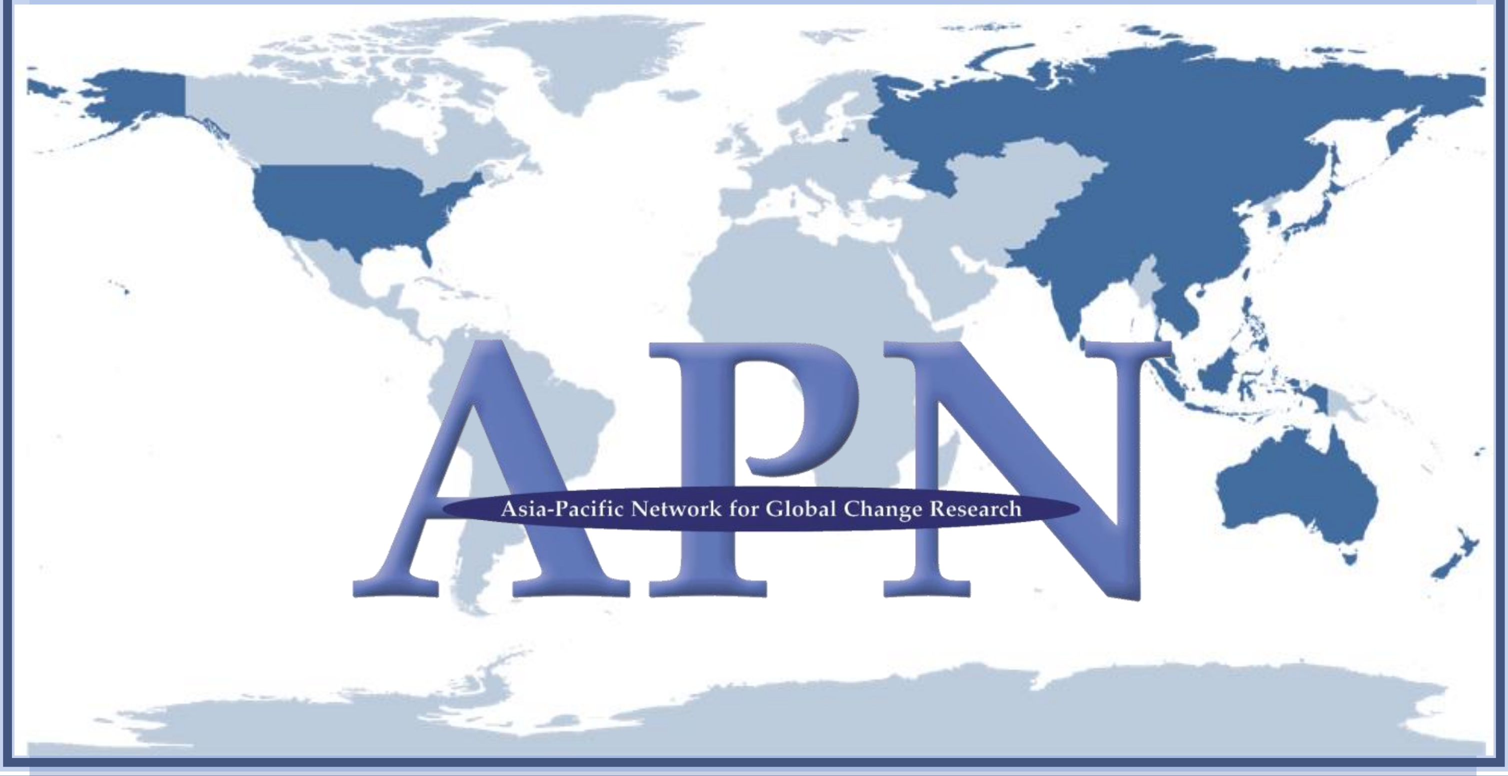
FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2012-04CMY-Salik

Impact of Climate Change on Mangroves Ecosystem in South Asia



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Impact of Climate Change on Mangroves Ecosystem in South Asia

ARCP2012-04CMY-Salik
Final Report submitted to APN

ISBN

Note from the Authors

Project "Impact of Climate Change on Mangroves Ecosystem in South Asia" (reference number: ARCP2012-04CMY-Salik) has been conducted from 2012 – 2015, with collaboration among researchers from Pakistan, Bangladesh, Sri Lanka and United States of America. While there have been some good outputs yielded from the research activities, the project is not without flaws. I have recently been informed that some sections written in the final report were taken directly from PhD thesis and subsequent publication produced by Dr Junaid Alam Memon and Dr. Gopal B. Thapa without due reference to the original authors.

Pages 18, 60 – 63 in this report have been highlighted to indicate that the text written was taken from the work of Dr. Junaid Alam Memon and Dr. Gopal B. Thapa.

I acknowledge the mistake and deeply regret this oversight. On behalf of the project team, I would like to express sincere apologies to Dr. Junaid Alam Memon and Dr. Gopal B. Thapa. As a scientist, I am against any form of plagiarism and committed to prevent it from happening in the future. I sincerely hope that despite the oversight, the results from the research activities will be of interest to the scientific community and can contribute to the advancement of global change science.

17 October 2017

Kashif Majid Salik
Sustainable Development Policy Institute, Pakistan
Project Leader, ARCP2012-04CMY-Salik "Impact of Climate Change on Mangroves Ecosystem in South Asia"

OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

The project focuses on the impact of climate change on mangroves ecosystem as well as the socio-economic vulnerabilities of coastal communities in three South Asian countries, i.e. Pakistan, Bangladesh and Sri Lanka. The project provides an assessment on changing hydrological conditions and its resultant land cover changes through a temporal GIS/RS analysis. Added to this the development of climate change scenarios for the study sites, environmental flows assessment, salinity distribution due to sea level rise (SLR) and institutional/policy analysis were also carried out. We tried to answer some key questions related to impacts and vulnerabilities of mangrove ecosystem and dependent communities by integrating the community's perceptions and experts' opinion along with observed and projected climate change scenarios. Some important questions include: what are the likely drivers of sensitivity and exposure, how they are impacting, and how much is the coping potential of coastal communities in the backdrop of climate change? What should be the key adaptation options for minimizing climate change impacts and vulnerabilities? What should be the likely environmental flows to delta and mangrove ecosystems due to changes in river flows under climate change? Can institutions and current policies play an effective role in the protection of mangroves ecosystem resources?

Based on these questions our analysis shows that these coastal communities, either engaged with fishery or agriculture sector, are highly sensitive or exposed to the climate change driven threats. Furthermore, there is a lack of adaptive capacity mainly due to the poor consumption patterns, less income diversification, high dependency ratio and lack of education. The adaptation options concluded are:

- Provision of safe drinking water and sanitation facilities, as lack of access has caused health problems among the deltaic communities and hence reduce productivity
- Ensuring environmental flows for sustainable ecosystem and improvement in livelihood opportunities
- Protection from climatic disaster while integrating climate change related information into the planning processes in formulating community development strategies, so as to reduce the risk of disaster
- Access to education and safe human settlements in order to protect life and property as well as provision of civic facilities
- Innovation in livelihood opportunities and insurance cover for the vulnerable fishermen and farmers
- Improve the state of preparedness for the coastal communities during extreme events through rapid evacuation drills, early warning systems, etc.

Keywords

Climate Change, environmental flows, vulnerability, hydrological, precipitation, rehabilitation.

Objectives

The main objectives of the project were:

i) To examine different climatic and hydrological factors under climate change scenarios and assessment of their linkages and interactions on mangrove ecosystems;

ii) To carry out vulnerability assessment for socio-economic variable, indicators and processes which are affecting mangrove ecosystem sustainability in South Asia;

iii) To provide necessary adaptation/recommendations with respect to for policy and institutional intervention for mangroves sustainability and development for decision makers at local, national and regional level.

Amount received and number years supported:
The Grant awarded to this project was:
US$ 54,000 for Year 1:
US$ 31, 000 for Year 2:
Activity undertaken:
Activity 1: Study site selection and characterization: Selection of appropriate study sites and their characterization by each country through literature review, expert opinion, etc., enabling the development of conceptual framework describing drivers, pressures, responses, trends and impacts on Mangroves ecosystem.

Activity 2: Scenario Development: a) Climate Change Scenarios were developed with the help of Climatology section of GCISC, using regional climate models (RCM). b) Water Flows Scenarios: Fresh water flows/discharge scenarios by using literature review, expert opinion and hydrological and hydrodynamic models.

Activity 3: Socio-Economic Vulnerability and Environmental Impact Assessment using GIS/RS techniques: Socio-economic vulnerability of mangroves ecosystem is assessed using techniques of GIS/RS, statistical and indices development. Institutional analysis related to mangroves was analyzed from national to regional level policy options.

Activity 4: Vulnerability Assessment of Mangrove ecosystem due to climate change: Vulnerability assessment of the mangroves ecosystem was assessed by using appropriate Landscape vegetation and structural dynamic models. These models predicted the dynamics of mangroves ecosystem in terms of responses to the projected scenarios of climate change and fresh water flows and its resultant impacts on salinity level, sediments transport and extreme disturbances.

Results:
In the aftermath of this two-year regional research project, as many as six studies have emerged. These studies include climate change scenarios development, mangroves forest cover change analysis under different hydrological regimes, environmental flows assessments under different ecological conditions, salinity distribution due to SLR, socio-economic assessment and institutional, and policy analysis. Different methodologies were used for the assessment of these studies, which are the combination of both quantitative and qualitative techniques. These studies would lead to new discussion on adaptation and water management. They also provided the ground for more advanced and complex scientific modeling techniques for detailed impact studies in the region. Also the results can provide in-depth understandings to researchers, academia, civil society and community based organizations, and local and national policy makers to develop policy options for the effective mangroves ecosystem protection and adaptations for local populations.

Relevance to the APN Goals, Science Agenda and to Policy Processes:
The proposed study is relevant to the APN Science agenda of both goal 1 and 2 i.e.

Goal 1: Supporting regional cooperation in global change research as it is relevant to this project to understand the impact of climate change on Mangroves ecosystem and its related vulnerabilities.

