequent flooding levels and strengthening the envelope against wind. This is a significant development need for Bangladesh. Since strengthening housing against this fallen tree hazard is not feasible, frequent tree trimming and maintenance are encouraged in communities highly exposed to this hazard.

Figure 4: Improved House

Mitigation techniques to reduce the vulnerability of housing to the natural disaster can be incorporated most economically and effectively during construction. However, there is a large stock of existing which has already built without adequate protection against natural hazards. Techniques for retrofitting (Chowdury, 1998) have been developed, particularly for brick masonry and mud-walled housing. These include adding a Ferro cement veneer, vertical corner reinforcement embedded in mortar, introducing tie-beams and adding buttresses.

6.1.3 Improvement of Community Places.

Figure 5: School-cum-Cyclone Shelter

The community places such as schools, religious institutions etc, are severely affected as they are inundated during floods/storm surge. LGED is constructing /repairing these cyclone shelters. Earlier shelters were built as single purpose structures but new ones are multi-purpose. They can also be used as local government offices, schools or health centers. Newer shelters may have a 'killa' (raised platform for livestock) nearby.

A typical shelter is a concrete building, shaped like two sides of a triangle, facing into the wind. To enter, people climb the staircase at the back, as it is slightly more sheltered from the wind. Railings are placed on both sides of the staircase to help people climb when winds are very strong. Cyclone shelters can have one or two floors. There are separate rooms for men and women (children usually stay with the women). Windows have metal shutters as glass can break into pieces and cause injuries. There are water supply and toilets downstairs or close to the building.

6.2 Transport Infrastructure:

Figure 6: Flood Damage Pavement

Cyclones and floods effect on the transport sector largely confined to the road system (including bridges, culverts, and ferries) and to inland water transport. Bangladesh has extensive rural roads (LGED, 2009) about 240,000 km under the jurisdiction of LGED. Only 10.5% of LGED’s road paved remaining is in only average to poor condition. Sub grades are often of poor quality, and most embankments are inadequately compacted, with pavements that are sensitive to moisture content. The annual maintenance fund which LGED receives from the government and development partners is largely inadequate. The storm surge mostly affects the slopes and shoulders of the road severely which creates large breaches in several sections of the road. Although bridges are designed based on thorough hydrological analysis, the existing structures could not provide adequate passage for the huge water resulting from unprecedented floods/storm surge. Such phenomenon affects the bridge approaches critically either by creating large breaches across the road or badly damaging the approach. Similarly roads in deeply flooded areas experience wave erosion and nearby rivers are affected by river erosion. Following measures are taken by LGED to tackle the situation

6.2.1 Raise roads

The height of the road embankment is designed based on recent major floods and / or statistical analysis of the past river stage data (where possible)

6.2.2 Increase the span of the bridges/culverts and Provide relief structures.

Figure 7: Span increased and approach strengthen

Conduct proper hydrological analysis and increase the span if the existing bridges remain in good condition. Besides approaches of the are strengthened which is discussed in the later section. As a thumb rule 10~15 meter per kilometer gap (LGED, 2005) is recommended for the low lying area. Culverts should normally be no longer than 6m spans. Bridges should be used if the gap exceeds 6m spans. Cut-off Wall of RCC Box Culvert shall be provided at upstream and downstream away from Box by at least two-third of Box height. Portable Steel Bridges (PSB) may be proposed with narrower ca rriageways, as emergency measures. Provide additional bridges/culverts from the view point of hydrological demand.

6.2.3 Conduct detailed morphological study for the bridges having span over 100m

Bangladesh' coastal morphological processes are extremely dynamic, partly because of the tidal and seasonal variations in river flows and run off. Climate change is expected to increase these variations. Therefore, LGED carries out in-depth morphological study for bridges over 100m span.

6.2.4 Protection of Bank / Slope of the road:

Slope protection methods involve placing harder, more durable materials, such as bricks, stones or rocks, to form a vertical or inclined barrier to absorb or dissipate the energy of the waves. The common protection measures are given below (LGED, 2005):

a) **Hand Placed Rip-rap**: This work consists of placing in position of stone boulders on earth or gravel bedding on the embankment slope or bank. b) **Brick Mattressing**: It consists of providing single or double layer brick soling encased in wire net over a filter bed of 25mm thick on the embankment slope, bridge approaches, side and water front slopes at the required locations. c) **Boulder Mattressing**: It consists of providing boulder mattressing encased in wire-net over a filter bed of 25mm thick on the embankment slope, bridge approaches, side and water front slopes at the required locations., d) **Sacked Rip-rap**: This work shall consist of supplying and placing of Sacks filled with mixture of sand and cement on the embankment slopes necessary to protect the embankment from erosion) e) **Brick Masonry Blocks/ Pre-cast Concrete Blocks (C.C. blocks**) are made from concrete in accordance with the relevant Specification and cast in moulds formed from steel sheet. After that these blocks are placed on the slopes of the road. This work consists of furnishing and placing of brick masonry blocks on the embankment slopes necessary to protect the embankment from erosion; f) **Geo-textile filter:** This is a fibrous texture materials placed beneath the cover layer. The specification of geo-textile is determined from grain size analysis. A sand layer is provided beneath the geo-textile to protect clogging. The laying of geo-textile to be done putting some lapping if no sewing is done. A minimum of 350mm side and end laps shall be kept while placing the geo-textile on slope; g) **Brick Retaining Wall**: Gravity-type Retaining Walls are used for the protection of slopes. Normally vertical wall are selected in such places where scope of the slope protection works are constrained due to non-availability of land. During construction expansion joints are provided at 30m interval; h) **RCC Retaining Wall:** This wall is completely made of RCC with mix-ratio- of concrete 1:2:4 of cement, sand and coarse material i) **Toe Walls**: Toe walls are made of brick masonry to support the different slope protection measures j) **Wave Protection Wall**: It is a special type of wall, which is placed far apart from a mound or road to protect and

Figure 8: Flood proof road

break the flood wave energy to minimize the losses. This is a continuous RCC wall composed of RCC columns at 3m interval.

6.3 Water Supply and Sanitation

Figure 9: Raised toilets and water supply system

Water supply and sanitation is vulnerable in coastal districts. Most of the demands for water supply in the coastal area are served from tube wells and surface ponds. Human waste is generally not treated and pit latrines are the most common facility. Waterborne disease is a major public health problem. Drinking water sources n many communities are contaminated by saline water and debris. In addition, in many areas groundwater sources are contaminated by arsenic and salinity in shallow aquifers, and the non-existence of deep aquifers. In order to combat the situation following activities have been undertaken: a) Rehabilitation /Construction of Sanitary latrines, replacement of slabs and other infrastructure) Raise latrines; c) Excavation/Re-excavation of derelict ponds; d) De-watering of ponds and removal of sludge before the monsoon ; e) Rehabilitation or reconstruction of pond sand filters; f) Construction / Rehabilitation of water points provided in schools, community facilities and cyclone shelters; g) Installation of shallow/deep tube wells in the worst affected areas where safe groundwater can be detected;

6.4 Small-Scale Water Resources Infrastructures

The coastal region has about 125 polders (A polder is a low-lying tract of land enclosed by embankments known as dikes, which forms an artificial hydrological entity, meaning it has no connection with outside water other than through manually-operated devices) provide first line of defense against storm surges and possible climate change-induced sea level. However, these are not well enough to provide full protection against cyclone like Sidr/Ayla. LGED's small-scale water resources infrastructures are affected due to the failure of these polders. In the short-term, LGED is re-constructing or rehabilitating damaged embankments. It is also repairing the damages of water control structures including the drainage system following current design standards. In the medium–term, it will consider improved design standards, including necessary bank protective works and anti erosion plantation in priority areas.

Figure 10: Rehabilitated embankment

6.5 Urban Drainage:

The current storm drainage systems of the municipalities were designed using historical rainfall data. It is likely that these design capacities will be exceeded in future. One of the major impacts of climate change is likely to be an increase in the number of episodes of short duration and heavy rainfall. The higher and more intense rainfall coupled with inadequate drainage systems would further exacerbate the situation. As a short term measure, LGED is adopting an integrated approach in developing a drainage plan, taking into account of storm water and other run-off, geographical layout, topography and site hydrology. In the long run LGED will however, aassess the drainage capacity of major municipalities and investigate structural and non-structural causes of water logging within the towns and their immediate surroundings using hydro-dynamic models.

Figure 11: Constructed Urban drain

7. COMMUNITY INVOLVEMENT IN ADAPTATION PROGRAM:

Figure 12 : Dialogue among the infrastructure users including local government representatives during planning session.

LGED has started implementing participatory processes in its planning/designing and implementation of infrastructure using basic participatory concepts and approaches i.e. Information Sharing and User' Input approaches. Consultations at all stages of development activities involve the potential users and beneficiaries. The Conceptual Framework for Participation and Consultation in LGED is given below:

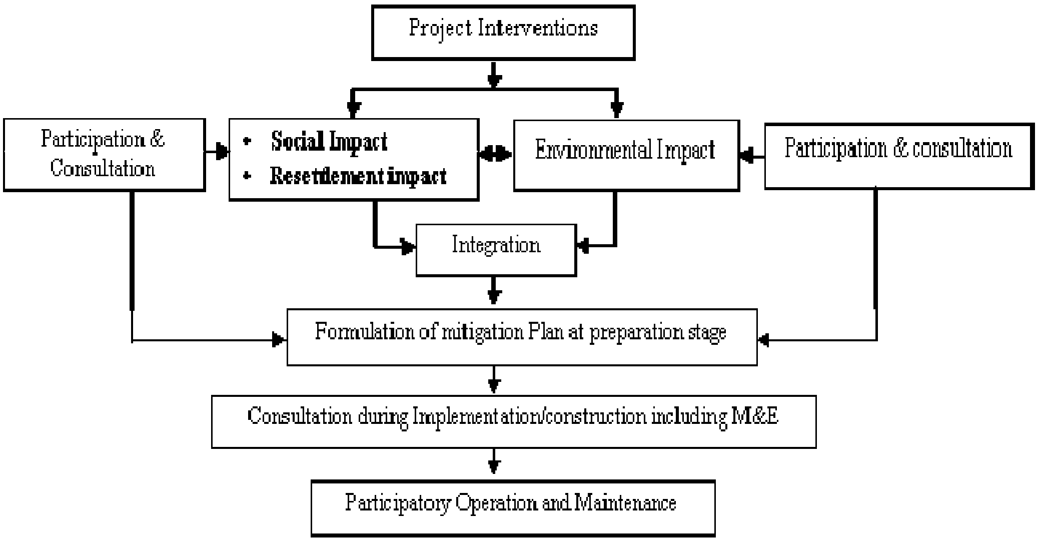

Figure 13: The Conceptual Framework for Participation and Consultation in LGED

8. NON-STRUCTRUAL MEASURES

8.1 Community Mobilization:

LGED is applying Participatory Learning and Action (PLA) as apart of community mobilization process. Participatory Learning and Action (PLA) is an umbrella term to investigating issues of concern to poor people, and to planning, implementing, and evaluating climate change adaptation activities. LGED's role is to facilitate the process, where by local people identify, prioritize and analyze their own problems, and develop their own solutions. LGED field engineers along with Community Organizers and Sociologists conduct PLA activities and incorporate the findings of it into the design and implementation of adaptation schemes. The communities will develop disaster readiness, response and protections plans as well as oversee specific community interventions.

8.2 Cyclone Preparedness and Health Nutrition

LGED undertakes education programs on cyclone preparedness, primary health-hygiene, nutrition, water-sanitation, arsenic, and home gardening in some selected villages.

8.3 Plantation, Home Gardening and Nursery

Establishment of tree, hedgerow plantations, vegetation on the crest, slopes and toes of roads, elevated settlements, and community places will assist for land stabilization and reduction of soil erosion, environmental restoration and local poverty elevation through income generating activities.

8.4 Incomes and Livelihood:

LGED is creating alternative income generating activities for them with the help of NGOs. It is also imparting training on skill development.

8.5 Boat for Evacuation, Schooling and Ferry:

To facilitate communication, LGED is providing boats for the community through UPs.

9. IMPACT OF ADAPTATION PROGRAM:

These investments in 'climate proofing' the country have had a major impact on economic growth and poverty reduction. Since the 1970's, average annual food grain production in Bangladesh has grown from about 9 million to 27-28 million tones(BCCSAP,2009), which has raised rural incomes and created jobs for poor people in agriculture and related sectors, and made the country largely food secure. Over the last 10-15 years (BCCSAP,2009), the number of fatalities from natural disasters has declined, as the country's ability to manage risks, especially floods and cyclones, has evolved and improved and community-based systems have been put in place. The ADB's evaluated one of such adaptation project of LGED and rated relevant, highly effective, efficient, and less likely to be sustainable. While the roads rehabilitated were found to be useful immediately after rehabilitation, they were inadequately maintained, causing several sections to fall into disrepair.

10. CONCLUSONS AND RECOMMENDATIONS

Despite these successes, we still have a long way to go to eradicate poverty and provide opportunities for all our people. We must scale up this work urgently. To do this we have already made climate change an integral part of our national development strategy and have started to build the country's capacity (communities, civil society, the private sector and government) so that we are able to tackle the impacts of climate change, in a routine way, as part of the development process. The resources currently available for adaptation are grossly inadequate to meet the needs of the country. Any delay will increase the risks associated with climate change, which could be expensive to manage later on but, more importantly, the human costs will be immeasurable.

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IMPACT OF CLIMATE CHANGE IN COASTAL ZONES OF INDIA AND ADAPTATION STRATEGIES AND POLICIES

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ABSTRACT

The coastal zone represents the transition from terrestrial to marine influence and vice versa. India has a 8,129 km long coastline in the mainland, and major island ecosystems are Andaman and Nicobar group of island and Lakshadweep islands. The seas around India have rich fishery resources with an annual catch of 2.95 million tonnes against a potential of 3.90 million tonnes. The marine fishing industry consists of 2 million fishermen living in 2400 fishing villages, catching fish with about 180 thousand artisan crafts, 30 thousand mechanized boats, 1.5 thousand landing centres and about 40 fishery harbours. However, the coastal zone is very vulnerable to cyclones, currents and frequent tides. Sea level rise due to global warming has been predicted and its implication to coastal zone could be disastrous. Prudent policies and sound programmes are necessary to reverse the harmful effects of human activities and weather adversities. In India, the multifaceted approach to the management of coastal resources has become known as integrated coastal management (ICM). The aim of ICM is to guide coastal area development in an ecologically sustainable fashion and is guided by the Rio Principles with special emphasis on the principle of intergenerational equity and, holistic and interdisciplinary in nature, especially with regard to science and policy. The ICM promotes the rational economic development and sustainable utilization of coastal and ocean resources and facilitates conflict resolution in the coastal zone, embraces all coastal and upland areas, the uses of which can affect coastal waters and the resources therein, and extends seaward to include that part of the coastal ocean that can affect the land of the coastal zone. The government of India has several strategies to develop coastal ecosystem which state, inter alia; the states and union territories should undertake the requisite steps to put a stop to indiscriminate occupation of coastal strips and their exploitation. Each coastal state should prepare a comprehensive plan, keeping in view the environment and ecological impacts, and regulate development activities accordingly. For the purpose of protecting and conserving the coastal environment, the Ministry of Environment and Forests issued the Coastal Regulation Zone Notification (CRZ), under the Environment Protection Act, 1986. This notification provides a unique regulatory framework without any parallel, globally speaking, for the conservation of the coastal resources by regulating development activities within the CRZ. A number of Expert Committees have also been constituted by the Central Government in the past to look in to these representations and the issues raised therein, the latest committee being headed by Prof. M. S. Swaminathan. The Indian Government has started Western Ghats Development Programme (WGDP) and Integrated Wasteland Development Project (IWDP) to develop coastal areas by investing huge amounts under five-yearly plans for resource conservation and enhancing crop productivity. The major development strategies for these areas include; development of fisheries, integrated watershed development programme, shifting cultivation to be replaced by integrated agriculture-horticulture programmes, improvement of cattle, strengthening marine and inland fisheries and maximizing crop productivity. All these strategies and policies of the government of India have resulted in 16 and 6 times increase in marine and inland fish production between 1950 and 2003 and, about four-fold increase in crop productivity. This has improved the working environment and quality of life of the coastal population.

Key words: climate change, coastal zones of India, adaptation strategies and policies

1. INTRODUCTION

Coastal areas are commonly defined as the interface or transition areas between land and sea, including large inland lakes. Coastal areas are diverse in function and form, dynamic and do not lend themselves well to definition by strict spatial boundaries. Unlike watersheds, there are no exact natural boundaries that unambiguously delineate coastal areas. Coastal zones are dynamically evolving systems comprising three components, i.e. the marine, the coastal, and the land subsystem. This is a typical division of a coastal zone and the only common feature that two different coastal zones may present. Concerning other features such as landscape morphology, ecological habitats, land uses, residential development and economic activities, etc., coastal zones present a multivariate environment with various characteristics. The activities on the hinterland areas significantly affect the sea area near the coastline as large amount of sediment load is carried from the main land to the sea. Possible impacts of climate change and associated rise in sea level in the coastal region in India are; inundation of the deltas, low-lying coastal areas and the fertile agricultural lands, destruction of coastal settlements in the flood risk areas and displacement of many coastal dwellers and possibly resulting in coastal hinterland migration. IPCC (2007) identified that the severe impact, that may be associated with climate induced sea level rise, would be influenced not only by the rising waters but also the increased intensity of climatic forces such as increased waves and tidal activities, storm surges, typhoons, increased rainfalls, increase monsoon winds and flash floods. Sharma and Sharma (2004) reported that about 51.4% of the eroded soil and 57.6% of the dissolved nitrogen from the adjoining hills and estuaries are carried to the sea through the fluvial system. The coastal ecosystem of India forms a very valuable resource community, supporting the livelihood security of several million people and greatly contributing to national economy (Sen et al., 2000). The coastal areas of India are subjected to vagaries of nature and non-stop, mostly intentional, anthropogenic factors. Strong relevant policies and their proper implementation, along with sound programmers, are necessary to contain the impacts of natural factors and reverse the harmful effects of human activities. Many workers have done research and developmental work in coastal areas of India and primary information has been taken from these studies and resultant literature (National Commission on Agriculture, 1976, Bandyopadhyay et al., 1988, Ministry of Environment and Forest, 1987, Ministry of Agriculture. 2005, Sen et al., 2000). The paper discusses the impact of climate change in coastal areas of India and, adaptation strategies and policies.

2. THE COASTAL ECOSYSTEM OF INDIA

India has a 8,129 km coastline. The peninsular region of India is bounded by the Arabian sea on the west, the bay of Bengal on the east and Indian ocean on the south (Fig. 1). It has two distinct islands ecosystems, the Andaman and Nicobar group of islands in the bay of Bengal and the Lakshadweep islands in the Arabian sea. The hinterland of the coastline has varied geomorphic and topographical features of mountains, valleys, coastal plains, riverine systems, climatic and soil conditions, water budgets and a wide range of cultivated crops (Sen et al., 2000). The economic jurisdiction of India in the sea for exploitation spreads over 2.02 million km^2 of an Exclusive Economic Zone (EEZ). Shore lands are the areas that have direct and significant impact on the coastal areas. In the Indian context, no systematic study has been made to demarcate the coastal zone based on well defined scientific parameters. Variable estimates have been made with regard to area under coastal ecosystem (Szabolcs, 1979), however, the latest compilation made by Velayutham et al (1998) shows 10.78 million ha area under coastal ecosystem of India. The study was based on the detailed analyses of the sub-ecological regions. None of these studies considered biotic properties for demarcating the coastal areas.

2.1 Climate

The climate of coastal areas of India has limited variations. Almost the entire coastal area of the country, excluding the Gujarat's north coast, receives a rainfall varying from 674 mm to 3500 mm (Ramakrishna et al., 2000) (Table 1). More than 80% of rainfall is received from June to September. However, the coastal areas of Tamil Nadu receive about 30% of total rainfall in the same period and remaining rainfall is received in November and December. The average maximum temperature varies from 25 to 35 ^{O}C and minimum from 20 to 24 ^{O}C (Bandyopadhyay et al., 1988). These high temperatures affect the growth of thermophyton crops like wheat, barley, mustard, linseed etc. (Sen et al., 2000). The climate of the coastal areas of India, especially in the eastern coast, is by and large uniform throughout the year and facilitate to grow three crops of rice in a year.

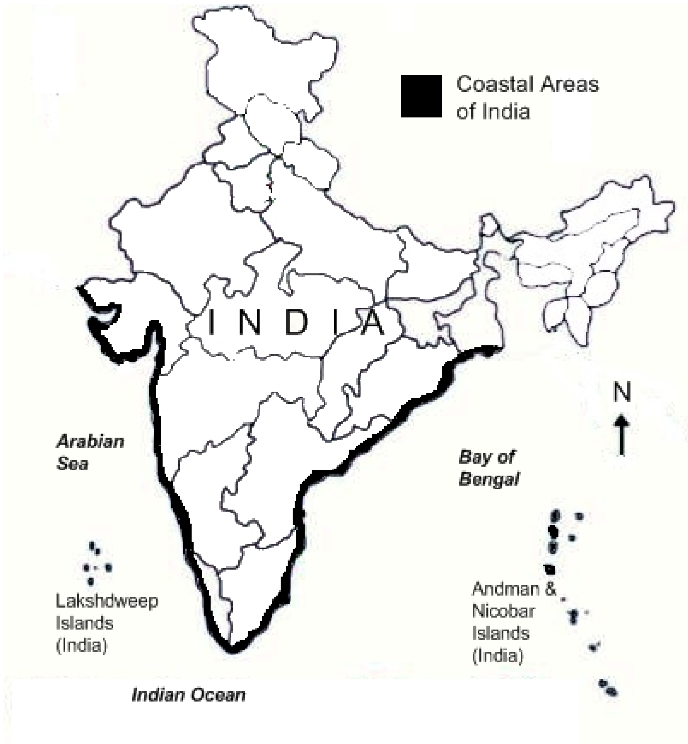

Fig. 1. Coastal ecosystem of India

Table 1**:** Monthly rainfall and temperature in the coastal belt of India.

Coastal region	**Rainfall range**	**Temperature range (^{0}C)**	
		Maximum	**Minimum**
Orissa	1400-1700	27-30	14-20
Andhra Pradesh	1060-1140	26-33	19-25
Tamil Nadu	750-1000	28-36	21-27
Kerala	2600-3000	25-27	22-25
Karnatka	3000-3500	28-32	20-26
Goa/Konkan	2000-3400	27-32	22-26
Gujrat	674-1205	28-33	21-27

2.2 Soils of coastal zone

Velayutham et al. (1998) have studied in detail the soil of coastal ecosystem in India. The soils of the coastal areas are very deep, fine loamy to fine in texture, and imperfectly to poorly drained. Mottels are observed below the surface soils. Soils occurring in lower delta are very deep, very poorly drained, and fine loamy in texture. The soils of the coastal zone are neutral to slightly alkaline in reaction and the pH values range from 4.2 to 7.8. The organic carbon varies from 0.15 to 0.75%, and CEC from 12.8 to 26.0 cmol(p+) kg^{-1}. Exchangeable Ca++ and Mg++ are the dominant cations in the exchange complex. Out of 107.8 thousand km^2 of coastal area, 25.2 km^2 or 23.37% is salt affected. The coastal soil of Andhra Pradesh occur on flat lands, low lands, swamps and marshes (Reddy et al., 1996). The low land soils are deep to very deep, imperfectly drained, cracking clay soils which are flooded and water logged. These soils are classified as Chromic/Entic Haplusterts and Vertic Ustropepts.

2.3 Mangroves and seagrasses

Seagrasses are salt tolerant plants and grow under water. They grow along with mangroves and reef communities at their respective seaward and landward boundaries (Sen et al., 2000). In the coastal ecosystem of India, the mangroves cover an area of 6560 km^2 and have about 35 species (Table 2), out of which 5890 km^2 or 91.1% area is in the east coast (Ministry of Environment and Forest, 1987). Sea

Table 2: Mangrove area in east and west coast of India

Coast	Area (km^2)	Per cent of total	Species
East coast	5890	91.1	30
West coast	670	8.9	22
Total	6560	100.0	35

grasses communities can trap and bind sediments, thus controlling erosion in shallow waters. Post-larval stages of commercially important fisheries concentrate and develop in these areas.

2.4 Fish and marine products

Traditional aquaculture has been practiced in West Bengal and Kerala states for many years. India started full scale scientific aquaculture in 1986-87 when some of the state governments such as Andhra Padesh, Maharashtra, Gujarat and Tamil Nadu made land allotments to private entrepreneurs. Of the total fish production in coastal states, about 2.95 million tonnes is from the marine sector and 2.28 million tonnes from the inland sector (Table 3) (Ministry of Agriculture, 2005). The marine

Table 3. State-wise fish production in 2003-04 in coastal area of India (000'tonnes)

State/Union Territories	Marine	Inland	Total
Andhra Pradesh	146.6	680.7	827.3
Goa	88.8	3.6	92.4
Gujarat	745.7	45.5	791.2
Karnataka	189.9	70.0	259.9
Kerala	526.3	76.2	602.5
Maharashtra	453.0	125.1	578.1
Orissa	156.1	190.0	346.1
Tamil Nadu	355.1	101.1	456.2
West Bengal	164.0	988.0	1152.0
Other coastal areas	125.0	4.1	129.1

fish production has almost doubled during the last about two decades. About 90% of the present fish production comes from the inshore waters. Fish species like mahseer and hilsa (Hilsa ilisa) and non-air-breathing catfishes may be incorporated into commercial cultural practices for higher production (Ayyappan, 1997).

3. CLIMATE CHANGE AND ADAPTATION STRATEGIES

Climate change could tip the Earth's delicate balance and unleash a host of geological disasters (Joshi, 2009). It may also trigger earthquakes and volcanic eruptions. It is likely to impact water resources, coastal areas and agriculture in India. The global climate change caused by the green house effect is estimated to result in an increase of 0.3 to 2.1 m water level in the sea by 2075 A.D. This may submerge extensive lowland areas near the coast with water in large part of Eastern India (Sen et al., 2000). So sensitive will be the situation that even slight changes in climate can rip the planet's crust apart, causing volcanic eruptions, landslides and tsunamis. 'Fast-action mitigation may still save us from the worst of the abrupt climate impacts, but we've got to start immediately. The Indian south-west monsoon remains a complex phenomenon and it would be difficult to predict the course of monsoon with the existing statistical, empirical or other dynamical models. The intensity and frequency of spells of rain, drought, cyclones and storms are getting worse every year. So, the climate change is likely to impact the coasts of India and the world greatly. There is urgent need to work towards enhancing the resilience of the country's development by anticipating and adapting climate change related impacts. Care has to be taken to work on the, (i) risk reduction strategies, (ii) policies and planning processes at the state and national level, (iii) integrating climate risks into management frameworks in coastal areas and, (iv) to take stakeholders into confidence. With possible impacts of climate change, an increase in cyclones, erratic rainfall and frequent flood incidences have been observed recently. The sediment load in flood water contains 1500-30000, 6.4-25.8, 2.3-8.5, 15.4-33.8, 0.3-1.6, 0.8-2.4, 0.1-0.3 and 6.3-18.4 mg L^{-1} of soil, NO_3-N, P-PO_4, K_2O, Zn, Mn, Cu and Fe, respectively (Sharma and Sharma, 2005). Large scale interactions between the plants, soil, livestock and hydrology on the land adjoining coastal areas have a significant impact in the coastal zones (Sharma and Sharma, 2005; 2009). A study conducted in the *Sagar* islands of West Bengal coast, being mantled by Quaternary sediments carried and deposited by the river Ganges and its distributaries showed that total dissolved salts (TDS) ranged from 495 to 740 mg L^{-1} with low to medium sodium adsorption ratio (SAR) values (Majumdar and Das, 2009). Relevant policies of the government and well thought strategies would give the necessary strength to reduce the impact of and adapt to climate change. Vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change and is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to changes in climate (Watson, 1996). Decreasing the vulnerability of socio-economic sectors and ecological systems to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long-term vulnerability of these systems to climate change (IPCC, 2000). However, it should be noted that some of these projected adverse effects can, to some degree, be reduced through proactive adaptation measures.

Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Smit et al. 2000). Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions (Watson et al. 1996). According to the IPCC Third Assessment Report (2001), adaptation "has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages." Sustainable and successful adaptation to climate change in coastal areas could be achieved if it is perceived as a process similar to spatial planning. It should be planned, implemented well in advance, monitored and evaluated before the occurrence of a natural disaster or an environmental change (Boateng, 2009). Tol et al, 2008 revealed that to identify the most appropriate coastal adaptation strategy, we must consider the full context in which the impacts of climate change arise and realise that the aforementioned strategies happen within a broader policy process, which includes consideration of numerous climate and non-climate issues and consider climate change as a multistage and iterative process. Klein et al (2000) observed that adaptation to climate change in coastal zones should be viewed as a process that comprises more than merely the implementation of technologies to protect against, retreat from, or accommodate sea level rise. There are two approaches in planning theory that explicitly address the substantive purpose of planning. One is descriptive, identifying the purpose of planning with its substantive fields such as land-use planning and development control, environmental planning, development planning, community or neighbourhood planning, and transportation planning (Alexander, 1992). The other is normative, usually with implied ideological associations such as "advocacy planning", a planning model meant for the poor and designed to promote the interests of disadvantaged communities (Davidoff, 1965). Coastal adaptation to climate change could be sustainable and effective if modern planning theories as highlighted above are applied. These complex principles and procedures are well developed and properly understood in spatial planning; hence applying sustainable spatial planning principles to coastal adaptation planning could ensure sustainability and effective adaptation policy development and implementation (Boateng, 2009). IPCC (2007) identified that one way of increasing adaptive capacity is by introducing the consideration of climate change development planning, by including adaptation measures in land-use planning and infrastructure design and measures to reduce vulnerability in existing disaster zones. According to Kates (2000), most efforts to address climate change to date have focused on mitigation, or preventive action to limit greenhouse gases, rather than adaptation. Kandlikar and Sagar (1999) found that while India is advanced in terms of climate change research and analysis with respect to other developing countries, adaptation issues have yet to come to the forefront. Sharma and Kumar (1998) observed that disproportionately greater attention has been paid to climate change mitigation than to adaptation measures.

4. MANAGEMENT OF COASTAL AREAS

4.1 Problems of coastal areas

Almost all problems that are encountered in coastal policy fall into three major domains of coastal policy problems: (i) those that relate to resource use conflicts, (ii) those that relate to resource depletion and (iii) those that relate to pollution or resource degradation. The problem of environment degradation in the coastal areas of India are, primarily impacted by demographic pressure, urbanization, solid waste disposal, natural disasters, tourism, mining in coastal areas, sea level rise, coastal construction, power plants, soil erosion and land degradation, impact of ports, destruction of mangroves etc. In the coastal regions salinity of groundwater due to the intrusion of seawater into the subsurface aquifer is a major problem, particularly in Tamil Nadu and Gujrat. Due to excess withdrawal of groundwater, the water table has fallen too far below thereby allowing seawater to percolate. In coastal regions of West Bengal and Orissa, the problem of fresh water is fairly acute. Coastal ecosystems like mangroves, coral reefs provide natural protection to coasts by dissipating considerable wave energy. The loss of inshore fish nursery habitats by coastal pollution from land-based activities cause significant change to ecosystems supporting fisheries. The rich biodiversity of the wetlands in India is seriously threatened by loss of wetlands due to sea level rise. India’s Sunderbans are highly vulnerable to sea level rise since it will change the salinity distribution and hence the productivity. According to estimates in West Bengal, quite a substantial amount of pollution load is discharged by the Kolkata Metropolitan District (396.9 t ha^{-1}), a large part of it (23.0 t ha^{-1}) is is carried away from Hooghly river directly into the *Sundarbans* estuaries (Yadav, 1987). Frequent cyclones is a common problem of coastal areas. In 1999, a super cyclone in the bay of Bengal took record toll of 15,000 human lives and half million of bovine population, apart from a total loss of agricultural crops and other infrastructure in ten coastal districts in Orissa. Between 1960 and 1981, India experienced 28 flood and 26 cyclone events with 14,700 and 24,930 deaths, respectively. During 1998, a storm resulted in death of more than 1,000 people as well as colossal loss of property in coastal region of Saurashtra.

4.2 Integrated coastal management (ICM)

The multifaceted approach to the management of coastal resources has become known as integrated coastal management (ICM), integrated coastal zone management (ICZM) or integrated coastal area management (ICAM). Pernetta and Elder (1993) have described it as meaning 'the process of combining all aspects of the human, physical and biological aspects of the coastal zone within a single management framework'. However, they have preferred the term 'holistic coastal management' to emphasize that 'careful planning and management of all sectoral activities simultaneously will result in greater overall benefits than pursuing sectoral development plans independently of one another.' The following points have been mentioned with regard to coastal area management:

(i) the aim of ICM is to guide coastal area development in an ecologically sustainable fashion,
(ii) ICM is guided by the Rio Principles with special emphasis on the principle of intergenerational equity,
(iii) ICM is holistic and interdisciplinary in nature, especially with regard to science and policy,

(iv) ICM promotes the rational economic development and sustainable utilization of coastal and ocean resources and facilitates conflict resolution in the coastal zone,

(v) an ICM programme embraces all coastal and upland areas, the uses of which can affect coastal waters and the resources therein, and extends seaward to include that part of the coastal ocean that can affect the land of the coastal zone,

(vi) overcoming the sectoral and intergovernmental fragmentation that exists in today's coastal management efforts is a prime goal of ICM,

(vii) institutional mechanisms for effective coordination among various sectors active in the coastal zone and between the various levels of government operating in the coastal zone are fundamental to the strengthening and rationalization of the coastal management process,

(viii) given the complexities and uncertainties that exist in the coastal zone, ICM must be built upon the best science (natural and social) available. The coastal ecosystem to be managed is comprised of a complex, dynamic web of interrelationships among human activities, societal demands, natural resources, and external natural and human inputs. The system is driven by human activities in terms of societal demands for use of the natural resources of the coastal area to produce desired products and services. Societal demands for outputs from a coastal area usually exceed the capacity of the area to meet all of the demands simultaneously. The coastal produce has, generally, free access to users and may lead to over-exploitation which may lead to pollution and habitat degradation. Management is an interactive, adaptive and participatory activities to achieve desired objectives and goals.

Management of coastal areas include, (i) multiple and conflicting demands on the coastal area, (ii) human population increases and associated demand for economic development within the coastal area, (iii) rate and magnitude of natural processes, e.g., shoreline erosion, ecological succession, land subsidence etc., (iv) limited resources for management, (v) potential climate change and its impact and, (vi) level of awareness about the government policies and programmes, economic conditions and attitude of the people.

4.3 Planning in coastal zones

Planning is an integral part of management. The purpose of planning in the coastal zone is to produce a framework to guide decision makers in the allocation of scarce coastal resources among stakeholders. The concept of planning is important in what practitioners do. In order to adequately manage coastal systems, particularly the control of cumulative impacts, coastal management institutions must have a land use and water use plan to guide their policy making and decision-making processes. Planning for integrated coastal management should consider explicitly plans and actions of other sectors of the economy, in terms of the time pattern of proposed, and in progress, capital investments and operation, maintenance, and replacement expenditures. From the preceding follows the principle that there should be a common framework across sectors for making economic and demographic projections, developing scenarios, and using similar analytical techniques for analyzing benefits and costs. Achieving such a common framework is difficult, since there rarely is an institution with overall responsibility for integrated planning and development.

5. GOVERNMENT OF INDIA POLICIES AND STRATEGIES

India has two national water policies of 1987 and 2002. The policies recognized water as a precious national asset embodying the nation’s resolve that planning and development of water resources would for water resources development and called for appropriate measures to optimize utilization of these resources not only for the people of the country but also foe the transfer of surplus water to the water-short areas. The success of national water policy will depend entirely on the development and maintenance of a national consensus and commitment to its underlying principles and objectives (Goverment of India, 1987; 2002). It envisages, *inter alia*, that erosion of land by sea in the coastal areas or by river waters has to be minimized by suitable cost-effective measures. The government of India has several strategies to develop coastal ecosystem which state, intra alia; the states and union territories should undertake the requisite steps to put a stop to indiscriminate occupation of coastal strips and their exploitation. Each coastal state should prepare a comprehensive plan, keeping in view the environment and ecological impacts, and regulate development activities accordingly. Water resources management for diverse uses should incorporate a participatory approach by involving not only governmental agencies but also users and other stakeholders in various aspects of planning, design, development and management of water resources schemes. A role for women should be envisaged. Private sector participation should be encouraged in all these aspects.

5.1 Revised Coastal Zone regulations

For the purpose of protecting and conserving the coastal environment, the Ministry of Environment and Forests issued the Coastal Regulation Zone Notification (CRZ), 1991) under the Environment Protection Act, 1986 (Ministry of Environment and Forest, 1986, 1991). This notification provides a unique regulatory framework without any parallel, globally speaking, for the conservation of the coastal resources by regulating development activities within the CRZ. A number of Expert Committees have also been constituted by the Central Government in the past to look in to these representations and the issues raised therein, the latest committee being headed by Prof. M. S. Swaminathan. The terms of reference of the committee were to review the reports of various Committees appointed by the Ministry of Environment and Forests on coastal zone management, consider international practices, and suggest the scientific principles for an integrated coastal zone management best suited for the country, define and enlist various coastal and marine resources and recommend the methodology for their identification and the extent of safeguards required for conservation and protection and revisit the CRZ Notification 1991 and recommend necessary amendments to make the regulatory framework consistent with recommendations on (a) and (b) above and the Environment (protection) Act, 1986. The Committee has evolved, *inter alia*, the guiding principles to govern future decisions on coastal zone management viz. (a) ecological and cultural security, livelihood security and national security should be the cornerstones of an integrated coastal zone management policy, (b) regulation, education and social mobilization should be the three major components of a participatory and sustainable Coastal Zone Management strategy, (c) the protection and sustainable development of the marine and coastal environment and its resources should be in conformity with international law, (d) coastal regulation needs to be based on sound, scientific and ecological principles and should safeguard both natural and cultural heritage. Bird sanctuaries and parks and breeding grounds of migratory birds should be protected, (e) the precautionary approach should be used where there are potential threats of serious or irreversible damage to ecologically fragile critical coastal systems and to living aquatic resources, (f) significant or irreversible risks and harm to human health and life, critical coastal systems and resources, including cultural and architectural heritage, would be considered unacceptable, (g) coastal policy and regulations should be guided by the principles of gender and social equity as well as intra-generational and inter-generational equity, All stakeholders should be involved in decision-making, (h) coastal protection and bio-resources conservation policies should be guided by techno-economic efficiency, the precautionary approach, 'polluter-pays' principle(s) and 'public trust' doctrine, (i) the principles contained in the Biodiversity Act (2002), should be applied to coastal bio-resources management etc.