Goal 2: It will contribute significantly to the APN Scientific Agenda by involvement of three South Asian countries and regional institutions, and provide appropriate environment for sharing knowledge and experiences for successful completion of this project. Furthermore, the project will provide policy recommendations in the South Asian context.

Self-evaluation:

The project outcome remained highly satisfactory, as it met all the objectives of the project. The project was successful enough to develop linkages and networking with national (WWF-Pakistan, IUCN, National Institute of Oceanography, Pakistan fisher folk forum etc.), international experts and organizations (Mangroves for Future-Bangkok, Institute of Water Modeling-Bangladesh, IUCN- Sri Lanka, etc.) working in coastal ecosystems and its dependent communities. Also, the project team is committed to develop joint research papers, reports and proposals during and after the project completion.

The collaborative work in the project with the involvement of a number of researchers and decision-makers of three South Asian countries helped in developing a network that would lead to expansion of much needed work in other coastal ecosystems of the region. The successful implementation of the methodologies developed for environmental flows (e-flows) assessment, cumulative vulnerability index (CVI), climate change scenario analysis, and institutional analysis has contributed towards enhancing adaptive capacity of the region to climate change. Through the international symposium and public fora organized under the project and information dissemination based on the outcomes of the research studies, the project has contributed to raising public awareness on climate change and its impact on mangroves ecosystem. In the beginning of this project, we had faced a temporary setback due to the exit of an important and experienced Indian research partner. However, this loss was mitigated by networking with other regional and national organizations as mentioned above. Some other practical difficulties also came to our way such as access to reliable hydrological data and software/models for conducting detailed studies.

Potential for further work:

One of the potential gaps, identified during the project which may provide future collaborative scientific works, is related to assessment of resilience as well as loss and damages due to extreme events such as sea level rise, floods/ droughts and storms. The further research should also consider economic cost of climate change impact on coastal ecosystems and associated services such as eco-tourism, local industry/agriculture, and livelihood loss. Based on these types of studies, one can influence local and national policy makers for adaptation and mitigation strategies for sustainable economic development of the mangroves ecosystem and its dependent communities.

Publications:

Salik, K. M. and Sehrish J. 2013. Coastal Population more at Risk; Socio-Economic Vulnerability Assessment of Indus Delta under Climate Change. Sustainable Development Policy Institute (SDPI), Islamabad, Pakistan, Research & News Bulletin, Vol. 20 No. 2

Salik, K. M., Mohammad M. H., and Sadia I. 2014. Socio-Economic Vulnerability of Mangrove Ecosystems to Climate Change in South Asia: A Case Study of the Indus and Ganges Deltas. APN Science Bulletin Issue 4 (March 2014). Retrieved from http://www.apn-gcr.org/resources/items/show/1932

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Zafar, W. Kashif M. S. 2014. Mangrove Forests and Changing Policy Concerns in Pakistan. Policy Review, climate change special. Sustainable Development Policy Institute (SDPI), Islamabad, Pakistan.

Salik, K.M., Hasan, M.M., and Ishfaq, S. (2014), Socio-Economic Vulnerability of Mangrove Ecosystem to Climate Change in South Asia: A Case Study of the Indus and Ganges Deltas. APN Science Bulletin (4), Asia Pacific Network for Global Change Research, ISSN 2185-761X.

Research Papers Submitted to Journals:

Salik, K. M., Sehrish J. and Waheed Z. Shabeh H. 2014. Socio-economic Vulnerability of the Indus Delta to Climate Change and the possible Adaptations: A Case Study of Keti Bandar, Pakistan. Int. J. Ocean & Coastal Management (in review process).

Salik, K. M., Mohammad Z. R., Waheed Z. Z., and Sadia I. 2014. Ecological Assessment of the Indus Delta at Keti Bandar Pakistan: A Desktop Analysis of Environmental Flow Requirements and Impacts of Climate Change-Induced River Flow Changes. Int. J. Environmental Earth Sciences (in review process).

Hashmi, M. Z., Salik, K. M., Saeed, U., Shehzad, N., Zafar, W. (2014). Spatiotemporal Patterns of Land Cover Changes under Changing Hydrological Conditions. Int. J. Ecohydrology (in review process).

References:
The complete list of references is provided in the end of 'Technical Report' section.

Acknowledgments
We would like to thank Asia Pacific Network (APN) for Global Change Research, Japan for funding this study under the project '*Impact of climate change on mangroves ecosystem in South Asia*'. We would also like to express sincere gratitude to all researchers and collaborative institutions such as WWF-Pakistan and IUCN-Pakistan for their valuable suggestions and kind support. We especially thanks to Dr. Ejaz Ahmad, Urooj Saeed, Ali Dehlavi and field staff of Keti Bandar of WWF-Pakistan for their outstanding cooperation and coordination during field activities and provision of GIS/RS facilities. Our warmest thanks to researchers of Global Change Impact Studies Centre for their valuable and crucial contribution in different studies of this report. In the last we are also thankful to Meteorological Departments of Pakistan and Bangladesh for providing time series climate data used in this project.

Preface

In South Asia, mangroves ecosystems are faced with the constant risk of disintegration due to human activities such as clearing of land for agriculture and urban development. However, climate change is another emerging threat to these ecosystems as well as services it provides. This project was proposed to understand the impact of climate change on community's wellbeing, land cover changes under different climatological episodes, and salinity distributions due to sea level rise. The report besides providing an assessment on freshwater flows and ecological health of mangroves, analyzes the role of institutions for the sustainability, development and conservation of mangroves.

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1. Introduction

The mangrove ecosystems are the inter-tidal and super-tidal muddy shores found in bays, lagoons and estuaries turn into an important component of our natural ecosystems. These are dominated by woody halophytes which are highly adapted with continuous water courses, swamp and backwaters (Pinto, 1986). They feed and breed an amazing diversity of economically and ecologically important flora and fauna (Walters et al. 2008, Valiela et al. 2009). Not only are they a source of livelihoods for dependent communities but they also contribute to global climate mitigation efforts through CO_2 sequestration.

The distribution of mangroves in the world is limited to the tropical and sub-tropical regions with best development between 25°N and 25°S. Mangrove ecosystems are found as discontinuous patches all around the coastal area of Pakistan, Bangladesh and Sri Lanka. Their high productivity mangrove ecosystems provide resources for household activities and livelihoods for coastal communities, who are usually marginalized in terms of economy. During the past decade most of these mangrove ecosystems in these countries have been exploited. Expansion of shrimp farming, urbanization, tourism and industries are some of the main causes for mass clearing of mangrove patches (IUCN, 2012).

Generally speaking, the identified study areas were common in that their residents were poor, and depends on mangroves' ecosystem services. They dwelled in small and scattered settlements usually around fringes of creeks that were highly vulnerable to natural calamities. Their socio-economic conditions were characterized by poor basic facilities and limited opportunities, as often reported in similar studies (see Agrawal 2008). In addition, they shared the following common features: (i) close proximity to mangrove forests; (ii) high local dependence on mangrove resources; (iii) prone to natural disasters (presently or in the past).

With the present trends of global warming, climate change related factors are also affecting the survival of mangrove ecosystems. Increasing temperature, increasing atmospheric CO_2, change of precipitation patterns, frequency and intensity of tropical storms and most importantly sea level rise are the main climate change driven factors that are affecting mangrove ecosystems and livelihood (McLeod and Salm, 2006). IPCC report (2007) depicts a climate change scenario that indicates that by the end of 21st century, there could be +1.1 to +6.4 °C variation (or increase) in the overall global temperature and –30 to +30 % variation in the precipitation. The expected variation in the world climate is quite alarming as the increase in air temperature will result in melting of glaciers at a faster pace (Oerlemans, 2001; Kuhn, 1981) and therefore increase variability of water availability for any type of ecosystems.

Scope of the project

This project was intended to study the impacts of climate change on mangrove ecosystems in South Asia (Pakistan, Bangladesh and Sri-Lanka) and to raise the awareness about that among policy makers at various levels. This project aimed to provide more insights to understand the climate change related socio-economic vulnerability for coastal communities, ecological assessment under different environmental flows (e-flows) regimes and institutional and political performance analysis for Indus Delta, Pakistan; Ganges-Brahmaputra Delta, Bangladesh; and Puttalam Lagoon of Sri Lanka in South Asia. Therefore, the specific objectives of study were:

Objectives

- To examine different climatic and hydrological factors under climate change scenarios and assess their linkages and interactions on mangrove ecosystems;
- To carry out vulnerability assessment for socio-economic variable, indicators and processes which are affecting mangrove ecosystem sustainability in selected study areas;
- To develop necessary framework of adaptation/recommendations with respect to policy and institutional intervention for mangroves sustainability and development for decision makers at local, national and regional level.

Implementation of the project activities

Major activities involved during the study were: (i) Climate Change Scenarios development (ii) Analysis of e-flows and ecological conditions and hydrological regimes on mangrove ecosystems and (iii) socio-economic impacts assessment; (iv) Policy review and recommendations; (v) In-depth Interviews with stakeholders (vi) Local stakeholder seminar.

Organizations involved in executing of project:

- Sustainable Development Policy Institute (SDPI), Pakistan
- International Union for Conservation of Nature (IUCN), Sri-Lanka
- Institute of Water Modeling (IWM), Bangladesh
- Global Change Impact Study Center (GCISC), Pakistan
- Department of Oceanography and Costal Sciences, Louisiana State University, USA

Selected study areas:

The selection of areas for case studies was based on the following criteria:

- Ecological importance for the country
- Mangrove ecosystem dependent communities
- Climate change induced disaster prone areas
- Effect of reduced e-flows to mangrove ecosystems

Based on the above criteria, the country-wise study areas selected were:

- Keti-Bandar, Indus Delta in Pakistan
- Dacope Upazila, Ganges-Bharamaputra Delta, Bangladesh
- Puttalam lagoon, Sri-Lanka

2. Methodology

Under this project, each partner country conducted a number of research studies employing varied methodologies depending upon the data availability and access as well as human resources. Detailed methodologies for each research component are given below:

2.1 Climate Change Scenarios Development for study sites of Pakistan, Sri Lanka and Bangladesh

For future climate change projections PRECIS model was used. PRECIS is a third generation Hadley centre RCM and is based on the latest GCM, HAdCM3 (Gordon at et al) having horizontal resolution of 50km. It has 19 vertical levels in the atmosphere, stared from the surface to 30 km in the stratosphere and four vertical levels in the soil (Cullen. 1993). PRECIS is a limited area high resolution model based on land surface and atmosphere. Model can be nested over a limited area in a GCM and is also locatable over any part of the world (Jones et al., 2004).