5.2 Coastal zones re-classification

The Committee has recommended the reclassification of the coastal areas into four zones such as; (i) Coastal Management Zone-I (CMZ-I): consisting of areas designated as Ecologically Sensitive Areas (ESA) such as, mangroves, coral reefs, sand dunes, inland tide/water bodies such as estuaries, lakes, lagoons, creeks & straits, mudflats, marine parks and sanctuaries, Coastal forests & wildlife, coastal fresh water lakes, salt marshes, turtle nesting grounds, horse shoe crabs habitats, seagrass beds, sea weed beds and nesting grounds of migratory birds, (ii) CMZ-II: consisting of areas identified as areas of particular concern such as economically important areas, high population areas and culturally/strategically important areas. The administrative boundaries of these areas would be boundaries of CMZ-II, (iii) CMZ-III: consisting of all other open areas including the coastal seas but excluding those areas classified as CMZ-I, CMZ-II and CMZ –IV and, (iv) consisting of islands of

The Andaman and Nicobar and Lakshadweep. The re-classification of coastal zones has been suggested for efficient management of these areas for livelihood security and face future challenges. Since the coastal management is a multi-disciplinary subject, the Committee has suggested a National Sustainable Coastal Zone Management Institute along with organizational structure to address issues relating to policy, law and conflict resolution to create public awareness.

6. CONCLUSIONS

The coastal regions of India are highly fragile and vulnerable to natural and anthropogenic factors. The region is frequently subjected to hazards of cyclones and tides resulting in colossal loss of agricultural production, human and animal lives, infrastructure and soil erosion, as well as land and environmental degradation. The likely impacts of climate change in the coastal zone, accompanied by a rise in sea level would further add to the miseries of the coastal areas. For the purpose of protecting and conserving the coastal environment, the Ministry of Environment and Forests issued the Coastal Regulation Zone Notification (CRZ, 1991) under the Environment Protection Act, 1986. This notification provides a unique regulatory framework without any parallel, globally speaking, for the conservation of the coastal resources by regulating development activities within the CRZ. There is strong need to properly implement the Coastal Regulation Zone Notification and Environment Protection Act to improve the economy and quality of life of the people of the coastal areas as well as get prepared to face the challenges as a consequence of climate change. The recommendations of Prof. Swaminathan committee have to be implemented in letter and spirit. The people's participation is necessary for the success of implementation of the government policies. Coastal policy and regulations should be guided by the principles of gender and social equity as well as intra-generational and inter-generational equity and all stakeholders should be involved in decision-making,

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MEETING THE CHALLENGES OF CLIMATE CHANGE IMPACTS ON THE COASTAL ZONE OF SRI LANKA

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ABSTRACT

Sri Lanka's coastal zone is important as a natural resource as well as a zone of heightened economic activity. As a natural resource, it consist of several wetlands rich in biodiversity. As a zone of high economic activity, the zone accommodates industries, urban centers and a nationally important transportation network, while being an area of high population density. As a result, the consequences of natural and man-made disasters, including those due to climate change, are heavily felt.

The coastal zone is a complex and dynamic system influenced by social, economic and physical parameters. Therefore, a pre-requisite for framing of adaptation strategies is to have a good understanding about the state of the coastal zone, the factors which contribute to the state and the action taken by the society to rectify or improve the situation. An analytical framework developed by European Environment Agency is found to be suitable for such an analysis.

The analysis show that the driving forces acting on the coastal zone include population density, urbanization, industrialization, Fisheries, Agriculture, poverty and climate change. The pressures resulting for these driving forces include depletion of coral reefs, destruction of mangroves, and removal of sand dunes. Furthermore, excessive drainage from agriculture laden with nutrients and disposal of domestic and industrial waste are the other pressures acting on the coastal zone. These pressures have created a state in which the coastal zone is vulnerable to the natural disasters and climate change. About half of the coast line is having a severe erosion problem. Coastal ground water system is at a state of vulnerability.

Pollution and depletion of ground water, salinity intrusion affecting drinking water, decrease in fish population, eutrophication in lagoons, and reduction of sand flowing to the coast are among the major impacts. The impacts resulting from the state of coastal zone were observed during the Asian tsunami of 2004. The vulnerability of the coastal zone resulted on extensive damage to the systems itself.

The society, including the government has responded by policy formulation, action plans, research, development activities and regulations. However, there appears to be several gaps between the responses and the challenges posed by the state of the coastal zone, as well as the impacts on it. Policy gaps are evident and it is difficult to address the pressures emanating from outside the coastal zone, such as agriculture, poverty and urbanization.

1. BACKGROUND

1.1 General description

Sri Lanka is an island located close to the equator and experiences a tropical monsoon climate. The total area of Sri Lanka is 65,600 km^2. The most recent estimate of the population made in 2007 is 20.01 million. The mean annual rainfall of Sri Lanka, based on the rainfall from 1961-1990, is 1860 mm. There is a substantial difference in surface water availability across the space and water resources development centered on reservoir building was adopted from the ancient times to address the spatial differences of water availability.

1.2 Climate change in the context of Sri Lanka

Sri Lanka has taken an active interest in activities related to climate change in the last two decades. The annual mean air temperature has shown an increasing trend in the over the entire island. This increase was found to be approximately 0.16ºC per decade (ANON, 2000) or 0.016 ºC per annum. The analysis of rainfall is more complex. Jayatillake et al (2005) analyzed the rainfall volumes between the periods 1931-1960 and 1961-1990 and showed that rainfall had noticeably reduced during the north-east monsoon and second inter-monsoon period, which bring the bulk of the rainfall to the dry zone of Sri Lanka. The variability of rainfall had also increased during these two seasons. Other studies show that the area of dry zone has increased.

The unpredictability of rainfall, increase of the area of dry zone and reduction of rainfall in that area would increase the importance of water storage facilities for economic activities. However, increase in temperature could pose further challenges to water system managers, because of the higher evaporation rates.

In the long term, the predicted sea level rise would affect the agriculture and drinking water supply in coastal low lying areas. Increased ocean temperatures will have adverse effects on the life in the coastal zone, as well.

1.3 Coastal zone management policy and institutional framework

A policy document titled “Coastal 2000: A Resources Management Strategy for Sri Lanka’s Coastal Region” was adopted by the Cabinet of Ministers in 1994. This was a production of studies carried out by the Coast Conservation Department with the help of external organizations. The document was designed to provide the direction for future strategic interventions in coastal zone of Sri Lanka (Clemett et al, 2004). Other than the policies directly dealing with the coastal zone management, there are other national policies which influence the coastal zone. They include the policies on environment, watershed management, water resources management, agriculture and drinking water.

The Initial National Communication (INC) on Climate Change in Sri Lanka (2000) recommended including the aspect of climate change in the national water resources policy that was being drafted at that time (Jayatillake et al, 2005). However, the national water policy was not finalized and the related activities have stopped now. The aspect of climate change is not fully incorporated into existing policies and programmes in the water sector. There are also gaps in institutional mechanisms, laws and their implementation.

Coast Conservation Department is the major State institution dealing with coastal management. It is responsible for regulating the development activities in the zone, and therefore controls the deposit of wastage, and removal of sand, coral, and vegetation. It is also responsible for preparing and implementing Coastal Zone Management Plans.

It is however estimated that there are more than 10 agencies responsible for various aspects of coastal zone management. Among the other agencies are the institutions dealing with fisheries, harbors, environmental conservation (Clemett et al, 2004), and Provincial and District administration.

2 PURPOSE AND METHODOLOGY

Considering the importance of coastal zone in the Sri Lankan economy, there is a need to frame adaptation strategies for addressing the likely impacts. However, the coastal zone is a complex and dynamic system influenced by social, economic and physical parameters. Moreover, adaptation strategies are guided by existing policies and are implemented through existing institutional framework. Before framing adaptation strategies, it is important to analyze the current policy and institutional framework to assess whether the existing system is capable of implementing such measures. In such an analysis, the policy maker should have a good understanding about the state of the coastal zone, the factors that contribute that state, and the actions taken by the society to rectify or improve the situation.

As water resources play a key role in the social and economic development in Sri Lanka, the impacts of climate change will be heavily felt among the economic sectors that depend on water resources including agriculture, drinking water and sanitation. Such impacts will lead to change in the consumption patterns in the water use sectors, which will in turn exert pressures on the coastal zone, and this has to be taken into account in framing adaptation measures.

Therefore, this paper attempts to assess the coastal zone in a holistic manner, to provide a basis for framing adaptation strategies by the relevant experts. In the assessment, climate change will be used as one of the driving forces that contribute to shape the state of the coastal zone.

Several analytical frameworks have been developed in the recent past to enable a holistic and integrated assessment of the environment. The DPSIR (Driving forces, Pressures, State, Impact, Response) framework developed by the European Environmental Agency is adopted by several researchers (van Buuren et al, 2000, Jorge et al, 2002) in the assessment of marine and coastal systems, and based on the results, can be considered as capable of supporting a sound decision making process. It is a set of cause-effect relationships or causal links between the components or elements of the framework, describing how the system being analyzed is related to the processes of the society (Adriaanse et al, 2000), and thereby facilitates the description of relationships between the origins and consequences of environmental problems, and their dynamics (Smeets and Weterings, 1999).

3 ASSESSMENT OF COASTAL SYSTEM OF SRI LANKA

3.1 Driving Forces

Driving forces result from social, demographic and economic activities in societies (Jorge et al, 2002). They influence or result in changes in production and consumption levels. In the literature surveyed for this paper, climate change has not been identified as a driver. However, preliminary assessment of the coastal system showed that some of the pressures on the system could be resulting from climate change. Therefore, climate change is considered as a driver acting on the coastal zone, in this analysis. Therefore, the major driving forces that influence Sri Lanka's coastal zone include population density, urbanization, industrialization, agriculture, poverty and climate change.

Population density, urbanization and industrialization: These three inter-linked parameters constitute a major driving force in the coastal zone. The State of the Environment Report of UNEP for Sri Lanka states that 32% of the total population, 65% of the urban population, 90% of the industrial units and 80% of the tourist infrastructure are located in the coastal zone. The Figure 1 shows the population density in the administrative districts and it can be seen that the coastal districts in the west and south west have very high densities. This is due to the relative abundance of water and location of air port, harbors and transport infrastructure. But the current programs to expand harbor facilities in Hambantota and Trincomalee, and establishment of a second international airport in the south close to Hambantota, will result in increasing the population density in other coastal areas and further urbanization.

At present (based on 2001 census) eight out of the ten highly populated towns are located in the coastal zone (DCS, 2008). Figure 1 shows the location of principal towns, of which data from Jaffna, Mannar, Trincomalee and Chilaw was not available in the 2001 census. It has to be noted that tourism and urbanization of the coastal zone took place at a period during which about one-third of the coast was inaccessible due to security reasons. In a more peaceful situation that prevails since mid 2009, there is a strong possibility that such activities will expand rapidly in the northern and eastern coasts.

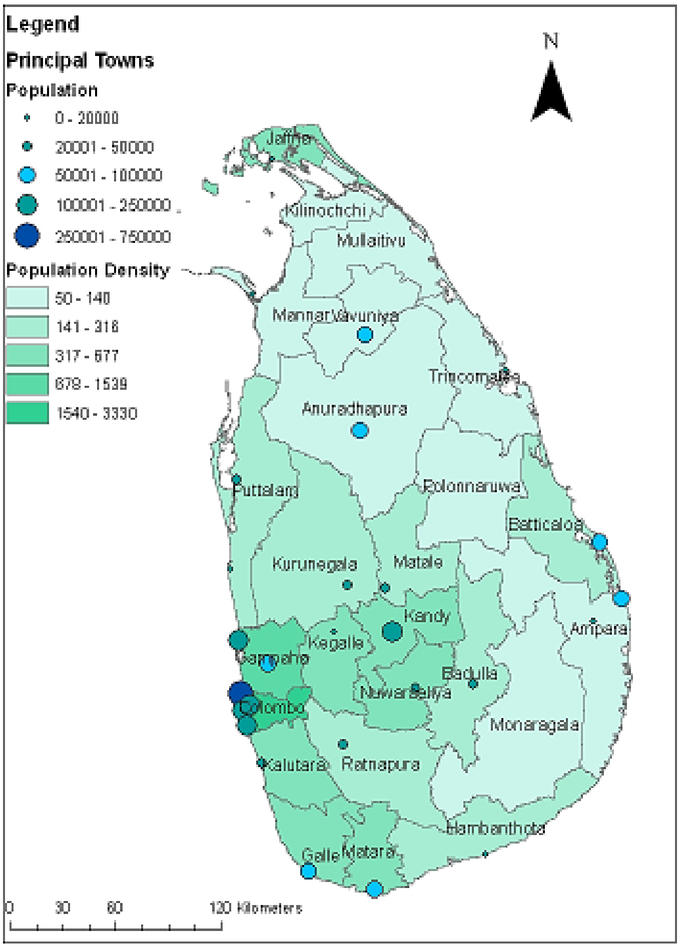

Figure 1. Population density in administrative districts and population in principal towns according to the Census of 2001

(Note: Population density measured in persons/sq.km.)

About 79% of the industrial establishments with five or more persons engaged, and about 83% of the persons engaged in industries are located in the coastal districts. It can be seen that the concentration of industries is heavy in the western coastal districts at present. However, due to reasons mentioned above, the coastal districts in north and east would experience an increase in the industrial activities in the future (DCS, 2009).

Fisheries: Fishing industry comprises of inland as well as marine fish production. Marine fish production contributed to about 90% of the total fish catch and the coastal fish catch was about 60% (CBSL, 2005). The expansion of the prawn industry especially in the north-western coast has resulted in damage to the environment (UNEP, 2005).

Agriculture: The major agricultural areas including irrigated areas are located mainly inland. However, the agricultural activities have a significant impact on the coastal resources. The coastal wetlands are ecosystems high in biodiversity. The Bundala wetland system, located in the south-eastern dry zone, comprising five lagoons is the first Ramsar wetland site in Sri Lanka and is a habitat for migratory water birds. Studies carried out in the southern coastal areas show that agriculture has been intensified in the areas upstream of these lagoons in the recent times. Drainage water from the newly developed agricultural settlement areas are sometimes conveyed into the lagoons of the Bundala wetlands system, which affects the water balance, nutrient status and ecology of these wetlands.

Poverty is an important economic driver. The statistics show that poverty is relatively high in the inland agricultural districts. But the number of poor people is significant in the coastal areas as well. The statistics show that about 39% of the people below the poverty line are located in the coastal districts excluding those in the north and east (DCS, 2005). A large proportion of these poor people live in coastal areas in shanties and unauthorized dwellings.

Climate change: The climate change, as a driving force, creates several pressures on the coastal zone. Most obvious pressure caused by climate change is sea level rise. Among the anticipated consequences of sea level rise include inundation of low-lying coastal settlements and coastal wetlands and salinity intrusion. The increase of wave height will make the coast more prone to erosion. Climate change could contribute to ocean acidification and higher ocean temperatures. Both these phenomena can impact coastal life, especially the corals.

3.2 Pressures

Pressures are caused by the driving forces and could directly cause environmental problems (Jorge et al, 2002).

High population densities in the coastal zone result in competition for coastal resources. This is combined with economic drivers such as poverty. Studies note that coral mining is a major problem depleting the resource. There are laws to restrict this activity but implementation is somewhat difficult due to scarcity of alternate employment. It is noted that coral provides about 90% of the lime for construction industry (UNEP, 2005).

Another serious problem is the clearance of mangroves and other coastal vegetation for aquaculture, housing and firewood. River sand mining and beach sand mining has resulted in a pressure on the coastal system as well, by depleting the flow of sand. In the recent times the government imposed restrictions on river sand mining to arrest river bank erosion and to ensure safety of transport infrastructure. However, the demand for sand is high in the construction industry and a large number of people, due to poverty and unemployment, depend on it for livelihood. Therefore, sand mining continues in locations considered “safe” for the river-based infrastructure. Sand mining and prawn industry has contributed to increased salinity intrusion in the coastal areas.

High population densities, poverty and tourism industry has resulted in erecting many structures such as hotels and private dwellings along the coast. Some of these structures are erected without proper planning. Post-tsunami studies have shown that some tourist infrastructure has resulted in removing sand dunes in the south, for better view of the sea, making the coast vulnerable to tsunami waves.

The research work by International Water Management Institute found several pressures created by the irrigation development upstream of Bundala national park lagoon system, especially Embilikala and Malala lagoons. The flow of agricultural drainage to the system resulting in a drop of salinity levels has contributed to a decrease in fish and shrimp populations in the affected lagoons. Another pressure is created by the loss of grazing land of livestock due to irrigation expansion. This resulted in cattle straying into the national park, and dung and urine from cattle has been introduced to the agricultural drainage. Furthermore, fertilizer use has been increased in irrigated agriculture due to fertilizer subsidy and the emphasis on intensive agriculture. The agricultural drainage has resulted fluctuating water levels affecting the wading birds as well (Matsuno, 1999).

Waste disposal and pollution: Considering the high population densities in the coastal zone, high level of industrialization and unplanned development, it is evident that waste disposal is affecting the coastal zone adversely. The waste includes domestic, waste oil and solid waste. In 1991, between 67,500- 90,000 cubic meters of untreated sewage from city of Colombo was dumped daily to Kelani river, which ultimately flow to the ocean. Waste oil from sea vessels also pollutes the coast (UNEP, 2005).

3.3 State of the coastal zone

The state, in the DPSIR framework, refers to the physical, biological and chemical situation of a system at a given point of time. State is changed by the pressures.

The coast line of Sri Lanka extends over about 1,600 km (UNEP, 2005). As mentioned in previous sections, the coastal zone supports a large population and their livelihoods. In addition, a large proportion of the principal transport infrastructure including highways and railway lines are located in the coastal zone. Coastal erosion had been a serious issue along some sections of the coast line. An erosion rate of 0.30–0.35 m per year for 45%-55% of the coastline had been observed in the recent times (ANON, 2000).

The coastal wetlands comprise of estuaries, lagoons, and mangrove swamps. There are 45 estuaries and 40 lagoons along the coast line. The lagoons are important for fisheries, salt production and tourism and also act as barriers against salt water intrusion (CEA/ARCADIS/EUROCONSULT, 1999). The three Ramsar Convention sites in Sri Lanka are Anawilundawa (1,397 ha), Bundala (6,250 ha) and Madu Ganga (915 ha). Bundala and Maduganga comprise of coastal lagoons, and Anawilundawa is also located close to the coastal zone. Out of the 41 wetland sites of Sri Lanka listed in the Directory of Asian Wetlands, (CEA/ARCADIS/EUROCONSULT, 1999) 27 are located in the coastal zone. Among the major threats are removal of mangroves, aquaculture, and pollution by agricultural waste.

These wetlands are rich in bio-diversity. The species that contribute to the bio diversity include fish, animals such as crocodiles and about 16 marine mammal species and large number of flora species (UNEP, 2005). However, these coastal ecosystems are in a threatened state and have become vulnerable to natural disasters and climate change due to the pressures acting on them.

The mangroves are listed as a threatened and rapidly diminishing wetland type in Sri Lanka. The main mangrove areas are located in the eastern coast, north-east, and north-west. Extent of mangroves has been estimated differently from the figure given in the table. The vegetation is located discontinuously and are badly affected by the development activities, use for firewood and aquaculture. It is noted that about half the mangrove area was lost in the western coast (UNEP, 2005a).

Coral reefs are mainly located in the north-west, east and south coasts. They are badly affected by mining for lime and blasting for fishing. All types of coral reef habitats are believed to be extending over 680 sq.km and having 190 species of hard corals (UNEP, 2005a).

Coastal groundwater system: Panabokke and Perera (2005) discuss coastal sand aquifers in Sri Lanka located in north west and the north-eastern region. They cover about 125,000 hectares and support human settlement, agriculture and tourist industry. It is noted that the sustainability of these groundwater aquifers are affected by various natural disasters and human activities. Apart from the tsunami of 2004, over extraction, pollution and salinity intrusion deplete the usable groundwater.

3.3 Impacts

Impacts in the DPSIR framework include the effects of state of the environment on the population, economy, and ecosystems.

3.3.1 The impacts of Asian tsunami

The population, economy and ecosystems in the coastal zone were badly impacted by the Asian tsunami of 2004. On the one hand tsunami was an event impacting the state of coastal zone. On the other hand, the state of the coastal zone aggravated the impact of tsunami.

Among the direct impacts, it is noted that about two thirds of the coast line was affected. Between 35,000 to 40,000 people died, and the damage to economy is estimated as US$ one billion. Fisheries sector took the biggest toll with 75% of the fishing fleet being destroyed. Salt water intrusion damaged about 60,000 wells (Imbulana et al, 2006).

Among the ecosystems, it is noted coral reefs, mangroves and sand dunes were substantially destroyed by the tsunami. Surveys carried out in the southern and eastern coasts revealed extensive damage to the coral reefs. In Trincomalee, it was found that nearly half the coral reef area was ripped off. Almost all the remaining corals were damaged (UNEP, 2005a). Mangroves met with a similar fate. However, the mature mangroves resisted the waves and in some areas were unaffected.

It was evident that the state of the coastal zone aggravated the damage. In the regions where coral mining was carried out unabated, the destruction of the coast was severe. The areas the ecosystems were less disturbed and were found to have absorbed the disturbances of the tsunami well (UNEP, 2005a).

3.3.2 Impacts due to population and livelihoods

Prawn ponds in the north-western province are observed to be drawing substantial volumes of freshwater from deep tube-wells, adversely affecting the level and the quality of water in shallow wells and causing conflicts with domestic water consumers. The leaching of salts from agriculture to the groundwater table has been identified as the major cause for increased electrical conductivity in north western aquifers (Kuruppuarachchi and Fernando, 1999).

The introduction of mechanical pumps for pumping from the shallow limestone aquifers in the Jaffna Peninsula has led to over-extraction of water, causing salinity intrusion to groundwater aquifers. (Panabokke and Perera, 2005). Sri Lanka's major cities such as Colombo, Galle, and Matara are located in coastal areas and drinking water supply is obtained by river intakes close to the sea. Some of such intakes are already affected by the salinity intrusion, due to reasons such as prawn industry and sand extraction from rivers. It is predicted that such problems would aggravate due to sea level rise.

3.3.3 Impacts from agriculture outside the coastal zone

The intensification of agriculture due to irrigation expansion is impacting the state of the coast wetlands. The animal and agricultural waste causes eutrophication (Matsuno, 1999). Drainage has resulted in flooding of developed lands, and opening the lagoons to the sea to protect them has resulted in fluctuating water levels in the lagoons, affecting wading birds etc. (Smaktin et al, 2004). It is also reported that there has been a decrease in fish and shrimp populations owing to a significant drop in salinity levels, the accumulation and enrichment of nutrients in the lagoons, contributing to possible extinction of species as well as changes to habitat diversity. The economic and social impacts have also been felt by local communities with the ensuing decline in eco-tourism and fisheries.

3.3.4 Impacts from climate change

The direct impacts such as inundation due to sea level rise cannot be easily recognized at this stage. The sea level rise can also increase the rate of coastal erosion. There is a need to monitor such trends. Rise of ocean temperatures are another concern. The mass coral bleaching incident that occurred in 1998 is a fore-warning of the situation to occur. It is estimated that about 80% of the corals were dead as a result. This was followed by changes in fish population, species composition and reef structure. Experience showed that the recovery takes time (UNEP, 2005).

The fishery industry is one of the water related industries that would be affected by the impacts of global warming and sea level rise (ANON, 2000). It is noted that the level of impact of climate change will vary and will also depend on attributes of the species. A temperature rise of about 2^0c may have substantial impacts on the distribution, growth and reproduction of fish stocks.

In addition there are several likely impacts on the coastal zone resulting from change of living and occupational styles, both within and outside the coastal zone. The drop in dry zone rainfall and the increased variability of rainfall have renewed the interest in inter-basin water transfers and water storages, which was somewhat dimmed after the conclusion of Accelerated Mahaweli Development Project in mid 1980s. Similarly, availability of irrigation water, fertilizer subsidies and high food prices have prompted the farmers to adopt more intensive agriculture. These developments will have immediate and long term impacts on the coastal zone, including pollution of coastal water bodies, change in the habitat composition, and further reduction of sand flowing to the coastal zone.

3.4 Responses

Responses are the reactions of the society and individuals to undesired impacts on the environment in order to prevent, mitigate, ameliorate or adapt to changes in the environment (Shah et al, 2000). The responses in Sri Lanka to the above mentioned impacts include policy formulation, action plans, research, and development projects. These responses address coastal zone management as well as climate change.

In the field of climate change, Sri Lanka ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1993 which was entered into force in 1994 (ANON, 2000). The Initial National Communication (INC) on Climate Change was published in 2000 by the Ministry in-charge of the subject of Environment. (Jayatillake et al, 2005). The Ministry of Irrigation and subsequently the Ministry of Agriculture carried out a series of case studies related to the World Water Assessment Programme (WWAP) of the United Nations. While the focus of the studies was on water resources, the second and third phases of the studies had an emphasis on the climate change. The studies revealed the changes in seasonal rainfall, decrease of rainfall predictability, and shifting of dry zone demarcation, both at national level and river basin level.The responses made by the irrigation sector to climate change include building storage reservoirs, improving and modernizing the hydro-meteorological information system and adopting scientific water resources planning. Irrigation systems have been modernized in the recent times, which would reduce the drainage flow to coastal wetlands.

In the field of coastal zone management the responses can be summarized as follows:

- Enactment of laws and regulations and their implementation.
- Preparation and implementation of National Coastal Zone Management Plans of 1990 and 1997, and “Coastal 2000”
- Regulating or banning coral mining and infrastructure development in the coastal zone, fishing methods etc
- Adopting measures for the protection of bio-diversity including declaration of protected areas. At present about 14% of the land area is protected (UNEP, 2005)

There had been several initiatives to involve the communities in the management of the coastal zone. The donor-funded projects have contributed to strengthen community organizations in the coastal zone, contributing to conservation and sustainable utilization of coastal resources. The active organizations include women’s organizations, cooperative societies and youth organizations (Clemmet et al, 2004).

4 CONCLUSIONS

In section 3.1, climate change was identified as a driving force acting on the state of the coastal zone. Direct pressures resulting from climate change are not readily identified at this stage because phenomena such as sea level rise are not accurately quantified yet. Responses address some of the likely impacts of climate zone. The assessment of the coastal zone and fitting them in to the DPSIR framework result in the conceptual relationship illustrated in Figure 2. The assessment reveals several gaps between impacts and the responses.

The analysis listed the responses made by the society and government to address the climate change on the one hand and coastal zone management on the other hand. However, the national policies have not fully incorporated the climate change, though there are action plans to address climate change. Policy gaps in the water sector are highlighted by the current challenges in that sector. Policy coverage is required for sub sectors such as groundwater management and irrigation, and filling such gaps could be an opportunity to incorporate climate change considerations. It can be seen that formulating sectoral policies and development strategies incorporating climate change considerations is more advantageous compared to having a single strategy to address the issues such as climate change and pollution. In the absence of such policies, it is difficult to address issues such as pressures emanating outside the coastal zone, including pollution from agricultural, domestic and industrial waste. The likely impacts of climate change can aggravate the current impacts from outside. The management of river basins in an integrated manner could address these issues, and therefore is an important policy consideration.

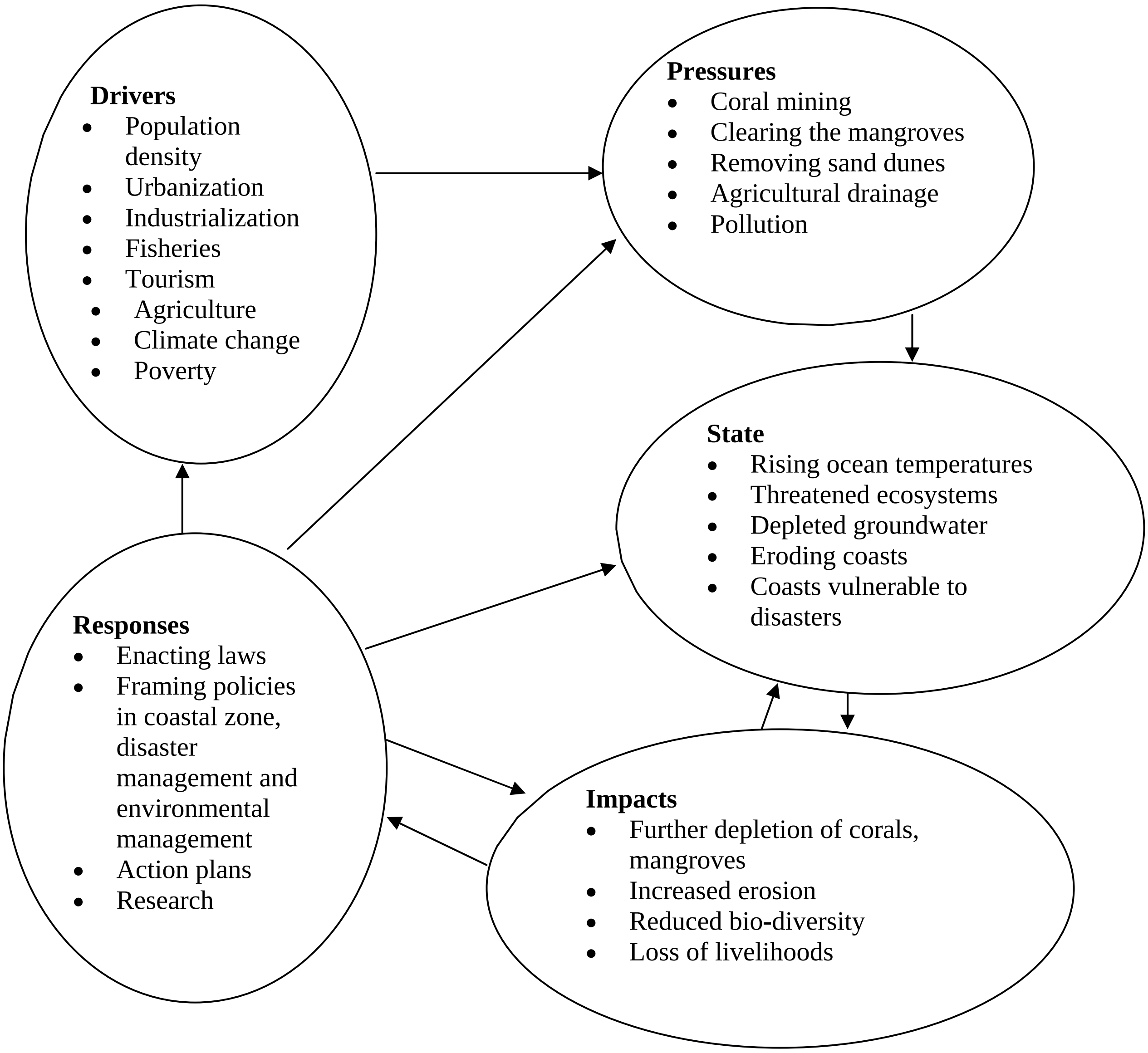

Figure 2. DPSIR framework applied to the coastal zone of Sri Lanka

Research and community participation are some of the other areas that need improvement. Monitoring of phenomena such as coastal erosion, sea level rise and pollution of water bodies has to be given the due attention, as well. Such an action would be important, as a substantial portion of the coastal zone in Sri Lanka is being opened up for rapid development after ending the war that lasted nearly 30 years.

There is also a need to make responses corresponding to the pressures arising from drivers such as poverty and urbanization, which would enhance greater community participation in the coastal zone management.

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CLIMATE CHANGE ADAPTATION STRATEGIES OF SELECTED COASTAL COMMUNITIES IN THE PHILIPPINES

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ABSTRACT

The Philippines, being an archipelago, has a long shoreline that extends up to 34, 000 km. Much of its 7, 100 islands are at risk of inundation due to sea level rise. Other climate change impacts like coral bleaching, sea water intrusion, coastal erosion, and flooding of coastal zones have also been observed. The local government units (LGUs) are in the forefront of disaster risk management (DRM) including climate risk management (CRM). Their enhanced capacity to cope with climate change impact is necessary to formulate effective and sustainable adaptation strategies to minimize risk and prevent the recurrence of disaster.

This paper presents the results of a study that aimed to analyze Philippine DRM policies, assess the adaptive capacity and adaptation strategies of LGUs and coastal communities to climate change impacts and draw policy implications for more effective and sustained adaptation.

The study covered five coastal municipalities located in three Luzon provinces. Three of these municipalities have an average elevation of 1.3- 1.5 meters above sea level and are experiencing the impact of accelerated sea level rise and sea water intrusion. Two municipalities are exposed to storm surges that destroyed houses and fish pens along the coasts. Data were collected through key informant interviews and focus group discussions with LGU officials and community residents.

Results of the study show that the existing Philippine DRM policies were designed to address only the extreme climatic events such as typhoons, which require emergency relief and rescue response. Policies and protocols to address the problems associated with accelerated sea level rise and sea water intrusion have not yet been formulated. Moreover, the magnitude of these problems has not yet been fully assessed and decision makers are not yet aware or conscious of such problem.

Results of the study also show that: a) the adaptive capacity of the LGUs is quite low; b) their adaptation strategies are more reactive than pro-active; c) long-term solution to protect coastal communities from flooding have not yet been formulated; d) LGUs have limited capacity to institute long-term measures that could prevent the recurrence of disaster and e) their adaptation strategies are not based on scientific risk and adaptive capacity assessment. Only one LGU has long-term adaptation plan and climate change adaptation policies to redirect urban and business development away from risky areas and enforce local ordinances to regulate land use and ground water withdrawal. Some communities have developed simple adaptation strategies that merely accommodate and live with the risk.

Effective and sustainable adaptation strategies anchored on strong LGU and community partnership should be instituted to minimize exposure to risk and mitigate the impacts of climate change on coastal zones. Among the possible adaptation options are: a) construction of coastal zone protection system (e.g., dikes); b) regulation of settlements along the coasts; c) construction of flood control system; d) strengthening of LGU-community-private sector networks and linkages to expand their response capabilities; and e) institution of localized and community based early warning system.

1. INTRODUCTION

The International Panel on Climate Change Fourth Assessment Report (2007) confirmed that climate change as indicated by global warming is unequivocal. This is evidenced by observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, AR4, 2007). Observations since 1961 reportedly show that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise.

Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003: about 3.1 [2.4 to 3.8] mm per year.

The Philippines, being an archipelago, has a long shoreline that extends up to 34, 000 km. Much of its 7, 100 islands are at risk of inundation due to sea level rise. Other climate change impacts like coral bleaching, sea water intrusion, coastal erosion, and flooding of coastal zones have also been observed.

Manila is one of the sites being monitored by the Global Sea Level Observing System. Manila Bay coastal area plays an important role in the country's economy in terms of industry and commerce, agriculture, aquaculture, and tourism. The bay is adjacent to the most densely populated, urbanized, and industrialized areas including the Metro Manila and the provinces of Bulacan, Cavite and Pampanga. An increase in sea level will accelerate and worsen flooding in the northwest delta plain of Manila Bay which is already experiencing subsidence at an alarming rate of at least three centimeters a year due to groundwater extraction (Jabines and Inventor, 2007). In the Pampanga area, subsidence rates exceeding 3 cm/year during the past 30 years have been recorded (Siringan and Rudolfo 2001, Panganiban, 2008). Monitoring of Manila Bay has shown a small rise in relative sea-level before the 1960s and then a more rapid increase of between 20cm and 40cm through to the present. This is aggravated by excessive land reclamation and possible subsidence.

Analysis of Manila Bay area suggests that a 100cm rise in sea-level would lead to over 5,000 hectares of the Bay area being regularly inundated, affecting over 2.5 million people. Even a 30cm rise in sea-level - anticipated by about 2045 would threaten over 2,000 hectares and about 0.5 million people. These risks would be further enhanced if sea-surges associated with intense storm activity were to increase (Hulme and Sheard 1999).

In the Philippines, the local government units (LGUs) are in the forefront of disaster risk management (DRM) including climate risk management (CRM). Their enhanced capacity to cope with climate change impact is necessary to formulate effective and sustainable adaptation strategies to minimize risk and prevent the recurrence of disasters.

This paper aimed to analyze Philippine Disaster Risk Management (DRM) policies, assess the adaptive capacity and adaptation strategies of LGUs and coastal communities to climate change impacts and draw policy implications for more effective and sustained adaptation.

2. RESEARCH METHODS

The study covered five coastal municipalities located in three Luzon provinces, namely: Guagua, Pampanga, Kawit, Cavite, Rosario, Cavite, San Juan, Batangas and Tanuan City, Batangas (Figure 1). Three of these municipalities, which border the Manila Bay, have an average elevation of 1.3- 1.5 meters above sea level and are experiencing the impact of accelerated sea level rise and sea water intrusion. Two municipalities, which lie along the coasts of Tayabas Bay and Taal Lake are exposed to storm surges that destroyed houses and aquaculture farms.