Data set used with PRECIS:
PRECS RCM is forced by model derived boundary conditions output data provided by 30-year integration of ECHAM4 GCM of Germany. Simulation has been done on an idealized 360-day calendar for A2 and B2 scenarios.

a. A2 Scenario

This scenario is based upon regionalization, emphasis on human wealth Regional and intensive (conflict of civilizations). It describes a very heterogeneous world. In this scenario, there is a continuous population growth, per capita growth and technological changes are more uneven, and slower than in other scenarios.

b. B2 Scenario

It is based on regionalization emphasis on sustainability and equity regional and extensive (mixed green bag). In this scenarios emphasis is on local solutions to economic, social and environment sustainability. Increasing population rate but lower than A2, less rapid and more assorted technological changes that other scenarios. It focuses on local and regional level with environment protection and social justice.

Methodology
The Model was driven by the input data of ECHAM4 GCM covering the domain of South Asian from 5 degrees to 50-degree north and 55 degrees to 100 degrees east. Simulations were done for the time periods comprising 1961-1990 (base line), 2010-2039 (2020s), 2040-2069 (2050s) and 2070-2099 (2080s) with the horizontal resolution of 0.44 degree (50km).

CRU data set (New et al, 1999) of monthly mean temperature and precipitation on 0.5-degree resolution is used for the validation and comparison of downscaled data. Model output data was not on regular grids therefore one had regridded to regular latitude / longitude grids (dx = dy =50 km) to make possible comparisons. Validation is done for the 30-year annual mean climatology of temperature and precipitation.

Validation
The first step to move for the future projections of any particular RCM, Model validation is necessary. To validate ECHAM4, CRU data is used for the calculation of biases in the model. 30-year average bias for temperature (left column) and precipitation (right column) is shown in Figure 1. Spatial patterns are compared for model and CRU data. The model's response in simulating temperature is always better than precipitation because of high variability in precipitation which is local or short distance phenomena and model usually is not able to capture these local atmosphere conditions.

In case of temperature, model shows a good agreement with CRU over western highlands, east and west Baluchistan and coastal areas of Pakistan. Cold bias is observed over northern parts of Pakistan and warm bias occurs over central Punjab and lower Indus plains as shown in Figure 1. Precipitation patterns are reasonably captured by the model over most parts of Pakistan except the northern parts because of the complex topographic terrain. Model shows the high over estimation of precipitation over northern parts of Pakistan.

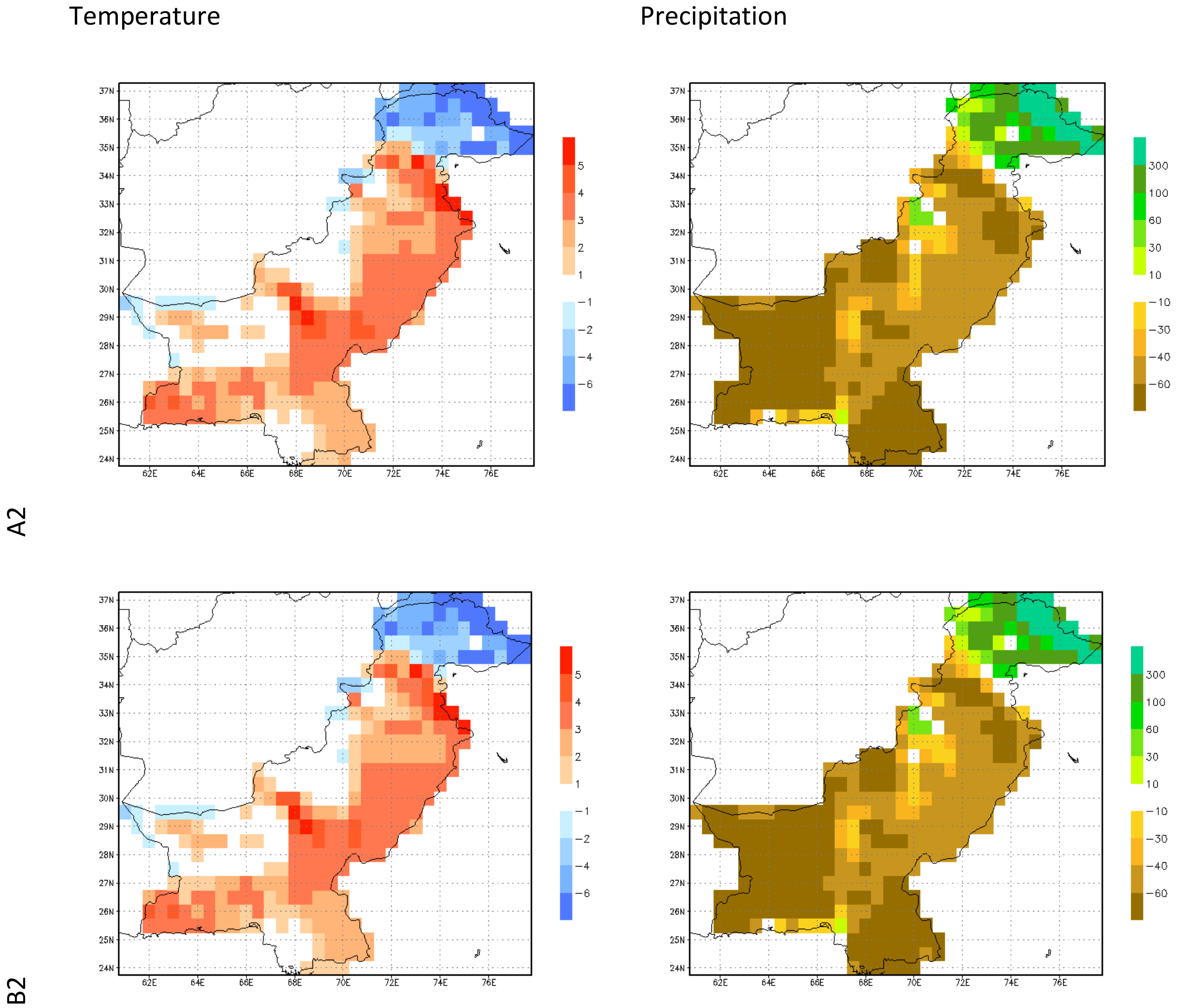


Figure 1: Biases of temperature and precipitation over Pakistan for the period 1961-1990.

Correlation between model data (i.e. ECHAM4 downscaled data) and CRU dataset for temperature and precipitation is calculated for 30-years (1961-1990) and is shown in Figure 2. Model and CRU temperature is very strongly correlated over most parts of Pakistan particularly over northern parts, central & south Punjab and west Baluchistan where correlation is up to 0.98.

In case of precipitation, less correlation is observed over northern and western parts of Pakistan whereas the reasonable correlation is observed over monsoon dominated region (sub-montane region) of Pakistan, which shows that model is able to capture the monsoon path of Pakistan.

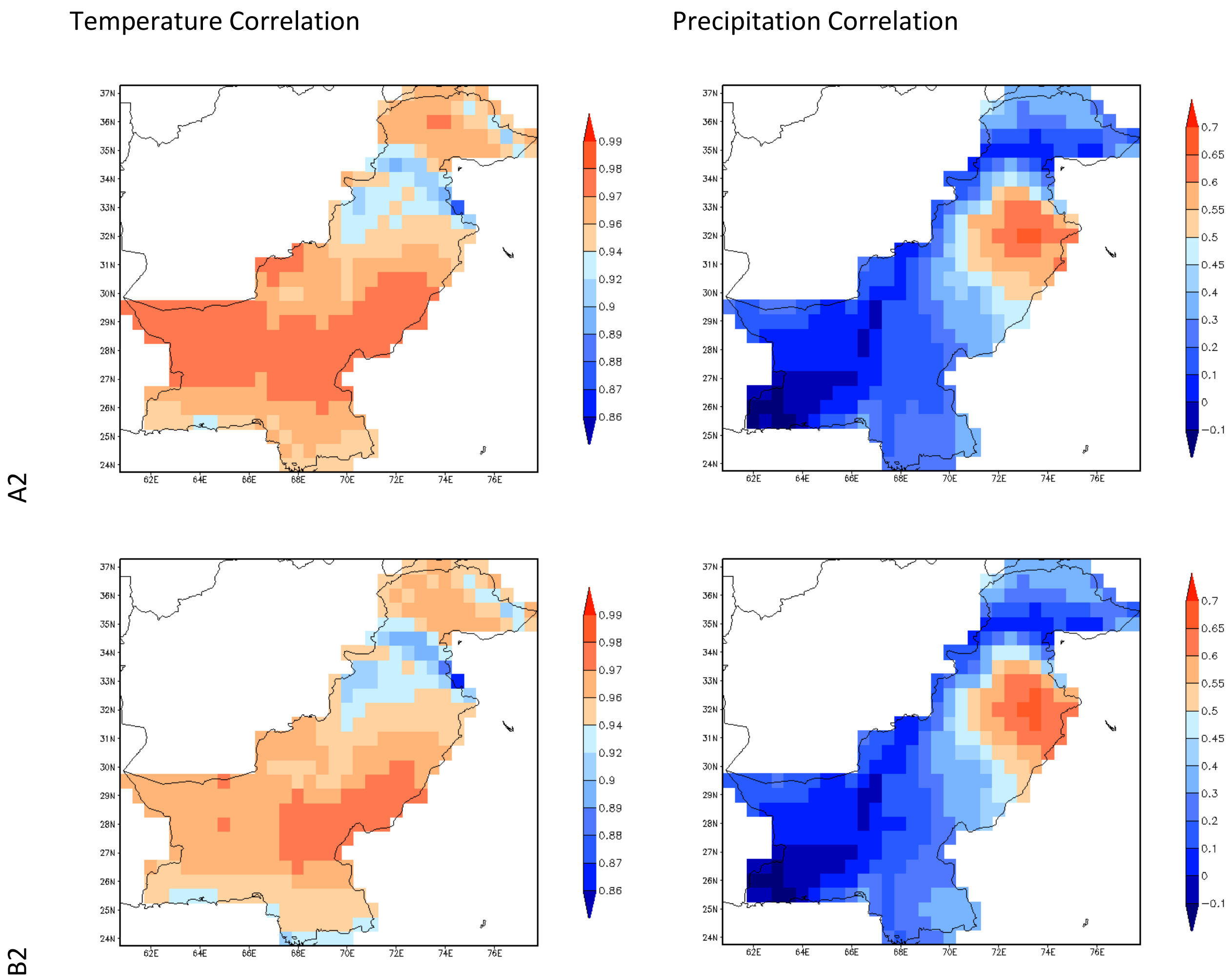


Figure 2: Correlation of monthly temperature and precipitation for the period 1961-1990.

2.2 Hydrological Analysis- Methods and Procedures

For assessment of hydrological impact on mangroves ecology, its growth and extent due to climate change following methodological tools and procedure were employed:

1) To understand the change in growth and extent of mangroves forest due variations in flow regimes in the study area RS/GIS based land cover/use mapping techniques were used. For this image classification was carried for a single time instance of each of the five selected years (based on availability and quality of the imagery) during the period of 1987-2011. These years were selected owing to their hydrological significance as depicted in Table 1 and Figure 3.

Table 1: Hydrological significance of the five selected years for land-use/land cover analysis

Year	Hydrological significance
1992	A major recorded during the monsoon season causing a lot of damage
1998	Start of a drought that is ranked as the worst during the recent history of the country
2002	End of the drought period that started in 1998
2010	An extremely devastating flood
2011	A major flood that that came when the country was still trying to recover from the devastations of previous year flood

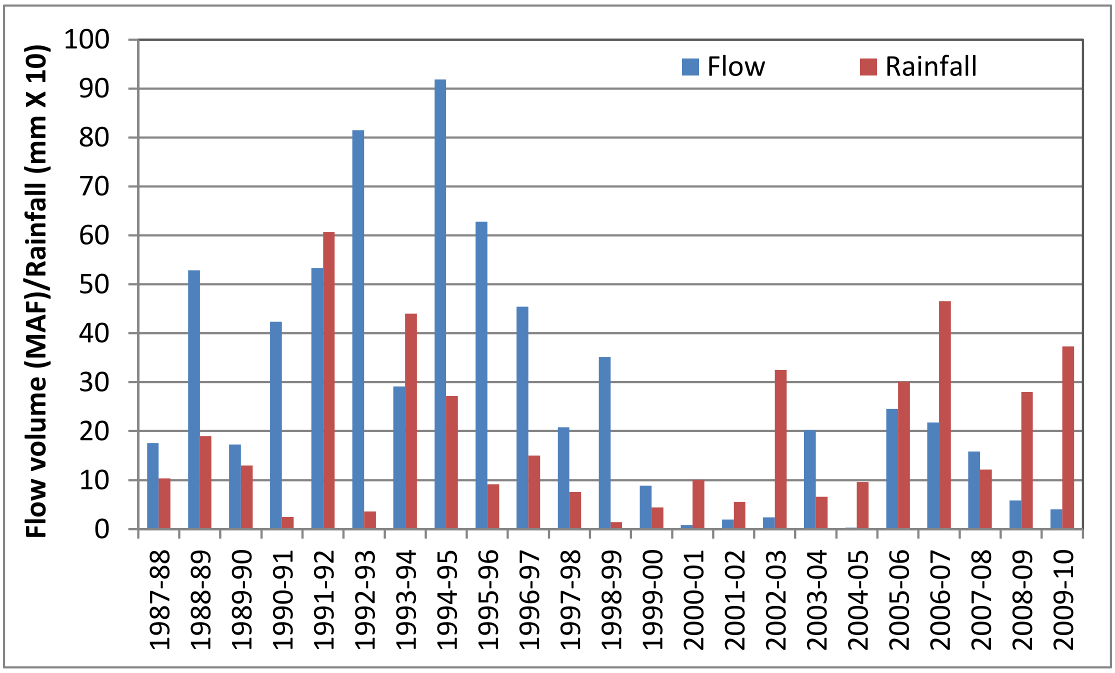


Figure 3: Hydrological regime of the study area for the period 1987 to 2010

Fig.3 shows that starting from hydrologic year 1988-89, a wet hydrological regime (in terms of river flow downstream of Kotri barrage and local rainfall) was prevailing including two big river flood events in 1992-93 and 1994-95. On the other hand, year 1997-98 is seen as start of the worst drought of the recent history of this region. The dry hydrologic conditions seem to get better after year 2002-03.

The events of river flooding bring the nutrient rich soil and control the sea water intrusion leading to lowering soil salinity levels. In some cases, it may cause some negative effects e.g. plant death due to prolonged inundation, uprooting, and soil erosion (Jiménez and Lugo 1984). Therefore, this study included a flood frequency analysis based on annual maximum data for the period of 1976-2003 and fitting GEV distribution to this data. The results of this flood frequency analysis are given in Table 2.

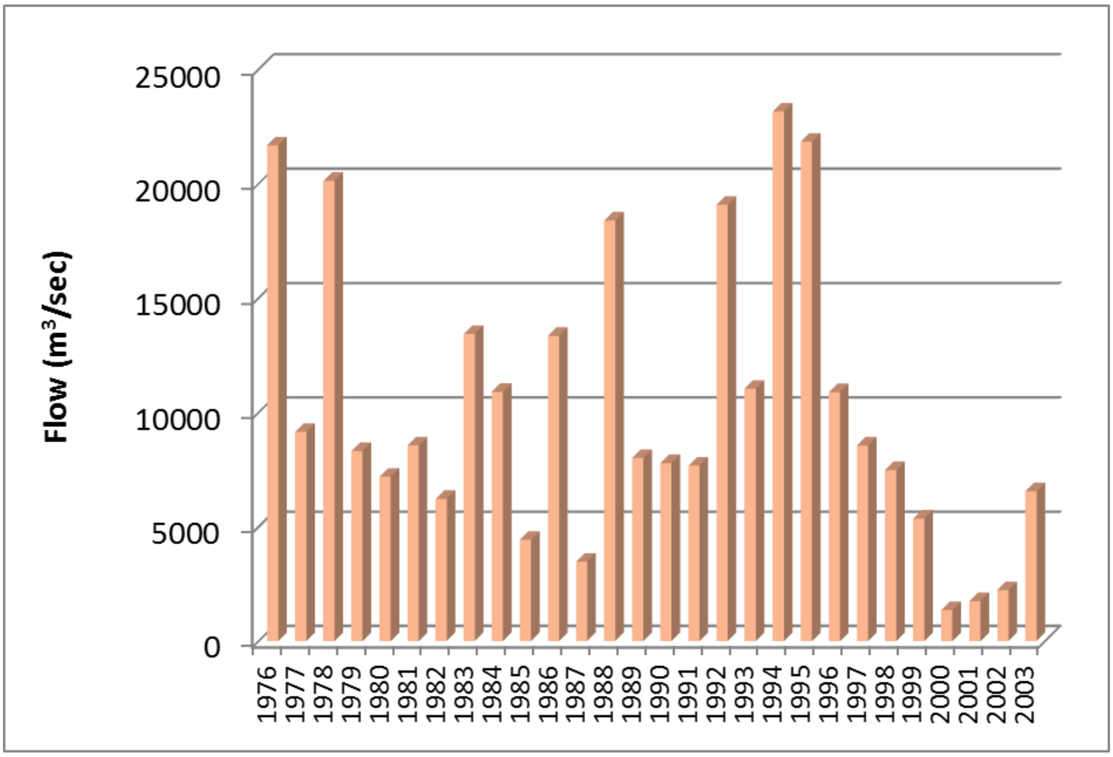


Figure 4: Annual maximum flow recorded downstream of Kotri barrage

Table 2: Discharge values of different return periods based on 1976-2003 annual maximum data

Return Period	Discharge (cumecs)
5	14694
10	18554
20	22363
50	27451
100	31385
200	35412

Work Flow Diagram for Classification

Temporal thematic maps were generated on historic and current data sets of the project area. The flow chart describes the method adopted for the change analysis.