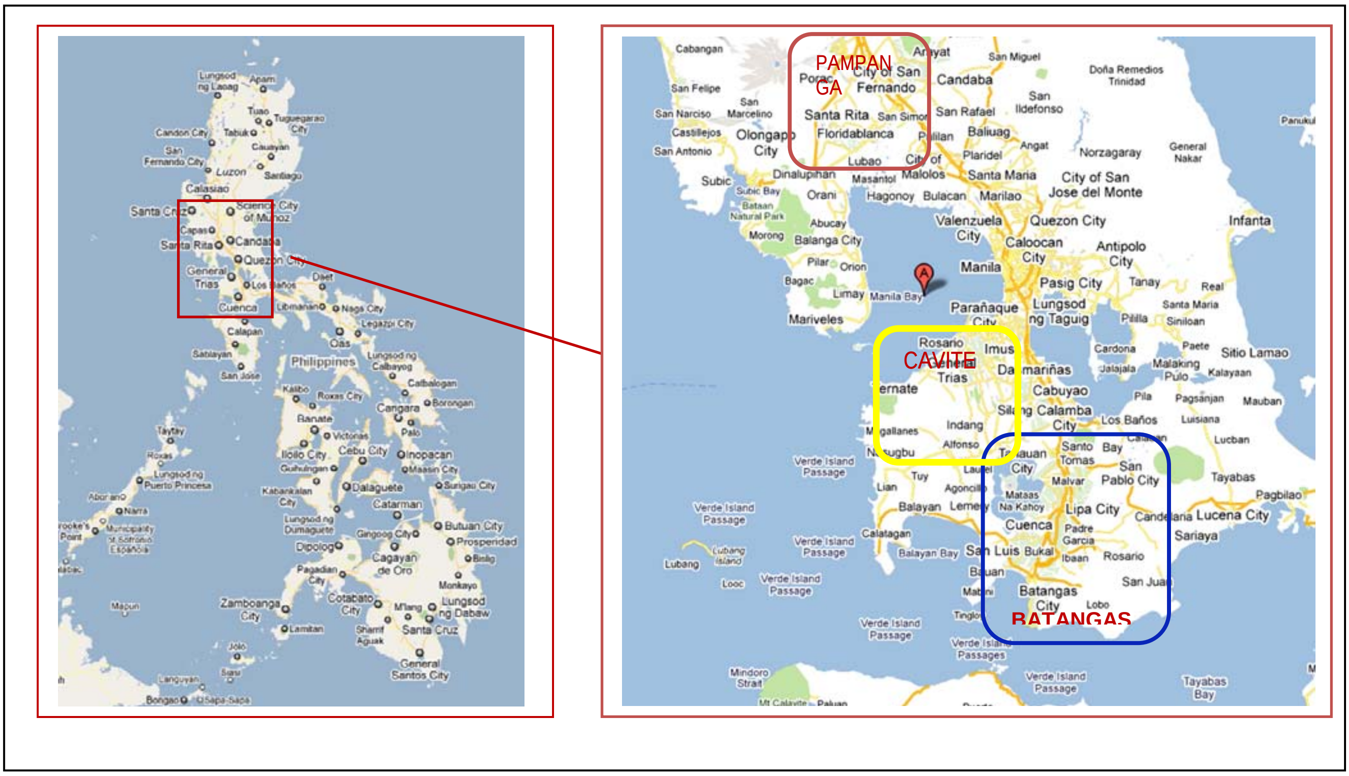

Figure 1: Map of the Philippines showing the study provinces
Source: www. maps.google.com

Data used for this study were collected from both primary and secondary sources. Primary data on the climatic events experienced by the community residents for the last 30 years and the adaptation strategies that households, communities and LGUs employed were collected through key informant interviews (KIIs) and focus group discussions (FGDs).

Timeline analysis was used to determine the major natural occurrences experienced by the local communities that reflect climate variability and extremes in the last 30 years. A combination of stakeholder analysis, participatory vulnerability assessment, and community mapping techniques were used to identify the vulnerable sectors in the communities and where they are located, to determine the extent and nature of their vulnerability to climate variability and extremes. The choice of these techniques was to engage the local stakeholders in the process of assessing their current vulnerability. Visual aids were used to help the FGD participants illustrate the varying degrees of impacts of these extreme climatic events on the affected sectors.

The LGU officials were also interviewed to find out their response strategies, the constraints/barriers and facilitating factors encountered. The people's recollection of events was validated and supplemented with historical records kept by national and local government agencies concerned. Selected coastal communities within the study municipalities were chosen as the specific study locale.

3. VULNERABILITY OF STUDY COMMUNITIES TO CLIMATE CHANGE IMACTS

This section briefly describes the geophysical characteristics of the study communities, the climatic events that they have experienced and the impacts of such event on the different sectors of society.

3.1 Geophysical Characteristics of Study Sites

C1, C2 and C3 are exposed to the same climate risks largely because of their similarity in terms of their geophysical attributes. These climate change associated risk are typhoon of increasing intensity and accelerated sea level rise that cause flooding, climate variability and saline water intrusion. On the other hand, C4 and C5 are also exposed to typhoons and associated storm surges and windstorm that caused heavy damages to their livelihood sources and housing (Table 1).

Table 1: Distinct geophysical attributes and climate events experienced by the study communities

Community	Location	Distinct feature	Climatic events experienced
C1	Guagua, Pampanga	traversed by a major river system that empty to Pampanga Bay onto Manila Bay lahar deposits along waterways lowering of water table average elevation-1.4 m above sea level	typhoon flooding accelerated sea level rise saline water intrusion ground subsidence ground water contamination due to sea water intrusion
C2	Rosario, Cavite	deltaic plain traversed by two big rivers that empty into Manila Bay average elevation is 1.4m above sea level serves as a catch basin and discharge point of the watershed unit along the Tagaytay ridge poor permeability and water percolation	typhoon flooding accelerated sea level rise occasional inundation ground water contamination due to sea water intrusion
C3	Kawit, Cavite	average elevation-about 1.3m above sea level hook-shape shoreline traversed by two major river systems that empty into Manila Bay	typhoon flooding accelerated sea level rise saline water intrusion occasional inundation
C4	San Juan, Batangas	located along Tayabas Bay	typhoon flooding storm surges windstorms
C5	Tanauan City, Batangas	located along Taal Lake	typhoon flooding storm surges windstorms

3.2 Climate Events Experienced

According to the key informants and FGD participants, strong typhoons have been experienced even in the 1970s and 1980s but typhoons have increased frequency and intensity since the 1990s. An average of 20 typhoons enter the Philippine Area of Responsibility each year and about 47 percent of total precipitation is attributed to these typhoons (Hilario, 2008).

The community residents also noted climate variability and highly variable rainfall pattern and distribution which became more pronounced particularly in the 2000s. They observed that heavy downpour that lasted for only a few minutes even during sunny days was a common occurrence in the recent years.

In the Philippines, Type 1 climate within which C1 to C5 belong is characterized by distinct wet and dry seasons. Hence, rainfall is expected to be high during rainy season and low during the dry season. In fact, historically, it is not uncommon to have two to three months of dry spell during the dry season and 30 days of continuous rain during the wet season. However, the community residents noted that in the recent years, typhoon would come even during the dry season and dry spell can be experienced even during supposedly rainy season.

In C1 and C3, fisherfolks have observed sea level rise. In C3, fisherfolks uses mangrove trees as sea level gauge. They reported that sea level usually goes beyond the set mark particularly during high tide. Sea water now also inundates some areas in C1, C2 and C3 during high tide, which was not observed in the past. Flooding due to high tide usually lasts for three to five hours.

Flooding brought about by different climatic events where experienced in all the study sites. For instance, C1, C2, C3 and C5 experienced flooding caused by typhoons and heavy rainfall. On the other hand, in C2, C3, and C3, flooding was also caused by accelerated sea level rise.

4. ADAPTIVE CAPACITY AND ADAPTATION STRATEGIES OF COMMUNITIES

People's response to the effects of the climatic events they have experienced is influenced by several factors, namely: a) social and behavioral or the extent of their social networks, attitudes towards risks and uncertainty and other community residents; b) economic capability including resources availability, which determines their capability to choose which of the adaptation options they should take; c) technology, which affects their ability to avoid, minimize or take advantage of the impacts of the climatic events; and d) knowledge and skills, which could influence their attitude towards the risks and their ability to decide which adaptation options to take and how available resources can be used to improve their adaptive capacity and resilience.

4.1 Social and Behavioral

Many residents refused to take precautionary measures and evacuate to safer places despite impending typhoon-induced hazards. They were resistant to leave their houses and would rather take the chance and hope that the storm will subside or the typhoon will not reach land. In many instances, people would rather go up to their rooftops until they were rescued and forcibly brought to evacuation centers.

Strong social cohesion was pervasive in the study communities. Neighbors, regardless of socioeconomic condition, provided food, shelter and even clothes to those in need. A family of six whose damaged house was no longer livable opted to share a shanty with a relative with five children. Shared poverty is a virtue that many Filipino families posses.

4.2 Economic

Residents of the study communities were generally poor and have limited economic options, but their limited aspirations and wants and their positive outlook and attitudes in life enhance their resilience and adaptive capacity.

As expected, economically better-off victims have greater resilience. They were able to obtain loans as new capital for the same business, and upgrade their facilities. For instance, the fish processors elevated their fish processing plants beyond the estimated flood water level.

Financial constraints greatly limited the people's adaptation options. Poor families had to contend with flooding and windstorm every time typhoon and high tide occur but could not build strong houses, elevate their houses or relocate to other place due to limited financial capability and livelihood sources. Their only recourse was to temporarily evacuate and, after the typhoon event, literally pick-up parts of their house and belongings that were blown by the strong windstorm, such as what happened in C4 and C5. Those whose houses were often inundated had to live with flooded basements and ground floor every time sea water level rose in C2 and C3.

Residents who have financial resources had their ground floor elevated through land-filling their basements, carports and ground floor. Some others transferred residence and looked for employment and livelihood sources elsewhere.

4.3 Technology and Infrastructure

Appropriate technologies are important aids in enhancing people's adaptive capacity. Design and construction of houses, fences and carports were among the adaptation strategies that people have thought of to minimize or cope with the adverse impacts of the climate events that the study communities experienced.

All the study communities have access to mass media, which were the primary source of information on the climatic events. In times of extreme climatic events such as typhoons and its associated flooding, people can easily access the information, which government agencies provided, through radio and TV. Some households could access such information through the internet. On the other hand, in some communities, some households applied infrastructure technologies. For instance, C1 and C3 residents elevated their houses and buildings.

C1 and C3 have developed their adaptation strategies to protect themselves against sea water inundation caused by accelerated sea level rise. For instance, house owners land filled their ground floors that have been inundated or built double fence to prevent sea water intrusion. Ground elevation was also increased through land fill before construction of houses and other buildings. Roads and bridges were also elevated by more than one meter in anticipation of future risks due to flooding.

In C4 and C5, where the houses of the focus group discussion participants are made of light materials, the immediate response action was to reinforce their houses by tying their roofs or putting heavy objects such as tires or hollow blocks to prevent the roofing materials from being blown away by the wind. Sometimes, those items were able to hold the roofing materials in place. Others, whose roofing materials have worn-out, use pails to catch the rain water that falls through the holes.

In flood prone areas, residents applied temporary adaptation measures, such as placing their appliances and furnitures on the second floor of their 2-storey houses or on stilts in anticipation of possible flooding. Households generally prepared alternative lighting materials and cooking fuel at the start of the rainy season because disruption of power supply was common during the typhoon period. Candles, lamps with rechargeable batteries and kerosene lamps, as well as charcoal-fuelled stove were common adaptation strategies used by many households.

4.4 Knowledge and Skills

The people's understanding of the climate change phenomenon is essential for them to make appropriate adaptation decisions. Their response to risks and disasters is also affected by their knowledge about possible sustainable adaptation options and their ability to apply such options.

All the study communities are aware of the risks that they are exposed to but only C1 residents were conscious of the need to take individual and collective actions to protect themselves against such risks and were undertaking information dissemination. People reinforce river walls and used sandbags to prevent rivers from overflowing to settlement sites. They also participated in information dissemination by tapping information from the local communication systems and relaying information to neighbors and other sectors at risks.

Community residents of C2 and C3 were aware that the flooding and saline water intrusion problems were increasing but were not taking actions whether in the form of individual or collective actions to develop long-term solutions. They lamented the fact that some of their settlement sites were often inundated by sea water, but their primary action was only to wait for the sea water to recede.

C3 residents have observed that the current level of high tide exceeded the indigenous high tide markers that they have been using but could not understand the reason behind it. They likewise noticed that their water supply has become salty and caused corrosion of their kitchen wares but could not do much about it.

C4 and C5 have quite limited knowledge about the need to undertake more long-term and sustainable adaptation options. They were still doing their traditional but temporary remedies to prevent their roofs from being blown by the wind. They should be made to comprehend the increasingly devastating effects of typhoon, the consequent flooding and the possible adaptation options that they can choose from.

5. ADAPTIVE CAPACITY AND ADAPTATION STRATEGIES OF LOCAL GOVERNMENT UNITS

Different LGUs responded differently to the climate events depending on the extent of vulnerability, the sectors affected and their own capabilities. The adaptive capacity of LGUs was assessed by rating the mechanisms that they have instituted and the kind of technology and infrastructures that they built.

5.1 Institutions and Governance

Data show that almost all of the LGUs, except C1, have low adaptive capacity and limited adaptation strategies. Climate risk management frameworks and structures were in place but the organizations were not very effective in performing their tasks. Climate change adaptation was not integrated in their programs and policies. They have limited trained manpower and utilization of “Calamity Fund” for disaster preparedness was restricted (Table 2).

The Philippine Disaster Risk Management frameworks and structures have been in place since 1978 with the issuance of Presidential Decree (PD) No 1566 that aimed to strengthen the Philippines disaster control, capability and establish the National Program on Community Disaster Preparedness. The salient features of PD No. 1566 are: 1) promotion of self-reliance and mutual assistance among local officials and their constituents; 2) emphasis on disaster preparedness; 3) organization of the national, regional, provincial, city/municipal and barangay disaster coordinating councils (DCCs); 4) mobilization of all government agencies and delegation of disaster response leadership through local government authorities; 5) conduct of periodic drills and exercises by concerned agencies/DCCs; 6) authorization of LGUs to program funds for disaster preparedness activities; 7) preparation and updating of a National Disaster and Calamities Preparedness Plan by the OCD which shall be used by national government entities as guide in disaster preparedness planning; and 8) documentation of disaster preparedness plans at all government levels.

In compliance with the 1978 law, all the LGUs in the study communities organized their local DCCs. These DCCs were responsible for the formulation and implementation of their disaster risk management plans, which was supposed to be prepared based on the DRM Manual.

However, the disaster risk management manual only dealt with extreme climatic events and have not given attention to climate variability, accelerated sea level rise, salt water intrusion and other climate change related events. This is why all the LGUs in the study communities rated high in terms of frameworks and structures. However, they have a relatively low rating in terms of effectiveness of organizations, human and financial resources capabilities.

Another contributing factor to the LGUs' low average institutions and governance rating was their adaptation programs and policies. Except for C1, the other LGUs rated low on this aspect because adaptation to climate events was not yet incorporated and integrated into their overall planning. As mandated in PD 1566, LGUs are to prepare a DRM program that outlines the LDCCs activities before, during and after a disaster.

In recognition of the climate change issue, the national government issued Memorandum Circulars (MCs) to alert LGUs about the need for awareness-raising and capacity-building and to empower LGUs in autonomously responding to climate change and preparing their adaptation plans. Under these circulars, all LGUs are mandated to undertake an initiative on mobilizing local action to address the impact of climate change in four phases: Phase 1- Awareness-Raising; Phase 2 – Legislative and Executive Actions; Phase 3- Assessment of Actions and Phase 4- sustaining strategies.

Table 2: Comparison of the adaptive capacity ratings of the LGUs in the study communities, 2009.

Indicator	**Rating**				
	C1	**C2**	**C3**	**C4**	**C5**
Institutions and Governance	5	2.8	4	3	3.2
Risk Assessment, Monitoring and Warning	5	2.67	2.67	2.67	2.67
Knowledge, Education and Information	5	2	2.33	2.67	3
Average	5	2.49	3	2.78	2.96

5.2 Risk Assessment, Monitoring and Warning

C1 LGU again rated high on this indicator because it is the only LGU that has a vulnerability and hazard map and risk monitoring and early warning system. These hazard mapping and the establishment of monitoring and early warning system were initially prompted by their need to respond to the threat of lahar flows from Mt. Pinatubo. These systems were later on upgraded and modified along CRM. Thus, C1 LGU enforced building code and land use plan, to regulate development in risky areas. Boring tests were required and the height of structures was regulated, construction of artesian wells is now prohibited, infrastructure and business development were directed away from risky areas and roads were elevated so that vehicle traffic flow will not be constrained by flooding. The public market was temporarily transferred to higher grounds every time the central business district was flooded. Permanent relocation of the public market was being contemplated but its advantages were being weighed against the economic dislocation that it may cause.

The other LGUs have yet to document their risk assessment, monitoring and early warning systems, prepare their hazard maps and design community-based flood warning systems that can provide meaningful information to individuals and policy makers.

5.3 Knowledge, Education and Information

Almost all of the LGUs in the study communities have serious deficiencies with respect to this adaptive capacity indicator. Only C1 LGU has established a knowledge management system that store information on the climate events experienced, the sectors affected and costs of damages, the actions taken and their climate change adaptation plan. This knowledge management system was installed through the initiative of the LGU staff and was accessible to all stakeholders. C1 LGU also shared their data with researchers who could help them analyze such data and formulate recommendations to address their climate change related problems.

They have a continuing public education program that was open to all sectors of the community. The other LGUs were not able to sustain such programs due to lack of support from the local executives. They claimed that they kept climatological data but these were not systematically organized. Likewise, information on the climatic events experienced and their impacts were kept in storerooms and were not accessible to stakeholders.

5.4 Technology and Infrastructure

Among the LGUs studied, only C1 has risk monitoring and early warning devices such as rain gauge and flood indicator and a comprehensive information dissemination system (Table 3).

Table 3: Climate change adaptation technology of LGUs in five communities, 2009.

Climate Change Adaptation Technology	C1	C2	C3	C4	C5
Risk monitoring and early warning	Rain gauge, flood indicator, "BIONIC" info system	None	None	None	None
Communication	Internet, landline phone, mobile phone, telefax machines, 2 way radio, mass media	Internet, landline phone, mobile phone, telefax machines, 2 way radio, mass media	Internet, landline phone, mobile phone, telefax machines, 2 way radio, mass media	Internet, landline phone, mobile phone, telefax machines, 2 way radio, mass media	Internet, landline phone, mobile phone, telefax machines, 2 way radio, mass media
Transport	Boat, off road vehicles	off road vehicles	Boat, off road vehicles	Off road vehicles	Off road vehicles
Infrastructure	Elevated road, elevated houses and buildings	None	Elevated houses and buildings, elevated road and bridge	None	None

6. CONCLUSIONS AND POLICY RECOMMENDATION

6.1 Conclusions

Results of the study show that the existing Philippine DRM policies were designed to address only the extreme climatic events such as typhoons, which require emergency relief and rescue response. Policies and protocols to address the problems associated with accelerated sea level rise and sea water intrusion have not yet been formulated. Moreover, the magnitude of these problems has not yet been fully assessed and decision makers are not yet aware or conscious of such problem.

Results of the study also show that: a) the adaptive capacity of the LGUs was quite low; b) their adaptation strategies were more reactive than pro-active; c) long-term solution to protect coastal communities from flooding have not yet been formulated; d) LGUs have limited capacity to institute long-term measures that could prevent the recurrence of disaster and e) their adaptation strategies were not based on scientific risk and adaptive capacity assessment. Only one LGU has long-term adaptation plan and climate change adaptation policies to redirect urban and business development away from risky areas and enforce local ordinances to regulate land use and ground water withdrawal.

Some communities have developed simple adaptation strategies that merely accommodate and live with the risk.

6.2 Recommendations

Effective and sustainable adaptation strategies anchored on strong LGU and community partnership should be instituted to minimize exposure to risk and mitigate the impacts of climate change on coastal zones. Among the possible adaptation options are: a) construction of coastal zone protection system (e.g., dikes); b) regulation of settlements along the coasts; c) construction of flood control system; d) strengthening of LGU-community-private sector networks and linkages to expand their response capabilities; and e) institution of localized and community based early warning system.

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LOCH SPORT - PLANNING FOR CLIMATE CHANGE

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ABSTRACT

Loch Sport is located on a sandy peninsula between Lakes Victoria and Reeve in the Gippsland Lakes, in eastern Victoria. The town ranges in elevation from 0.5m Australian Height Datum (AHD) to 25m AHD, with approximately 800 of 2800 lots subject to flooding from the surrounding lakes under existing conditions. The Gippsland Lakes are separated from Bass Strait by an outer barrier dune, which currently provides protection from swells and storms.

The low lying part of town is highly susceptible to flooding under current climatic conditions, from a number of factors including catchment inflows, wind induced wave action, tidal influence and increased mean sea level as a result of low atmospheric pressure. Predicted climate change conditions will increase the risk of flooding in the town, including an increase in the 1 in 100 year flood level as mean sea level rises.

Some pressure exists for intensification of both permanent residential and visitor accommodation within Loch Sport, however best practice floodplain management principles and guidelines suggest that development in lower lying areas of the town is not compatible with the existing or future flood hazard.

Under future climate conditions, assuming a mean sea level rise of no less than 0.8 metres by 2100 (Victorian Coastal Council, 2008), it is likely that flooding will be more frequent, to greater depths and impact on an increased number of landowners. Survey data indicates that a number of properties on the fringes of the lakes are below 0.8m AHD, and are therefore likely to be permanently inundated by 2100.

Government Policy has required the floodplain management authority to consider mean sea level rise. However no direction has been given on how this should be done. This exposes the floodplain management authority and the community to uncertainty and further complicates floodplain management in the region.

The challenges we are facing are not unique to the Loch Sport community.

Adaptation to climate change will require a coordinated and strategic response, which acknowledges existing development and prepares communities for the future.

Strategic planning is a key tool to ensure that sustainable development in towns such as Loch Sport continues, while acknowledging that some areas will not be suitable for development as our climate changes. However planning decisions do not always wait and are required to be made now by individual councils and floodplain management authorities. Often these decisions are being made without sufficient strategic direction from state and federal government on how to respond.

1 INTRODUCTION

Loch Sport is located 266 kilometres east of Melbourne (Figure 1) and is located in the middle of the Gippsland Lakes system, with Lake Victoria located along the northern shore line and Lake Reeve and the Ninety Mile Beach to the south. Loch Sport is a popular tourist destination for numerous water sports and leisure activities and therefore the population fluctuates on a seasonal basis.

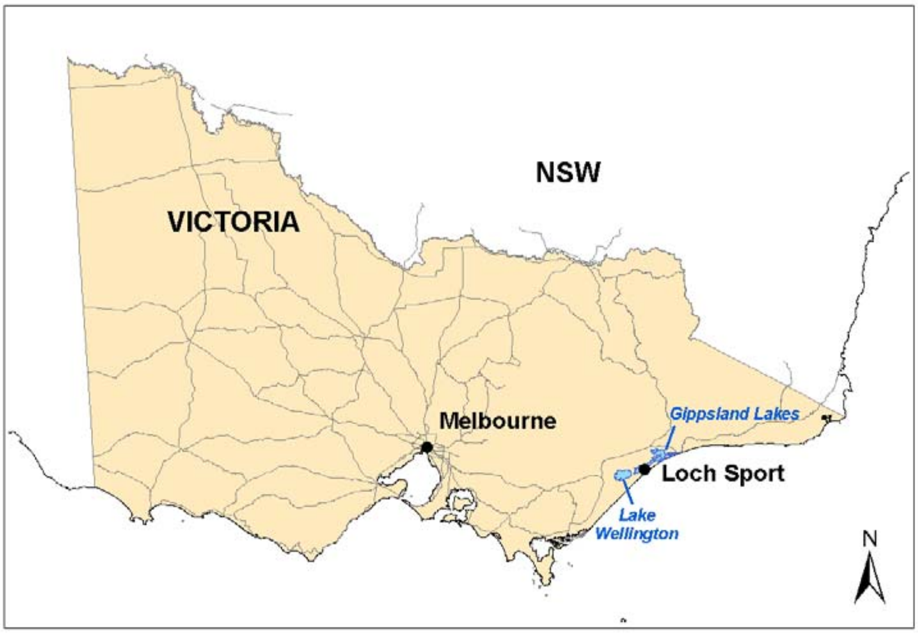

Figure 1. Location of Loch Sport

Given it's proximity within the Gippsland Lakes system and Ninety Mile Beach, Loch Sport is prone to flooding under current climatic conditions. In June 2007 floods up to the 20 year Average Recurrence Interval (ARI) resulted in closed roads and a number of properties being inundated. The need for emergency service resources was required despite the June 2007 floods being well below the state wide adopted 100 year ARI standard used to assess development.

2 OBJECTIVES

Floodplain management in Victoria seeks to minimise the State's exposure to flood risk and damage costs. Floodplain management in coastal areas has rapidly evolved over recent years as the potential for climate change to impact these areas has been recognised through the Victorian Coastal Strategy. Coastal Councils and Floodplain Management Authorities are now faced with the challenge of implementing this strategy.

This paper considers the implications of the Victorian Coastal Strategy on Loch Sport, but the issues are not unique to this town. The paper aims to highlight the issue of coastal flooding, and to identify a range of options to ensure that planning decisions accurately reflect the future flood risk in Loch Sport.

3 METHODOLOGY

The paper considers the application of current best practice floodplain management, and through the use of GIS mapping, identifies areas currently at risk from flooding, and those properties that will become flood-prone as mean sea levels (and therefore mean lake levels) rise throughout the century. The study has identified a number of risks that need to be considered, and identifies options such as changes to the Planning Scheme, development of a Local Floodplain Development Plan, and strategic planning to protect, accommodate or retreat from the risk, as appropriate.

4 FLOODPLAIN MANAGEMENT ISSUES

4.1 Best Practice Floodplain Management

Best Practice Floodplain Management in Victoria requires the consideration of flooding and its impacts to the 100 year ARI standard. This standard is generally accepted across all of Australia as the appropriate compromise between managing the risks associated with flooding and the economic and social benefits of using land within a floodplain. Floodplain Management standards and their application have progressively been introduced over many years as the community and government have recognised the need to manage the flood risk. Unfortunately significant residual risk remains in many of our existing urban areas which were developed prior to the current standards being introduced.

Floodplain management uses a risk based approach to firstly identify and quantify the hazard, then understand the likelihood and consequence of the hazard and then apply management actions to avoid or minimise the risk to the individual and the community. Planning is identified as the key tool for ensuring that the community's exposure to flood risk is not increased.

Flood depth and velocity are the key parameters used to assess flood hazard. In areas affected by flooding associated with lake systems velocities are generally low and flood depth becomes the over riding constraint. Victorian guidelines for defining floodways suggest that a high hazard exists in depths greater than 0.5 metre. Where these depths occur intensification of residential or commercial development is generally not supported.

For Greenfield areas it is relatively simple to incorporate floodplain management objectives into good planning decisions. However floodplain management in existing urban areas is much more complex as the communities understanding of the flood risk is generally low resulting in a low appreciation of the potential constraints. In general the community struggles to understand the need to manage the existing flood risk and will struggle to come to terms with the need to manage a future risk that will develop over many years.

4.2 Victorian Coastal Strategy

The Victorian Coastal Strategy (VCS) was developed by the Victorian Coastal Council, and adopted by the Victorian State Government prior to its release in December 2008. The Strategy is intended to guide long term planning and use of the Victorian coast, including public and private land.

The VCS considers the impacts of climate change on our coast, and introduced new policy to plan for sea level rise of not less than 0.8 metres by 2100. Additionally, the VCS calls on planners and decision makers to apply the precautionary principle to planning decisions, to consider other coastal hazards such as storm tides and coastal erosion, to avoid development within primary sand dunes and low-lying coastal areas, and to ensure that planning and management frameworks can respond quickly to emerging climate change science.

The VCS identified a number of actions required to enable the implementation of this new policy. The actions include:

- Establish a mechanism to support policy and decision-making in relation to the risks and impacts of climate change
- Develop benchmarks for coastal vulnerability assessments
- Develop comprehensive vulnerability assessments for the whole Victorian coast
- Develop a methodology to provide guidance to all planners and managers as to how to apply the policy of planning for sea level rise of not less than 0.8 metres by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions for decision-making; and
- Upon completion of the vulnerability assessments:

- o Investigate opportunities within the Victorian Planning Provisions to address climate change risks and impacts, including consideration of new provisions; and
- o Develop appropriate adaptation strategies to support local and regional level decision-making

The Strategy assigns lead and partner agencies to undertake these actions but, crucially, it does not stipulate timeframes for this work to be completed. It is now over 12 months since the release of the strategy, and the floodplain management authority is not aware that any of the above actions have been completed.

In the absence of any additional guidance from State Government, the floodplain management authority has implemented a precautionary approach to all coastal planning referrals, by adding 0.8m to the declared or estimated 1 in 100 year ARI flood levels in coastal areas of the region and applying Best Practice Floodplain Management principles to the future flood level.

For Loch Sport, this means that the adopted 1 in 100 year flood level for 2100 is 2.7 metres AHD (current declared level of 1.9 m AHD + sea level rise of 0.8m = 2.7 m AHD).

4.3 Coastal Vulnerability

In light of the VCS the long term viability of the Loch Sport area also requires consideration. The Department of Planning and Community Development General Practice Note (December 2008) states that, for construction of a dwelling or development on a vacant allotment, *"Assessments of* [coastal hazard] *impacts may be advisable for sites immediately adjacent to the coast or near an existing floodplain."*
The VCS has identified a number of threats associated with climate change for coastal communities in Australia. Most of these can be summarised under natural hazards and socio-economic hazards. Naturally occurring hazards (e.g. storm surges, increased rainfall intensity, increased riverine flows) are those which threaten human life, physical infrastructure, lifestyle and biodiversity. Socio-economic threats include tourism and agriculture based economies (Victorian Coastal Council, 2008). Coastal communities like Loch Sport have a higher level of vulnerability, making the capacity to adapt to climate change more challenging.

The VCS has identified actions to address the coastal vulnerability issue by "*development of comprehensive vulnerability assessments for the whole Victorian coast (through the Future Coasts program) to provide guidance to all planners and managers as to how to apply the information for decision-making*".

More recently, the CSIRO's November 2009 publication identifies the potential vulnerability of coastal communities (such as Loch Sport) arising from climate change induced mean sea level rise.

4.4 Permanent Inundation

As the climate changes and the sea levels continue to rise, the low lying areas of Loch Sport will become permanently inundated. Based on a mean sea level rise of 0.8 metres approximately 109 properties are at risk of becoming permanently inundated by 2100.

4.5 Deeper flooding and increased frequency of flooding of existing areas

Loch Sport ranges in elevation from 0.5m AHD to 25m AHD, and under current declared flood levels 798 lots are wholly or partly below 1.9m AHD and subject to flooding from Lake Victoria or Lake Reeve.

Current projections suggest a rise in the mean sea level, and therefore mean water level in the Gippsland Lakes, of 0.15 m by 2030, 0.5 m by 2070 and 0.8 m by 2100. (IPCC 2007 A1F1 (high emissions) scenario)

The mean increase in lake levels will result in more frequent flooding of low lying areas. By 2100, what is currently considered the 1 in 20 year flood event (1.4m AHD) is likely to occur much more frequently, as only a 0.6m increase in lake levels required to meet this level.

The current 1 in 100 year flood level for Loch Sport (1.9m AHD) is likely to become the 1 in 50 year flood event by 2030 and the 1 in 20 year flood event by 2070.

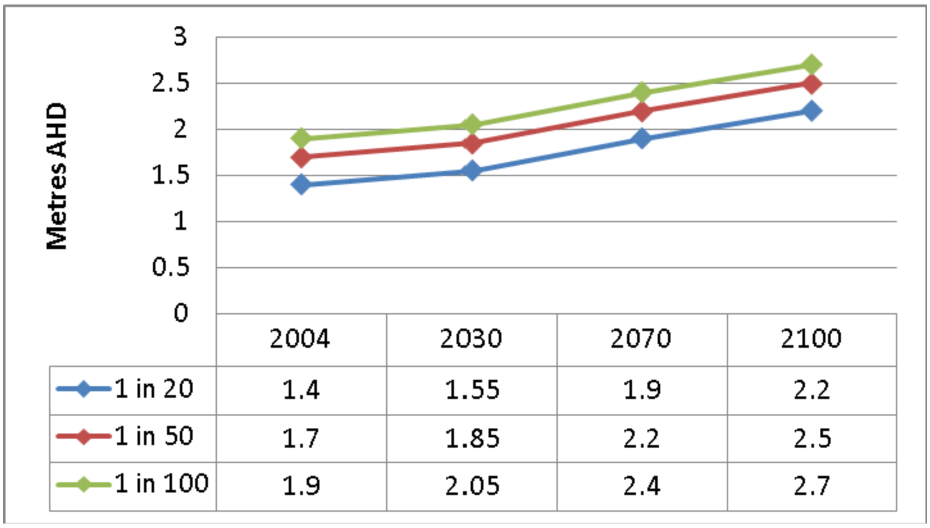

Figure 2: Change in flood frequency 2004 - 2100

In addition to more frequent flooding, mean sea and lake level rise will result in deeper flooding over low lying areas. Properties on the fringe of the flood prone area that currently only experience minor flooding (e.g. 0.2 metres deep) will be likely to have flood waters up to 1.0 metres deep by 2100, while those properties that are particularly low lying and currently subject to flood depths of up to 1.2 metres during a 1 in 100 year flood will be subject to flood depths of 2.0 metres by 2100.

This increased flood depth significantly increases the risk of loss of life and damage to private and public assets.

4.6 Flooding of new areas

Under existing 100 year ARI flood conditions (i.e. 1.9m AHD), 798 freehold properties (residential and business zones) are susceptible to flooding from the Gippsland Lakes (Table 1). With the onset of climate change, the VCS has identified that a mean sea level rise of no less than 0.8 metres by 2100 will occur, taking the 100 year ARI flood level to 2.7m AHD. The impact of mean sea level rise will result in a 50 percent increase in the number of properties inundated, from 798 to 1203.

Table 1. Number of freehold properties (zoned residential and business only) that fully or partially intersect flood extent)

100 year ARI Flood Levels	No. properties affected	Total area affected (Ha)
Current: 1.9m AHD	798	54.18
By year 2100: 2.7m AHD	1203 (50% increase)	93.52 (72% increase)

From a Best Practice Floodplain Management perspective, there are a number of implications of flooding in new areas. The depth of flooding on properties will increase, resulting in the flood hazard increasing. Egress is also an issue, with some existing road infrastructure becoming permanently inundated with the onset of mean sea level rise. The ramifications of depth of flooding both on private property and road infrastructure results in increased flood hazard for residents that in turn, creates additional burden on emergency services.

4.7 Flooding of egress

In the vicinity of the town marina, there are two key routes through town to the eastern two-thirds of Loch Sport – along Basin Boulevard and via Sanctuary Road/Reeves Street (also known as National Park Road).

Based on the 2007 flood experience and LiDAR surface elevation data, Reeves Street is known to flood relatively early in a flood event, when levels in Lake Reeve reach about 1.0 m AHD. Basin Boulevard begins to flood when flood heights exceed about 1.1 m AHD on the Lake Victoria side of town.

This means that, under current conditions, all road access to the eastern two-thirds of Loch Sport is severed in anything greater than about a 1-in-20 year flood event.

The depth of flooding over these roads in a 1 in 20 year flood under 2004 conditions (when the flood modelling for the Gippsland Lakes was completed) is likely to be 0.3 m on Basin Boulevard and 0.4 m on Reeves Road. During a 1 in 20 year flood under 2100 conditions the flood depth is likely to reach 1.1 metres and 1.2 metres respectively.

Under current climatic conditions, these flood depths are well in excess of the known safe depths for 4WD vehicles, which has significant implications for emergency management and the need to evacuate anyone with an illness or serious injury.

4.8 Planning Scheme Overlays

The current Planning Scheme Overlay for Loch Sport consists of an out-of-date Land Subject to Inundation Overlay. This Overlay identifies land in flood storage or flood fringe areas affected by the 100 year ARI flood (Victorian Planning Provisions, March 1999). The current overlay does not accurately represent the flood risk throughout the town, and does not recognise the higher risk floodway area, where flood depths during a 100 year ARI are likely to exceed 0.5 metres.

Detailed flood mapping has identified 542 properties that should be covered by Floodway Overlay, to clearly articulate the higher flood risk in these areas. The Floodplain Management Authority is currently working with the Wellington Shire Council to amend the Welling Planning Scheme to better reflect the flood risk, including the addition of the Floodway Overlay where required.

4.9 Adaptation Strategies

It is generally accepted that there are three options for adaptation to climate change and associated rising sea levels: protect, accommodate or retreat.

‘**Protect’** relies on engineered solutions such as sea walls, raised road levels and construction of levees to provide protection from rising sea levels, tidal inundation and storm surges. Issues to be considered include the location of any proposed barriers, the design criteria and lifespan for the infrastructure, available resources and responsibility for construction and maintenance of any physical barriers. As Loch Sport is built on a peninsula between Lakes Victoria and Reeve, with waterfront on the north and south of the town, a significant amount of infrastructure would be required to protect the town from inundation.

‘**Accommodate’** assumes that residents will adapt to and accept an increased frequency of inundation as lake levels continue to rise. New development would be directed to higher land, but the existing private and public infrastructure would remain in situ, and be subject to deeper flooding, more often. The financial hardship and emotional stress associated with increased flooding is unlikely to be tolerated in the longer term, and Loch Sport's high retiree population is unlikely to be willing to accept this increased burden.

'**Retreat'** requires strategic planning to relocate those parts of existing settlements that are subject to coastal inundation to land which is unlikely to be at risk from future sea level rise.

The properties likely to be affected by coastal inundation in Loch Sport by 2100 are predominantly privately owned residential lots, however some community infrastructure such as roads, boat ramps, public toilets and picnic areas will be subject to frequent or permanent inundation. As discussed above, 109 residential lots that are particularly low lying are likely to be permanently inundated by 2100. Many of these lots contain existing dwellings, and these residents will need to consider how and when they relocate to higher ground.

Relocation of existing residents to higher ground then poses the question of compensation and ownership of the land once it is vacated. Unless strategic planning is done now it is likely that as the sea rises and inundation becomes more frequent and therefore less tolerable that residents will simply abandon their dwellings and properties. This will leave a legacy of abandoned buildings and properties which the community will have to deal with.

5 POTENTIAL FLOODPLAIN MANAGEMENT RESPONSES

5.1 Continued Best Practice Floodplain Management

As discussed above planning in a floodplain management context only manages the potential increase in risk associated with flooding. The VCS has directed floodplain management authorities to also deal with the future risk associated with mean sea level rise. This can be done through existing referral processes. However significant gaps remain such as those properties outside existing flood overlays and those existing dwellings that will become permanently or more frequently inundated into the future. Current floodplain management practice has no mechanism for the removal of existing assets from high hazard areas.

5.2 Update overlays and zones to reflect new risk

Immediately: Update the Wellington Planning Scheme to reflect current understanding of flood risk – including the use of the Floodway Overlay where flood depth is greater than 0.5m and the Land Subject to Inundation Overlay for the fringe areas of the floodplain.

By end 2010: Statewide implementation of a new Coastal Inundation Overlay (CIO) for those properties that will be subject to inundation by 2100 (e.g. all properties in Loch Sport below 2.7m AHD). This will highlight the future flood risk at the property, and enable careful consideration of the proposed development at a particular property. Developments with a limited life span may be appropriate, however intensification such as subdivision should not be considered.

Consider: Urban Floodway Zone for all properties that are wholly below 0.8m AHD (or where up to 75% of the property is below 0.8m). UFZ prohibits development, and would protect those property owners from loss of assets and infrastructure as sea and lake levels rise.

5.3 Local Floodplain Development Plan

A Local Floodplain Development Plan (LFDP) is a potential means of addressing existing and future flooding scenarios where land has *already* been zoned for development. Floodplain development plans apply to land that is covered partially or wholly within the 100 year ARI flood extent and the

Floodway Overlay. While a current LFDP does exist for Loch Sport which covers flooding up to 1.9m AHD, it is now out dated and requires review to incorporate increased flood levels associated with future mean sea level rise. A LFDP can be incorporated into the relevant Planning Scheme. Such plans have been developed to provide a performance-based approach for decision making that reflects the nature of flooding in the area and best practice in floodplain management.