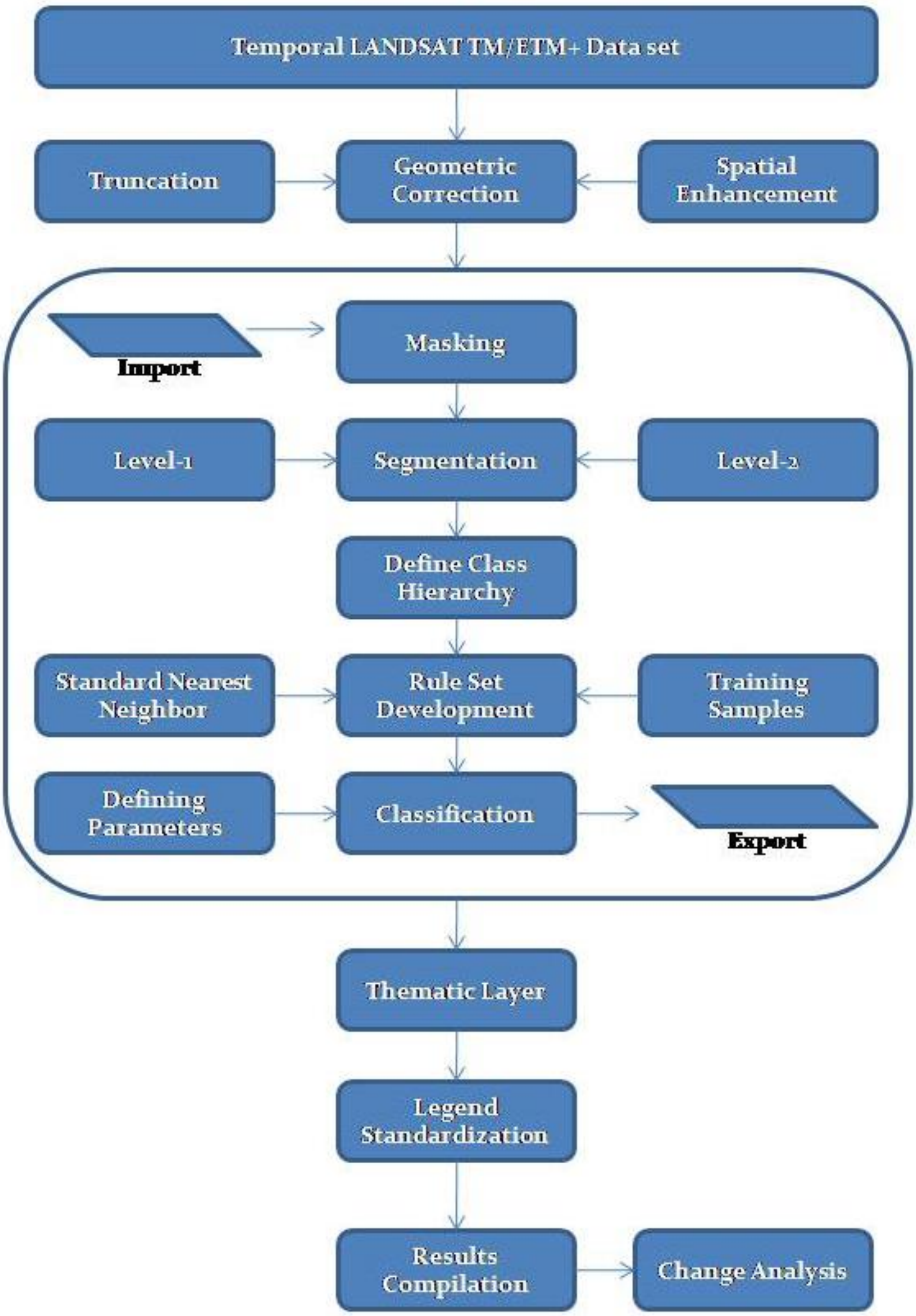
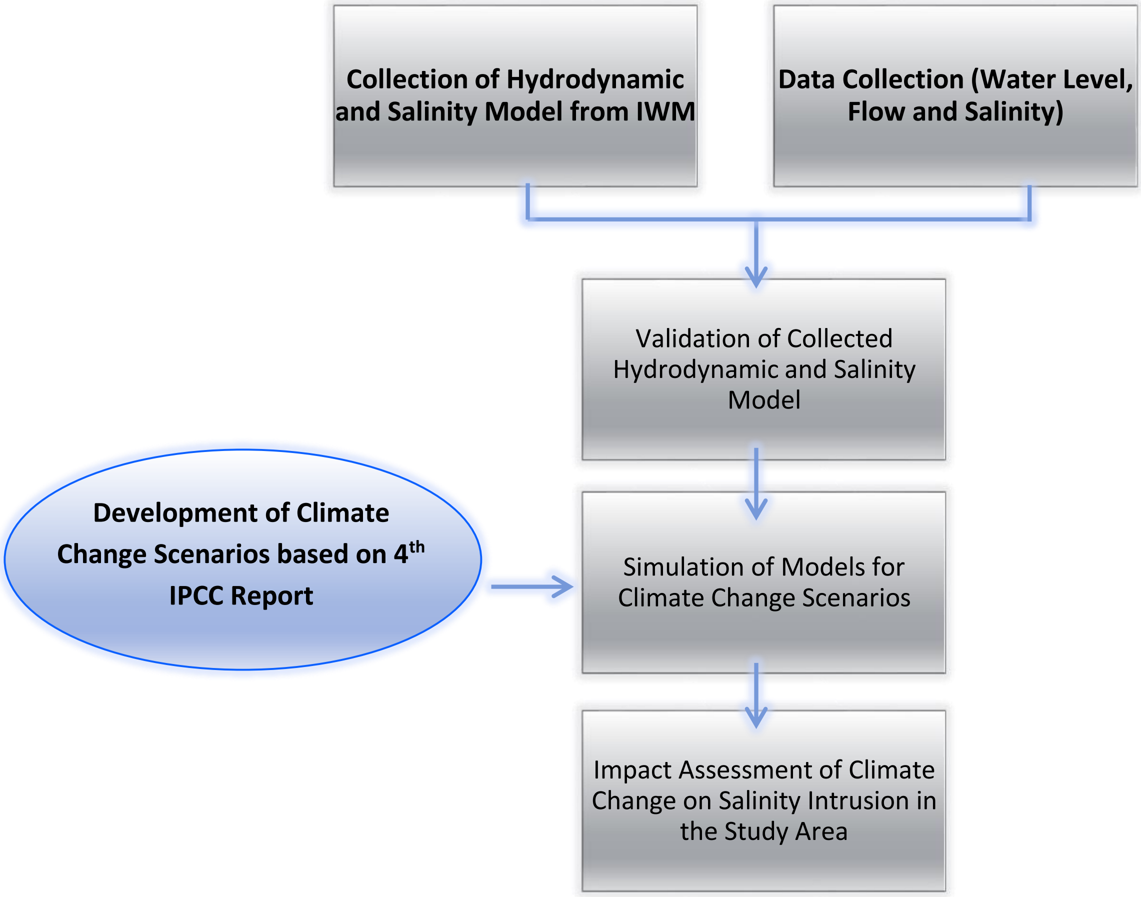


Figure 5: Flow diagram of Land Cover / Land Use Mapping

2) Water Flow and Salinity Modeling: Water level, flow and salinity distribution at and around the study area has been assessed by using two types of salinity model namely Southwest Regional Hydrodynamic and Salinity Model and Bay of Bengal Salinity Hydrodynamic and Model. The available salinity models for the coastal area of Bangladesh has been developed based on MIKE11 and MIKE 21 FM modeling system and applied for a number of projects over the last 20 years to find the spatial and temporal variation of water level, flow and salinity level over a year and also to examine the effect of climate change on landward movement of salinity front and in assessing the fresh water availability. The models for water flow and salinity for the coastal region of Bangladesh are well calibrated and validated and calibration results showed good agreement with the measured water flow, water level and salinity over the time and space.



Steps to Assess the Climate Change Impact on Salinity Intrusion

2.3 Environmental Flow Assessments

This analysis consists of two stages of analysis. The first stage involves assessment of existing state of deltaic ecology where the river downstream of Kotri Barrage is categorised into an arbitrary environmental management class (EMC), based on Smakhtin *et al.*'s (2007) prototype model developed at IWMI. Selected indicators from IWMI model were replicated in this study, based on data availability, and expert knowledge.

Participatory stakeholder consultations were conducted in Indus Delta, Pakistan, with government and municipal departments, fishermen community, and local residents over two weeks in April 2013.

The scoring for each of the indicators ranges from a scale of 1 to 5, where 1 is the lowest and 5 is the maximum. The sum of all the indicators when added is expressed as the percentage of maximum possible sum. The percentage derived gives a reasonable estimate of the most likely environmental management class (EMC) into which a river may be placed, and the e-flows required for it. Smakhtin *et al.* (2007), who have developed the basic model, place the final scores into 6 separate classes, each corresponding to an arbitrary EMC.

The second stage of the methodology derives e-flows downstream of Kotri Barrage using the Global Environmental Flow Calculator (GEFC ver.1) which is a desktop-based method used for rapidly assessing environmental flows (e-flows) in rivers (Smakhtin *et al*. 2007; Smakhtin 2008). The GEFC first requires selection of data source which can either be user-defined (manual) or extracted from simulated global flow database (default). All data entered records monthly discharges (m^3/s) at a resolution of 0.5 degree. These data are provided by the Water Systems Analysis Group of the University of New Hampshire, USA. The input data provided to the software is used as the reference flow. Reference flow or natural flow is defined as the flow time series of the river recorded during a period when it was flowing without any major anthropogenic intervention (Smakhtin and Anputhas 2006).

The GEFC makes use of monthly time series and corresponding flow duration curves (FDC) which are cumulative distribution function of river flows. The FDC is represented by 17 percentage points on the probability axis, which are 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99.

In addition to FDC for natural reference conditions, the GEFC calculates FDC for six environmental management classes that Smakhtin and Anputhas developed (2006). An environmental management class (EMC) is the e-flow required to sustain or improve an ecosystem in its 'prescribed or negotiated condition' (Smakhtin and Anputhas 2006). Here, FDC for each EMC is estimated by lateral shifting of reference FDC by 1 percentage point to the left on the probability axis (Smakhtin and Anputhas 2006). The 17 percentage points mentioned above are therefore used as steps in the process of FDC shifting. Lower tails of the FDCs represent low flow and are estimated through linear interpolation procedure (cf. Smakhtin et al. 2005). The results are used by experts for classifying studied river system(s) in corresponding EMCs; alternatively, they can also be used to assess e-flows required to keep rivers in a particular EMC. For this study, FDC for different EMC's were derived from the FDC of the Kotri downstream reference flow-time series. The model then estimates the e-flow time series for each of the EMCs from the corresponding derived FDCs.

After determining e-flows requirement under present conditions of the Indus delta, the third and final stage of the research simulates future impacts of climate change on river ecology under two hydrological scenarios:

i. Scenario 1: Increase in river flows due to more glacier melt under warmer climate and also increase in precipitation in the UIB and downstream catchments;
ii. Scenario 2: Decrease in river flows due to no glacier melt contribution following the vanishing of glaciers in the UIB accompanied by reduced precipitation the UIB and downstream catchments.

Observed 10-daily stream flow record of selected Indus River section for the period of 1936-37 to 2005-06 has been acquired for use in this study. The earlier part of the data record (1936-37 to 1954-55) is used for deriving reference flow variability, whereas prevailing river flows are calculated from post-Tarbela Dam data, (i.e. 1976-77 to 2005-06). Monthly average flow data were obtained from the original 10-daily time step data to fulfil the requirement of the software employed (GEFC, explained in next section) in this study.

2.4 Socio-economic Vulnerability Assessment

In this study, Composite Vulnerability Index (CVI) has been used to provide an indicator-based estimation of socio-economic factors of the coastal area in relation to the environmental and climatic parameters (Gornitz*et al.* 1993; Cooper and McLaughlin 1998; Heltberg and Osmolovskiy 2011). Here, we define vulnerability as an estimation of sensitivity and exposure to specific stresses related to climate change, leading to potential impacts that affect the adaptive capacity of a community or any system (Adger *et al*., 2004).

Our study is based on an analysis of existing scientific literature, observed and projected climate change information over the study area, and responses collected from the local communities during the field survey. Based on this selection, comprehensive questionnaire was designed by incorporating the indicators related to exposure, sensitivity and adaptive capacity.

Following Heltberg and Osmolovskiy (2011), we do not weigh the considered variables in the present study. The data of all the considered variables for sub-index *S*, *E* and *A* was normalized using equation 1 (UN-ECLAC 2003; Hasson *et al*., 2014):

$$\acute{X} = \frac{(X - X_{min})}{(X_{max} - X_{min})} \ldots Eqn. (1)$$

Where *X* is any considered variable, X_{max} is the maximum value of the variable, and X_{min} is the minimum value of the variable among its investigated sample. The normalized variables were used to calculate the respective sub-indices (Exposure, $\bar{E}$, Sensitivity, $\bar{S}$, and Adaptive Capacity, $\bar{A}$) using the equations 2 to 4 respectively. The index values have been analyzed through composite analysis after categorizing the normalized indices at different levels to ensure consistency in the results (Comer *et al.* 2012; Hammill *et al.* 2013). Consequently, four categories of vulnerability levels have been developed to categorise the impact of three sub-indices i.e., exposure, sensitivity, and adaptive capacity against vulnerability. Finally, the CVI is calculated by using Eqn. 5.

$$\bar{E} = \frac{1}{6}\left[\sum_{x=1}^{x=4} \frac{1}{12}\left[\sum_{m=1}^{m=12} \acute{E}_{x,m}\right] + \frac{1}{2}\left(\acute{E}_5 + \acute{E}_6\right) + \acute{E}_7\right] \ldots Eqn. (2)$$

$$\bar{S} = \frac{1}{4}\left[\frac{1}{3}\left\{\sum_{x=1}^{x=3} \hat{S}_x\right\} + \frac{1}{2}\left\{\sum_{x=4}^{x=5} \hat{S}_x\right\} + \frac{1}{4}\left\{\sum_{x=6}^{x=9} \hat{S}_x\right\} + \frac{1}{4}\left\{\sum_{x=10}^{x=13} \hat{S}_x\right\}\right] \ldots Eqn. (3)$$

$$\bar{A} = \frac{1}{8}\left[\sum_{x=1}^{x=4} \acute{A}_x + \frac{1}{2}\left(\acute{A}_5 + \acute{A}_6\right) + \frac{1}{2}\left(\acute{A}_7 + \acute{A}_8\right) + \frac{1}{2}\left(\acute{A}_9 + \acute{A}_{10}\right) + \frac{1}{2}\left(\acute{A}_{11} + \acute{A}_{12}\right)\right] \ldots Eqn. (4)$$

$$CVI = \frac{1}{3}[\bar{E} + \bar{S} + (1 - \bar{A})] \ldots Eqn. (5)$$

Where $\acute{E}_x, \acute{S}_x, \acute{A}_x$ are all the normalized variables belonging to Exposure, Sensitivity and Adaptive Capacity sub-indices respectively (See Table 2), *m* is month of the calendar year, $\bar{E}, \bar{S}, \bar{A}$ are the composite values for Exposure, Sensitivity and Adaptive Capacity sub-indices respectively and *CVI* is the composite vulnerability index.

Table 3: Categorization of vulnerability Levels (Adopted and transformed from Comer *et al.* 2012 and Hammill *et al.* 2013)

Index value Scale	Exposure/ Vulnerability	Sensitivity/ Vulnerability	Adaptive Capacity/ Vulnerability	CVI
0.0≤CVI≤0.3	Low/ Low	Low/Low	Low/ Very high	Low
0.31≤CVI≤0.5	Medium/ Medium	Medium/ Medium	Medium/ High	Medium
0.51≤CVI≤0.7	High/ High	High/ High	High/ Medium	High
0.71≤CVI≤1.0	Very High/ Very High	Very High/ Very High	Very High/ Low	Very High

2.5 Institutional analysis and mapping

This study followed a two-step analysis. Firstly, a thorough policy analysis attempted to understand the context within which the existing mangroves governance systems had evolved. Based on foundation of first-stage analysis, the second-stage analysis assessed the institutional appropriateness for the management of mangroves under the jurisdictions of three agencies namely: Port Qasim Authority (PQA), Sindh Forest department (SFD) and Sindh Board of Revenue (BoR). The information reflecting the opinions of these agencies was collected through in-depth interviews with the concerned officials and, wherever possible, substantiated with group discussions. The indicators for institutional analysis were drawn from the literature on common property resources.

3 Results & Discussion

3.1 Climate Change Scenarios for three study sites in South Asia

a. Future Projections for Mangroves Site of Pakistan

Delta of the Indus River is the main location of mangroves in Pakistan. Coastline of Sindh and Baluchistan provinces is the major mangrove forests carrier.

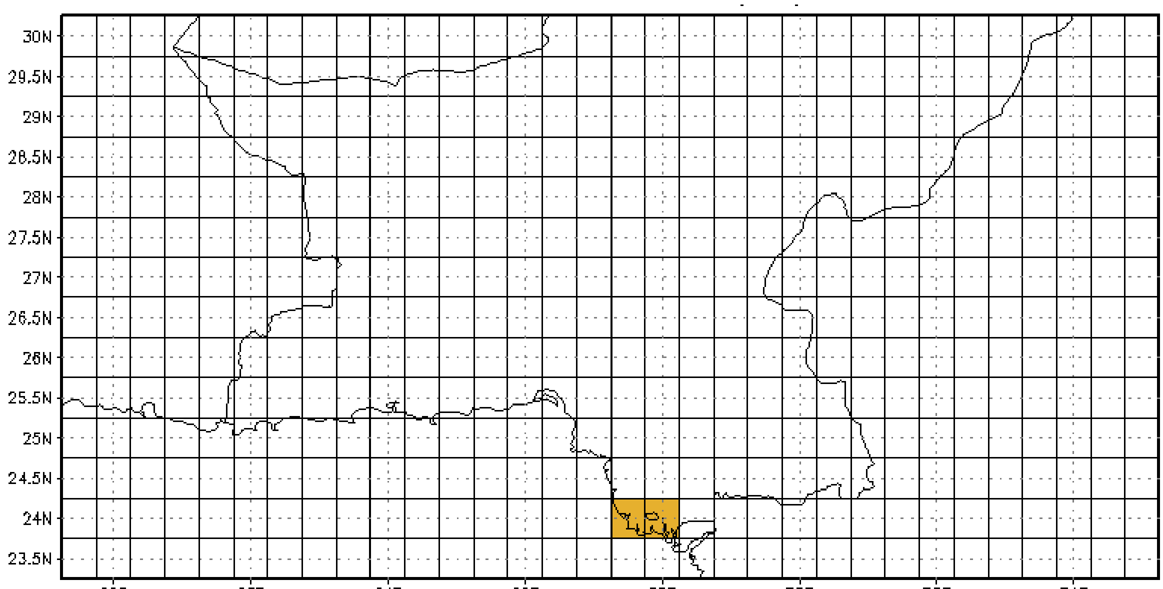


Figure 1: Mangroves site of Pakistan

Temperature (Mean, minimum & maximum) and Precipitation changes are consolidated for 2020s, 2050s and 2080s under A2 and B2 scenario and for different seasons in Table 1, 2, 3 & 4. Changes in A2 scenario are higher than B2 scenario as envisaged in IPCC AR4. Maximum temperature rises up to 4.67 °C over the mangroves area at the end of this century. Temperature changes in winter is higher than summer for both A2 and B2 scenario in the case maximum, minimum and mean temperature as shown in Table 1, 2 and 3 alternatively. Rise in minimum temperature is more than that of maximum and mean temperature for both A2 and B2 scenarios. Annual minimum temperature change is 4.44 °C, annual mean temperature change is 4.05 °C and annual maximum temperature change is 3.68 by the end of 2080s for A2 scenario.

Precipitation is very complex variable for a regional climate model to simulate, because it is a local phenomenon and is difficult to capture the true picture of the variable over a large domain. It also has some uncertainties therefore variability is found in the results. In case of precipitation, increased precipitation is observed for all the season except spring (March, April), where it decreases up to 23 % for A2 scenario. In monsoon (July, August & September) season precipitation is increasing up to 74 % for A2 scenario and 140 % for B2 scenario over the mangroves area of Pakistan as shown in Table 4.

Table 1: Maximum Temperature Projections (°C) over Mangroves in Pakistan

Seasons	**A2 - Scenario**			**B2 - Scenario**		
	2020s (2010-2039)	**2050s (2040-2069)**	**2080s (2070-2099)**	**2020s (2010-2039)**	**2050s (2040-2069)**	**2080s (2070-2099)**
Annual	1.08	2.24	3.68	1.15	1.98	2.80
Winter (DJF)	1.45	3.13	4.67	1.62	2.91	3.77
Spring (MA)	1.17	2.23	3.86	1.16	2.13	2.96
Summer (MJ)	1.05	1.79	3.00	1.02	1.50	2.45

Monsoon (JAS)	0.77	1.81	3.15	0.85	1.49	2.15
Autumn (ON)	0.94	1.93	3.57	0.96	1.65	2.48

Table 2: Minimum Temperature Projections (°C) over Mangroves in Pakistan

Seasons	**A2 - Scenario**			**B2 - Scenario**		
	2020s (2010-2039)	**2050s (2040-2069)**	**2080s (2070-2099)**	**2020s (2010-2039)**	**2050s (2040-2069)**	**2080s (2070-2099)**
Annual	1.33	2.80	4.44	1.39	2.48	3.44
Winter (DJF)	1.66	3.58	5.35	1.81	3.15	4.23
Spring (MA)	1.33	2.76	4.33	1.36	2.47	3.40
Summer (MJ)	1.19	2.26	3.58	1.14	1.88	2.78
Monsoon (JAS)	1.02	2.20	3.75	1.13	2.09	2.77
Autumn (ON)	1.45	2.99	5.17	1.46	2.77	3.94