Through the development of a LFDP, identification of future flood extents, finished floor levels, low risk egress to flood free land where emergency services exist and minimising risk to life and loss of infrastructure, can be identified.

While a useful planning tool, a LFDP should not replace strategic planning which aims to ensure that sustainable development in towns such as Loch Sport is directed by adoption of appropriate zones.

5.4 Strategic Planning Incorporating Best Practice Floodplain Management

As discussed above it is generally accepted that adaptation strategies relevant to coastal communities exposed to climate change induced hazards have three elements; protect, accommodate and retreat. A strategic plan is required for Loch Sport which will include all three elements as follows:

'**Protect' -** is most relevant to existing high value areas where the financial and environmental cost of providing an engineering solution is offset by the value of the assets being protected. For Loch Sport there are potentially 1200 properties that could benefit from protection. Sea walls are costly to construct and maintain and come at an environmental cost. For areas such as Loch Sport it is unlikely that the huge financial cost to construct a sea wall would be justified given the value of the assets to be protected. However any strategic plan for Loch Sport needs to consider this option as part of development of the plan.

'**Accommodate'** is relevant to those fringe areas that will become inundated into the future but where the flood depth does not exceed a medium hazard. For Loch Sport this equates to approximately 270 properties. For these properties future flooding will be infrequent and floodplain management requirements can be managed by placing conditions on permits to raise floor levels above the future flood level. To allow conditions to be placed on permits requires the current planning scheme to be updated and for these areas to be identified in the Land Subject to Inundation Overlay. For all areas subject to greater flood depths and high to extreme hazards **"Retreat"** remains the only option.

'**Retreat'** is relevant to those areas that will in the future be exposed to a high or extreme hazard. For Loch Sport this equates to approximately 930 properties. For these properties future flooding will be frequent and hazardous. In this portion of the floodplain, development options will be limited as state government direction has stated that careful consideration needs to be given to any development that results in the intensification of residential or commercial occupancy or results in the foot print of long lived assets increasing. This will mean that no development is allowed on existing vacant lots and the renewal or redevelopment of existing buildings being carefully considered.

A strategic plan needs to be developed with the involvement of State Government, Council, the floodplain management authority and the community to identify those properties exposed to the greatest hazard and develop a plan that minimises the costs to adapt over time.

6 CONCLUSION

Reliance on floodplain management authorities to implement the VCS and manage coastal inundation using Best Practice Floodplain Management principles will only ensure that the community's exposure to the flood hazard does not increase. Reducing the community's exposure to the existing and future flood hazard over the coming decades will require coordinated, decisive and strong action. State

Government, councils, floodplain management authorities and the community need to work together to develop a strategic plan for each community. This plan will need to incorporate all three adaptation strategy components in order to deal with the different levels of hazard. Failure to do this will result in the slow degradation of our coastal communities as sea levels continue to creep forward and diminish our community's ability to use the coastal fringes in the same manner as they have in the past.

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IMPLEMENTING CLIMATE CHANGE POLICIES CONSISTENT WITH INTEGRATED COASTAL ZONE MANAGEMENT: A CASE STUDY OF VICTORIA, AUSTRALIA

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ABSTRACT

Whilst the proliferation of publications on climate change science is remarkable and makes the updating of responses to impacts of climate change on coastal environments daunting, the area of policy responses is even more confusing and complex. This is because policy responses do not need to consider the science of climate change alone but also have to weigh up the social and economic implications of the impact of climate change on coastal communities.

In a federated nation such as Australia this has the added complication of three tiers of Government (Federal, State and local) having to interact in order to co-ordinate any policy responses. These complications should be aided by the internationally accepted concept of Integrated Coastal Zone Management (ICZM) which has been prevalent in Australian coastal planning and management for several decades.

This paper uses the State of Victoria, Australia as a case study of how Governments are responding to these challenges through using the principles of ICZM. The paper will review recent inquires and investigations in Australia and canvas the policy responses to these reviews, concentrating on the State of Victoria.

The paper analyses how consistent these evolving policy responses are with ICZM and suggests lessons for other jurisdictions arising from the Victorian experience.

1. INTRODUCTION

Scientific and technical studies and publications of the nature and potential biophysical impacts of human induced climate change are proliferating at an ever increasing rate (Newton, 2009). Keeping up with this literature alone is a daunting task. The same is true of the literature that attempts to take these scientific discussions into policy outcomes i.e. when interpreting the science of climate change and taking this into the policy realm.

The policy discussion necessitates not only consideration of scientific data but also of social and economic impacts. If climate science is complicated and difficult to understand then adding the human elements of economic and social concerns 'ramps up' the complexity to another level altogether.

According to the Oxford Dictionary policy is 'the course or general plan of action adopted by a government or party or person'. Hence policy responses are the plans, strategies and institutional arrangements (agencies, bodies, legislation, regulations etc.) that are adopted by governments on behalf of their communities in the face of a particular challenge. Hence 'policy responses' is really an ‘art’ - the art of balancing competing interests to achieve an outcome commensurate with the impacts assessed and predicted by science.

This paper will examine how one governmental jurisdiction – the State of Victoria, Australia – has responded so far to the policy challenge that the impact of climate change on the coastal zone creates. This is done by providing a brief background on the impact of climate change on Australian coasts prior to discussing the various aspects of Australian national coastal policy and its response to climate change. Then a similar approach is used to describe the situation in Victoria before discussing how consistent these responses to climate change are with Integrated Coastal Zone Management (ICZM). Finally the implications for other jurisdictions (nations and states) of the Victorian experienced are discussed.

Background on Climate Change and Coasts

Whilst the potential impacts of climate change on coastal areas have been discussed for sometime the recent review of overall potential impacts of climate change prepared by Newton (2009) provides a useful summary. Newton (2009) identifies ten categories of potential impacts from climate change – four of these areas are exclusively marine and coastal, whilst the marine and coastal environment is the only ecosystem which is impacted on by all ten categories of impact.

Newton (p. 133; 2009) very succinctly summarises the importance of this coastal impact:
“Australia’s coastal zone is highly vulnerable to the impacts of climate change due to the large proportion of the population living on the coast (about 85 percent), the large number of assets in the region (human and natural), and the extent of likely biophysical changes at the land-sea interface. The coast is also the conduit to Australia’s export economy, with over 70 onshore and offshore trading ports. One third of ship losses are already linked to weather related problems”.

Finally before proceeding further the distinction between “mitigation” and “adaptation” as responses to the impact of climate change need to be clarified. Mitigation is addressing the sources of climate change (increased carbon dioxide and equivalent gases in the atmosphere) and attempting to lower the source of this problem i.e. reducing the concentration of these gases in the atmosphere. Hence attempts at carbon trading schemes, carbon taxes and regulation of carbon emissions are all attempts at mitigation. Adaptation on the other hand is the action taken to adapt to the observed impacts of climate change – such as altering the location of buildings, building sea walls and other structures etc. Within Australia the Federal Government is taking the lead on matters concerning mitigation (at present through attempts to introduce a carbon pollution reduction scheme) whilst State governments in particular, because of their constitutional role in land planning and management, are at the forefront of adaptation responses. The financial implications of too rigid a division of mitigation/ adaptation roles is critical as well in a practical sense as ‘mitigation’ may well bring in extra revenue (through a carbon trading scheme or carbon taxes) whilst most of the costs of responding to climate change on the coast are going to be via adaptation. This ‘vertical fiscal imbalance’ has plagued coastal management in Australia for decades (Wescott, 2009) and present a major challenge in addressing the impacts of climate change on coastal areas.

2. AUSTRALIAN COASTAL POLICY

Under the Australian 1901 Constitution matters not mentioned in the Constitution as being the responsibility of the federal (Commonwealth or Australian) Government remain the responsibility of the State (formerly colonial) governments. The environment in general, and coastal planning and management in particular, are not mentioned in the Constitution. In fact the planning and management of Crown (public) land (which includes coastal land and waters out to generally three nautical off shore) is not mentioned and hence the management of these areas and the natural resources and biophysical environment associated with them (including so called national parks and conservation reserves) are State (and latterly Territory) government responsibilities.

2.1 Integrated Coastal Zone Management (ICZM)

Integrated Coastal Zone Management (ICZM) is now in its fourth decade and is a well established concept described in detail by a range of authors across the world (e.g. Sorenson, 1997) and is well summarised by Cicin-Sain and Belfiore (2005) as possessing the following main features:

- intergovernmental (vertical) integration;
- intersectoral (horizontal) integration;
- spatial integration;
- science-management integration;
- international integration.

In Australia several states have made significant progress in implementing ICZM in the past 15 years (see Harvey and Caton, 2003; Wescott, 1998, for Victoria). Given that ICZM is the internationally accepted basic program for delivering conservation and sustainable use of coastal environments globally ICZM would be expected to be used as the base on which a policy response to the impacts of climate change on the coast would be founded.

2.2 The Impact of Climate Change on Coasts: Australian National Policy Responses.

In terms of coastal policy the two major political parties contesting the federal election in November 2007 had significantly contrasting positions. The then opposition had prepared a coastal policy for the election (Australian Labor Party, 2007) that promised an inquiry into the impact of climate change on coastal communities, a firm commitment to increasing federal funding of coastal projects and a commitment to an increased federal role.

Whilst coastal policy was certainly not one of the major issues in the 2007 federal election climate change was a significant issue and a major policy differentiator between the two major political parties.

On the day after the Federal Election the new Treasurer claimed the election was based on winning the ‘sun-belt’ seats (The Australian, page 1, 26 November 2007) the ‘sun-belt’ being described as the electorates outside the capital cities that abut the coastline from northern Queensland to the Victorian/South Australian border.

There are 33 seats which are not inside the major capital cities of Brisbane, Sydney and Melbourne. After the election the distribution of these seats between the major parties was 16 to the new Labor Government and 16 to the former coalition Government (11 to the Liberal Party and 5 to the National Party) with one seat held by an independent. The Rudd Labor Party had won from their opponents in this election seven of these coastal seats which was a very significant contribution to their overall victory. There are now 16 “marginal” non-metropolitan coastal seats ensuring a continued political focus on Australia’s coast at the election due this year.

The question of whether ‘seachange’ (i.e. the movement of city voters to coastal country electorates hence altering the demographics and hence voting patterns in these electorates) has contributed to the increase in marginal seats on the coast is still open to debate. Nevertheless the juxtaposition of increased political interest in climate change (stimulated again through the release of the final Garnaut Report, Garnaut, 2008), and the possible influence of ‘seachange’ on coastal electoral demographics has certainly altered the coastal ‘political landscape’ in Australia (Wescott, 2009).

2.2.1 ***House of Representatives Committee Report on the Impact of Climate Change on Coastal Communities.***

In October 2009 the final report of the Parliamentary Committee inquiry promised by the Rudd opposition was published amid sensational media reports on the potential value of coastal properties which were at risk from increased sea level (House of Representatives, 2009). The report suggested that there were 711,000 addresses within 3 km. of the coast, and less than 6 metres above sea level, that could be considered at risk.

Less widely reported was the proposed policy responses to climate change that make up the bulk of the report. These included a revised suite of institutional arrangements which would see the Federal government playing an increasing role in the traditionally (and constitutionally) state government areas of coastal management and coastal planning.

In summary the report made 47 recommendations spanning from recommending studies of international responses to climate change, establishment of national data bases, examination of legal liability issues relating to permit issuing in areas prone to inundation as a result of climate change, insurance schemes covering coastal areas etc. through to new governance arrangement for coastal management in Australia.

They also recommended that the Australian Government consider the benefits of a nationally consistent sea level rise planning benchmark.

The outcomes on institutional arrangements recommended that the Council of Australian Governments (COAG) initiate a new Intergovernmental Agreement on the Coastal Zone (IACZ, recommendation 44) which would:

- define the roles and responsibilities of the three tiers of government,
- include a formal community consultation mechanism,
- incorporate principles based on strategic regional coastal management and landscape scale ecosystem based management,
- include a well resourced implementation program,
- be overseen by a new Coastal Zone Ministerial Council, and
- that the IACZ be made public.

The Committee saw this IACZ as leading to a National Coastal Zone Policy and Strategy as a means of implementing ICZM in Australia. This would incorporate a National Catchment – Coast – Marine Management program to, among other matters, ensure a consistent response to climate change challenges. The Committee also recommended a National CZM unit within the Department of Environment, Water, Heritage and the Arts and that this agency should develop a Coastal Community Sustainability Charter based on the Victorian model.

The report also foreshadowed the imminent publication of the 'first cut' national assessment of sea level changes predicted for the Australian coast.

2.2.2 ***First Cut National Assessment***

In 2007 the Council of Australian Governments (COAG) produced a national 'Climate Change Adaptation Framework'. The Framework recognised the need for national assessments of key sectors and regions to allow for informed decision making about responses (adaptations) to climate change. The Framework identified as one of its key actions the preparation of a "first pass' national assessment of Climate Change Risks to Australia's Coast. The detailed report that followed (Department of Climate Change, 2009) was published in November 2009 against a background of national debate on a Carbon Pollution Reduction Bill that was before federal parliament. The report covers the science of climate change and the biophysical nature of the Australian coast and describes the implications of climate change over the four broad coastal regions identified for Australia. It proceeds to identify the key risks to infrastructure and services and concludes with a discussion on coastal adaptation including identifying barriers to adaptation and the case for early action on coastal adaptation.

The report identifies that the sea level around Australia has been relatively constant for 6-7,000 years and hence, particularly post European, settlement has been based on an assumption of relative steady sea levels.

This report uses the base of a 1.1 metre sea level rise by 2100 arguing that this is a plausible level on which to base a risk based assessment approach. The report points out that even under a 0.5 metre sea level rise that events which currently happen every 10 years may in fact happen as frequently as every ten days and that the current 1 in 100 year event corresponds in intensity to the June 2007 storms which hit the central coast of NSW causing losses of $1.3 billion. The report argues that a 1.1 metre rise would place $63 billion of existing buildings at risk with a range of the number of properties affected being between 157,000 and 247,600. The report expresses particular concern about the capacity of towns and communities outside capital cities to cope with such major risks.

The report argues for early action to reduce risk. The three well documented approaches of either to protect, accommodate or retreat in the face of threats from sea level rise and increased storm intensity and frequency are covered. The report suggests identifying 'triggers' to identify when on ground responses need to commence. Finally the report argues that where possible the avoidance of future risk is the most cost effective approach i.e. avoiding development in areas at risk where no or little development has yet occurred. This will require the application of revised planning and building regulations. The need for nationally agreed standards and leadership through the Council of Australian Governments is emphasised.

2.3 The Impact of Climate Change on Coasts: Victoria

Wescott (1998, 2002) has described the Victorian coastal planning and management institutional arrangements in detail. The central legislation is the Victorian Coastal Management Act 1995. Again despite the use of the term 'management' this refers to planning and management arrangements. The strategic planning of the Victorian coast to meet the objectives of this Act is implemented through the Victorian Coastal Strategy (VCS). The VCS is drafted by the lead coastal agency, the Victorian Coastal Council, which prepares a draft and then shepherds it through a statutory public participation process before presenting the Victorian government with a final Strategy. The Victorian Government then publishes a final Coastal Strategy which becomes the prime policy document for the next five years or until a revised Strategy is produced. There have now been three Strategies produced since 1997.

These documents identify the major issues confronting the Victorian coast and then outline the various actions that need to be taken by specified agencies to meet these challenges and the objectives of the Act. These actions may require action from various tiers of government (State or local) and various agencies and bodies.

Implementation of the Strategy can either be carried out directly by these agencies e.g. through Local Councils writing the proposed action into local planning schemes; or through Coastal Action Plans (CAPs) which are regionally based statutory planning documents prepared by one of three Regional Coastal Boards (Central, Western and Gippsland). In terms of climate change impacts (or other state wide challenges) it is the Victorian Coastal Strategy which is the key policy document.

2.3.1 *Victorian Coastal Strategy*

The third Coastal Strategy (VCC, 2008) built on the two previous strategies to present a detail response to the impacts of climate change on the Victorian coast. The Strategy should act as the integrating document for policy responses to specific challenges.

Published in December 2008 it highlights climate change as one of the three major challenges facing the Victorian coast (the others being coastal development and marine ecological integrity) and was the first statutory document in Australia to state an expected sea level rise (0.8 metres by 2100) on which to base planning decisions. The Strategy refers to implementation and further development of a program through the “Future Coasts” approach.

2.3.2 ***Future Coasts (www.climatechange.vic.gov.au/futurecoasts)***

Responding to the identification of climate change as an emerging issue for coastal management in the second Victorian Coastal Strategy (2002), and despite scepticism by the Howard federal government, the Victorian government established the “Future Coasts” project. Originally the program was within the Department of Sustainability and Environment (DSE) – when planning functions were in this Department but “Future Coasts’ is now a joint program of DSE and the Department of Planning and Community Development (DPCD).

Future Coasts aims to improve the understanding of physical impacts of climate change on the coast, improve understanding of risk assessment and adaptive measures, develop policy and tools to respond to these challenges and build capacity to manage risk and apply the policies developed. The Program has two major components a ‘Science and Modelling Project’ and a ‘Coastal Policy and Planning Project’. There have been many excellent tools developed under this program and the web site illustrates these (e.g. a flood visualisation tool).

In the most recent Future Coasts newsletter (Issue 4 November 2009) they highlight seven areas of their work (which are a good summary of the program and its relationship to broader contexts): Digital Elevation Model (DEM) program, the ‘Smartline” geomorphic mapping of the Australian coastline, the national Coastal Risk Assessment program, the forthcoming Future Coasts paper on ‘Impacts and Responses’ to impacts on the coast of climate change, the Coastal Climate Change Advisory Committee, the CSIRO technical reports (see below) and seminars on sea level rise and training. A major component of Future Coasts work is the Victorian Coastal Vulnerability Assessment (VCVA), which has led to the program and reports described below.

In the past eight months there have been three significant publications emanating from the Future Coasts program. These three publications, commissioned by Future Coast probably give an overview of the current status of appraisal of coastal impacts of climate change on the coastal zone in Victoria and will be summarised in order of publication.

Norman (2009) summarises the current international, national and state policy responses to climate change’s impacts on the coast. The author summarises how different nations are attempting to respond within their own cultural, economic, social and infrastructure arrangements. This paper is an excellent starting point for anyone surveying the “tool kit” available in general to policy respondents. This is enhanced by the fact that it is done from the perspective of Victoria and hence a series of recommendations are made (p.44) which is of great value to our considerations here.

Norman (2009) observes that in countries where there is a significant national response to climate change this has provided a framework for local implementation of adaptation responses, but in some cases, where this national focus is absent, it has been ICZM that has provided the framework for a response locally. Norman (2009) states that planning for adaptation is at an early stage in Australia but the House of Representative’s report and the first cut National Assessment is intended to stimulate a national response.

Meanwhile most state responses are confined to establishing a benchmark for sea level rise and starting to establish planning responses to these benchmarks. A key issue identified is the link between emergency management, coastal inundation and land use planning. A national role in coordinating state and local activity is probably required in Australia. Norman (2009) calls on all levels of government to study the international responses so far and to adapt them to local, state and Australian national conditions. This is of course in keeping with the principles of ICZM with strategic overview and local implementation adapted to local cultural and institutional conditions.

In November 2009 the first two papers (of a series by CSIRO) were released by the State Minister for Conservation and Climate Change (Hon. Gavin Jennings) shortly after the release of the first National Assessment described earlier. These two papers (McInnes et al, 2009a and 2009b) describe potential sea levels along the Victorian coast in 2030 and 2070 in the first paper and more specifically, in the latter paper, for Port Phillip Bay. The papers conclude that that sea level rise will cause a greater impact that wind speed change (which will also occur) and the sea level rises which now occur as a result of extreme storm events (coupled with high tides) will occur more frequently in the future.

The overall Victorian study found that 1 in 100 year storm tide levels are highest around Westernport Bay where they exceed 2.0 metres above current levels. The area from west of Port Phillips Heads to Wilsons Promontory also has 1.8 m levels predicted.

CSIRO carried out a more detailed Digital Elevation Model (DEM) for five specific areas which contain extensive areas below 2 metres in elevation: Portland, Port Fairy, Barwon Heads, Tooradin and Seaspray. In these areas it is coastal reserves and low lying wetlands that will be particularly affected. Amongst other results the study provided an indication of the date after which inundation might be a significant threat e.g. in Barwon Heads by 2030 whilst in Port Fairy after 2030 and in Portland after 2070.

These reports, like the national assessment mentioned earlier are of course plotting the potential impacts of sea level rise and extreme events (particularly in terms of inundation) if no adaptation occurs in the meantime. Whilst the reports make this clear the media reporting of these documents tend to ignore this and report as if no government action will occur. There will be of course be policy responses to these changes, and we are seeing them already in Victoria, the question is more about when they will occur (in the next ten years or twenty years time etc?) and the extent of the responses.

2.3.3 *Green paper on Climate Change*

There are two other policy development processes proceeding in Victoria at present which may have some influence on the impacts of climate change on coastal environments.

The most developed is a Green paper / White paper process for the conservation of biodiversity ‘in a time of climate change’. The final stage in this process was the publishing of a White Paper (i.e. a Government Policy) on Biodiversity in Victoria in late 2009. Whilst there is a significant section in the policy on the marine environment (e.g. a commitment to a Marine Plan for Victoria) the potentially most critical aspect for coastal environments is a proposed dismantling of the Victorian coastal planning and management system and its replacement with a modified form of the catchment management authority approach across the state. The ramifications of this proposal are considerable, but as yet unclear.

In June of 2009 the Victorian Government held a major symposium on adaptations to climate change impacts across the state. At this gathering the Government released its Green Paper on climate change for public discussion and submissions. The departments concerned are now processing public submissions and a White Paper is expected to follow sometime in 2010.

The relationship between these two white papers (climate change and biodiversity) is not clearly spelt out in either papers but will be critical to Victoria’s long-term response and adaptation to the impacts of climate change.

3. DISCUSSION

ICZM with its objectives of sustainable development and its five components could provide a much needed framework in which to tackle the challenges of the impacts of climate change on coastal areas.

If we use these five components of climate change to assess the Victorian policy approach at present we may gain insight into how adequately the State is dealing with adaptation.

In terms of *intergovernmental (vertical) integration* clearly Australia has only just begun to examine the implications inherent in a constitutional arrangement which separates out mitigation and adaptation responses i.e. the historical approach in Australia works against an integrated approach between levels of government.

Although this has been recognised as an issue in the last two years with both the House of Representative reports and the ‘first cut’ national assessment there is little real progress in this area yet. This is the major challenge for Australia – actually delivering some true intergovernmental cooperation with the Federal government actually ‘walking the walk’ as well as ‘talking the talk’. Wescott (2009) covers the possible approaches which would assist with this implementation.

In terms of the second component - *intersectoral (horizontal) integration* – in Victoria more progress has been made, particularly with the third Victorian Coastal Strategy as a strategic planning document responding to climate change and the Future Coasts program co-ordinating adaptation discussions and data collection. Again the challenge is for the Government to follow through on these two initiatives and deliver real funding and actual projects on the ground. There is little sign of this at present. A worrying feature though is the two green and white paper processes occurring. The Biodiversity paper is not encouraging, as it underestimates the impact of climate change on coastal environments and possibly is the biggest threat to a coordinated response in Victoria because it goes to the extraordinary step of proposing the existing functioning coastal planning and management system in Victoria be dismantled. Hopefully with the second green / white paper process (Climate Change) the Government will realise the folly of changing a functioning coastal management system and look to enhancing horizontal integration - but with a focus on the coast and not inland agricultural land. The Government also needs to very soon explain the actual relationship between these key documents and the overall policy processes in Victoria.

Ironically it is in the area of *spatial integration* (particularly catchment-coastal integration) that is being used by the Victorian government to justify changes to coastal planning in Victoria. This has certainly created a conundrum. Do you risk possibly losing a functioning coastal policy system by attempting to enhance one aspect - catchment - coastal integration?

Also the extent of marine planning may need to be addressed further (it is in the Biodiversity white paper and as a priority issue in the Coastal Strategy) if adaptation responses are to be integrated across the coast / marine interface.

Future Coasts is apparently providing a useful integration of science and policy and may be a useful model for elsewhere in terms of science-*management integration*.

Finally *international integration*, after the comprehensive failure of the Copenhagen meeting in December 2009 the continuing extent of the federal government’s concern and political will have flow on effects to Victoria. Certainly the federal government needs to focus on educating and communicating to the Australian public its national and international response to climate change rather than seeing it as an issue to use to “wedge” the federal opposition. The Rudd Government in 2010 will have to see climate change as a top priority issue for Australians if it is to meet its earlier commitments.

Overall Victoria is doing some excellent work on the impacts of climate change on coastal communities particularly through the Coastal Strategy (strategic planning) and the Future Coasts program. But the major question confronting the Brumby State Government is how to 'fit it all together'. At present the Biodiversity White paper and the pending Climate Change White paper seem to be confusing the picture and in the case of the first may actually be a negative factor.

The major opportunity for the Victorian Government is to use the White paper on Climate Change to integrate all the responses to the impact of climate change on the coastal zone. It also must be used to overturn the foolish proposal in the White Paper on Biodiversity to dismantle a coastal planning and management system that is working well and offers the best chance to adequately plan and manage adaptation to climate change in Victoria's most critical environment – the coastal zone.

3.1 Implications from Victoria for other Jurisdictions.

The Victorian experience has some positive contributions to make to other jurisdictions.

The Future Coasts program could be a model for linking science to management and in community education whilst the setting of a bench mark for sea level rise in a statutory document such as the Victorian Coastal Strategy (and in fact the institutional arrangements as whole in Victoria) are good models for other jurisdictions.

Vertical integration though remains a challenge in Australia and whilst there is an opportunity to finally enhance a federal government role in this nation attempts to do so in the past have failed. This is the key concern in a federated system – can you get Governments (particularly if they are of different parties) to co-operate and to truly share power across historical divides?

Finally Victoria's experience begs the question of how the various aspects of climate change science, planning and management can be truly integrated into a viable policy response.

The question of a need for a designated lead agency, a clear statement of how leading agencies interact, the priority and status of the various strategies and plans and the provision of genuinely new and adequate funding are particularly pertinent.

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RISK BASED APPROACH TO ADAPTATION TO CLIMATE CHANGE AND SEA LEVEL RISE – A PILOT STUDY AT A COASTAL SITE IN VIETNAM

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ABSTRACT

At present, natural hazards, for examples, coastal erosion and severe climatic events such as storms, floods and droughts have already affected very large numbers of people in Vietnam, and push many households back to poverty on an annual basis. Therefore, even modest climate change (CC) and sea level rise (SLR) are likely to intensify the problems. A modest SLR may increase coastal erosion, and augment storm surges and river mouth flooding to the extent that extreme flooding and breaching of sea dykes with existing design criteria may become more common. To understand the risks due to CC and SLR, a pilot study has been conducted at a coastal area in Northern Delta of Vietnam. With results of the evaluation of CC and SLR impacts and risks, adaptation measures were proposed to reduce the risks to acceptable levels.

The study area is located at the mouth of Van Uc River, a river of the Red – Thai Binh River system in the North Vietnam. This is a densely populated rural area with livelihood of people mainly relies on agriculture and aquaculture. The study area has low land surface, and thus is easily flooded if storm surge in combination of high waves cause breaking of sea dike. The flood will be more serious in case of SLR due to CC. Present environmental problems include degradation of ecological system, both in the sea and inland, water pollution, un-planning aquaculture development, flooding during heavy rainfall, especially in combination with strong typhoons, coastal erosion, degradation of mangrove forests, conflicts between nearshore fishing and aquaculture etc. Risks, associated with CC and SLR, were evaluated for normal and extreme weather conditions. For normal weather conditions, impacts due to gradual increase in air and water temperature, sea water level, salinity intrusion were evaluated. For extreme weather events, probability of strong typhoons, storm surge, high waves, dike breaking and flooding was evaluated for different SLR scenarios; then damages due to flooding were studied. Numerical models were applied for the calculation of salinity intrusion and flooding due to SLR in combination with storm surge and dike break. Detailed risk evaluation was conducted for human life, agriculture, aquaculture, environment, and infrastructure. With results of the study, adaptation measures were proposed to reduce the risks to acceptable levels. WWF's climate witness community toolkit was also applied for the establishing community action plan to respond to CC and SLR. With representative features of the study area, results of the pilot study could be applied for building action plan to respond to climate change in the coastal areas of the Northern Delta of Vietnam.

1. INTRODUCTION

Climate change will manifest largely as changes in the frequency and consequences of extreme events and inter-annual and similar variations, rather than as long-term trends in average conditions. The risks of climate arise from current climate variability and extremes and from the future, incremental changes in those risks as a result of longer-term changes in climate extremes and variability (ADB, 2005). Risk management is defined as culture, processes and structures directed towards realising potential opportunities whilst managing adverse effects (IPCC, 2007). The overall goal of a risk-based approach to climate change adaptation is to manage both the current and future risks associated with the full spectrum of atmospheric and oceanic hazards (ADB, 2005).

Recently, climate change (CC) and sea level rise (SLR) scenarios have been adopted by the Ministry of Natural Resources and Environment of Vietnam. According to report, with the average scenario, at the Northern Flat Land of Vietnam, the average temperature may increase 1.4^oC by 2050 and 1.6^oC by 2100; the annual rainfall may increase 4% by 2050 and 8% by 2100. On the other hand, the seasonal distribution of rainfall also changes. The dry season rainfall may decrease by about 4% by 2050 and 7% by 2100. The mid-range emission scenario predicted that the sea level may rise 30cm by 2050, and 75cm by 2100. On the other hand, the maximum SLR for the highest emission scenario might be 100cm.

Dasgupta *et al* (2007) analyzed impacts associated with a minimum 1 metre rise in sea level over the next century in 84 coastal developing countries. Their analysis suggests that Vietnam is one of world's top five most vulnerable countries to sea level rise and the most vulnerable to impacts in East Asia. According to Dasgupta *et al* (2007), a one metre SLR would affect approximately 5 percent of Viet Nam's land area, 11 percent of the population, 7 percent of agriculture and would reduce GDP by 10 percent.

As CC may change the frequency and intensity of existing risks and hazards, as well as introducing some long-term shifts in climate regimes, it may lead to prolonged dry seasons and increasing storm frequency and intensity. At present, natural hazards, such as coastal erosion and severe climatic events such as storms, floods and droughts have already affected very large numbers of people in Vietnam, and push many households back to poverty on an annual basis. Therefore, even modest CC and SLR are likely to intensify the problems. A modest SLR may increase coastal erosion, and augment storm surges and river mouth flooding to the extent that extreme flooding and breaching of sea dykes with existing design criteria may become more common. On the long term, the sea level rise can have great consequences on the likelihood of local population. It seems that arable lands will be flooded or polluted by saline water; aqua-cultural farms will have to be relocated; nearshore fishing may disappear. The increase of salinity intrusion may make adjacent non flooding areas not be suitable for rise cultivation due to lack of fresh water for irrigation. Observations showed that increase of salinity and water level may cause gradual changes in flora species of mangrove forest, leading to a total disappearance of mangrove forest at low land areas. Increase of flooding, especially at river mouth, may force coastal inhabitants be relocated. River estuaries may change due to changes in tide and currents. The disappearance of mangrove forest increases the possibility of dike breaking by high wave attacks during typhoon, and the disappearance of wild life habitats. The decrease of pH, increase of water temperature and rise of sea water level may cause degradation of coastal biodiversity.

Planned adapting to CC and SLR will contribute to the resilience of a society to natural fluctuations in climate. Planning to address the effects of climate change is most likely to be effective and cost-efficient if it is integrated into local government standard work programmes.

With the above discussion, it is necessary to carry out study on CC and SLR impacts and adaptation measures to whole coastal areas of Vietnam. However, due to limitation in time and budget, we carried out the study only in Vinh Quang, a commune in Tien Lang District, Hai Phong City. This is a low land area with diverse social-economic activities and ecological system, a typical area that has the potential of high impacts of CC and SLR. In the study, we evaluated the risk due to increase in storm surge flooding, in combination with sea dike break. Based on the risk evaluation, we proposed adaptation measures to reduce the risks to acceptable levels. Due to representative natures of the study area, obtained results could be generalized for all similar areas in Vietnam.

2. MATERIALS AND METHODS

2.1 Study area

The study area is a commune in Tien Lang District, Hai Phong City. As presented above, this is a low land area at the mouth of Van Uc River. The land use map of the area is shown in Fig. 1. As shown in the figures, the north-east side of the area is Van Uc River; and south-east side faces the sea. The study area is 1929.60 ha with agricultural land area of 592.2 ha, mangrove forest area of 695.9 ha, and aquaculture area of 354.9 ha. The land area for public use is 277.7ha.

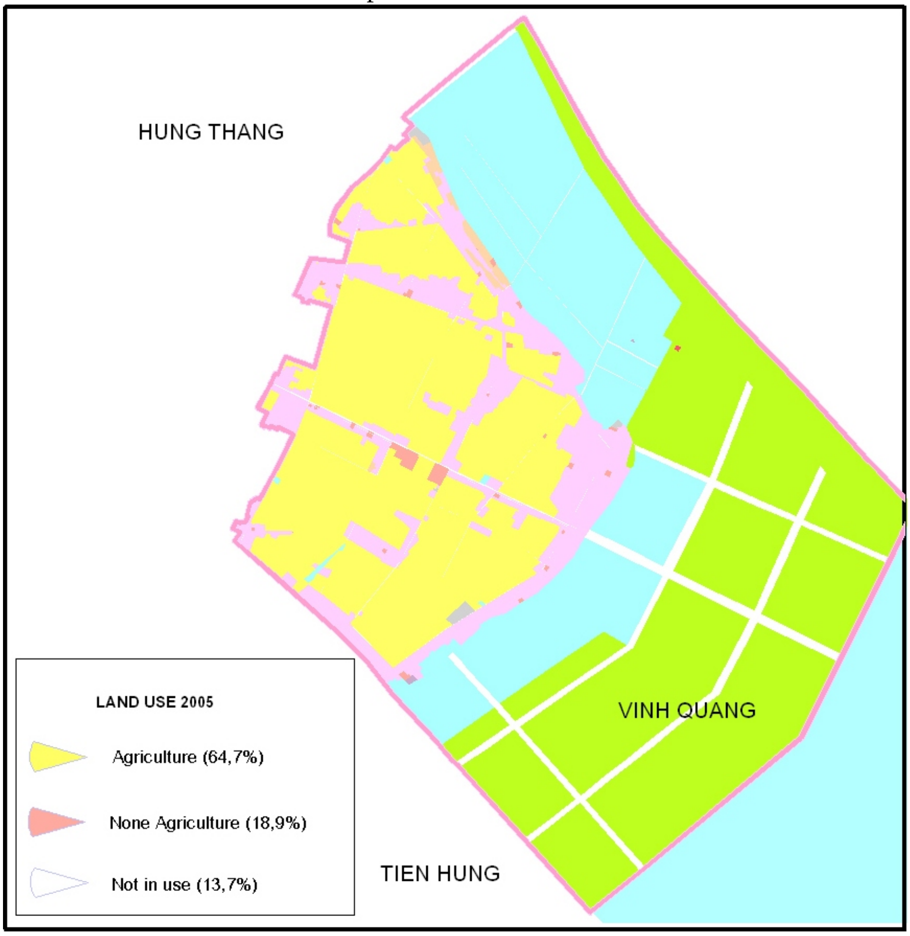

Fig. 1. Land use map of Vinh Quang Commune

As the study area has two sides in contact with river or sea, the total dike length surrounding the area is 6.3 km with armor protected sea dike length of 3 km. The average crown height of the dike is 5 m. Total population of the commune is 8610 people with monthly average income of VND 1.4 millions/person (2008 figures).

Similar to other places in the Red River Delta of Vietnam, the area is frequently subjected to natural hazards, such as tropical cyclones, storm surge, high waves, heavy rainfall etc. The annual average number of tropical cyclones attacking the area is 2.2. Natural hazards, especially storm surge, cause huge economic losses. It was estimated that the Damrey typhoon in September 2005 caused economic loss of about VND 10.7 billions (US$ 542,000), mainly to aquaculture. On the other hand, the mangrove forest of the area is in very good conditions, and acts as a barrier to prevent high waves attacking sea dike during tropical cyclone. Then, at the moment, wave overtopping of the dike, and thus dike failure risk, are almost nil.

2.2 Study methods

To evaluate the risks that CC and SLR impose on the area, in this study, we used numerical methods in combination with statistical analysis. The numerical model was used for the computation of the inundation in the area and salinity intrusion into the river with different SLR scenarios while the statistical analysis was used for the evaluation of extreme climatic events with different happening frequency. Details of the numerical models can be found in Vu (2010). Before used for computation, the models had been verified both with experiment data and field observation data on flood due to tsunami in Patong Beach, Phuket, Thailand (Vu et al, 2010, Vu, 2010). The data on the parameters of tropical cyclones for the period from 1951 to 2008 in the Tonkin Gulf was used for the evaluation of the parameters of maximum tropical cyclones with happening periods respectively of 20 years, 50 years and 100 yeas. Risks due to flood and salinity intrusion were evaluated, and appropriate adaptation measures for reducing the risks to acceptable levels were proposed. On the other hand, the WWF’s climate witness community toolkits were used for community action plan development.

3. RESULTS OF RISK ESTIMATION

3.1 Inundation related risks

The maximum water level due to storm surge in combination with high tide is calculated based on the observed data at Hon Dau station, a marine hydrometeorology station located about 7 km from the study area. According to the Vietnam Institute of Meteorology, Hydrology and Environment (2009), the SLR after 50 years and 100 years from 1998 would be 30cm and 75cm, respectively. However, it seems that these values are underestimated. Then, another 100 year SLR value of 100cm is also proposed. Maximum water levels with happening frequency of 0.2% (once per 50 years) for three selected SLR scenarios are presented in Table 1. The selected values of maximum water levels will be used for the evaluation of risks due to inundation and salinity intrusion.

Table 1 Maximum water levels for 3 selected SLR scenarios

Scenario	Maximum water level with happening frequency of 2% (Relative to Hon Dau Datum)	Maximum water level with happening frequency of 2% (Relative to National Datum)	SLR (cm)	Forecast water level (cm)
Scenario 1	432	246	30	276
Scenario 2	432	246	75	321
Scenario 3	432	246	100	346

For the computation of inundation, it was assumed that sea dike failure with breaking width of 80m during a tropical cyclone with the above mentioned different maximum water levels. A numerical model for flood propagation on a complex topography (Vu et al, 2009) is used for inundation calculation. Results of calculation are presented in figures from 2 to 4.