Table 3: Mean Temperature Projections (°C) over Mangroves in Pakistan

Seasons	**A2 - Scenario**			**B2 - Scenario**		
	2020s (2010-2039)	**2050s (2040-2069)**	**2080s (2070-2099)**	**2020s (2010-2039)**	**2050s (2040-2069)**	**2080s (2070-2099)**
Annual	1.20	2.52	4.05	1.29	2.24	3.11
Winter (DJF)	1.57	3.35	5.00	1.74	3.02	3.99
Spring (MA)	1.22	2.41	4.01	1.25	2.26	3.12
Summer (MJ)	1.11	2.06	3.29	1.11	1.71	2.62
Monsoon (JAS)	0.90	2.02	3.45	1.02	1.83	2.49
Autumn (ON)	1.21	2.49	4.41	1.26	2.24	3.22

Table 4: Precipitation Projections (%) over Mangroves in Pakistan

Seasons	**A2 - Scenario**			**B2 – Scenario**		
	2020s (2010-2039)	**2050s (2040-2069)**	**2080s (2070-2099)**	**2020s (2010-2039)**	**2050s (2040-2069)**	**2080s (2070-2099)**
Annual	108.31	54.76	83.40	98.72	119.23	115.40
Winter (DJF)	22.94	-24.71	68.76	133.32	-2.79	92.70
Spring (MA)	0.31	20.81	-23.11	-34.69	-21.89	24.63
Summer (MJ)	-13.10	24.15	21.57	5.49	-19.55	13.48
Monsoon (JAS)	124.14	56.79	73.95	121.93	142.56	140.72
Autumn (ON)	128.64	108.94	255.02	15.14	107.99	34.06

b. Future Projections for Mangroves Site of Sri Lanka

There are many types and species of mangroves located in Sri Lanka. The widest spread mangrove occurs in Puttalum. The mangroves ecosystem in Sri Lanka is rapidly decreasing due to anthropogenic activities mainly due to the extraordinary tourism sector. Mangroves also influence the livelihood of the local coastal communities by playing an important role for hydrological functions and provide breeding facilities for fish and other aquatic species. Mangroves ecosystem are also very important to barrier the tsunami waves and protection of human inhabitations.

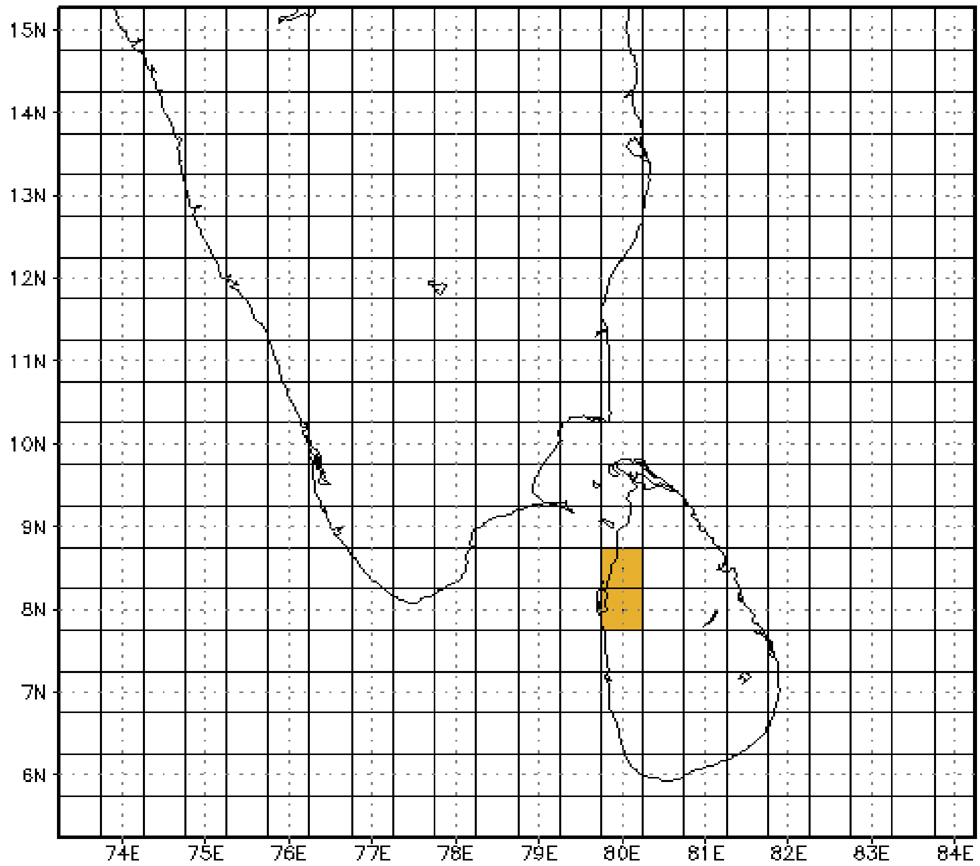


Figure 2: Mangroves site of Sri Lanka

Temperature (Mean, minimum & maximum) and Precipitation changes are calculated for 2020s, 2050s and 2080s under A2 and B2 scenario and for different seasons over the mangroves area of Sri Lanka is consolidated in Table 5,6, 7 & 8.

Changes in winter and autumn temperature are higher alternatively as compared to other season for mean, maximum and minimum temperature. Minimum temperature change is higher than mean and maximum temperature. Annual temperature change is 3.85 °C, annual mean temperature change is 3.56 °C and annual maximum temperature is 3.49 °C in 2080s as shown in Table 5, 6 & 7. The lowest temperature change is observed in summer (May, June) season for all maximum, minimum and mean temperature and for both A2 and B2 scenarios.

In case of precipitation, it is observed that precipitation change is decreased in winter, spring and autumn seasons for both scenarios. The highest precipitation change is seen in summer season which goes up to 100 % as shown in Table 8.

Table 5: Maximum Temperature Projections (°C) over Mangroves in Sri Lanka

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	0.87	1.98	3.49	0.92	1.77	2.53
Winter (DJF)	1.08	2.47	4.00	1.32	2.37	3.17
Spring (MA)	0.96	2.19	3.73	1.15	2.03	2.82
Summer (MJ)	0.70	1.28	2.89	0.58	1.22	1.68
Monsoon (JAS)	0.68	1.64	3.00	0.74	1.43	2.01
Autumn (ON)	0.96	2.35	3.90	0.77	1.74	2.92

Table 6: Minimum Temperature Projections (°C) over Mangroves in Sri Lanka

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	0.97	2.18	3.85	1.07	2.00	2.84
Winter (DJF)	1.01	2.50	4.34	1.23	2.29	3.23
Spring (MA)	0.90	2.19	3.84	1.01	1.94	2.87
Summer (MJ)	0.86	1.78	3.33	0.88	1.68	2.38
Monsoon (JAS)	0.97	2.00	3.49	1.05	1.85	2.54
Autumn (ON)	1.13	2.38	4.27	1.15	2.19	3.11

Table 7: Mean Temperature Projections (°C) over Mangroves in Sri Lanka

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	0.88	2.01	3.56	0.96	1.81	2.59
Winter (DJF)	1.01	2.43	4.05	1.23	2.21	3.09
Spring (MA)	0.92	2.10	3.63	1.05	1.92	2.73
Summer (MJ)	0.75	1.49	3.02	0.72	1.41	1.98
Monsoon (JAS)	0.81	1.79	3.18	0.88	1.60	2.23
Autumn (ON)	0.96	2.26	3.96	0.90	1.87	2.89

Table 8: Precipitation Projections (%) over Mangroves in Sri Lanka

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	8.95	13.89	17.14	33.43	16.93	14.25
Winter (DJF)	-27.78	-30.61	-58.37	-15.71	-44.42	-55.37
Spring (MA)	1.45	-19.94	-8.29	13.55	-9.86	-14.86
Summer (MJ)	29.54	83.67	69.61	122.04	85.48	100.08
Monsoon (JAS)	15.82	27.39	39.34	37.62	26.14	30.21
Autumn (ON)	2.49	-12.05	-8.70	8.40	2.80	-15.08

c. Future Projections for Mangroves Site of Bangladesh

The Sundarbans is the largest mangrove forest in the world covering the parts of Bangladesh and Indian state of West Bengal. Sundarbans is a UNESCO World Heritage site. Bangladesh is confined by sundarbans South, East and West and is densely covered by mangrove forests.

Most the mangroves types exist in the world are grown in Sundarbans e.g. mangrove scrub, brackish water mixed forest, littoral forest, wet forest and salt water mixed forest. The vegetation of Sundarbans located in Bangladesh is very different from other non-deltaic coastal mangrove forests.

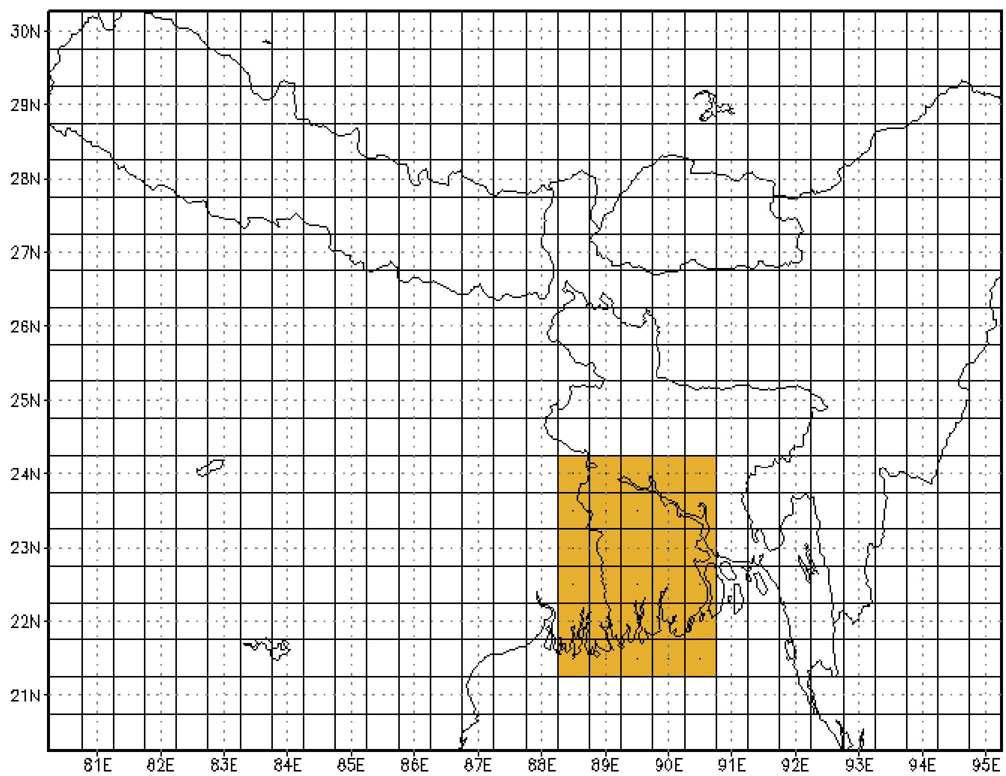


Figure 3: Mangroves site of Bangladesh

Temperature (Mean, minimum & maximum) and Precipitation changes are calculated for 2020s, 2050s and 2080s under A2 and B2 scenario and for different seasons over the mangroves area of Bangladesh is shown in Table 9,10,11 & 12.