In reality, the dike at the area can only sustain tropical cyclone of intensity 9 in the Beaufort scale. However, since a thick mangrove forest exists in front of the dike, high waves during cyclone and other extreme weather conditions can not reach the dike, and thus the likelihood of dike breaking is very low. However, if mangrove forest dies due to SLR, and no adaptation measure is implemented, then likelihood of dike breaking during tropical cyclone is very significant.

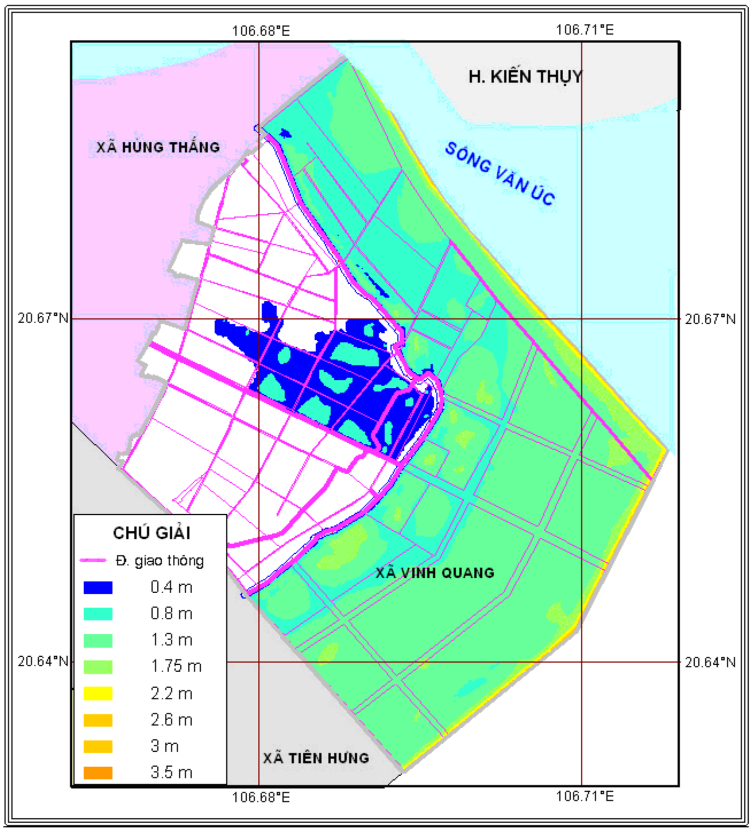

Fig. 2. Inundation area and depth for the case of SLR of 30cm

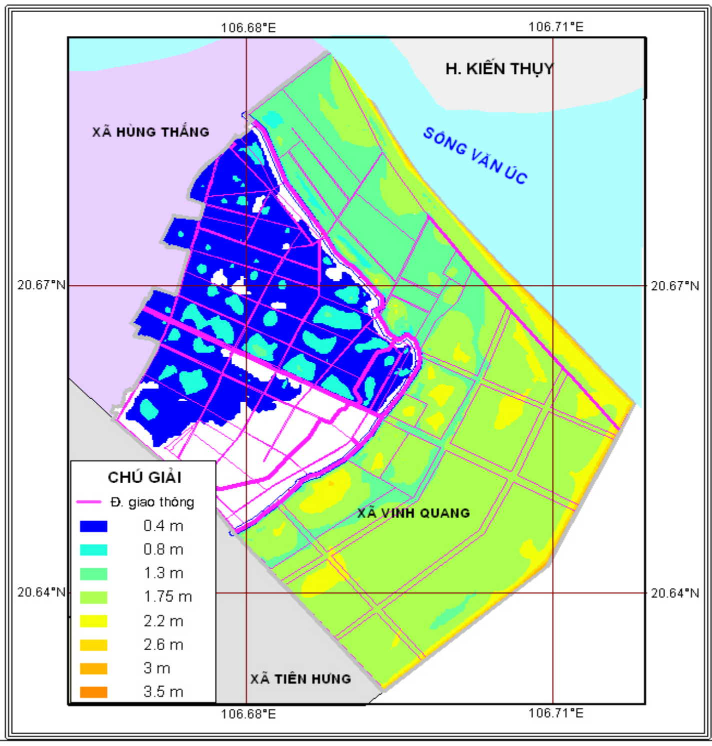

Fig. 3. Inundation area and depth for the case of SLR of 75cm

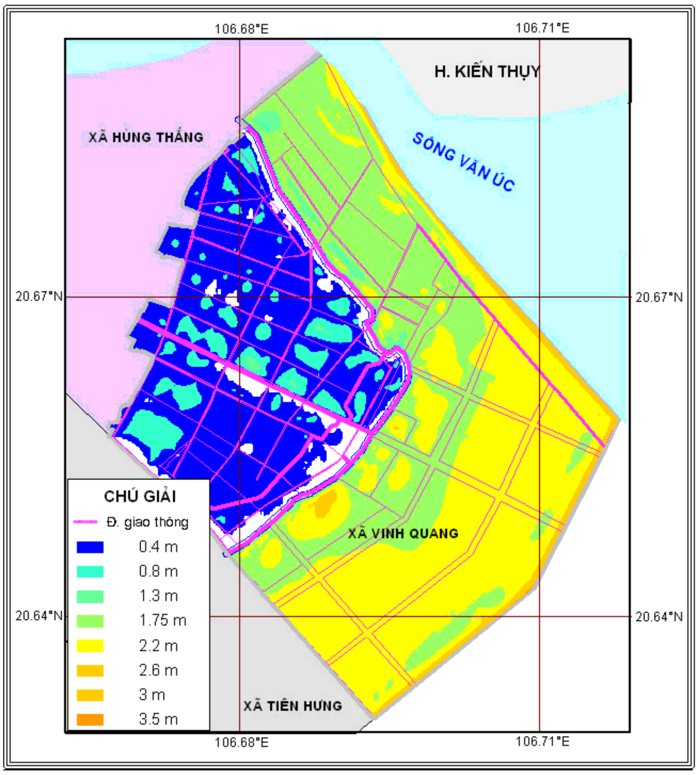

Fig. 4. Inundation area and depth for the case of SLR of 100 cm

Results of flood calculation are used for evaluating risks to human life, agriculture, aquaculture and infrastructures. Risks due to flood is defined as hazard x consequence (Mens *et al*, 2008). The risks of flooding to human life are evaluated using many factors, including inundation depth, flow velocity, debris flow, flood warning activities, infrastructures, age and health of local residents etc. The flood hazard *HR* is evaluated by using the following equation (Mens *et al*, 2008)

$$HR = D(V + 0.5) + DF \qquad (1)$$

where D is inundation depth (m), V is flow velocity (m/s), DF is the debris factors, being a function of flood depth, flow velocity and land use. The flood vulnerability is evaluated using the following equation

$$AV = SO + NA + FW \qquad (2)$$

where *SO* is the flood rising speed, *NA* is a measure of the natural characteristics of the flood area, and *FW* is the factor for flood warning.

The percentage of local residents under flood risks is as

$$PR = HR \times AV \qquad (3)$$

The number of injured residents *N(I)* is evaluated following the formula

$$N(I) = N \times X \times Y \qquad (4)$$

where *X* is the ratio of residents with flood risks per total residents *N*, and *Y* is a factor measuring the vulnerability of local residents. The number of flood fatality is a function of injured people.

Using results of flood calculation and other data, we evaluated the number of residents under flood risk as presented in Table 2. According to the table, the percentage of residents impacted by flooding for the commune is 7.3%.

Table 2. Number of people under flood risks

Number of people under flood risks			Risk degree
Scenario 1	Scenario 2	Scenario 3	
26	24	23	Low
59	16	19	High
198	77	7	High
35	314	207	Very High
12	66	355	Very High
11	18	26	Extremely High
341	514	637	Total number

The calculated degree of inundation for different SLR scenarios is presented in Table 3. From the table, it can be found that for all three SLR scenarios, 100% of aquaculture farms is inundated with the depth of more than 2m while 100% of paddy fields is inundated with depth of more than 1.25m.

With the inundation degree presented in Table 3, the degree of damage and risks due to heavy rainfall and dike break for rice field is presented in Table 4. It can be seen from the table that the degree of damage depends not only on the inundation depth and period, but also on the growth stage of rice. The damage due to dike break for all three SLR scenarios is extremely high. This is because rice is also affected by salinity during sea water intrusion.

The estimated damage of aquaculture in if storm surge combines with high tide in the context of SLR is evaluated following IPCC (2007) and Hobday et al (2008) and is also extremely high. In reality, during September 2005, a strong typhoon attacked the area with high storm surge, and almost all shrimp, crabs and other aquaculture products are lost to the sea (Vu, 2009).

Table 3. Inundation degree

Inundation characteristics and impacted objects	SLR 30cm		SLR 75 cm		SLR 100cm	
	Area (%)	Depth (m)	Area (%)	Depth (m)	Area (%)	Depth (m)
Average inundation depth	0.5-1m		0.5-1.2m		0.5-1.5m	
Maximum inundation	3.4		3.85		4.1	
Mangrove forest	100%	2-2.5m	100%	2.25-3m	100%	2.5-3m
Aquaculture farms	100%	> 2m	100%	> 2m	100%	> 2m
Paddy fields	100%	>1.25m	100%	>1.25m	100%	>1.25
			11%	>2.25	72%	>2.25

Table 4. Risks of flood to rice crop (IPCC, 2007, Adams et al, 1999)

Criteria	Month			
	6	7	8	9
Happening possibility (tropical cyclone and heavy rainfall happening frequency)	Low (D)	Possible (B)	Highly likely (A)	Likely (C)
Damage degree (inundation area)	100%	100%	100%	100%
Inundation depth	More than 1.25m	More than 1.25m	More than 1.25m	More than 1.25m
Inundation period	24 hrs.	24 hrs.	24 hrs.	24 hrs.
Growth stage of rice	Seeding - planting	Young	Flowering	Harvest
Mitigation measures	Reserve young plant	Re-planting	Drainage (pumping)	Drainage (pumping), harvest
Recovery	Easy	Lightly difficult	Difficult and costly	Very difficult and costly
Rice impacts	Low **(L)**	Low damage **(L)**	Significant damage **(M)**	Very significant damage **(H)**
Risk to paddy field	**L**	**M**	**E**	**E**
Impacts due to dike breaking	Extremely high (E)	Extremely high (E)	Extremely high (E)	Extremely high (E)
Total risks due to dike breaking	E	E	E	E

Damages to infrastructures due to flood can be classified as direct damage and indirect damage. The direct damages are damages caused directly during the flooding time, including damages to private and public properties. The indirect damages are lost as consequences of flood. These include lost due to disruption to economic activities, economic difficulties, in-favorable impacts to society (The State of Queensland, 2002).

To evaluate the flood damages to resident houses, the houses were classified as durable houses, one storey 20 year old houses, degraded houses and partly damage houses. Based on the data of housing in the area, flood depth and flood flow velocity, it was estimated that direct flood damages to houses in the commune for three SLR scenarios are respectively 942 millions VND, 1116 millions VND and 3548 VND. The indirect flood damages for the said three SLR scenarios are respectively 141 millions VND, 341 millions VND and 532 millions VND (Vu, 2009). The risks of other kind of infrastructures (such as road, dike etc.) due to flood are also evaluated.

3.2 Salinity intrusion

Impacts of salinity intrusion to the area can be evaluated with salinity intrusion due to dike break causing flood during tropical cyclones, and increase of salinity intrusion to rivers and ground water during normal weather conditions. From the results of flood calculation, it was found that if dike break causing flood, the salinity intrudes all the commune and cause very serious economic and environmental damages.

The calculation of salinity intrusion was carried out using a numerical model. For the calculation of salinity intrusion into rivers during normal conditions, it was assumed that salinity at the seaward boundary does not change for different sea level rise scenarios. It was found that the increase in SLR leads to an increase in salinity intrusion until a distance of 30kms from the river mouth. The increase in salinity intrusion causes difficulties for freshwater uptake for irrigation.

3.3 Coastal erosion

The calculation of coastal erosion was carried out using a numerical model for the simulation of wave propagation, nearshore currents due to wind, waves and tides, and a numerical model for the transport of cohesive sediment and bottom topography change. It was found that coastal erosion increases with SLR. Coastal erosion has a very strong relation with the existence of mangrove forest. With the existence of mangrove forest, the erosion during tropical cyclones happens only outside of the mangrove forest. Without mangrove forest, scouring during tropical cyclones happens until dike toe. Then, the scour causes high risks to dike and can lead to dike break. With mangrove forest, almost all wave energy dissipated and wave run up on the dike is almost zero. Then, protection of mangrove forest is critical for the sea dike protection.

4 WWF’S CLIMATE WITNESS COMMUNITY TOOLKIT FOR COMMUNITY ACTION PLAN DEVELOPMENT

The purpose of using climate witness community (WWF, 2009) toolkit for the development of climate change adaptation at community level is to enhance the knowledge of community and local government about the risks of CC and SLR, and together with researchers from the RIMSI, to develop the community action plan. For this, a workshop was organized at the community. During the workshop, 60 people from the community, including personals from local government, businessmen, farmers, male, female, young and elders took part in the works. The participants were divided into 3 groups: elders and young, males and females with different economic and working background. The participants together with researchers from RIMSI discussed various problems, including the present status of natural environment, bio-diversity, natural hazards, vision for the future etc., and possible solutions for the present problems and future problems. As the results, following prioritized problems with possible solutions are identified:

5. ADAPTATION MEASURES

Based on the estimation of risks and community action plan development, following adaptation measures have been proposed:

1) *Strengthen education and knowledge of government employees, leaders and community on CC and SLR, and impacts of CC and SLR and adaptation measures. Increase the capacity of local government employees and community to respond to natural disasters and protect natural environment.*
2) *Plan, manage, protect and develop mangrove forest for the dike and coastal protection. Especially, efforts should be directed to replanting the mangrove forest with new species that can withstand high salinity and long inundation time.*

3) *Strengthen efforts for poverty eradication, create new jobs to improve livelihood of local people, especially those who are significantly affected by CC and SLR and living below poverty line; focus on the reduce the risks of agriculture activities, diversify jobs, develop industry, service and other economic activities.*
4) *Re-planning land use and aquaculture with consideration of risks due to CC and SLR. Increase the application of scientific knowledge to reduce risks and ensure sustainable development.*
5) *Make an appropriate fishing development plan to ensure the recovery of biodiversity, protection of ecological system and sustainable development.*
6) *Apply the method of integrated coastal management to make appropriate plan for wise use of coastal resources, protect environment and harmonize interests of concerning parties to insure sustainable development.*
7) *Establish new financial mechanisms for adaptation to CC and SLR, and natural disaster prevention and mitigation.*
8) *Upgrade infrastructures, especially dike and roads.*
9) *Build local forces to respond to natural hazards.*
10) *Strengthen environmental protection, sanitary, epidemic prevention and community health.*
11) *Implement and continuously improve community action plan to respond to CC and SLR.*
12) *Continuously monitor, evaluate the effectiveness of adaptation measures to CC and SLR and improve if necessary.*

Table 5. Prioritized problems and solutions

Prioritized problems	Solutions
1. Flood due to heavy rainfall and possible sea dike failure	- Improve drainage system - Mangrove afforest - Improve sea dike - Enhance local community awareness through education - Improve early warning system
2. Environmental pollution and biodiversity degradation	- Treatment of waste water and solid wastes - Impose strict regulation on fishing, including strict banning of destructive fishing activities - Protect mangrove forest - Enhance local community awareness through education
3. Freshwater shortage	- Improve planning and management water resources - Economic usage of electricity and water - Create new tanks to store clean water - Protect underground water - Improve community water management systems

6. CONCLUSIONS AND RECOMMENDATION

The research results show that CC and SLR does not create new problems for the Vinh Quang community, but only has the potential of making existing problems more serious. The adaptation needs to combine different methods, but should focus on the strengthening community knowledge about CC and SLR and adaptation plan.

To improve the effectiveness of adaptation measures, there should be a monitoring plan to collect necessary data for evaluation. This could be done only if there is a financial support.

The pilot study is carried out for a commune in Tien Lang district, Hai Phong provinces. However, due to its representative natures, results of the study could be used for establishing adaptation measures and community action plan to respond to CC and SLR for similar areas in Vietnam.

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ENHANCING COASTAL RESILIENCE IN ASIA AGAINST CLIMATE CHANGE: CHALLENGES AND MEASURES

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ABSTRACT

According IPCC WGII report (IPCC WGII, 2007) Asia has 11 mega cities covering more than 10,000 km^2. Most of these regions are highly populated and are important production systems that also are home to unique bio-diversity. Climate change can seriously affect most of these regions due to increase in flood risk, intensifying typhoons and adverse impacts associated with sea level rise and loss of bio-diversity. Maldives, Vietnam, Bangladesh, Myanmar, China, Thailand and Pakistan are some of the countries that are especially vulnerable. Sea level rise pose threats to both water security and food security as salinity intrusion can seriously affect food production in fertile agricultural areas such as Mekong Delta. In addition to these mega deltas, there are a large number of small islands that are extremely vulnerable to sea level rise.

In response to UN's call for National Adaptation Programmes of Action (NAPA) from the Least Developed Countries (LDCs), 13 projects on coastal zones and marine ecosystems have been prioritized, mainly by small island nations. In the national communications to UNFCC, the 3rd highest concern (after water and agriculture) was the effect of climate change in coastal and marine ecosystems, as reflected in the communications by 53 parties. How should Asia prepare against these potential threats? Increasing population, accumulation of assets and urbanization are already making serious negative impacts to coastal regions. At the same time, the large uncertainty of climate change predictions at spatial resolutions that are necessary to make risk assessment at local level makes it more difficult to divert investments from urgent immediate challenges. This paper examines a number of proposed and ongoing response plans in the region to discuss appropriate strategies that would improve the coastal resilience and support sustainable development.

1. INTRODUCTION

Climate change will reconfigure patterns of climatic hazards as well as physical, social and economic vulnerability of coastal regions. The combination of increasing climatic hazard, together with declining resilience may combine against the effectiveness of measures for resiliency such as social development, enhanced preparedness, and early warning. According to IPCC[1], most vulnerable areas in Asia by climate change include the Small Island States and Asian mega deltas, as well as coastal zones. Many scientists have discussed the correlation between extreme weather events (such as typhoons, storms, etc.) and global environmental change—particularly within the Intergovernmental Panel for Climate Change (IPCC). As the water cycle becomes more intense through climate change, many climate related hazards will become more severe, including floods, droughts, heat waves, wildfires and storms, which will affect societies and economies in many different ways.. Due to rise in sea level for instance, more agricultural lands would be lost due to salinity intrusion and loss of bio-diversity. This review interprets the result of reports and studies on the impact of climate change to

[1] http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10.html

coastal vulnerability on developing countries produced by the World Bank, United Nations Development Programmee (UNDP), United Nations Environment Programme (UNEP), the International Institute for Environment and Development (IIED), Organization for Economic Co-operation and Development (OECD), Food and Agriculture Organization (FAO, 2009), Nicholls (2007), Nicholls (2009) and others in order to profile the regions and to discuss appropriate strategies that would improve the coastal resilience and support sustainable development. This interpretation provides a base-line of current knowledge on coastal protection technological aspects in reducing climate change effects particularly in the coastal zone area. In addition, this review also examines the policies of technology transfer and implementation in order to enhance coastal resilience in Asian countries.

2. THE IMPACT OF CLIMATE CHANGE ON COASTAL ZONE OF ASIAN COUNTRIES

2.1 Climate change and sea level rise scenario

The IPCC Fourth Assessment Report (AR4) concludes that the global warming is clearly identifiable. Atmosphere and ocean temperatures are higher than they have been at any other time during at least the past five centuries, and probably for more than a millennium[2]. The projections of future climate change patterns are largely based on computer-based models of the climate system that incorporate the important factors and processes of the atmosphere and the oceans, including the expected growth in greenhouse gases[3] from socio-economic scenarios for the coming decades. The report has examined the published results from many different models and on the basis of the evidence as at 2007 has estimated that by 2100[4]: (1) The sea level will rise (SLR) between 18 and 59 cm, (2) The oceans will become more acidic, (3) It is likely that tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures.

Based on this scenario, Asian countries will become most severely affected area by SLR. Climate change can seriously affect most of these regions due to increase in flood risk, intensifying typhoons and adverse impacts associated with SLR and loss of bio-diversity. SLR will bring more coastal area under inundation causing loss of land, and displacing people. Mc Granahan *et. al.* (2007) identified that almost all coastal areas and small islands states are vulnerable to SLR. As illustrated in Table 1, about two thirds of the population in this zone is in Asia. While the small island states have by far the largest share of land in this zone, their population percentages are comparatively small. This is in part because some of the most populous small island states have smaller number of settlements in the low elevation areas. Another factor for the low vulnerability is that small island states do not have large rivers.

2.2 Impact on food and water security

Agriculture is a major sector in some of Asian countries' economies. Increase in salinity intrusion and increase in soil salinity will have serious negative impacts on agriculture. The presently practised rice varieties may not be able to resist increased salinity. The rise in sea level and availability of less freshwater particularly during dry season during low flow periods will cause inland intrusion of saline

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2 IPCC Fourth Assessment Synthesis Report: http://195.70.10.65/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

3 Greenhouse gases (GHGs) "are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds." The primary greenhouse gases include H2O, CO2, N2O, CH4 and O3. IPCC Fourth Assessment Report, Working Group I, Glossary of Terms: http://ipccwg1.ucar.edu/wg1/Report/AR4WG1_Print_Annexes.pdf.

4 IPCC Fourth Assessment Report, Working Group I, Summary for Policymakers: http://195.70.10.65/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf.

water. As a result, many mangrove species, intolerant of increased salinity, may be threatened. The shrinking of the mangrove areas will have an effect on the shrimp production and coastal protection (Primavera, 1997; Frankic and Hershner, 2003; Hoanh *et al.,* 2006).

Table 1: Population and land area in the Low Elevation Coastal Zone (LECZ) by region, 2000

	Population and land area in LECZ				**Share of population and land area in LECZ**			
	Population (million)		Land (1000km^2)		Population (%)		Land (%)	
Region	**Total**	**Urban**	**Total**	**Urban**	**Total**	**Urban**	**Total**	**Urban**
Africa	56	31	191	15	7	12	1	7
Asia	466	238	881	113	13	18	3	12
Europe	50	40	490	56	7	8	2	7
Latin America	29	23	397	33	6	7	2	7
Australia & New Zealand	3	3	131	6	13	13	2	13
North America	24	21	553	52	8	8	3	6
Small Island States	6	4	58	5	13	13	16	13
World	**634**	**360**	**2700**	**279**	**10**	**13**	**2**	**8**

Source: McGranahan, G., D. Balk, and B. Anderson (2007)

Increased water salinity may also not be suitable for many fishery species (Maarif, 2008). Furthermore, sea level rise, by reducing the fresh water fishing area, will cause reduction of fish production. Pond culture in the coastal area will be affected by intrusion of salt water into ponds, unless embankments are made around them. Shrimp farming in the coastal area is a worthwhile business (FAO, 2009). Increase in salinity and decreasing of mangrove is likely to make vulnerable the business (Primavera, 1997; Zeidler 1997, Adger *et al*. 2002; FAO, 2009).

From the point of view water resources, backwater effect generally refers to the retardation of a river outflow by a rise in the level of water at the river mouth. Mostly it is an estuarial phenomenon. The effect may be from a main river to its tributary or from a sea to a river. Not only do conditions at the river mouth retard the discharge, but occasionally flow reversal may occur, that is flow may be from the sea to the river. It is particularly important during rainy seasons. As a result of back water effect, flood water inside the coastal area continues to accumulate, bringing more areas under inundation and increasing the length and depth of flooding in areas already inundated. Not only that, even the ground water aquifers will bear the brunt of salinity intrusion. The low elevation coastal zone[5] approximately accounts for only 2 percent of the world's land area, but contains 10 percent of the population, and 13 percent of the urban population. Low-lying settlements may become unfeasible, which may result in increased potential for movement of population and loss of infrastructure.

2.3 Responses and supporting to adaptation

Climate change will influence all countries; however people in the poorest countries and poor people in richer countries are expected to suffer the most. Millions of people are likely to be affected by floods, storm surges, erosion and other coastal hazards every year due to rising sea levels by the 2080s, particularly in the large deltas of Asia and Africa and the small island states. According to the IPCC[6], Asia's coastal areas, and especially its heavily populated delta regions, will become even more prone to increased flooding because of both rising sea levels and river flooding. In connection to these, the United Nations Framework Convention on Climate Change (UNFCCC) supports adaptation to the impacts of climate change primarily through four funds for adaptation as follow:

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[5] Low elevation coastal zone (LECZ) is defined as adjoining coastal land less than ten meters in altitude

[6] IPCC Fourth Assessment Report, Working Group II Report: http://195.70.10.65/ipccreports/ar4-wg2.htm.

1. Least Developed Countries Fund (LDCF), established under the UNFCCC to help developing countries prepares and implements their National Adaptation Programmes of Action (NAPAs).
2. Special Climate Change Fund (SCCF), also established under the UNFCCC to support a number of climate change activities such mitigation and technology transfer, but place top priority on adaptation.
3. Global Environment Facility (GEF) Trust Fund's Strategic Priority for Adaptation (SPA) which pilots 'operational approaches' to adaptation.
4. Adaptation Fund (AF) which was established under the Kyoto Protocol and is intended to assist developing countries carries out 'concrete' adaptation activities.

UNFCCC addresses what can be done to reduce global warming and to cope with whatever temperature increases are expected. In relation to this National Adaptation Programmes of Actions (NAPA), which are documents produced by the Least Developed Countries (LDCs)[7] for the UNFCCC to identify immediate and urgent needs for adaptation to climate change launched. The NAPA process is a mechanism through which national stakeholders can understand the problem of climate change and their responsibility in building resilience for community to its harmful impacts, and identify a selection of suitable adaptation projects. The NAPA Document focuses on eleven sectors which are covered: 1. Food security (agriculture, livestock, fisheries, and other livelihood sources), 2. Coastal zones and marine ecosystems, 3. Early warning and disaster management, 4. Education and capacity building, 5. Energy, 6. Health, 7. Infrastructure, 8. Insurance, 9. Terrestrial Ecosystems (land management, forest ecosystems, wetlands/lakes, natural sites), 10. Tourism, 11. Water resources. Some projects and activities are very cross-sectoral in nature, it have been put into a 'cross-sectoral' group.[8] A NAPA project generally contains 11 sections, including:[9] 1. Introduction and background information on the country; 2. Synthesis of available vulnerability and adaptation plans and policies; 3. A framework for the adaptation programme; 4. An assessment of main vulnerabilities; 5. Potential barriers to implementation; 6. Identification of priority adaptation needs; 7. Development of a list of adaptation activities and projects; 8. A ranking of priority areas; 9. Identification of the most urgent needs 10. An implementation strategy; and 11. Project profiles for priority activities.

2.3.1 *Lesson learnt from NAPAs*

Response to UN's call for NAPA, 13 projects on coastal zones and marine ecosystems has been prioritized, mainly by small island nations. They provide requests for resources for activities, which LDCs identify as their priority areas for adaptation to climate change. NAPA takes into account existing coping strategies at the grassroots level and build upon that to identify priority activities. The NAPA process is supposed to be participatory, incorporating inputs from local level communities. Community level input is considered important because communities are the main stakeholders. NAPAs focus on urgent and immediate needs, those for which further delay could increase vulnerability or lead to increased costs at a later stage. Hence the documents are prepared in a simple and easily understood format for both the public and decision makers. An example of activities undertaken by the countries within the framework of NAPAs' projects can be seen in Table 2. Notable among these efforts in relation to climate change impacts is that Bangladesh was the first country to complete a NAPA's project. Bangladesh successfully completed the NAPA in

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[7] The Least Developed Countries (LDCs) are a group of 49 countries considered to be the world's poorest based on three criteria of *low income*, *human resource weakness* and *economic vulnerability* developed by the Economic and Social Council of the United Nations. The low-income criterion, based on a three year average estimate of the GDP per capita is that it must be under US$900 to be included in the LDC group and above US$1035 to graduate from the group. The human resource weakness criterion uses the Augmented Physical Quality of Life Index (APQLI) based on nutrition, health, education and adult literacy while the economic vulnerability criterion uses the Economic Vulnerability Index (EVI) based on such indicators as instability of agricultural production, instability of export of goods and services, economic importance of non-traditional activities (share of manufacturing and modern services in GDP), merchandise export concentration, and the handicap of economic smallness. In general, LDCs have very low levels of capital, human and technological development. The LDCs share of the world's per capita GDP is less than 1% despite having more than 10% of the world population. Source: UNCTAD, http://www.unctad.org/ldcs

[8] http://unfccc.int/cooperation_support/least_developed_countries_portal/napa_project_database/items/4583.php

[9] : http://unfccc.int/national_reports/napa/items/2719.php

2005, while Cambodia in 2007, Maldives in 2007 etc. As of February 2010, the UNFCCC secretariat had received NAPAs from 44 LDCs [10].

Table 2 National Adaptation Programmes of Adaptation Coastal Zones/ Marine Ecosystems

Country	Project Title	Coast (USD)	Sector Component(s)
Bangladesh	– Reduction of climate change hazards through coastal forestation with community participation	23,000,000	– Coastal zones
Cambodia	– Community mangrove restoration and sustainable use of natural resources	1,000,000	– Restoration and protection of coastal ecosystem
Maldives	– Coastal protection of safer islands to reduce the risk from sea induced flooding and predicted sea level rise – Increase resilience of coral reefs to reduce the vulnerability of islands, communities and reef dependant economic activities to predicted climate change	3,055,000 1,062,000	– Coastal zones

3. ADDRESSING THE PROBLEM OF CLIMATE CHANGE IN COASTAL ZONE

3.1 Enhancing resilience

Resilience can be interpreted as elasticity. . In relation to society and climate change, Timmerman (1981) defines resilience as measure of a system's or part of a system's capacity to absorb and recover from the occurrence of hazardous event. While, UN-ISDR 2009 uses the term of resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions[11].

A disaster occurs when a vulnerable community, such as an exposed and poorly prepared community, is subjected to a natural hazard, and the severity of the disaster depends on the intensity of the hazard (Twig, 2007). The first task in responding to climate change is to mitigate the vulnerabilities (Paton and Johnston, 2001). The second task in responding to climate change is to manage its impacts. Sea-level rise, coupled with coastal storms, will increase the impacts of storm surge and river flooding and damage livelihood systems and protective ecosystems.

Climate change will therefore affect disaster risks in two ways, firstly through the possible increase in weather and climate hazards, and secondly through increases in the vulnerability of communities to natural hazards, particularly through ecosystem degradation, reductions in water and food availability, and changes to livelihoods. In the absence of measures to reduce disaster risks, the likely consequences on coastal zones, as projected by IPCC, in general terms as follows:[11]

[10] http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php

[11] For a complete listing of major projected impacts by sector, see IPCC Fourth Assessment Report, Working Group I, Summary for Policy Makers: http://195.70.10.65/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf and IPCC Fourth Assessment Report, Working Group II, Summary for Policy Makers http://195.70.10.65/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf.

1. Increased frequency of high precipitation in some regions will trigger floods and landslides, with potentially large losses of life and assets. These events will disrupt agriculture, settlements, commerce and transport and may further increase pressures on urban and rural infrastructure.
2. Increases in the number and intensity of very strong cyclones (typhoons and hurricanes) will affect coastal regions, with potentially large additional losses of lives and assets.

3.2 Adaptation and the role of the Hyogo Framework

Adaptation is defined by the IPCC as "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*"[12]. Examples of adaptation include preparing risk assessments, protecting ecosystems, improving agricultural methods, managing water resources, building settlements in safe zones, developing early warning systems, instituting better building designs, improving insurance coverage, developing social safety nets and enhancing public awareness and education. These measures are intrinsically linked to sustainable development, as they reduce the risk to lives and livelihoods and increase the resistance of communities to all hazards. Ideally, adaptation and mitigation should be considered jointly, as some adaptation measures can contribute to reducing vulnerability.

Disaster risk reduction can be defined as action taken to reduce the risk of disasters and the adverse impacts of natural hazards, through systematic efforts to analyze and manage the causes of disasters, including through avoidance of hazards, reduced social and economic vulnerability to hazards, and improved preparedness for adverse events. The Hyogo Framework for Action (HFA) provides the foundation for the implementation of disaster risk reduction. Its intended outcome for the decade is the substantial reduction of losses, in lives and in the social, economic and environmental assets of communities and countries[13]. HFA specifically identifies the need to promote the integration of risk reduction associated with existing climate variability and future climate change into strategies for the reduction of disaster risk and adaptation to climate change.

3.3 The need for the use of technologies

As described above, it is useful to consider the available adaptation options in coastal zones. Adaptation acts to reduce the impacts of sea-level rise and climate change, as well as other changes (as well as exploiting benefits). These decisions need to be made in the face of the large uncertainty about future climate (and many other factors), so there is a need to think in a risk- and uncertainty-based manner rather than looking for deterministic solutions.

Adaptation in the coastal context is widely seen as a public responsibility (Klein *et. al.*, 2000). Therefore, all levels of government have a key role in developing planned adaptation measures. Planned adaptation options to sea-level rise are usually presented as one of three generic approaches (Bijlsma *et. al.*, 1996; Klein *et. al*, 2001):

1. Retreat (to manage/planned) – all natural system effects are allowed to occur and human impacts are minimized by pulling back from the coast;
2. Accommodation – all natural system effects are allowed to occur and human impacts are minimized by adjusting human use of the coastal zone;
3. Protection – natural system effects are controlled by soft or hard engineering, reducing human impacts in the zone that would be impacted without protection.

In practice, many responses will be hybrid and combine elements of more than one approach. It is also notable that most assessments of adaptation only consider mixtures of retreat ("do nothing") and protection, and the accommodation option remains largely an assessed. Table 3 shows some selected options related to adaptation (NRC, 1987; Klein and Nicholls, 1998; Nicholls, 2007; Nicholls, 2009)

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[12] IPCC Fourth Assessment Report, Working Group II, Glossary of Terms: http://195.70.10.65/pdf/glossary/ar4-wg2.pdf.
[13] http://www.unisdr.org/eng/hfa/hfa.htm.

Table3. Technologies for adaptation in coastal zones

Protection	**Retreat**	**Accommodation**
Hard structures – dykes, bulkhead/sea-walls, tidal barriers, detached breakwaters, gabions, timber piles, armour unit, groyne, revetment, bag made from geotextile, artificial coral reef	– Establishing set-back zones – Relocating threatened buildings	– Early warning and evacuation systems – Hazard insurance
Soft structures – dune or wetland restoration or creation, beach nourishment	– Phasing out development in exposed areas – Creating upland buffers	– New agricultural practices, such as using salt-resistant crops – New building codes
Indigenous options – walls of wood, stone or coconut leaf, afforestation	– Rolling easements	– Improved drainage – Desalination systems

3.3.1 *Priority and technology for adaptation in coastal zone*

According to the expert meeting from Parties under the Nairobi Work Programme[14] on impacts, vulnerability and adaptation to climate change; in particular on climate-related risks and extreme events in coastal zones, it recommended the needs of technology assessment of NAPAs projects. Priorities in developing countries are to protect coastal areas, including preventing soil erosion, limiting the development of coastal areas, building coastal infrastructure. The problem is, the selection of technology to reduce the impacts of climate change is often having negative side effects. If not carefully considered, technology adaptation in coastal areas can have adverse social, economic, and environmental consequences. A good example of this is the construction of seawall as well as breakwater to protect the continuing erosion in a coastal area. There is ample evidence that show the handling of coastal erosion in some places has created a new worse problem in other places around it. If any, few coastal adaptation technologies have no negative side-effects. It is also important to remember that there is no coastal adaptation technology appropriate and suitable to all places. In turn the suitability of particular adaptation technology is highly sensitive to local conditions (Klein *et. al*, 1998).

Technology required for adaptation to the coastal area will vary depending on local environment and capacity to adapt to sea level rise. Variations technological options for adaptation to climate change depends on each area, including: natural resources, human resources/expertise, equipment availability, environmental factors, public perceptions, legal restrictions, sources of funding, political will, and so on. Moreover, the technology needs are determined by the relative scale of the problem and the availability of resources. From coastal engineering point of view, if there is no constrained by funding, availability of materials, or work force, construction of almost any feasible protection against sea-level rise can be carried out in very short time, relative to the rate of sea-level rise (NRC, 1987). Now, the question is what technologies are available to respond to the problem of SLR and its associated effects? Engineering solutions developed in countries with coastal engineering traditions like Japan, Netherland, United Kingdom, USA, cannot simply be transferred to developing countries. However, in

[14] http://www.iisd.ca/vol12/enb12340e.html

the case of similar coastal characteristics, climate conditions and ecosystem, appropriate engineering solution can be applied as long as consideration is made reagarding all the factors outlined above in the local context.

4. CURRENT PRACTICE

It is clear that climate change will increase the hazard potential in many Asian countries. The vulnerability of coastal areas of Asian countries and Small Island Developing States (SIDS) has been a subject of increasing world interest, as reflected by the number of the NAPA projects. Most NAPAs prioritize projects that promote food security and water resources. In the case of SIDS, much of the low-lying land areas are only 1-4 meters above the present mean sea level. Therefore, the ecological and socio-economic risks associated with the projected increase in sea level rise (SLR) are particularly significant. As a consequence, increased coastal erosion and land loss on the coastal zones will have a direct impact on local economies due to significant dependencies such as settlement, tourism, fisheries, and agriculture.

As mentioned above, the IPCC 2nd Assessment Report (SAR) describes three strategic concepts to cope with sea level rise: to retreat (to manage), accommodation, and protection. The SAR also identifies six major losses caused by sea-level rise in coastal areas: the increased frequency of flooding, erosion, inundation, rising ground water-tables, salt-water intrusion, and the influence of biological/biodiversity effects. Human and environmental systems/ecological systems will need to adapt to the negative effects of climate change, including extreme changes in climate and climate variability, through a combination of technology and behavioral adjustments.

Coasts are naturally prone to fracture due to attacks from both land and sea. Regardless of whether coastal zones are managed or not, they are not static, but a dynamic, unpredictable, adaptive and interdependent set of subsystems. However, these characteristics are frequently unnoticed in planning, design and implementation of coastal projects. The dynamics of the coastal zone is both a difficulty and challenge for coastal managers. On the one hand, it is not easy to model and predict the effectiveness of a particular adaptation technology in coastal areas, nor the positive or negative effects associated with a particular technology. Moreover, the problem of coastal zones is the accumulation of many inappropriate practices, such as development in hazardous coastal zones, sand mining, and including the selection of inappropriate technology.

In a limited scale, as described in Table 2, Cambodia and Bangladesh for instance, make some effort to adapt to climate change through conventional efforts like planting trees, especially mangrove plants. While Vietnam, regardless of whether under the NAPA project or not, also use the coastal structures to protect low-lying areas from flooding and erosion in coastal areas, particularly in the Mekong Delta (Mai *et. al.* 2009). They also conducted studies of the impact of water quality on agricultural, fisheries and fresh water availability, as well as the tidal propagation and salinity intrusion, and evaluated the effects of water and land use management on hydrology and salinity-related phenomena in coastal zones (Hoanh *et. al*., 2009).

As described above, NAPA activities have applied only a limited amount of coastal engineering practices in coastal zones, except for the Maldives (see also in Table 2). This may be because of the limited funds and lack of coastal adaptation technology. To bridge the limitations of adaptation technology in developing countries and to multiply the availability of alternative solutions, supporting greater technology transfer is one option. However, countries in Asia, as well as SIDS, do not have a strong tradition in coastal engineering. In the future, for adaptation to climate change in coastal areas, particularly for protection of coastal zones, the implementation of coastal structures (dykes, revetment, artificial reef, detached breakwater, groins, etc.) should be considered as a solution. The best option is to support adaptation of technologies that can merge or combine the needs of coastal protection and improve environmental values (including increased bio-diversity and abundance) as well as amenities which can improve livelihoods (Black and Mead 2009; Scarfe *et. al*., 2009). Good examples of this are artificial-reefs such as the multi-purpose reef built in Narrowneck (Australia), Kerala (India), and other places (Black, 2003; Mathews *et. al*, 2003; Harris, 2003).

5. FUTURE DIRECTIONS

The above discussion has amply demonstrated that adaptation should not be considered as a one-time response, but a continuous process that is closely linked with the development options of a country. Climate change challenges should therefore be taken as a development opportunities that take an holistic approach to enlarge livelihood options, enhance resilience and introduce new technologies improving protection and accelerating development. How should this be addressed systematically? The major challenge is the uncertainty of future climate. Even at global scale, it is well known that prediction models differ widely in their projections regarding future climate of a particular location, especially in the rainfall predictions. Once these results are downscaled to local scale at high spatial resolutions required for impact assessment, significant differences from past observations make it necessary to carry out bias corrections to ensure that future projections are reasonable at local scale. However, at current prediction skills, differences in the outputs from different GCMs make it difficult to reduce uncertainties sufficiently to make concrete future implementation plans. Given this uncertainty, the best option available at present is to make incremental adaptation planning, or 'adaptive adaptation' where a combination of hard and soft measures are designed to minimize adverse impacts of climate change, but ensure that these measures are flexible enough so that they can be changed and improved as the uncertainty of future climate predictions decrease.

Current best practices in national planning adopt the following measures; (a) select a future climate change scenario from the suite of IPCC future scenarios that would best represent the development plans of the country (b) downscale the predictions to local scale using either dynamic or statistical methods (c) carry out impact analysis for the forecasted future weather time series using impact assessment models such as flood inundation or crop yield models for a selected set of future events (d) prepare risk maps based on the impacts (e) introduce measures to enhance resilience against climate change impacts based on the risk maps where ever feasible and in future development programs. The steps from (a) to (e) should be repeated periodically to accommodate improvements in global knowledge and predictive skills of future climate.

Many countries have embarked on developing action plans on the above procedure. The Vietnamesse approach is a an excellent example described in 'Climate change, sea level rise scenarios for Viet Nam (MONRE, 2009)' and the National Target program to respond to climate change (Government of Vietnam, 2008. The Strategic Research 4 program of the Ministry of Environment, has conducted impact analysis for Japan and assessed the cost of adaptation. (S-4 project team, 2008 and 2009)

6. CONCLUSION REMARKS

Coastal zones of several countries in Asia are highly vulnerable to climate change. The main points discussed in this paper are the impacts due to the increase of SLR. For adaptation and enhancing resilience of coastal communities to climate change, particularly increasing SLR, strategies must include coastal protection technology, as well as to accommodate and retreat from the seashore. At this time, mastering the technology for the protection of the coastal zones is still very limited among Asian countries and SIDS. For that, technology transfer from the countries with a strong coastal engineering tradition (mostly developed countries) is needed. In this regard, multi-purpose coastal protection technology should be more promoted. However, in selecting the appropriate technology in each region, the local capacities and local values must be considered. The best medium for technology transfer for capacity building is, especially in terms of NAPAs, by means of cooperation in education and training, nationally and regionally.

In the future, it is important for each country to prepare its own climate change scenarios and national target programs that identify climate change related risks and stipulate potential remedial measures. Finally, the HFA framework, which will end in 2015, can be used as a tool to determine the resilience of coastal zones of Asia to climate change.

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USE OF SYNTHETIC IMPACT RESPONSE FUNCTIONS FOR THE ANALYSIS OF VULNERABILITY TO FLOOD DAMAGE IN GIPPSLAND COASTAL ZONES

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ABSTRACT

The paper presents an example of the development and use of synthetic impact response functions in the Gippsland Coastal region in order to prioritise flood impact issues and derive information for quantification of impacts for adaptation measures. We used this approach to identify key issues of concern for flood impacts in this region. The analysis also showed that some of the issues are considered not to be significantly affected by floods and thus may not require adaptation measures. The analysis did not provide high agreement on some issues. Different approaches would be required to assess the importance of these issues and to establish response functions for them.

1. INTRODUCTION

A holistic and sustainable approach is needed for coastal zone management (Post & Lundin, 1996; Neumann and Livesay, 2001; Walsh, 2004; APN, 2005; Dutta et al., 2005). The real challenge in achieving optimal sustainable management strategies in coastal zones relies on the ability to design, develop and implement an integrated management program that not only maximizes the benefits to society and its economy based on accurate understanding of the impacts of changes in physical processes, but that also ensures that the ecosystems are adequately protected or preserved. The requirement for ecosystem protection is based on recognition of the inherent value of natural systems as well as a utilitarian recognition that degraded ecosystems cannot provide many of the products and ecosystem services that we have previously taken for granted. It is therefore necessary to assess socio-economic and environmental impacts of sea level rises to better understand the vulnerability of the coastal zones for devising adaptive and integrated management principles.

Process-based and distributed mathematical models can be utilized to capture changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing (Gordon et al., 1996; Hong et al., 2002; Nakayama et al., 2004, Dutta et al., 2007); thus contributing to our knowledge about the vulnerability in coastal zone systems. Such modelling approaches can provide better understanding of changes in the complex and interrelated biogeochemical and physical processes in coastal zones such as nutrient flux, salinity, floods, erosion and sedimentation. In order to assess vulnerability for the development of adaptive management strategies, it is necessary to identify and prioritize the important issues and to quantify the impacts of the changes in physical processes due to floods and high water levels associated with sea level rise. In order to quantify impacts, it is necessary to firstly identify relationships between characteristics of the floods and associated quality variables and key issues and secondly to quantify these relationships (Berning et al., 2000).

Impact response functions are essential components of vulnerability and impact assessment models, which relate impacts of flood inundation and water quality variables to key issues (Krzysztofowicz and Davis, 1983; Smith, 1994). There are several types of hazards for coastal areas associated with climate change and sea level rise. In this study, the hazard of interest is flooding. The flood inundation variables which govern the impact characteristics and which are considered for stage-damage functions are: flood depth, duration, velocity and frequency and water quality. The response functions are usually derived in one of two ways. Damage data from past floods may be incorporated into the model, but if such information is unavailable or unreliable, an alternative approach is to generate synthetic response functions from hypothetical analysis of flood events based on land cover and land use patterns and the key issues for the region (Das and Lee, 1988; Smith and Greenaway, 1988; Smith, 1994). Berning et al. (2001) call for incorporation of social and environmental components into these models, but damage functions for these elements of a model are difficult to estimate (Dougherty & Hall, 1995; Kang et al., 2005). According to Viljoen et al. (2001), including the environmental impact dimension into the holistic damage assessment methodology should render further benefit. Various authors including Dougherty & Hall (1995) suggest use of expert advice in determining synthetic response/loss functions/ estimations of loss. In this study, information regarding the likely impact of inundation on key issues with social, economic or environmental value was generated by surveying stakeholders with experience of past flood events.

This project involves a vulnerability analysis for a key coastal zone in Gippsland, Victoria, under climate change conditions. The vulnerability analysis required the identification of relevant flood hazard parameters and key issues for the study region; and the synthesis of impact response functions using expert and stakeholder opinion. The outcomes of the vulnerability analysis are potentially useful as a basis for the development of adaptation measures for the region. The project required the engagement of experts and key stakeholders in order to identify and prioritize the key issues and to generate synthetic response functions. A significant outcome of the project is an insight into how stakeholders' knowledge and expertise (at regional and local levels) might be utilized for establishing such response functions for quantification of the likely impacts of climate change in coastal regions.

2. STUDY AREA

The Gippsland coast is home to thousands of people who live in or near one of the many coastal towns and settlements located between San Remo on the eastern extent of Western Port Bay and Mallacoota near the New South Wales Border. Despite these built up areas, the Gippsland coast remains in a largely natural state, and is characterised by diverse natural and cultural values, including important habitat for a range of species protected by National Parks, reserves and public foreshore land (GCB, 2008).

The region includes the Gippsland Lakes System (Figure 1) which is a series of coastal lagoons – large areas of shallow water that have been almost wholly sealed off from the sea by a coastal dune system. "The Lakes" are Australia's largest navigable inland waterway and include three main water bodies: Lake Wellington (138 km2) in the west, fed by the La Trobe, Thompson, Macalister and Avon Rivers, and linked by the McLennan Strait to Lake Victoria (110 km2) and Lake King (92 km2) (Boon et al., 2007). These lakes are now well recognized as a major natural resource with economic, environmental and cultural significance. However, the benefits and attractions offered by the lakes have been compromised over the years by many undesirable changes in water quality caused by various stressors, such as land use (mainly agriculture), land use change, pollution and eutrophication (Green, 1978; Pitt & Synan, 1987; Harris et al., 1998; Webster a& Wallace, 2000; Longmore, 2000; Grayson et al., 2001; Webster et al., 2001).

Climate change, sea level rise and coastal subsidence all have the very real potential to significantly impact on the Gippsland coast, affecting both natural values and built infrastructure on private and public land. Coastal erosion, flooding and large scale changes to Gippsland's coastline caused by climate change not only have the potential to impact on a very broad range of environmental and cultural values, but may also pose a direct threat to an array of physical assets along the Gippsland coast. Physical assets associated with townships and potentially at risk range from isolated boat ramps and jetties to valuable private properties fronting prime foreshore land. The most vulnerable coastal sites are low-lying areas and/or those that have a high potential for erosion, and hence shoreline retreat (GCB, 2008).

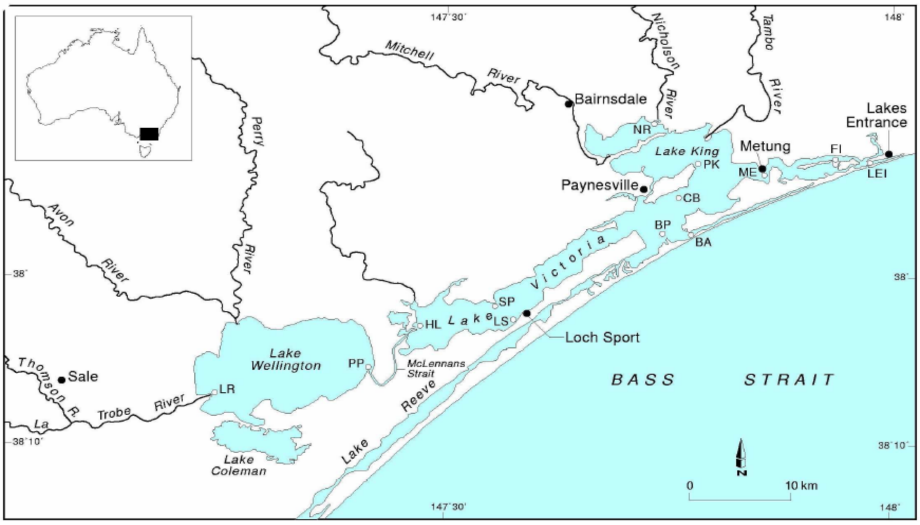

Fig. 1: Map of the Gippsland Lakes System

3. PROJECT APPROACH AND METHODS

A systematic approach has been implemented throughout the project, from the selection of experts and stakeholders to the design and distribution of the questionnaires and to the statistical analyses of the data provided by stakeholders, which in turn enabled the prioritization of issues and impact response functions for adaptation measures. The roles of the experts and stakeholders were to identify relevant flood hazard parameters and key issues for the region; and to provide data for the generation of synthetic response functions for impact analysis. The questionnaire was devised as an instrument to collect data for generating synthetic response functions. Each aspect of the project activities and approach is discussed below.

3.1 Identification of hazard parameters and key issues

Two groups were formed in order to identify relevant flood hazard parameters and key issues for the study region. A 'Stakeholder Reference Group' was formed by inviting stakeholders from government, non-governmental and industry sectors familiar with the region and its natural resource management issues. The main criteria used for selection of stakeholders were: interest in the topic, familiarity with regionally relevant issues and appropriate educational qualifications and/or work experience in relevant projects. The second group was formed by recruiting international water and coastal zone experts from six countries of the Asia-Pacific region. Members of this expert group had been working collaboratively on a project on coastal zones and climate change (Dutta, 2007).

Each of the two groups was engaged in brainstorming meetings in order to identify the most important flood inundation and water quality parameters (hazard parameters) associated with coastal zone flooding that could be simulated by the process-based model. In addition, the groups identified the key social, economic and environmental issues on which these hazard parameters could impact. The key issues were used to develop a set of criteria, indicators and appropriate response functions relating to various scenarios where the intensity of the flood hazard parameters varied due to climatic and anthropogenic changes in the study area. (Belfiore, 2003). Tables 1 and 2 show the flood inundation parameters (4), water quality parameters (3), and the key issues (22) identified for impact analysis, respectively.

Table 1: Flood inundation & water quality parameters to be modelled under climatic change conditions

Flood inundation parameters	Water quality parameters
Depth, Duration, Velocity, Frequency	Nutrients (TN, NO_2, NO_3, TP, PO_4), Salinity, Turbidity

3.2 Questionnaire design

A questionnaire was designed to gather information regarding stakeholders' views of the likely impacts of various levels of coastal inundation on key issues and assets in the study area. For the purpose of structuring the questionnaire, magnitudes of different flood inundation and water quality parameters were classified into three categories: low, medium and high. The stakeholder and expert groups were both consulted regarding the suitability of these categories, and a range of references were used to finalize realistic magnitude ranges for the flood inundation and water quality parameters within these three categories for coastal lakes and wetlands in Victoria (VGG, 1988; VGG, 1996; DEWR, 2007; EPA, 2007). These take account of generally accepted standards for aquaculture, wetland biodiversity, recreational activities, etc. Tables 3 & 4 show the magnitude ranges of different flood inundation and water quality parameters for the three categories.

Table 2: Key issues in coastal areas identified for climate change impact analysis

Key issues (with abbreviations)	
Infrastructure	*Drainage (Dr)*
	Roads (Rd)
	Railways (Rl)
	Ports & Harbours (Pt)
	Dykes (Dy)
	Coastal protection structure (Co)
	Landuse planning (LU)
Buildings	*Residential (RB)*
	Non-residential (NR)
Potable water (PW)	
Water quality (WQ)	
Erosion (Er)	
Tourism (To)	
Population	*Short-term displacement (SD)*
	Long-term resettlement (LD)
Agriculture (Ag)	
Fishery (Fi)	
Fish habitat/distribution (FH)	
Wetland health	*Extent (WEx)*
	Flora biodiversity - no. of veg. species (WFl)
	Fauna biodiversity - no. of bird species)(WFa)
Mangroves (Ma)	

Table 3: Flood inundation magnitude scale

Category	Depth (m)	Duration (days)	Velocity (m/sec)	Frequency (return period)
Low	<0.6	< 0.5	< 0.5	> 20 yrs
Medium	0.6-1.5	0.5-2	0.5 – 1	5-20 yrs
High	>1.5	>2	> 1	< 5 years

Table 4: Water quality magnitude scale

Category	TN (µg/L)	NO_2^- (µg/L)	NO_3^- (µg/L)	TP (µg/L)	PO_4^{3-} (µg/L)	Salinity (µ S/cm)	Turbidity (NTU)
Low	<350	<10	<10	<10	<5	< 30	< 5
Medium	350-750	10–50	10-50	10-30	5-10	30- 100	5-20
High	>750	>50	> 50	>30	>10	> 100	> 20

(*TN = Total nitrogen, NO_2=Nitrite, NO_3=Nitrate, TP=Total phosphorous, PO_4= Phosphate, Salinity: measure of concentration of total dissolved solids in water, µg/L: micrograms per litre, mg/L: milligrams per litre, µ S/cm: Micro siemens percentimetre, NTU: nephlometric turbidity units*)

The questionnaire was designed by the group of international experts in order to generate data describing stakeholders' assessments of the different impacts of the three categories of flood inundation and water quality parameters (as given in Table 1) on key social, economic and environmental issues (as given in Table 2). The data collected was used in the formation of synthetic response functions relating the level of flooding to the level of impact. The main purposes of the questionnaire were: to investigate which issues (assets) were of most concern to stakeholders; whether the intensity (high, medium or low) of flood parameters affects those issues of most concern; and to facilitate development of synthetic response functions

3.3 Administration of the Questionnaire

Stakeholder reference group participants provided anonymous responses to the questionnaire. In total, over 300 stakeholders were identified to participate in the survey. Questionnaires were distributed to the participants either by email or surface mail. In the latter case, a reply paid envelope was provided for return of the completed questionnaire. Other respondents chose to scan and return their questionnaires to the research team via email. The total number of completed questionnaires received was 33, a response rate of about 10%.

The questionnaire was lengthy and reasonably complex and required respondents to indicate their perceptions of the likely level of negative impact for each of the flood inundation and water quality parameters (Table 1) on each of the key issues (Table 2) for each of the three conditions (high, medium, low) (Tables 3 & 4). Respondents used an impact ranking score in the range 1-5 to indicate predictions regarding the extent of the impact in each case. The instructions within the questionnaire defined each of the ranking scores as per Table 5. The participants were explicitly given the option of not completing those sections of the questionnaire that were perceived as beyond their expertise.

Table 5: Impact ranking scores and their definitions as used in the questionnaire

Impact ranking score	Impact definition
1	No/little impact (0-5% damage)
2	Low Impact (5-25% damage)
3	Moderate impact (25-50% damage)
4	High impact (50-75% damage)
5	Extreme impact (75-100% damage)

3.4 Statistical Analysis of the questionnaires

A statistical method was designed to analyse the data obtained from the returned questionnaires and to create synthetic response functions. In relating the impact ranking score for a particular flood inundation or water quality parameter, x, on an individual key issue (such as drainage or agriculture), the impact ranking score (1-5 integer scale), y was analyzed, rather than its associated predicted percentage damage (Table 5). This was done in order to homogenize the spreads of response scores across the low, medium and high levels of magnitude of each parameter.

For any combination of parameter and issue, the number, s, of stakeholder survey responses ranged from 21 to 33, since 12 respondents did not complete the section of the questionnaire relating to the water quality parameters. Denoting the low, medium and high responses for the *i*th individual stakeholder by y_{Li}, y_{Mi} and y_{Hi} respectively,

$$b_i = \frac{y_{Hi} - y_{Li}}{2} \tag{1}$$

is the slope of the fitted least squares regression line (assuming equal spacing of the three parameter levels).

In the next step of the statistical analysis, responses of all stakeholders were combined for each hazard parameter. A 95% confidence interval for the underlying slope (CIs) was calculated as shown in equation (2).

$$CI_s = \bar{b} \pm t^* \times se(\bar{b}) \tag{2}$$

Here, $\bar{b}$ is the mean value of slope, $se(\bar{b})$ is the standard error of $\bar{b}$ and t* is the 97.5th percentile of the t distribution with (s-1) degrees of freedom.

The half-width of the above confidence interval was used as a numerical indicator (termed 'disparity') of the level of agreement among respondents, as well as assisting in developing an inference for the underlying impact.

The quadratic response function fitting the three points $(L, \bar{y}_L)$, $(M, \bar{y}_M)$ and $(H, \bar{y}_H)$ was determined for each combination of hazard parameter and issue as a basis for comparisons across issues.

3.5 Sensitivity Analysis

Relationships between the impact ranking scores for the effects of high, medium and low magnitudes for all combinations of flood hazard parameters and key issues were grouped into the following four classes (Figure 2):

Class 1: High sensitivity & High Agreement (or low disparity)
Class 2: High sensitivity & Low Agreement (or high disparity)
Class 3: Low sensitivity & High Agreement (or low disparity)
Class 4: Low sensitivity & Low Agreement (or high disparity)

The key issues that show high sensitivity to increasing magnitude for a particular hazard parameter (i.e., steep slope or high $\bar{b}$ value in Eq. 1) and for which there is high agreement among respondents (i.e., high correlation or narrow confidence interval for the slope CIs) are placed in Class 1. All the key issues in this class show a reasonably strong, linear relationship with increasing magnitude of the particular flood hazard parameters; and good agreement among stakeholder respondents about these relationships. Key issues in Class 2 appear to be sensitive to the increasing magnitude of the hazard parameters, the opinions of different stakeholders about these relationships are

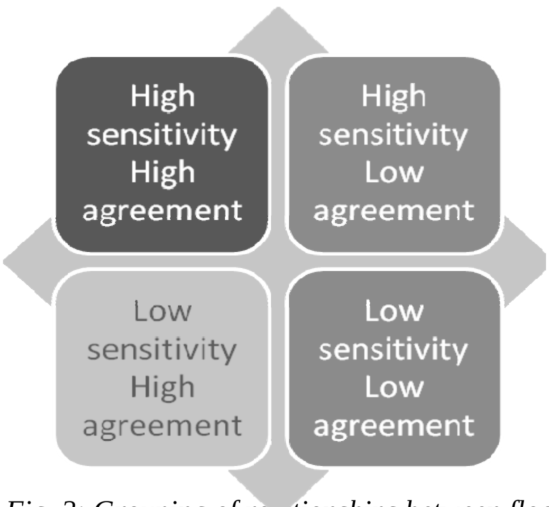

Fig. 2: Grouping of relationships between flood hazard parameters and important issues

varied. Class 3 includes key issues which stakeholders agree are not particularly affected by an increase in magnitude of the hazard parameters. The key issues in Class 4 also appear to be less sensitive to the hazard parameters, however, there are more widely varying perceptions among stakeholders about these relationships. The criterion used to define sensitive issues was $\bar{b} \geq 0.5$. The criterion used to define high agreement was a disparity measure of below 0.3. A disparity measure above or equal to 0.3 was considered to indicate low agreement.

4. RESULTS AND ANALYSIS

4.1 Prioritization of Issues

Table 6 displays the key issues in each of the four classes, for each hazard parameter.

Table 6: Categorisation of key issues for each hazard parameter

High sensitivity, high agreement (low disparity)		**High sensitivity, low agreement (high disparity)**	
Depth	SD, Ag, RB, Dr, Rd, NR, LU, LD, To, Co, Pt, WQ, Dy, Rl, PW, Ma	Depth	Fi, FH, WFl
Duration	Fi, Co, Pt, PW	Duration	Ag, Rd, Dr, SD, RB, LU, To, LD, WQ, NR, Er, Rl, Dy, Ma, FH, WFl
Velocity	-	Velocity	Ag, Rd, Er, Dr, Rl, Dy, Co, LU, Pt, Fi, RB, SD, NR, WQ, FH, Ma, LD, PW, To, WFl
Frequency	LD, Ag, RB, SD, NR, To, Rl, Pt, Co, Dy, PW	Frequency	LU, Rd, Er, WQ, Dr, FH
Nutrients	-	Nutrients	-
Salinity	PW, WQ, Ag, FH, Fi, WFl, WFa, WEx, LD, SD, RB, NR, To	Salinity	-
Turbidity	PW FH, WQ, Fi, WFa, WFl, To, WEx, Ma, LD	Turbidity	Ag, Dr, LU
Low sensitivity, high agreement (low disparity)		**Low sensitivity, low agreement (high disparity)**	
Depth	WFa	Depth	WEx
Duration	WFa	Duration	WEx
Velocity	WFa	Velocity	WEx
Frequency	**-**	Frequency	Fi, WFl, Ma, WEx, WFa
Nutrients	Er	Nutrients	NR, RB, LU, Rd, Dr, Co, Rl, To, WFl, WFa, WEx, WQ, PW, LD, SD, Ag, Ma, Fi, FH, Dy, Po
Salinity	Rd, Ma, LU, Po, Co, Dy, Er	Salinity	Dr, Rl
Turbidity	SD, Rd, Co, Dy, Er, RB, NR, Po, Rl	Turbidity	-

Class 1 (High sensitivity, high agreement) is of most interest since there is good agreement among stakeholders in terms of the impact of these hazard parameters on certain key issues; and these impacts are thought likely to increase with the magnitude of the hazard. The following hazard parameters had at least one issue in this class:

Depth: Stakeholders agree about the high sensitivity of many issues to flood depth (Table 6). Of these, the five most highly sensitive issues with high agreement (or low disparity) are: short term displacement (SD); agriculture (Ag); residential buildings (RB); drainage (Dr) and roads (Rd) as shown in Figure 3. Low disparity (or high agreement) among stakeholders about the high sensitivity of these issues indicates that these issues are the ones most likely to be affected by increasing flood depths, thus prioritising them for adaptive management strategies. It is assumed here that consensus among a relatively small group of stakeholders reflects reality.

Duration: According to at least some of the stakeholders who participated in the survey, many issues are quite highly sensitive to the hazard: flood duration, but not all respondents are in agreement about the effect of this hazard on the various issues. The key issues which were scored as most highly sensitive were: Agriculture (Ag), Roads (Rd), Drainage (Dr), short term displacement (SD) and residential buildings (RB), however there was poor agreement (disparity ≥0.3) among respondents about the effect of flood duration on all of these issues (Figure 4). It is apparent that careful consideration should be made in assigning cut-off values for agreement levels, since there is a risk of inappropriately discounting sensitive issues where agreement falls below the cut-off level. An alternative approach would be needed establish response functions for issues about which there is some disagreement about the degree of sensitivity and which managers wish to consider for impact analysis and adaptive measures.

Stakeholders did agree that Fisheries (Fi), Coast protection infrastructure (Co), Ports & Harbours (Pt) and Potable water (PW) were key issues with sensitivity to flood duration (Figure 4).

Velocity: The five key issues which scored as most highly sensitive to flood velocity were: Agriculture (Ag), Roads (Rd), Erosion (Er), Drainage (Dr), and Railways (Rl) (Figure 5). However, the disparity amongst stakeholders responding to the questionnaire was high for these five, and for 16 of the remaining 17 key issues. Good agreement was only apparent regarding a low perceived sensitivity of wetland fauna (WFa) to flood velocity (Figure 5). The low levels of agreement in the stakeholders' assessment of the impacts of flood velocity suggest that the effects of this hazard parameter are not well understood. More research is needed in order to be able to establish response functions for this hazard parameter.

Frequency; Many issues were regarded as quite highly sensitive to frequency and there was good agreement from stakeholders about most of these (Figure 6). Five of the most highly sensitive issues were: long term displacement (LD), agriculture (Ag), land use (LU), residential buildings (RB) and short term displacement (SD).

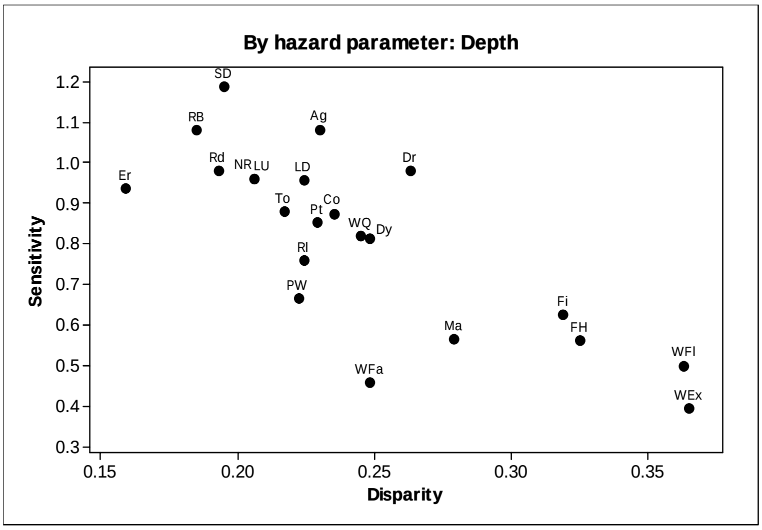

Fig. 3: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Depth

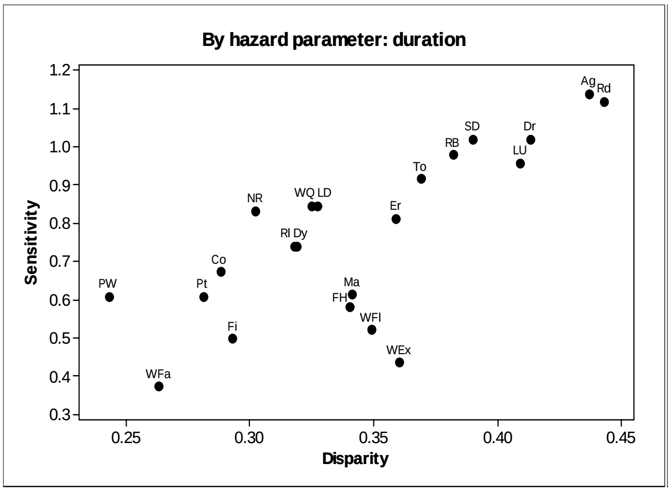

Fig. 4: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Duration

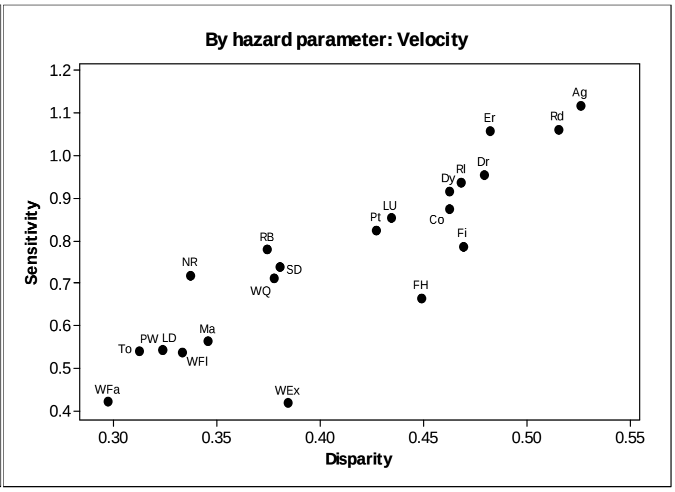

Fig. 5: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Velocity

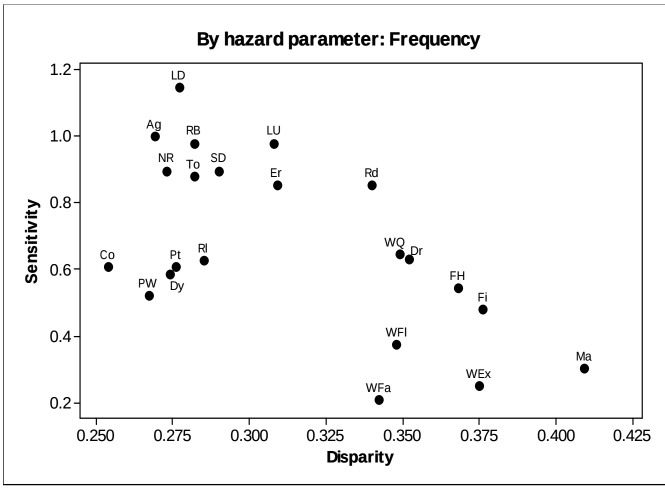

Fig. 6: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Frequency

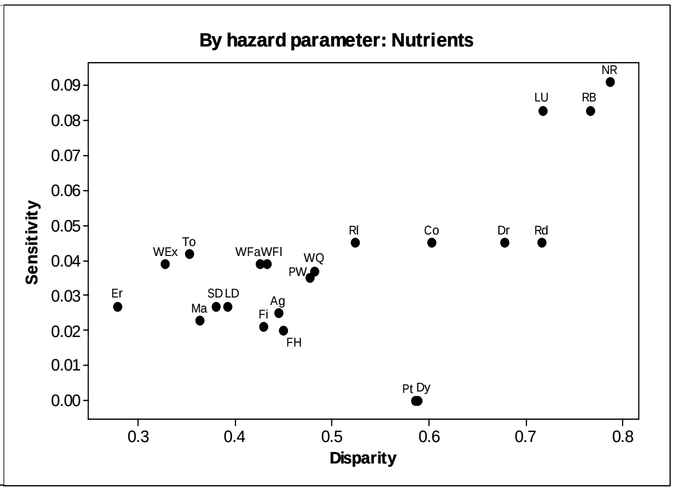

Fig. 7: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Nutrients

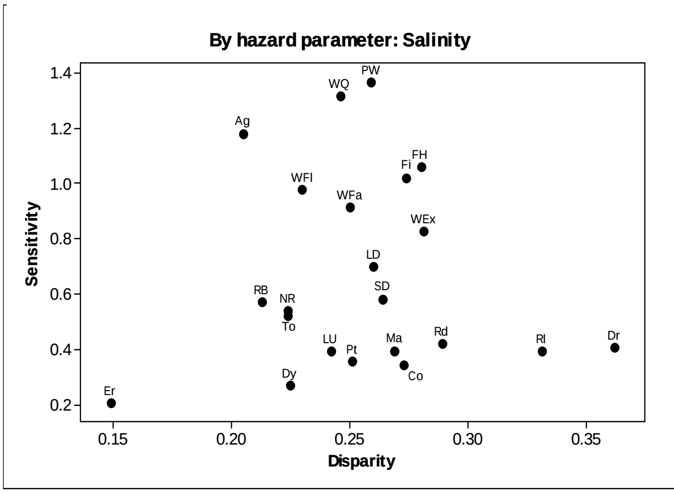

Fig. 8: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Salinity

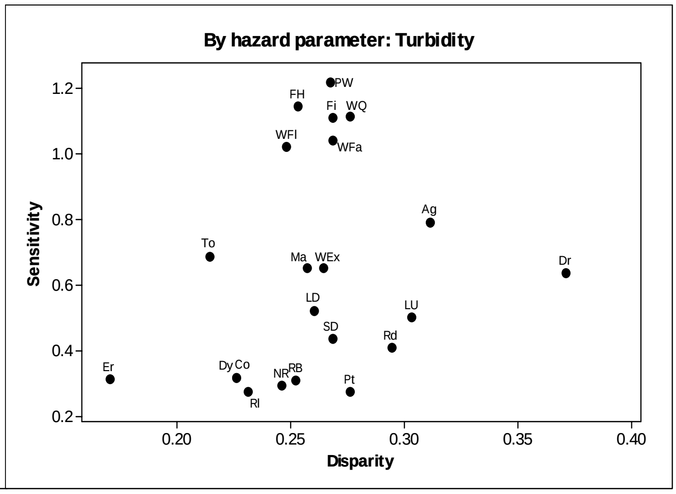

Fig. 9: Scatter plot showing the sensitivity and disparity of key issues for the hazard parameter: Turbidity

Nutrients: No issues were identified as highly sensitive to nutrients and disparity levels were high in almost all cases (Figure 7). Again, more research is needed in order to be able to establish response functions for this hazard parameter.

Salinity: Many issues were identified by stakeholders as quite highly sensitive to salinity and there was generally good agreement about this perception. Five of the most highly sensitive were: potable water (PW), Water quality (WQ), agriculture (Ag), fish habitat (FH) and fishery (Fi) (Figure 8).

Turbidity: Six issues considered to be most highly sensitive to turbidity were: potable water (PW), fish habitat (FH), Water quality (WQ), fishery (Fi), fauna biodiversity (WFa) and flora biodiversity (WFl). There was good agreement among stakeholders regarding the likely effect of turbidity on these issues (Figure 9).

4.2 Response functions

A response function represents the impact of a hazard parameter on a particular issue. In this study, response functions were synthesised only for relationships between hazard parameters and issues classified in class 1 (high agreement, high sensitivity). The response functions were established as described in Section 3.4. In all cases, the fitted function was denoted by:

$$y = a + bx + cx^2 \tag{3}$$

where, y: predicted impact in % to the particular issues, x: defined magnitude of a hazard parameter (coded -1, 0, 1 respectively for Low, Medium and High categories) and a, b and c are the coefficients.

Each response function predicts the impact of a particular hazard parameter on a particular issue. Predicted mean impact ranking scores were converted to predicted mean percentage impacts based on the ranges given in Table 5. The values of the three coefficients (a, b and c) for the various response functions are presented in Tables 7 & 8 for flood inundation and water quality parameters, respectively.

The outcomes from the statistical analysis have revealed the strong views of stakeholders on the importance of some issues (Class 1) for adaptive measures and no clear agreements on some other issues (Classes 2 and 4). Further, there are clearly some issues (Class 3) about which stakeholders agree there is no need for concern. The approach was beneficial as:
Synthetic response functions can be generated in the absence of data from previous flood events. The use of synthetic response functions is therefore particularly useful where high quality, reliable physical data on past flood impacts have not been collected or are difficult to obtain.

The synthetic response functions quantitatively summarise stakeholder opinions about the likely impact of flood hazards on key issues. Key issues of concern for the region were identified along with issues where understanding appears to be limited and where more research may be needed. The outcomes of this methodology could be incorporated into broader investigations of disaster impacts (Dutta et al., 2003), although this is not pursued here.

A limitation of the approach is that response functions can only be generated for issues of which stakeholders are aware. This method is not useful for identifying ‘sleeper’ issues. A particular limitation of this study is that, although considerable effort was made to identify a large number of stakeholders in the region, only 10% of those approached responded to the questionnaire. A greater response may have been achieved if the questionnaire had been designed to be more accessible. It was a lengthy, complex instrument and required a considerable time investment to complete. It is acknowledged that the impact response functions would be better estimated on the basis of a larger stakeholder sample.

Table 7: Established impact response functions for flood inundation parameters vs. issues

Issues	Coefficients of impact response functions								
	Depth			Duration			Frequency		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Dr	2.52	0.98	-0.04	-	-	-	-	-	-
Rd	2.84	0.98	-0.12	-	-	-	-	-	-
Rl	2.44	0.76	0.16	-	-	-	2.17	0.63	0.25
Pt	2.25	0.85	-0.04	1.83	0.61	0.17	1.96	0.61	0.35
Dy	2.08	0.81	0.38	-	-	-			
Co	2.21	0.88	0.25	1.83	0.67	0.39	1.96	0.61	0.43
LU	2.76	0.96	0.08	-	-	-	-	-	-
RB	3.08	1.08	0.32	-	-	-	2.92	0.98	0.13
NR	2.96	0.96	0.24	-	-	-	2.67	0.9	0.21
PW	2.71	0.67	-0.08	2.61	0.61	0.09	2.43	0.52	0.26
WQ	2.72	0.82	0.04	-	-	-			
To	2.8	0.88	0.16	-	-	-	2.52	0.88	0.32
SD	2.83	1.19	-0.04	-	-	-	2.42	0.9	0.21
LD	2.29	0.96	0	-	-	-	2.79	1.15	0.04
Ag	2.75	1.08	-0.25	-	-	-	2.36	1	0.08
Fi	-	-	-	1.76	0.5	-0.04	-	-	-
Ma	1.35	0.57	-0.17	-	-	-	-	-	-

Table 8: Established impact response functions for water quality parameters vs. issues

Issues	Coefficients of impact response functions					
	Salinity			Turbidity		
	a	*b*	*c*	*a*	*b*	*c*
RB	1.29	0.57	0.29	-	-	-
NR	1.08	0.54	0.46	-	-	-
PW	2.65	1.37	-0.12	2.76	1.22	-0.28
WQ	2.7	1.31	-0.04	2.88	1.12	-0.38
To	1.5	0.52	-0.04	1.79	0.69	0.04
SD	1.46	0.58	0.17	-	-	-
LD	1.64	0.7	0.04	1.39	0.52	0.17
Ag	2.44	1.18	0.04	-	-	-
Fi	2.17	1.02	0.21	2.26	1.11	0.3
FH	2.12	1.06	0.28	2.25	1.15	0.21
WEx	1.78	0.83	0.43	1.65	0.65	0.17
WFl	2.04	0.98	0.3	1.91	1.02	0.13
WFa	1.91	0.91	0.17	1.91	1.04	0.26
Ma	-	-	-	1.48	0.65	0.17

5. CONCLUSIONS

The paper has presented a systematic approach by which relevant stakeholders can be actively engaged in prioritising flood impact issues and collating information for quantification of impacts for adaptation measures, and has demonstrated the approach through successful implementation in the

Gippsland Coastal region. As an outcome of the project, we identified key issues of concern for this region for flood impacts and the synthetic response functions for some of these key issues (with high agreement) for quantification of impacts of floods on these key issues in the region. The analysis also showed that some of the issues are considered not to be significantly affected by floods (Class 4) and thus may not require adaptation measures. The outcomes of the analysis did not provide high agreement for issues under Classes 3 and 4. Different approaches would be required to determine the importance of these issues and to establish response functions for these for various relevant hazard parameters.

Synthetic response functions as developed in this study can be used to quantify the likely impacts of flood hazards of various magnitudes. This allows natural resource managers and decision makers to better understand the risks associated with sea level rise and to prioritise adaptive management strategies for the region. Although not demonstrated in this study, a further application of the response functions may be to use them in order to analyse the effectiveness of proposed adaptive measures.

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FLOOD VULNERABILITY ANALYSIS IN COASTAL ZONES: A COMPARATIVE ANALYSIS ACROSS FIVE ASIA-PACIFIC COUNTRIES

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ABSTRACT

There is increasing concern that the current management practices for many coastal regions are unsustainable. Very few countries have planned to deal with the exacerbation of problems of environmental decline in the face of climate change leading to more serious flood events caused by sea level rise, severe storms, tidal waves, etc.. It is therefore necessary to assess socio-economic and environmental impacts of floods to better understand the vulnerability of the coastal zones, as part of devising adaptive and integrated management principles. The paper presents a systematic approach in which relevant stakeholders in five Asia-Pacific countries were actively engaged in identifying and prioritising flood impact issues. Key issues of concern for flood impacts for coastal areas in Australia, Japan, Sri Lanka, Thailand and Vietnam are compared.

1. INTRODUCTION

Coastal areas are one of the most important regions from social, economic and environmental viewpoints. They are home to a large and growing proportion of the world's population. They include important ecosystems such as coastal floodplains, mangrove forests, marshes and tideflats, as well as beaches, dunes, and coral reefs (Costanza *et al.*, 1997). The coastal zone is also important for marine fisheries because the bulk of the world's marine fish harvest is caught or reared in coastal waters (Wilkinson, 2000). Coastal areas help prevent erosion; filter pollutants; and provide food, shelter, breeding areas and nursery grounds for a wide variety of organisms. Coastal regions also provide critical inputs for industry, including water and space for shipping and ports; opportunities for recreational activities such as fishing and diving; and other raw materials, including salt and sand.

Coastal regions are undergoing environmental decline due to the large growth of human populations, rapid urban and industrial development, overexploitation of natural resources and poor management. By 2025, it is expected that around 75% of the world's human population will live within 200 km of a coastline (Creel, 2003). There is an increasing concern that the current management practices are unsustainable. Of particular concern are low-lying areas, which are also affected by sea water intrusion. The Intergovernmental Panel on Climate Change predicts that global mean sea level may rise as much as 88 cm by the end of the 21st century (IPCC, 2001). Several coastal zones are facing severe socio-economic and environmental problems due to their lower elevation. Very few countries have planned to deal with the exacerbation of these problems in the face of sea level rise.

This project involves a vulnerability analysis for selected key coastal zones in the five countries: Australia, Japan, Sri Lanka, Thailand and Vietnam. The vulnerability analysis required the identification of relevant flood hazard parameters and key issues for the study region; and the synthesis of impact responses using expert and stakeholder opinion. The outcomes of the vulnerability analysis are potentially useful as a basis for the development of adaptation measures for the region.

The project required the engagement of experts and key stakeholders of the five selected regions in order to identify and prioritize the key issues. A significant outcome of the project is an insight into how stakeholders' knowledge and expertise (at regional and local levels) might be utilized for establishing such response functions for quantification of the likely impacts of climate change in coastal regions. This paper presents a comparative analysis of the results of vulnerability studies in the five selected countries to identify similarities and differences in the outcomes.

2. STUDY AREAS

The following five coastal areas were selected from five participating countries in the Asia Pacific region. The geographic locations of these study sites are shown in Fig. 1.

1) Gippsland Coastal Region, Australia : The Gippsland coast is home to thousands of people who live in or near one of the many coastal towns and settlements located between San Remo on the eastern extent of Western Port Bay and Mallacoota near the New South Wales border. Away from these built up areas, the Gippsland coast remains in a largely natural state, being characterized by diverse natural and cultural values, and including important habitat for a range of fauna species protected by National Parks, reserves and public foreshore land (GCB, 2008). The coast includes the Gippsland Lakes System which is a series of coastal lagoons – large areas of shallow water that have been almost wholly sealed off from the sea by a coastal dune system.

Fig. 1: Locations of the study areas in 5 countries

2) Kushiro Coastal Region, Japan: Kushiro wetland located on the eastern side of Hokkaido is the largest wetland in Japan registered by the Ramsar treaty and the coastal area is highly developed for industrial purposes. The main river flowing through Kushiro wetland is Kushiro River whose length is 154 km and the river basin area is 2510 km^2.The incline of the Kushiro wetland area is relatively gentle. The human population in this highly developed coastal area is about 230,000. In recent years, changes in water circulation and mass transport have been considered problems which damage the ecological systems of the wetland.There is significant potential for damage in the Kushiro coastal region from disastrous storm surges or flood events.

3) Colombo, Sri Lanka: Climate change has clearly affected the weather pattern of Sri Lanka and this is evident in the climatological measurements of the last 3 - 4 decades. Overall rainfall has not shown a significant change in most parts of the country while some other indicators such as the length of rainy spells and average rainfall per spell have clearly changed; and studies show that the rainfall intensity has increased (Herath and Ratnayake, *2004*; Ratnayake and Herath, 2004). More frequent rainfall induced disasters such as landslides and floods in the recent past can be attributed to this increase in intensity of rainfall (Padma Kumara *et al. 2005*). Colombo, the capital city and financial hub of Sri Lanka, is one of the major coastal cities adversely affected by the floods. Colombo received two occurrences of its record highest rainfalls in the last two decades. Such frequent extreme events have focused the attention of the public and have forced the authorities to attempt mitigating works. Several drawbacks of the current management system have been identified and among the technical aspects the inadequate capacities of the drainage networks, loss of flood retention spaces and poor management is highlighted. The Colombo floods result in heavy economic losses, mainly due to two factors. The poor existing drainage facilities with inadequate drainage capacities are the main reason for floods when heavy rains occur in the city area. The other factor is the overflowing of the Kelani River which flows through the northern parts of the city.

4) Bangkok and Gulf of Thailand: Bangkok, the capital city of Thailand, with latitude 13° 45' N and longitude 100° 31' E, is one of the larger cities in Asia and is a regional hub. It is located on the lower flat basin of the Chao Phraya River, the largest and most important river in Thailand which has a drainage area of 160,103 km^2 and an annual suspended sediment discharge of 11×10^6 tons (Milliman *et al.*, 1995). It originates in the northern most part of Thailand and discharges to the Gulf of Thailand after flowing approximately 1,200 km. The average annual discharge is about 770 m^3/s with a peak of 4,560 m^3/s recorded in 1995 (Thammasittirong, 1999). The coastal environment of the Chao Phraya delta is classified as low-energy micro-tidal. Somboon (1992) showed that the shoreline has migrated about 90 to 100 km southward from the center of the central plain in Thailand over the last 6000 years, which corresponds to a migration rate of about 15 m yr^{-1}. Bangkok has a hot and humid tropical climate; the hottest month is April with average maximum temperatures of 35°C and average minimum of 26°C, while December is the coolest month with average maximum temperatures of 31°C and average minimum of 21°C. The rainy season spans May to October, and the average annual rainfall in Bangkok is 1500 mm. Floods, mainly caused by upstream inflow and high intensity rainfalls, are the most frequent natural disasters in Bangkok. They affect a large number of people and cause huge economic damage almost every year. Due to its low elevations, ranging from 0 m to 4 m above mean sea level, tidal effect is prominent in the Chao Phraya river up to several kilometers inside Bangkok and that contributes significantly to floods (Engkagul, 1993). There are usually two high and two low tides per day in the Gulf of Thailand, but these are often asymmetrical with amplitude of 1-2 m. The daily variation of tides is normally from -0.5 m to 1.5 m with a peak of 2.5 m recorded in 1995. For Bangkok, the steady rise in sea level poses a threat for the investment, operation and safety levels of the flood-control system, which could have an estimated annual pumping cost of up to US$20 million (Sabhasri and Suwarnarat, 1996). The Fourth Assessment Report of IPPC (IPCC-AR4) has highlighted the grave consequences of sea level rise including catastrophic floods to several low-lying coastal cities around the world including Bangkok (IPCC, 2007).

5) Nam Din Coast, Vietnam: Nam Dinh coast is one of the most populated coasts in Vietnam. It has the most fertile soil in Vietnam, very suitable for rice cultivation. The coast is suitable also for other marine related economic activities such as salt production, fishing, shrimp and fish farming etc. Additionally, the area is located near Hanoi, the Capital City of Vietnam and some of its beaches have become recreation sites for Nam Dinh and Hanoi City dwellers. The Nam Dinh coast has been formed by the deposition of sediment from the Red River with its four branches, the main river, the Ninh Co River, the Day River and the So River. The sediment from the river consists mainly of silt and fine sand. Thus, near the river mouth, deposition of silt and fine sand has enabled the development of mangrove forests. There are very wide mangrove forests, such as the Giao Thuy and the Nghia Hung mangrove forests. There are several distinct ecological systems in the area such as the marine ecological system, the mangrove forest ecological system and the estuarine ecological system. Thus, the coast is ecologically very diverse. Recently, with economic development, a port was constructed in the Ninh Co River estuary. Industrial developments, such as ship building and thermal power generation are proceeding. At present, the coast is facing serious environmental problems, the first being accelerating erosion. At the place with most serious erosion, the coast has retreated about 2km. forcing many local people to relocate inland. This is a densely populated area with extensive economic activity, and the natural hazard causes large economic losses.

3. METHODOLOGY

A systematic approach was taken to develop a standardized methodology which was applied in the five selected regions across five countries. The methodology has been elaborated elsewhere (see Dutta *et al.*, 2010 “Use of Synthetic Impact Response Functions for the analysis of vulnerability to flood damage in Gippsland Coastal Zones" in these proceedings). The major steps involved in the methodology were:

- Selection of experts and stakeholders
- Identification of hazard parameters and key issues
- Questionnaire design
- Administration of the Questionnaire
- Statistical Analysis of the questionnaires
- Sensitivity Analysis

As elaborated in Dutta *et al.*, 2010, two groups ('Stakeholder Reference Group' and 'International Expert Group') were formed in order to identify relevant flood hazard parameters and key issues for the study areas and their feedback was used to identify the most important flood inundation and water quality parameters (hazard parameters) associated with coastal zone flooding and the key social, economic and environmental issues on which these hazard parameters could impact. The key issues were used to develop a set of criteria, indicators and appropriate response functions relating to various scenarios where the intensity of the flood hazard parameters varied due to climatic and anthropogenic changes in the study areas. Tables 1 and 2 show the flood inundation parameters (4), water quality parameters (3), and key issues (22) identified for impact analysis, respectively.

Table 1: Flood inundation & water quality parameters to be modelled under climatic change conditions

Flood inundation parameters	**Water quality parameters**
Depth, Duration, Velocity, Frequency	Nutrients (TN, NO_2, NO_3, TP, PO_4), Salinity, Turbidity

Table 2: Key issues in coastal areas identified for climate change impact analysis

Key issues (with abbreviations)	
Infrastructure	*Drainage (Dr)*
	Roads (Rd)
	Railways (Rl)
	Ports & Harbours (Pt)
	Dykes (Dy)
	Coastal protection structure (Co)
	Landuse planning (LU)
Buildings	*Residential (RB)*
	Non-residential (NR)
Potable water (PW)	
Water quality (WQ)	
Erosion (Er)	
Tourism (To)	
Population	*Short-term displacement (SD)*
	Long-term resettlement (LD)
Agriculture (Ag)	
Fishery (Fi)	
Fish habitat/distribution (FH)	
Wetland health	*Extent (WEx)*
	Flora biodiversity - no. of veg. species (WFl)
	Fauna biodiversity - no. of bird species)(WFa)
Mangroves (Ma)	

A questionnaire was designed to gather information regarding stakeholders' views of the likely impacts of various levels of flood severity on key issues and assets in the study area. For the purpose of structuring the questionnaire, magnitudes of different flood inundation and water quality parameters were classified into three categories: low, medium and high. The stakeholder and expert groups were both consulted regarding the suitability of these categories, and a range of references were consulted to finalize realistic magnitude ranges for the flood inundation and water quality parameters within these three categories for coastal zones. The questions comprising the questionnaire were designed by the group of international experts in order to generate data describing stakeholders' assessments of the differing impacts of the three categories of flood inundation and water quality parameters (as given in Table 1) on key social, economic and environmental issues (as given in Table 2).

The questionnaire was administered independently in each case study area by the country project leader of the on-going collaborative project sponsored by APN (Dutta, 2007). A similar approach was followed in Australia, Japan, Vietnam and Thailand in administering the questionnaire. The questionnaires were sent out to stakeholders familiar with the study areas either by email or surface mail and anonymous responses to surveys were received from the respondents. However, in Sri Lanka, stakeholders were invited to participate at a seminar and the questionnaire was distributed to all the participants at the seminar. All the participants then completed their questionnaire on-site.

The questionnaire was lengthy and reasonably complex and required respondents to indicate their perceptions of the likely level of negative impact for each of the flood inundation and water quality parameters (Table 1) on each of the key issues (Table 2) for each of the three conditions (high, medium, low). Respondents used an impact ranking score in the range 1-5 to indicate predictions regarding the extent of the impact in each case. The instructions within the questionnaire defined each of the ranking scores as per Table 3. The participants were explicitly given the option of not completing those sections of the questionnaire that were perceived as beyond their expertise. The number of responses received from stakeholders varied from country to country (Table 4).

Table 3: Impact ranking scores and their definitions as used in the questionnaire

Impact ranking score	Impact definition
1	No/little impact (0-5% damage)
2	Low Impact (5-25% damage)
3	Moderate impact (25-50% damage)
4	High impact (50-75% damage)
5	Extreme impact (75-100% damage)

Table 4: Number of responses to questionnaire survey in different countries

Country	Australia	Japan	Sri Lanka	Thailand	Vietnam
Number of responses	33	35	50	34	50

A statistical approach was designed to analyse the data obtained from the returned questionnaires from all five countries. In relating the impact ranking score for a particular flood inundation or water quality parameter, x, on an individual key issue (such as drainage or agriculture), the impact ranking score (1-5 integer scale), y was analyzed, rather than its associated predicted percentage damage (Table 3). This was done in order to homogenize the spreads of response scores across the low, medium and high levels of magnitude of each parameter. For each issue x and hazard parameter y, the Sensitivity is a measure of the impact on y of increasing x, averaged across all stakeholders' assessments, and the Disparity is a measure of the variation among individual assessments. The approach has been explained in Dutta *et al.,* 2010.

4. RESULTS AND DISCUSSION

4.1 Similarity and Differences

Figure 2 presents the scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) for different hazard parameters against the 22 issues for five countries. Overall, the patterns among different countries are broadly comparable for the various individual hazard parameters, except for Sri Lanka.

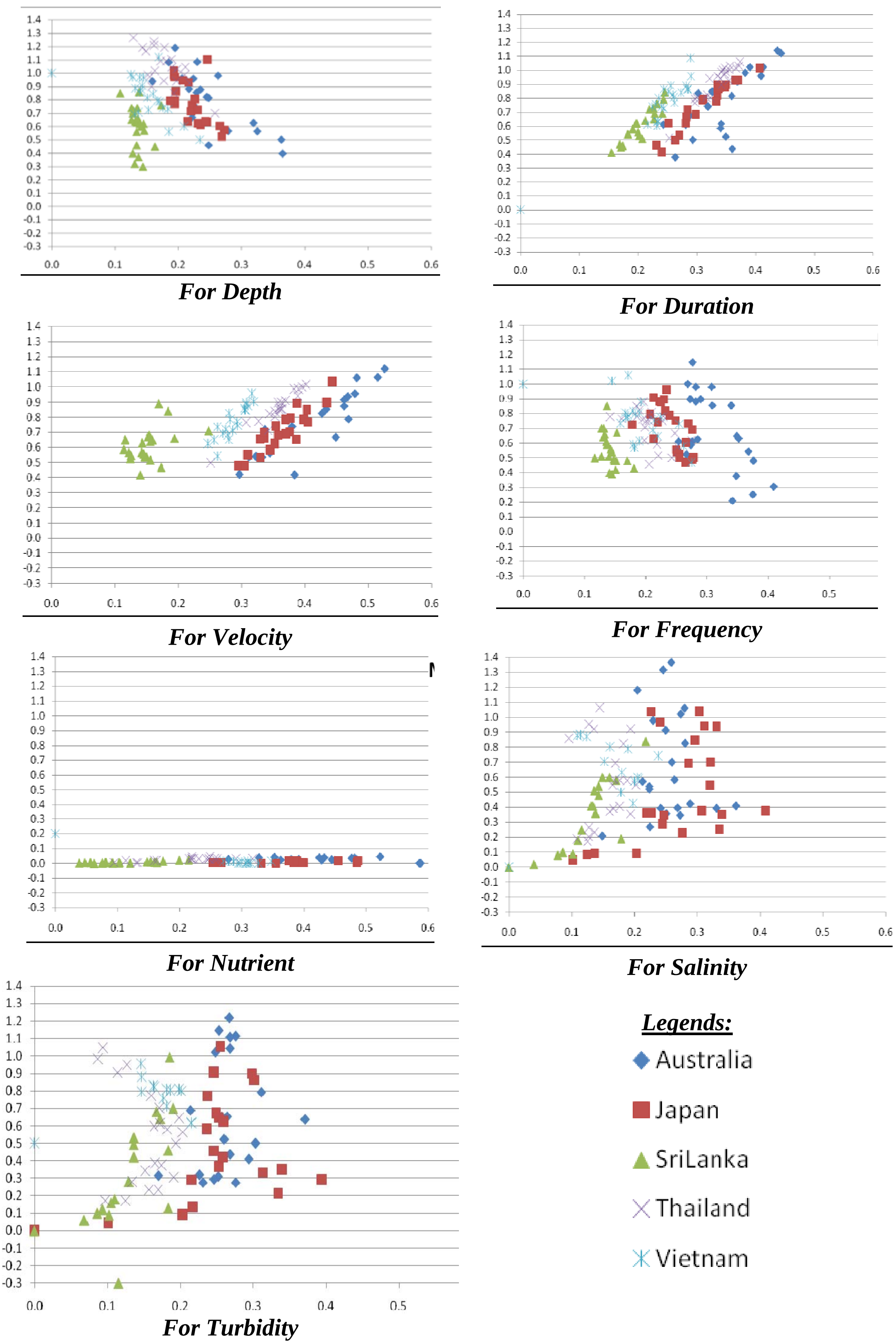

Fig. 2: Scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) of all 22 issues for 4 inundation and 3 water quality parameters for five countries

For the SriLankan data, disparity was low for all issues and hazard parameters. For the inundation parameter "Depth", different issues showed similar trends for Japan and Thailand. For Vietnam, more issues showed high sensitivity compared to other countries. For Australia and Sri Lanka, more issues were less sensitive to "Depth" than for the other three countries. The trend was similar for all countries for "Duration" with higher disparity for Australia for more issues than other countries. Similarly, for "Velocity" and "Frequency", disparity was higher for Australia compared to other countries. In the case of Australia, more issues were less sensitive to "Frequency" than other four countries. For water quality parameters, no issue showed any sensitivity to "Nutrient" for any countries. For Salinity, trend was similar for Thailand, Vietnam and for Japan and Australia. For Turbidity, again trends were similar for Japan and Australia. More issues show higher sensitivity against Turbidity for Vietnam. The agreement was higher for Vietnam and Thailand, compared to Japan and Australia for Turbidity.

These relationships show that in different countries, stakeholders had different perceptions of impacts of flood inundation on various issues. For some issues, there were high levels of agreement compared to other issues. The low disparity for the Sri Lankan data was probably due to the way the questionnaire was administrated, which reflected more of collective, rather than individual, opinion of the stakeholders.

4.2 Classification of relationships between impact ranking and key issues

Relationships between the impact ranking scores for the effects of high, medium and low magnitudes for all combinations of flood hazard parameters and key issues were grouped into the following four classes as explained in Dutta et al., 2010.

Class 1: High sensitivity and High Agreement (or low disparity)
Class 2: High sensitivity and Low Agreement (or high disparity)
Class 3: Low sensitivity and High Agreement (or low disparity)
Class 4: Low sensitivity and Low Agreement (or high disparity)

The key issues that show high sensitivity to increasing magnitude for a particular hazard parameter and for which there is high agreement among respondents (i.e., high correlation or narrow confidence interval for the slope CIs) were placed in Class 1. All the key issues in this class show a reasonably strong, monotonic relationship with increasing magnitude of the particular flood hazard parameters; and good agreement among stakeholder respondents about these relationships. Key issues in Class 2 appear to be sensitive to the increasing magnitude of the hazard parameters, but the opinions of different stakeholders about these relationships are varied. Class 3 includes key issues which stakeholders agree are not particularly affected by an increase in magnitude of the hazard parameters. The key issues in Class 4 also appear to be less sensitive to the hazard parameters, however, there are more widely varying perceptions among stakeholders about these relationships.

Table 5 shows the Class 1 issues for different inundation and water quality parameters for five countries. It shows that Depth is considered to be highly sensitive to most of the issues and stakeholders across all countries had high agreement. Australia and Japan had similar issues showing high sensitivity and agreement. Thailand and Vietnam shared more similarity in terms of issues identified. Vietnam showed highest number issues with high sensitivity and high agreement than other countries.

The results show that stakeholders do not prioritise issues and/or hazards for adaptation and mitigation measures similarly across all countries. It is therefore important to take into account the different priorities of stakeholders in different countries.

Table 5: Issues that showed high sensitivity with high agreements for flood inundation and water quality parameters for five countries

Issues	Australia	Japan	Sri-Lanka	Thailand	Vietnam
Drainage	Dep	Dep, Frq	Dep, Vel, Frq, Dur, Sal	Dep,Frq	Dep, Dur, Frq
Roads	Dep	Frq, Dep	Dep, Dur, Frq, Vel	Dep,Frq	Dep, Dur, Frq
Railways	Dep, Frq	Frq, Dep	Dur, Dep, Vel, Frq	Dep,Frq	Dep, Vel, Frq, Tur
Ports	Dep, Dur, Frq	Dep, Dur, Frq	Dep, Frq, Dur, Vel	Dep,Frq	Dep, Dur, Frq
Dykes	Dep, Frq	Dep, Frq	Vel, Dur	Dep,Dur, Frq	Dep, Dur, Frq
Coast	Dep, Dur, Frq	Dep, Frq	Dur	Dep,Dur, Frq	Dep, Dur, Vel, Frq
Landuse	Dep	Frq, Dep	Vel, Dep, Dur, Frq	Dep,Frq, Sal,Tur	Dep, Dur, Vel, Frq
Residential buildings	Dep, Frq, Sal	Dep, Frq	Frq, Dur, Dep, Vel	Dep, Frq	Dep, Dur, Frq
Non-residential buildings	Dep Frq, Sal	Dep, Frq, Dur	Dur, Dep, Vel, Frq	Dep, Frq	Dep, Dur, Frq
Potable Water	Sal, Tur, Dep, Dur, Frq	Sal, Turb, Dur, Dep, Frq	Vel, Dur	Sal, Tur, Dep, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Water quality	Sal, Tur, Dep,	Tur, Sal, Frq, Dep	-	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Erosion	Dep	Dep, Frq	Vel, Dur	Dep, Frq	Dep, Dur, Frq, Tur, Sal
Tourism	Frq, Dep, Tur, Sal	Frq, Dep, Tur	Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur
Short term displacement	Dep, Frq, Sal	Dep, Frq	Frq, Dr, Dep, Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Long term displacement	Frq, Dep, Sal, Tur	Frq, Dep	Vel, Dur, Frq, Dep	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Agriculture	Sal, Dep, Frq	Frq, Dep, Tur	Dur, Sal, Tur, Vel, Frq, Dep	Dep, Sal, Frq, Tur	Dep, Dur, Vel, Frq, Tur, Nut
Fisheries	Tur, Sal, Dur	Tur, Frq, Dep	Dep, Frq, Tur, Vel, Sal	Dep, Tur, Sal, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal
Fish habitat	Tur, Sal	Dur, Dep, Frq	Dep, Vel, Dur	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Wetland extent	Sal, Tur	Dep, Dur, Tur, Frq	Dep, Dur, Vel, Frq	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Flora *diversity*	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Dep, Sal, Dur, Frq, Vel	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Nut
Fauna *diversity*	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Vel, Dep, Sal, Frq, Dur	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Mangroves	Tur, Dep	Dep, Frq	Tur, Dur, Sal, Dep, Vel	Dep, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal

4.3 Pairwise correlations between sensitivities

In order to compare the impact assessments across the five countries, the product-moment correlations between the sensitivity scores across the 22 key issues for each pair of countries and for each of the 7 hazard parameters were calculated; refer Table 6. A high positive correlation indicates a broadly similar perception across two country panels of the relative rankings of key issues in terms of how dramatically they are impacted by changes in the level of the relevant hazard parameter. Thus, in terms of the impact of increased flood depth on the range of key issues, the relative rankings are fairly consistent across Australia, Japan and Thailand, but more disparate across Sri Lanka and Vietnam and each of those sites with the first three. It is acknowledged that these patterns may be influenced by the selections of the panels or by the protocols used to obtain their survey responses. Overall, however, it would appear that there are some considerable differences between the perceptions at the various country sites of which key issues are most sensitive to changes in levels of the various hazard parameters.

Table 6: Pairwise correlations between sensitivities

Hazard parameters	**Countries**	Aust	Japan	Sri Lanka	Thailand	Vietnam
DEPTH	Aust		0.722	0.068	0.761	0.588
	Japan			0.288	0.740	0.545
	SriLanka				0.314	0.058
	Thailand					0.448
DURATION	Aust		0.732	0.609	0.670	0.434
	Japan			0.200	0.773	0.262
	SriLanka				0.409	0.103
	Thailand					0.224
VELOCITY	Aust		0.539	0.308	0.503	0.400
	Japan			0.600	0.353	0.133
	SriLanka				0.255	-0.058
	Thailand					0.238
FREQUENCY	Aust		0.793	0.296	0.558	0.053
	Japan			0.279	0.508	0.338
	SriLanka				0.377	0.374
	Thailand					0.223
NUTRIENTS	Aust		-0.096	-0.005	0.087	0.448
	Japan			0.027	-0.038	0.064
	SriLanka				0.283	-0.161
	Thailand					-0.636
SALINITY	Aust		0.916	0.428	0.936	0.702
	Japan			0.617	0.935	0.744
	SriLanka				0.449	0.308
	Thailand					0.781
TURBIDITY	Aust		0.939	0.464	0.915	0.635
	Japan			0.435	0.950	0.718
	SriLanka				0.386	-0.101
	Thailand					0.746

CONCLUSIONS

The paper has presented the outcome of a comparative analysis of outcomes of five case studies conducted in five countries to identify and prioritise flood impact issues through engagement of stakeholders towards adaptation and mitigation measures in coastal zones in Asia-Pacific region.

It is clear that stakeholders in different countries prioritise the flood impact issues differently, although there are similarities between priorities in Australia and Japan, and to a lesser extent Thailand.

Differences in methodology may explain a very different response in Sri Lanka, but Vietnamese and SriLankan stakeholders responded differently in their priorities.

Further research is needed if it is deemed desirable to develop a common methodology to flood vulnerability assessment across multiple coastal sites in different countries. Further research to look into the reasons behind similarities and differences in stakeholders responses in the selected countries would provide insight for development of common methodology.

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COMMUNITY ENGAGEMENT IN ANALYZING THEIR LIVELIHOOD RESILIENCE TO CLIMATE CHANGE INDUCED SALINITY INTRUSION IN SUNDARBANS MANGROVE FOREST

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ABSTRACT

The world heritage site 'Sundarbans mangrove forest' in the south-western part of Bangladesh is not only a biogenic coast rich in biodiversity but it also provides buffer for lives and livelihood opportunities to 3.5 million people living in its adjacent areas. Around 1.4 million people directly depend on the Sundarbans for their livelihoods that makes the Sundarbans a unique example of human-environment inter-relationship. Wood cutter (Bawali), honey collector (Mawali), fisher (jele), fuelwood collector, and snail and oyster collector are the major livelihood groups directly dependent on Sundarbans. Sundarbans is highly vulnerable to expected climate change and the climate change induced salinity intrusion is being observed distinctly. Coupled with the poverty, the changing status of the Mangrove ecosystem makes the livelihood dependent on it more vulnerable. Adaptive governance and engagement of the community in policy research and strategy formulation is still awaited to practice. This study is aimed to analyze the livelihood resilience of the Sundarbans dependent community to climate change induced salinity intrusion with iterative engagement of the community in the research process. The resilience analysis of livelihood groups offers elements of adaptive strategy to the policy makers for mitigating the vulnerabilities.

The overall study has been conducted through participatory approach, based on capital based sustainable livelihood assessment (SLA) method. Each stage of the research process (hazard analysis, resilience analysis) has been done with community participation through shared learning dialogue (SLD) that provided iterative transfer of information, knowledge and experience between community and researcher. The SLD provided opportunity of refining and verification of the research concept and process with the community engagement through series of iterative learning meeting with livelihood groups dependent on the Sundarbans mangrove forest. A capital based indicator framework was followed for resilience analysis. The indicator framework was made operational by developing word scenarios for each of the indicators that was outlined best case to worst case. Weighing of indicators, development of word scenarios for each indicator and the employment of the indicator framework were done through SLD. SLD provided base of analyzing the contribution of each livelihood capitals (natural, financial, physical, social and human) to livelihood resilience that gives indication of what to be prioritized in formulating adaptation strategy. Through the study, it has been found that the livelihood resilience of the wood cutter is very low. The weightage of natural capital in contributing livelihood resilience is highest but its contribution score is lowest due to deteriorated forest health and high vulnerability to salinity intrusion, which gives indication of prioritization of natural capital in formulating adaptation strategy.

1. INTRODUCTION

Human induced Climate change is unequivocal (IPCC, 2007a). Bangladesh is one of the most vulnerable countries having dense population on low lying coastal zone (IPCC, 2007b). The world heritage Sundarbans located between the low lying coast of Bangladesh and India (figure 1) which have national and international importance due to richness of biodiversity and uniqueness of human environment inter-relationship, is highly vulnerable to climate change induced salinity intrusion. Around 1.4 million people depend on the forest of having 334 plant species, 49 species of mammal, 8 species of amphibian as many as 120 fish species, 315 bird species and 53 species of reptiles (Hossen et al., 2008 and SBCP, 2001). The large dependency of the human society, diversified wild life resources and the complex coastal profile make the Sundarbans a hardly understandable human-environmental system. The climate change induced changes in coastal processes and profile have made the largest mangrove forest highly vulnerable by deteriorating the forest health and productivity (CEGIS., 2006; and McLeod, et al., 2006). This change in Mangrove forest is risking the destitute community dependent on it by reducing the livelihood opportunity.

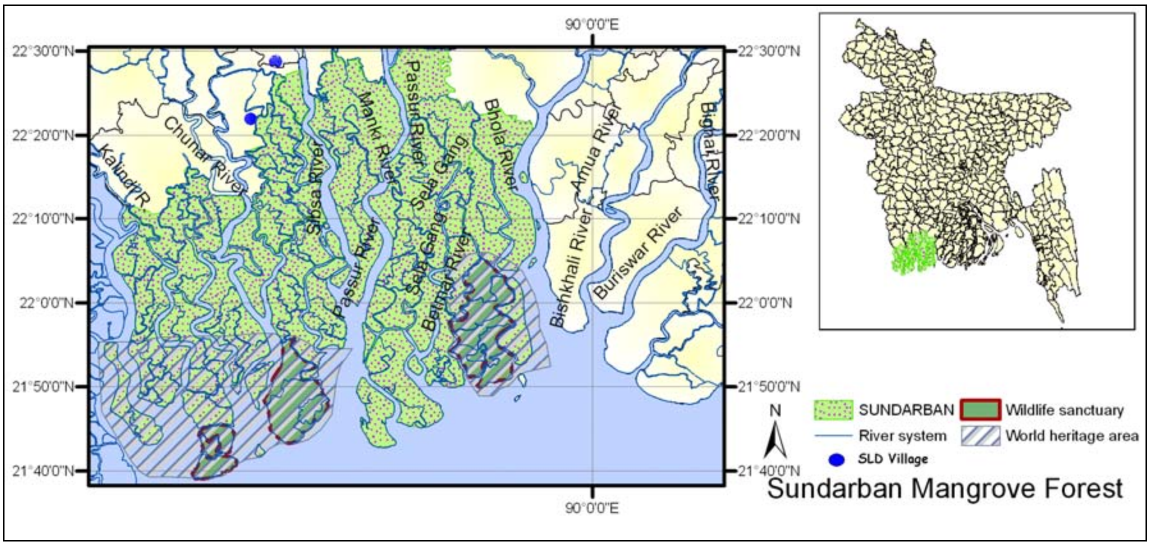

Figure 1: Map of the Sundarbans Mangrove Forest

The Sundarbans provides buffer for lives and livelihoods of 3.5 million people (SBCP, 2001). Around 1.4 millions people are dependent on Sundarbans for their livelihood activities where 0.25 millions are directly dependent on it for their household income (Hossen et al., 2008). Bawali (wood cutter), Nypa palm (used as roof materials) collector, Mawali (honey and bee wax collector), Jele (Fisher), Majhi (Boatman), crab collector, medicinal plant collector, shrimp fry collector and Chunery (oyster and snail collector) are the major livelihood groups dependent on Sundarbans mangrove forest (Hossen et al., 2008 and SBCP, 2001). Their livelihood strategy completely depends on forest productivity and seasonality. Coupled with the poverty, the deteriorating status of the forest and rising salinity have made the livelihood more vulnerable to the climate change (Sadik and Rahman, 2009). The livelihood resilience analysis provides ground to identify the potential impacts on livelihood system and possible policy intervention, and mitigation measures to manage and adapt the changes.

Despite the substantial advances in scientific understanding, options of confronting the climate change and responses to impacts are still in debate that calls for narrowing gap between research community and stakeholder community. The prudent engagement of the stakeholder community in research process and dissemination is the overarching theme of climate change research. The overall aim of this study is to assess the livelihood resilience of the community dependent on Sundarbans Mangrove forest with engagement of the community in the research process through Shared learning dialogue, an effective method of participation. The study was conducted within the impact zone of the Sundarbans, i.e. 20 km strip of land adjacent to Sundarbans (Iftekhar and Islam, 2004). The resilience assessment was done following the participatory model and of livelihood resilience assessment (Sadik, 2009) where the livelihood resilience was described as a set of networked capacity of five livelihood capitals (natural, financial, physical, human and social) to buffer the vulnerabilities, to withstand the shocks, to recover the impacts, and to prepare for future vulnerabilities by taking continual learning from vulnerabilities. The model also describes 23 indicators for assessing livelihood resilience. Each stage of the research process (hazard analysis, weighing of indicators, developing word scenarios and resilience analysis) has been done with community participation through shared learning dialogue (SLD) that provided iterative transfer of information, knowledge and experience between community and researcher. The SLD provided opportunity of refining and verification of the research concept and process with the community engagement through series of iterative learning meeting with Sundarbans dependent livelihood groups (wood cutters, fishers and honey collectors).

2. COMMUNITY ENGAGEMENT

2.1 Target community

In the impact zone of Sundarbans 18% of the households are dependent on Sundarbans for their lives and livelihoods (SBCP, 2001). Sundarbans provides buffers for lives and livelihoods for 3.5 million people (SBCP, 2001), while 1.4 million people are indirectly and 0.25 million people are directly dependent on Sundarbans for their livelihoods (Hossen et al., 2008). Their livelihood is resource extraction from Sundarbans. Table 1 gives details of the population dependent on Sundarbans mangrove forest according to their livelihood activities.

Table 1: Population dependent on Sundarbans (collected from field through SLD)

Livelihood group (translated in English)	% (From SLD)	Extracted resources	Harvesting season
Bawali (wood cutter)	55	Timber, fuelwood	December to March
		Nypa palm, grass for matting, reed for fencing	Mid November to mid March
Mawali (honey collector)	15	Honey, bee wax	March to June
Jele (fisher)	25	Fish, shrimp	Round the year
Chunar (oyster and snail collector) and Fry collector	5	prawn fry, oyster, snail, crab	Round the year

The research deals with the community dependent on the Sundarbans for their livelihoods. In this paper only the livelihood resilience analysis of Bawali (wood cutter) is presented. The Figure 1 shows the villages where learning meetings of SLD were conducted.

2.2 Organizing and administrating shared learning dialogue (SLD)

SLD was the primary methodological process followed throughout the study. SLD is an iterative process consists of series of learning meeting in which analyst and different communities of actors can share insights and come to a common understanding (Moench et al., 2008). In SLD process, clarification of the research purposes, research issues, problems are done in more explicit way to make the community well understood about the research issues and problem that reflects effective participation in research process and data collection.

SLD process was followed at the three parts of the study: i) analyzing impact of salinity intrusion, ii) adopting indicator framework; weighing of the indicators and word scenarios development, and iii) assessing livelihood resilience. The main learning goals of the SLD were i) to refine and verify the preliminary assumptions about livelihood groups, impacts of climate change induced salinity intrusion, and livelihood resilience and ii) analyzing and assessing livelihood resilience. The SLD process was executed by conducting three learning meetings during two field visits at two villages of Sundarbans Impact Zone (SIZ) with Bawali.

Learning meetings were informal where, meeting places and times were selected by the communities. Two PRA tools; resource mapping and seasonal calendar were used to collect qualitative data and to understand livelihood strategies. Figure 2 represents the shared learning process of this study.

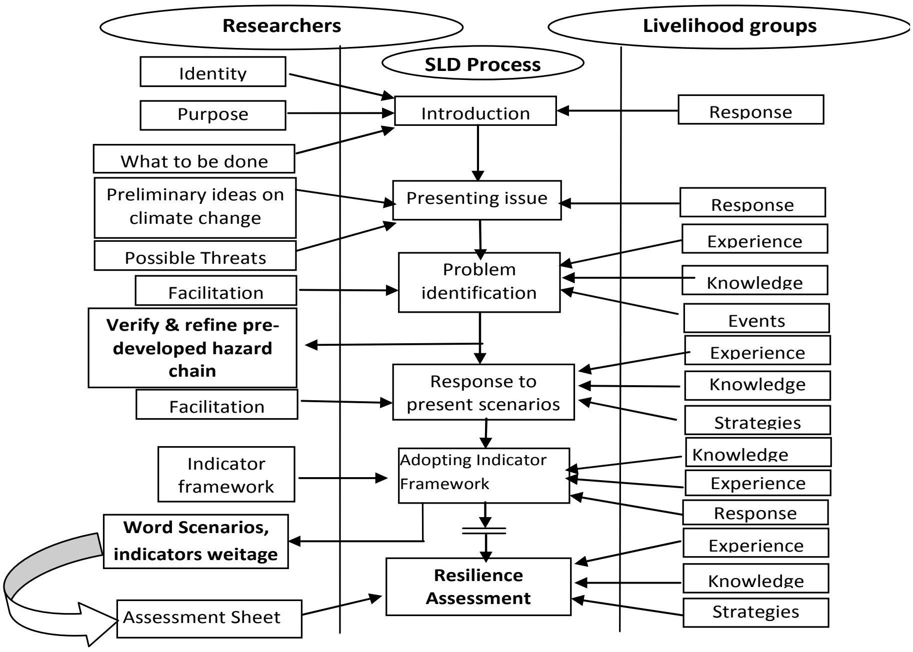

Figure 2: Process of SLD

3. EVOLVING HAZARDS OF CLIMATE CHANGE INDUCED SALINITY INTRUSION

The impact was analyzed based on Sustainable livelihood assessment approach by developing hazard development chain with community engagement following the SLD process. Hazard chain gives better understanding of the process of developing salinity intrusion hazard and the evolving nature of the hazard.

All of rivers in the Sundarbans have increasing trend of water salinity and crossed the threshold line (20 ppt) (Islam and Gnauck, 2008; Hoque et al., 2006). Because of the increasing trend in salinity, the isohaline map of the Sundarbans is gradually changing (Islam and Gnauck, 2008; Hoque et al., 2006). Under the base condition, low saline water zone (5ppt-10ppt), moderate saline water zone (10ppt-20ppt) and high saline water zone (>20ppt) are; 45%, 50% and 5 % respectively (CEGIS, 2006 and Rahman, 2008). Climate change induced sea level rise will push the salinity front toward inland. Due to 88cm SLR, 20% of the low saline zone of Sundarbans will be transformed into moderate saline water zone and 25% of the moderate saline water zone will be transformed in to high saline zone from the base condition (Rahman, 2008).

Plant distribution, density, plant height and canopy, and vegetation growth in Sundarbans are followed by the salinity (Hossain, 2008; McLeod and Salm, 2006; CEGIS, 2006; and Elisson et al., 2000). Natural regeneration of vegetation and forest succession depends on salinity regimes (Siddique, 2001). Salinity reduces the productivity, growth of the mangrove timbers (McLeod and Salm, 2006). The survival capacity of seedlings is decreasing with increase of salinity (Siddique, 2001). A significant decrease in forest regeneration and productivity, and increase of top dying, root rot diseases and other fungal diseases are noticed due to increasing salinity (Siddique et. al., 2001and CEGIS, 2006). It is speculated, the salinity ingress due to 88 cm SLR will brings 13% loss in forest productivity and 27% loss in regeneration (Rahman, 2008). Salinity intrusion also cause change in fish composition and shifting of fishing zone. These changes in productivity ultimately affect other livelihood capitals. The hazard chain (Figure 3) shows the hazard development stages of the salinity intrusion which is the modified version of the Sadik and Rahman (2009) after refining through SLD process. The control stages can break the chains or slow down the hazard development processes that are the directives of the mitigation and adaptation measures.

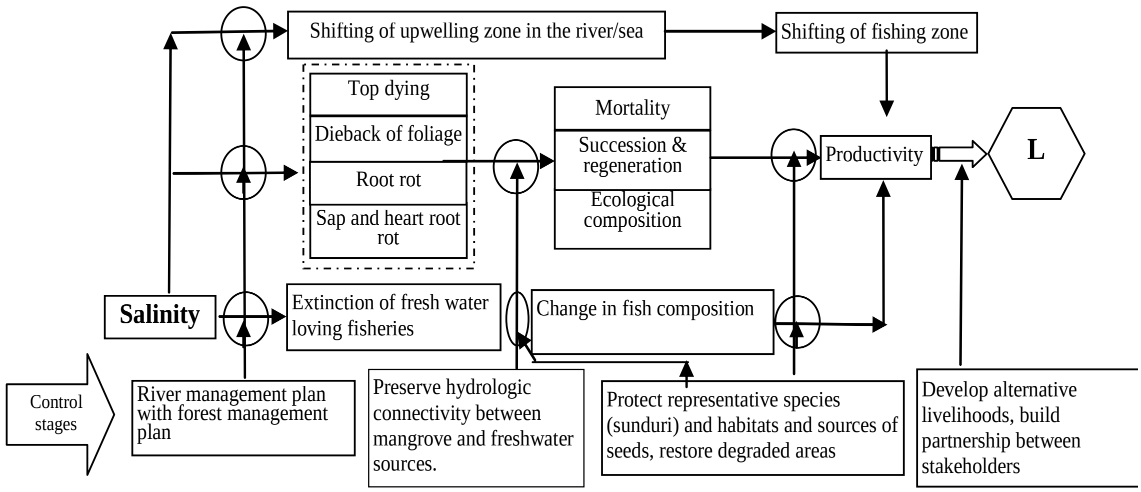

Figure 3: Hazard development chain of climate change induced salinity intrusion

livelihoods dependent on Sundarbans mangrove are affected due to changing climate by two ways; (i) reduction of productivity and (ii) Imposed policy of the government. In response to forest resources declination, the government has declared wild life sanctuary, fish sanctuary, banning of timber harvesting, harvesting seasons. That means, the resources, harvesting area, harvesting seasons are being compressed with policy intervention in response to deteriorated health status of forest health. The climate change induced salinity intrusion is reducing livelihood opportunities and shrinking the other financial capitals and also puts potential risk of health hazards by increasing the incidents of tiger attack in Sundarbans area. Thus a hazard initiates with ecosystem affecting hydrologic event, and progresses and develops in a sociotechnical system. Analyzing the evolving nature of the salinity hazard gives the directive of appropriate measures and options for adaptive governance of the forest.

4. LIVELIHOOD RESILIENCE MODEL

A capital based indicator framework for assessing livelihood resilience of mangrove dependent community was developed through SLD process that contains 24 indicators and captures both livelihood resources and its dynamic attributes (robustness, redundancy, rapidness and resourcefulness) (Sadik, 2009). Building on sustainable livelihood approach, the indicator framework was delineated into five livelihood capitals; natural, physical, financial, human and social capital (Table 2). This indicator framework was made applicable by developing word scenarios for each indicator. The summation of the weighted values of the indicators belonging to a livelihood capital gives the resilience contribution of the respective livelihood capital. The summation of the weighted resilience contribution of livelihood capitals gives the livelihood resilience of the respective community.

4.1 Weighing the resilience indicators

The weights and the typology of the indicators are shown in Table 2. Weights were assigned through SLD process with active engagement of the target communities. As the main goal of the SLD is to come in a common understanding, after a series of iteration the weights were finalized in the learning meeting with the target communities. Weights are given in the scale of 5, where weights describe the importance of the indicators.

Table 2: Typology and weights of the indicators

Indicator	Typology			Weightage (from SLD)
	Salinity sensitive	Capital Strengthening	Capital weakening	
Natural capital				
Status of Sunduri typed forest				4
Propagation of salinity front				5
Integration of river management in forest management plan				4
Measures taken to combat salinity intrusion				4
% of harvester following the harvesting rules				5
Spreading of top dying disease				3
Total weightage of the natural capital				***25***
Financial capital				
Timber and nonwood/fish/honey production				5
Having non forest based livelihood option				4
Source and system of credit				4
Support from GO/NGO in income generating activities				5
Sudden declaration of banning harvest in Sundarbans				5
Total weightage of the financial capital				***23***
Human capital				
Knowledge on non forest dependent livelihood				4
Knowledge on climate change				3
Level of adopted coping mechanism				4
Attack of Royal Bengal Tiger				3
Attack of sea pirates				5
Total weightage of the human capital				***19***
Physical capital				
Option of drinking water				5
Condition of coastal embankment/polders				4
Failure of coastal embankment (How often)				3
Total weightage of the physical capital				***12***
Social capital				
Reciprocity among GO, NGO and community in mitigating risk of salinity intrusion				5

Involvement of social organization in mitigating risk of salinity intrusion				3
Level of community initiated forest management to mitigate risk of salinity intrusion				3
Livelihood assistantship program launched by gov during banning period				5
Political influence on social organization				3
Total weightage of the social capital				***19***

The weights of the natural capital indicators range from 3 to 5. ‘Status of Sunduri typed forest’ and ‘% of harvester following harvesting rules’ have highest weight. Because, Sunduri typed forest represents the most diversified and resourceful forest type, and sustainable harvesting depends on obeying the harvesting rules. In case of financial capitals, ‘forest production’ ‘support from GO/NGO in income generating activities’, and ’sudden banning of harvest’ have highest weight, 5. Highly sensitivity of forest production to salinity intrusion, necessity of GO/NGOs’ supports in non forest based income generation, and unstable income due to sudden banning of harvest are the prime reasons that make the weightage of these indicators highest. The highest weighed indicator in the domain of human capital is ‘attack of sea pirates’ (weightage 5) that puts risk of health hazard and financial loss. In case of physical capital, option of drinking water bears the highest weight 5, because of being highly sensitive to salinity intrusion, and important livelihood capital. ‘Reciprocity among GO, NGO, and community’, and ‘livelihood assistantship program’ are the highest weighed indicators (weight 5) in the domain of social capital that strengthen the strategy and action of risk mitigation of salinity intrusion.

Among the weightage of the individual capital, the natural capital shows the highest weightage, 25 due to high dependency of livelihood groups on the natural capitals. The weightage of the other capitals are, 23, 19, 12 and 19 for financial, human, physical and social respectively.

The weights of the indicators also give a directive of adaptation strategy. The indicators and the capitals having highest weight should be given high priority during formulation of adaptation strategy to enhanced livelihood capitals.

4.2 Developing word scenarios

The indicator framework was made operational by developing word scenarios for each of the 24 indicators. Word pictures are the description of the asset circumstances. Word pictures of each indicator outline ‘best case’ to ‘worst case’ snapshot of resilience. Values were assigned as 1 to 5 for worst to best case scenarios. These word scenarios were developed in a participatory manner through SLD process. Then an assessment sheet was prepared containing word scenarios with respective indicators for each of the five capitals. This assessment sheet was followed to assess the livelihood resilience through SLD process.

5. LIVELIHOOD RESILIENCE OF BAWALIS

Followed by the assessment sheet containing word scenarios, the resilience contribution of the livelihood capitals was analyzed and assessed through SLD process executed by learning meeting with Bawali.

The resilience contribution of natural, financial, physical, human and social capitals are; 33.6, 52.2, 55.0, 55.8 and 48.4 respectively in the scale of 100 (Table 3) that make the livelihood resilience of the Bawali, 47.8 (in the scale of 100).

Table 3: Resilience contribution of individual livelihood capital

Livelihood Capital	**Total weight (from Table 2)**	**Resilience**		
		in scale of 100	**in scale of 5**	**Word Scenario**
Natural capital	25	33.6	1.7	Poor
Financial capital	23	52.2	2.6	Low
Physical capital	12	55.0	2.8	Low
Human capital	19	55.8	2.8	Low
Social capital	19	48.4	2.4	Low
Livelihood resilience		47.8	2.4	low

The increasing propensity of river water salinity, poor effective forest management with no mitigation and adaptation measures for salinity intrusion, the disobeyance of forest law, and the spreading of the top dying diseases in moderate to high saline zone have made the resilience contribution of the natural capital as low as 33.6 where the important weight is highest among the five capitals. The low economic returns, local credit system with rigid condition of sharing of harvested resources, unfriendly policy intervention of government and the few options of non forest dependent livelihood have made the resilience score of the financial capital only 52.2 in scale of 100. Vulnerable condition of the salinity protection structure (embankment) around the community villages, frequent failure of this structure and medium level options of drinking water not to be affected by the salinity intrusion have made the resilience score as low as 55.0. The medium level of adaptation option (diversifying livelihood, savings), medium level of climate change knowledge, high risk of tiger attack due to salinity intrusion and pirates attack have made the resilience score of human capital only 55.8.

In case of social capital, the low reciprocity between GO and NGOs in mitigating salinity intrusion hazards, low involvement of the social or community organization in mitigating salinity intrusion hazards and the political influence on the social organization have made the resilience contribution to livelihood resilience as low as 48.4.

The weighted summation of the resilience contribution of the individual livelihood capitals gives the livelihood resilience of the community as the livelihood resilience is defined as the networked capacity of the livelihood capitals. The low resilience score, 33.6, 52.2, 55.0, 55.8 and 48.4 for natural, financial, physical, human and social respectively have made the livelihood resilience of the Bawali (wood cutter) only 47.8 in the scale of 100 which is low.

It is seen from the Table 3 that the importance and resilience contribution of different livelihood capitals are different. They give a sense of strategic action in response to climate change induced salinity intrusion: where we should take policy interventions, which domain of livelihood capital requires prioritization. The resilience analysis followed by indicator framework has disclosed directives of capital based adaptation strategy to build the livelihood resilience to climate change induced salinity intrusion.

6. DISCUSSION AND CONCLUSION

Lack of integration between the livelihood resilience and adaptation strategy limits the sustainability of development pathways. What will be the strategy to mitigate the climate change risk and to reduce the vulnerability is the key issue in climate change debate. Resilience analysis through engaging the community provides a ground to identify policy intervention, and mitigation measures for adaptation strategy. Community engagement narrows the gap between the research communities and the local communities. The methodological process followed in this study provided the two way flow of knowledge, experiences and learning between local communities and the researchers.

The insights of the climate change induced salinity hazards development in the Sundarbans socioecological system became visible through the learning meeting with the target communities. Community engagement helped to identify the link between the successive events of the hazards development. Also the control stages that might break or linger the link were identified through the active participation of the target communities. The analysis of the evolving nature of the hazard helped to analyzing the livelihood resilience to change in the Sundarbans mangrove forest due to climate change induced salinity intrusion. The resilience analysis and assessment with engagement of the target community shows that the resilience of the livelihood group Bawali who largely depends on Sundarbans is only 47.8 (in scale of 100), which is low. The contributions of the individual livelihood capitals to livelihood resilience are 33.6, 52.2, 55.0, 55.8, and 48.4 for natural, financial, physical, human and social. Among the five capitals the natural capital have highest control on the livelihood resilience which got highest importance weightage of 25, because of large dependence of livelihood group on Sundarbans, highly sensitivity of ecosystem health and productivity to salinity intrusion. The second important capital is financial capitals having important weightage of 23, close to natural capital. These indicate that, strengthening of natural and financial capital will raise the livelihood resilience. The community engagement reveals that, community based adaptive governance of the forest, livelihood diversification, financial assistantship in generating alternative livelihood and strengthening of the social safety nets will give the livelihood resilience. Therefore, if this approach of community engagement is followed in formulating the adaptation strategy, the adaptation technology transfer and dissemination will be easier and fluent.

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BARRIERS AND BRIDGES TO THE EFFECTIVE ENGAGEMENT BY LOCAL GOVERNMENT OF KEY STAKEHOLDERS IN COASTAL CLIMATE CHANGE POLICYAND PLANS

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ABSTRACT

Our understanding of the coastal environment, new participants and evolving dimensions continue to test institutional arrangements and the capacity of scientists, decision-makers, politicians and other coastal stakeholders. This begs new approaches. Where there is competition for space on the coast, hard decisions must often be made about how land is zoned and subsequently used. This is compounded by the likely impacts of climate change in many coastal areas. In an era of increasing emphasis of stakeholder engagement in environmental management, and of focus on the crucial importance of the marine and coastal zone, the actual and potential role of marine and coastal communities and stakeholders has been little documented or analysed. This paper describes the results of an investigation into the challenges and opportunities for public involvement in the management, use and conservation of coastal resources in Australia, with lessons from overseas, including through the development of coastal adaptation strategies for local government.

A study was carried out from 2004-2009, using a multi-discipline and multi-method approach based in the social sciences to investigate: the challenges for incorporating local or lay knowledge into planning and decision-making for integrated coastal management (ICM); the economic impact and value of coastal resources; and to understand how coastal communities compete politically. The research was progressed through seven Australian (three each in Queensland and Victoria and one in Western Australia) and three international (two in the United States and one in Chile) case studies and focused strongly on the drivers and responses to engagement in ICM. The investigation found a number of institutional challenges that hindered or prohibited the progression of effective community involvement in the public policy process. These include but are not limited to: inability to effectively coopt non-government actors; challenges to the concept of sustainability; high transaction costs relative to the scope, capacity and interest of government; lack of effective mechanisms; institutional marginalisation through the political process; loss of corporate knowledge, low internal capacity and capacity to develop meaningful policy; low capacity for institutional learning; and inadequate timeframes. At the local government level in particular a range of issues were identified as being significant barriers to good policy making. These include: challenges around infrastructure and asset management; scale; resources (e.g. knowledge, funding and capacity); legal issues; risk; conflicting roles; and unreasonable demands by funding agencies.

Coastal planning and management in Australia is characterised by complexity and is notable for flux within polices, programs, institutional arrangements and funding. Sustainability policy dictates a widening of the policy community and debate in order to help define problems. Further, there is recognition that solutions to complex environmental problems requires the 'long-term integration of economic, social and environmental policies' (Ross & Dovers, 2008, p. 245). This tests the policy making capacity of governments on a number of fronts, however, there are significant opportunities to improve practice and outcomes around: strategic planning; a clear articulation of responsibilities; improved capacity building; monitoring and evaluation; and the use of innovative tools to assist with the resolution of ICM conflicts.

1. INTRODUCTION

The coast has been used, admired and managed for many thousands of years. Coastal areas contain some of the world's most diverse and productive resources, often provide better transport routes than inland areas, can have milder climates and provide access to a diverse range of recreational opportunities. As well as regions of high abundance and great beauty, coastal areas are also subject to intense natural variation and vulnerability. Cyclones and monsoons are regular climatic features in tropical and sub-tropical regions of the world. In the temperate regions, low-pressure systems deliver storms that can last for weeks, resulting in loss of life and damage to infrastructure. Globally, there are a number of commonalities that can be ascribed to coastal areas early in the twenty-first century. These are:

- Close to half of the world's population lives on or near the coast and by the year 2020 this proportion could rise to two-thirds (Harvey & Caton, 2003; Martinez*, et al.*, 2007; Agenda 21, Chapter 17.3 Section 3 United Nations, 1992);
- People have traditionally chosen to live near the coast because coastal resources have been relatively abundant, which meant that populations were able to settle and grow;
- Increasing development and population growth in the coastal zone combined with an increasing dependency on the coastal resource base is placing significant pressure on coastal systems; and
- The uncertainties related to climate change combined with the pressures of growth and development, complicate an already complex planning and institutional framework.

Ownership, access to and management of the coastline including the foreshore and nearshore zones has been an issue of serious public debate since at least the time of Roman Emperor Justinian in 530A.D. (Shorelines, 1995), and probably longer in Eastern and Polynesian cultures. Today, coastal management still has at its core a collection of laws and guidelines that attempt to manage issues such as access, extraction, safety and navigation. No less important, however, is the need to balance use and extraction against conservation and protection goals: sustainability. Cumulative impacts, population growth and the fact that most arable and habitable land on the coast is occupied means that the opportunity simply to relocate if a resource is depleted is often no longer an option.

Internationally and within Australia, government (Beeton, *et al.*, 2006; Commonwealth of Australia, 1980, 1991, 1995, 2006; Resource Assessment Commission, 1993; Stratton, 1969) and non-government (Harvey & Caton, 2003; Kay & Alder, 1999; Kay & Lester, 1997; Lazarow, *et al.*, 2006; Pew Oceans Commission, 2003; Thom & Harvey, 2001) policies, reports and publications argue strongly that our coastal resources are under pressure and that immediate and ongoing action (of an integrated nature) is critical. It is now widely accepted that coastal planning and management requires a focus on both resource outcome and management processes (RAC 1993, Kay and Alder 1999, Thom and Harvey 2000, Lazarow 2002). This implies an interaction between all levels of government, industry and the community for how we plan, manage, live, work and recreate in the coastal zone.

A distinct environmental agenda can in many ways be linked to the rise of the social justice movement in the 1960s and a broad questioning of the traditional mandate and knowledge of government (Hutton & Connors, 1999). In this respect, environmental issues were added to the list of responsibilities at various levels and sectors of government without necessarily cutting across agendas and programs. From the late 1980s and early 1990s, there was another shift in the debate, this time to the issue of 'sustainability', with its triple bottom line agenda. This has been codified internationally since the publication of the Bruntland Report in 1987 (World Commission on Environment and Development, 1987) and Agenda 21 (United Nations, 1992), a product of the first Earth Summit in Rio in 1992 established the link between ecologically sustainable (ESD) and ICM. The speed at which the environmental and then the sustainability agenda and issues have made their way into public policies and programs in the past two decades is remarkable in some respects. Prior to the 1970s, environmental issues were mainly treated as the management of resource extraction activities (for example, mining, fishing and forestry) and the development of environmental law over the past three decades is a good example of this legacy (Bonyhady, 2003; Wilkinson, 2003).

A number of authors (Berkhout, *et al.*, 2003; Common, 2003; Dovers, 2003b; Eckersley, 2003) comment on the significant new challenges that the sustainability agenda pose for government and what the implications for governance are. For example, Berkhout *et al.* (2003) argue that the mainstream sustainable development model of the 1980s is no longer well-matched with the contemporary dynamics of social, political and scientific processes in their engagement with dynamic natural systems. In Australia, Dovers (2000, p. 24) writes:

> *Much attention has been paid to the sorts of policy processes, public institutions, and management regimes capable of handling future demands in resource and environmental management. Uncertainty, complexity, and stretched temporal scales in natural systems challenge our arrangements, while increased community participation and emerging multiple interests beg new approaches.*

2. PUBLIC POLICY, PUBLIC PARTICIPATION AND INTEGRATED COASTAL MANAGEMENT

It is now generally accepted that coastal resources can only be effectively managed in the context of the social, economic and cultural environments in which management interventions seek to have a positive impact (Harvey & Caton, 2003; Kay & Alder, 1999; Thom & Harvey, 2001).

The role and significance of public involvement in ICM has grown considerably over the last 20 years at local and state levels and is expected to continue to grow over time. Public participation in the decision-making process has been offered as a method for legitimising state-based coastal management programs and also as a means to improve our knowledge and understanding of the coast, raise the profile of stewardship and ultimately provide for better solutions. There is strong evidence to suggest that the incorporation of local knowledge into coastal management projects can improve the state of coastal resources (Adger, 2003; Berkes, 1999; Hanna, 1990; Hanna, *et al.*, 1996), however, Dovers (2003a, pp. 148-149) argues that amongst the current institutional settings in Australia, there does not yet appear to be a coherent strategy for this:

> *Governments more broadly seem not to have settled on a coherent basis for when to use particular styles of policy formulation, and even seem distinctly bipolar when it comes to controlled versus participatory policy processes … In most cases, processes are invented as if for the first time.*

Further, no significant attempt has been made to measure the success or otherwise of local or lay knowledge in the development of coastal policies, programs and management plans (Clarke, 2006; Foxwell-Norton, 2006; Lazarow, 2002, 2006). There are a number of reasons for this, including:

- Challenges to existing conceptions of power and authority;
- Significant differences in interest, including conceptions of the public interest;
- A clash of meanings and lack of continuity surrounding the concept of what it means to involve the public or stakeholders in decision-making; and
- The challenge of effectively integrating environmental policy into decision-making.

3. IMPORTANCE OF THE COAST AND PRESSURE ON COASTAL SYSTEMS

The importance of coasts and coastal ecosystems is well understood through the economic, social and environmental values to humans. Coastlines around the world have been modified for thousands of years to facilitate the economic benefit, food production, recreational desires and coastal security concerns of humankind. Coastal engineering and infrastructure works include for example the construction of groynes, seawalls, artificial reefs, breakwalls, sand bypass systems, beach and nearshore sandbar grooming and nourishment and beach fill campaigns. Coastal infrastructure development such as ports and the training of riverwalls continue to support the economic development of many regions as trading hubs for a wide variety of materials including primary produce, fisheries and minerals, and coastal tourism is an important economic driver in numerous coastal areas.

In 2006, the Australian Government released the National Cooperative Approach to Integrated Coastal Management (Commonwealth of Australia, 2006, pp. 8-9), which identified four major pressures on the coastal zone: population growth and demographic shifts; industry trends; protection of the coastal resource base (for example, water quality and loss of habitat); and climate change. The pressures from and consequences of growth in the coastal zone can be summarised as follows:

- Population growth arising from the existing population base, migration from other regions and changes in settlement patterns within coastal nodes, which has an impact on coastal resources (see Gurran, *et al.*, 2005);
- Development and changes in industry and land use including the expansion of existing industries (goods and services) such as harbours and port facilities and the development and expansion of new industries (for example, Information Technology, hospitality and tourism), which has an impact on coastal resources; and
- Natural or human induced changes to the coastal ecosystems and the natural capital base, including from climate change and climate variability.

Many of the key coastal management issues faced today are common across borders and between nations. Countries often face similar planning and management concerns for the coastal zone, however, there are some marked differences between nations' ability to successfully progress these issues. The highly valued and often contested nature of access to and use of coastal resources underpins the importance of a robust and adaptive system of governance and management.

4. THE INVESTIGATION AND RESEARCH METHODS

This investigation was established to examine decision-making processes for the management, use and conservation of coastal resources and to generate new understandings of the interactions within and between human and natural systems. Three distinct research questions were identified: (1) what are the challenges for incorporating local or lay knowledge into planning and decision-making for ICM; (2) can we improve our understanding of the economic impact and value of coastal resources; and (3) how do coastal communities compete politically. This paper provides a targeted summary of a number of aspects of the investigation.

Ten case studies were deliberately selected to include a range of ICM challenges. Figure 1 shows the locations of the case studies and Table 1 describes the key ICM issues for each of the Australian case studies. Generally, the case studies document an example of how a sector or sectors of the community in a particular locale responded to a proposal or decision by industry or government to use or allocate for use a particular area of the coast in a manner felt to be inappropriate with the public interest or the interests of a group or groups purporting to represent the public interest. The scale and intensity of the proposals/decisions vary across the case studies.

A multi-discipline, multi-method investigation organised around a case study approach was developed to progress the study. The case for methodological pluralism has been successfully argued by a number of authors including Smith (2002), Adger (2003), Manning (1999) and Norgaard (1989). For example, Norgaard (1989, p. 37) argues that 'all the aspects of complex systems can only be understood through multiple methodologies'. The disciplines of political science, social research and economics, all from the social sciences were selected as being the most appropriate for the investigation. Five techniques were used across the disciplines. These include: seven research scoping studies; 52 key stakeholder interviews; approximately 1,000 surveys (web-based and face-to-face); examination of material and documents; and participant observation.

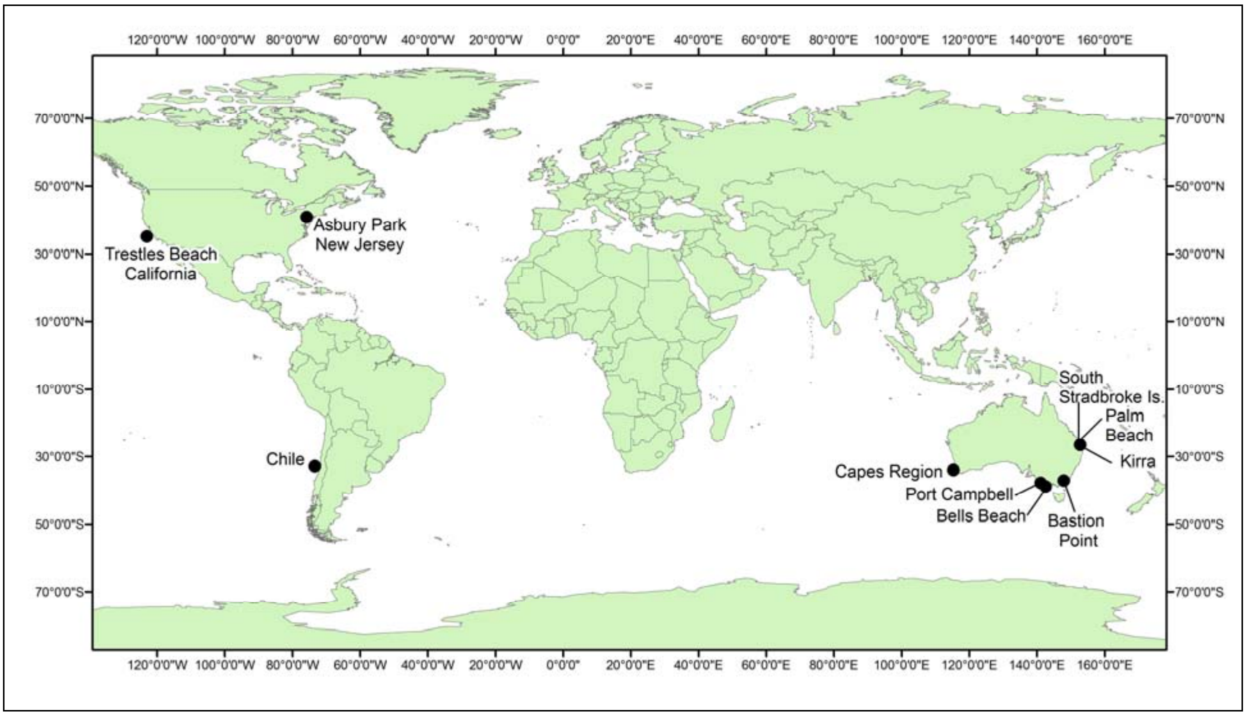

Figure 1: Case study locations

Table 1: Identification of key ICM challenges at Australian case study locations

Issue/Location	**South Stradbroke Island, Qld**	**Bastion Point, Vic**	**Palm Beach, Qld**	**Kirra Point, Qld**	**Bells Beach, Vic**	**Port Campbell, Vic**	**Capes region, WA**
Infrastructure & engineering issues							
Degradation of natural or built asset	✓	✓	✓	✓	-	-	-
Environmental issues							
Reef health	-	✓	✓	✓	-	-	-
Water quality	✓	✓	-	-	-	-	-
Ecosystem health	-	✓	✓	✓	-	-	-
Legislative and management issues							
Public access	✓	✓	-	-	✓	-	✓
Local knowledge	✓	✓	✓	✓	✓	✓	✓
Community involvement	✓	✓	✓	✓	✓	✓	✓
Attachment to place	✓	✓	✓	✓	✓	✓	✓
Stewardship	✓	✓	✓	✓	✓	✓	✓
Recreation	✓	✓	✓	✓	✓	✓	✓
Tourism	✓	✓	✓	✓	✓	✓	✓
Culture							
Surf culture	✓	✓	✓	✓	✓	✓	✓
Aesthetics	✓	✓	✓	✓	✓	✓	✓
Significance	✓	✓	✓	✓	✓	✓	✓
Economics							
Economic impact	✓	✓	✓	✓	✓	✓	✓
Non-market value	✓	✓	✓	✓	✓	✓	✓

5. FINDINGS

A range of strategies were employed by groups across the case studies also demonstrating significant differences in capacity. Six specific strategies or themes were identified: the use of legal instruments; community health impacts; appropriate (and access to specialised) knowledge; environmental economic information such as the value of natural assets; partnership approaches; and advocacy and politicisation of issues. The importance and priority of these themes differed per case study, however, the willingness of groups to engage in a sophisticated manner across multiple themes and outside of the traditional or mandated engagement channels, resulted in a number of institutional challenges that hindered or prohibited the progression of effective community involvement in the public policy process. These include but are not limited to: inability to effectively coopt non-government actors; challenges to the concept of sustainability; high transaction costs relative to the scope, capacity and interest of government; lack of effective mechanisms to progress engagement; agency and institutional marginalisation through the political process; loss of corporate knowledge, low internal capacity and capacity to develop meaningful policy; low capacity for institutional learning; and inadequate timeframes.

The study found that current policy settings place new demands on policy makers and managers. For example, setting up and maintaining the structures for active community participation, information and practical support is demanding on local government and regional agency staff. Further, access by the public to bureaucrats, the need for government staff at many levels to make themselves available to the public and a further requirement for many staff to proactively design and run public outreach programs is a task that is both time consuming and requires specialist skills, placing greater demands on staff. Many of the current formal mechanisms for community engagement were found to have significant limitations. This was compounded by the risks associated with proceeding with singular or prescriptive public involvement programs that may purposely or inadvertently exclude or favour a group or sector, and has been identified in other studies (for example, Fien, *et al.*, 2006; Harding, 1998).

At the local government level in particular a range of issues were identified as being significant barriers to good policy making. These include but are not limited to: challenges around infrastructure and asset management; scale; resources (for example, knowledge, funding and capacity); legal issues; risk; conflicting roles; and unreasonable demands by funding agencies. Each of these poses greater stress on the ICM process and individuals involved in the delivery of programs and services.

6. DISCUSSION

Over the past two decades, the Commonwealth, states, regions and local governments have made significant progress in the development of coastal management policies and programs (for example, National Coastal Policy, state policies in New South Wales, Victoria, Queensland and Tasmania, and the incorporation of marine and coastal issues into natural resource management planning frameworks). More recent policy iterations have placed significant importance on improving our understanding of and capacity to manage the expected impacts of climate change.

The seriousness of government commitment to more inclusive public involvement processes can be evidenced by the authorisation of a range of ‘community engagement’ type reports by centralised offices, such as the Department of Premier and Cabinet in Queensland, Victoria and Western Australia in the early 2000s (Government of Queensland, 2003a, 2003b; Government of Victoria & Victorian Local Governance Association, 2001; Government of Western Australia, 2002, 2003). However, what is at question is the ability of the agencies, including the line agencies to respond to such impetus (a whole-of-government approach) within a political (three-year) or even a policy cycle, given the accepted argument that institutional change is a much slower moving beast. Six years after the last of these documents was published, it appears that there has been no evaluation on this mark. For example, Bell (2004, p. 27) argues that:

Governments (at least to some extent) are recognising their knowledge and learning deficiencies and are rushing out the door to 'engage' the community. But the process, thus far, is still embryonic and still shaped too much by the centre and the 'cult of expertise'. In an ironic parallel movement, governments are also becoming more intolerant of dissent and are using spin doctoring and a compliant media to ram home their messages and knowledge.

Dovers (2000) argues that community participation in environmental management is about much more than environment; it is about politics, social decline, economic development and the future of communities. The public policy inquiry surrounding this investigation revolves around the 'challenge' brought about by the rise in public or stakeholder participation programs (and supporting rhetoric) attached to these policies and programs and the challenges this is having for traditional power relationships between government, its institutions and the constituency. This point is emphasised by Nursey-Bray (2000), who suggests that to participate effectively, participants require recognition of the validity of their knowledge, viewpoints and identity as well as access to the policy and management processes, and Bell (2004), who argues that knowledge based on networks and community engagement is ideally about inductive reasoning and learning, promising better knowledge and potentially more legitimacy. This raises a number of challenges for government processes that do not necessarily 'lend themselves to uncertainty, learning, or adaptation, since outcomes are frozen by legal and administrative procedures' (Bryan, 2004, p. 894). The similarity of issues between current coastal management strategies in certain locales and future adaptation strategies for 'at risk' areas suggests that a better understanding of these issues will improve our ability to forecast and manage the broad range of community climate change concerns.

7. CONCLUSION

Sustainability policy tests government. These challenges are magnified in the coastal zone where it is generally accepted that solutions to complex environmental problems requires the 'long-term integration of economic, social and environmental policies' (Ross & Dovers, 2008, p. 245). The progression of ICM dictates a widening of the policy community and debate in order to help define problems. This tests the policy making capacity of governments on a number of fronts as existing institutional architecture and a highly valued and contested playing field provide constant challenges for this evolving field across space and time. There are significant opportunities to improve practice and outcomes around: strategic planning; a clear articulation of responsibilities; improved capacity building; monitoring and evaluation; and the use of innovative tools to assist with the resolution of ICM conflicts. Given the significant interest and movement internationally and from all levels of government in Australia over the past two years across this policy space, more attention to the actual and potential role of marine and coastal communities and stakeholders in the progression of coastal and climate change policy and planning is both warranted and overdue. The findings from this study strongly suggest that ICM is more likely to be successful if key user groups, their relationship to the coast, knowledge and capacity, are better incorporated into planning and management. This is at the core of ICM and is an important step towards more sustainable coastal management practices.

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