Changes in temperature over the mangroves covered area of Bangladesh are higher than the mangroves of Pakistan and Sri Lanka. Temperature rise in minimum temperature is more than that of maximum and mean temperature for both A2 and B2 scenarios. Minimum annual temperature change is 3.33 °C, mean annual temperature change is 3.08 °C and maximum annual temperature change is 2.92 °C for B2 scenario. Winter (December, January & February) temperature change is always higher than any other season for both scenarios. Annual temperature will rise up to 5 °C by the end of this century in A2 scenario as shown in Table 10.

Precipitation is decreases in winter in 2050s and 2080s for both scenarios, whereas it increases almost 100 % in summer for A2 scenario and 72 % for B2 scenario. The annual precipitation change is 47 % for A2 scenario and 28 % for B2 scenario is observed by the end of century as shown in Table 12.

Table 9: Maximum Temperature Projections (°C) over Mangroves in Bangladesh

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	0.90	2.12	3.87	0.90	2.07	2.92
Winter (DJF)	1.73	3.87	6.37	1.78	3.35	4.95
Spring (MA)	0.76	2.02	3.35	0.56	1.83	2.64
Summer (MJ)	-0.42	0.30	1.90	-0.26	0.72	1.18
Monsoon (JAS)	0.83	1.54	2.76	0.88	1.70	2.20
Autumn (ON)	1.28	2.33	4.36	1.03	2.17	3.13

Table 10: Minimum Temperature Projections (°C) over Mangroves in Bangladesh

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	1.16	2.61	4.42	1.30	2.33	3.33
Winter (DJF)	1.99	4.28	6.34	2.13	3.39	5.02
Spring (MA)	1.08	2.64	4.14	1.11	2.13	3.22
Summer (MJ)	0.52	1.59	3.11	0.64	1.59	2.27
Monsoon (JAS)	0.87	1.80	3.26	1.01	1.83	2.46
Autumn (ON)	1.22	2.41	5.09	1.33	2.44	3.50

Table 11: Mean Temperature Projections (°C) over Mangroves in Bangladesh

Seasons	A2 - Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	1.02	2.34	4.10	1.10	2.17	3.08
Winter (DJF)	1.82	3.98	6.20	1.93	3.28	4.86
Spring (MA)	0.91	2.28	3.73	0.85	1.94	2.88
Summer (MJ)	0.08	1.01	2.56	0.23	1.18	1.79
Monsoon (JAS)	0.85	1.67	3.00	0.93	1.75	2.30
Autumn (ON)	1.25	2.36	4.68	1.19	2.29	3.28

Table 12: Precipitation Projections (%) over Mangroves in Bangladesh

Seasons	A2 – Scenario			B2 - Scenario		
	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)	2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Annual	8.43	23.30	47.51	28.43	18.91	27.75
Winter (DJF)	7.36	-18.70	-38.85	51.28	-20.89	-42.30
Spring (MA)	16.50	40.40	87.32	105.33	57.87	59.43
Summer (MJ)	45.88	75.68	104.55	64.73	33.56	72.51
Monsoon (JAS)	0.21	12.86	35.91	9.42	13.72	16.06
Autumn (ON)	-10.11	7.32	42.46	109.51	46.95	67.85

Conclusions

Dynamical downscaling has been done for the construction of future climate change projections under A2 and B2 scenarios for the time slices of 2020s, 2050s and 2080s. PRECIS Model of ECHAM has been used and future projections have been developed for mangroves site of Pakistan, Bangladesh and Sri Lanka.

Before the construction of future projections, output of the model was validated. The result showed that the downscaled GCM is able to capture the climatic features of the region fairly well. Some cold biases are observed over the northern parts of Pakistan and negligible biases are observed over west Baluchistan, KPK and coastal areas of the country. Whereas over estimation of precipitation is observed over northern parts of Pakistan (due to the complex topography and high variability in precipitation).

The future projections over the mangrove areas of Pakistan show the rise in maximum temperature up to 4.7°C in the end of this century. Temperature changes over the mangroves of Pakistan, Bangladesh and Sri Lanka for A2 scenario are higher than B2 scenario due to the rigid assumptions of A2 Scenario. Temperature changes in winter is higher than summer over all three sites of mangroves similarly rise in the minimum temperature is higher than mean and maximum temperature over all three mangrove sites. Temperature changes over the mangrove site of Bangladesh are higher than that of Pakistan and Sri Lanka. Increasing precipitation is observed over all the mangrove sites and for almost for all the seasons.

3.2 Pakistan, Keti Bandar, Indus Delta: Results and discussions

3.2.1 Site Selection and Characterization

The project site covers the area of Keti Bender and Kharo Chann. The study area lies in the Indus Delta and covers 27% of the deltaic area. It extends from 67º 45’ to 67º 17’ longitude and from 24º 46’ to 24º 20’ parallels and covers an area of 162,197 ha (1621 sq. km). The area comprises of major creeks i.e. Hajamro, Kaangri, Turshan, Khober, and Kaanhir (Figure 4).

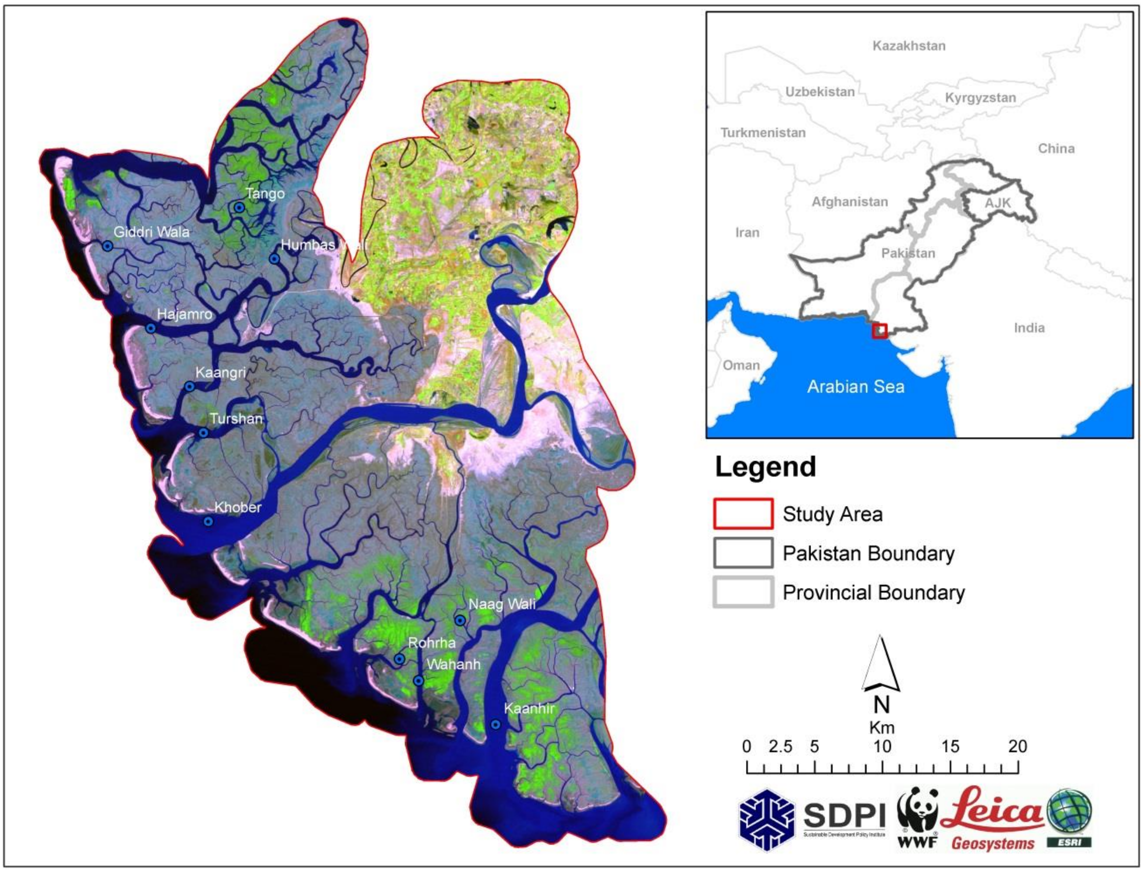


Figure 4: Map of the study area Keti Bandar showing major creeks

Physical Characteristics

Keti Bunder is one the nine Tehsils/Talukas of district Thatta, falling in the Indus Delta extending over the area of 60, 969 hectares. Mangorve forests, mudflats and creeks forms the entire extent of Keti Bunder. Besides a number of minor creeks, the major creeks are Hajamoro, Chan, Kangri and Khobar. Keti Bunder is western most Taluka of district Thatta located 200 km southeast of Karachi.

Keti Bunder has been worst hit by natural disasters several times, engulfing few hamlets in the past century. Currently Keti Bunder constitutes of 42 hamlets with the total population of 12000 comprising 2000 households inhabiting the town and the adjacent creeks. As Keti Bunder is landing and trading ground for fish, the area is mainly dominated by fishermen tribes.

Keti Bunder has three administrative divisions that are Khorabari, Keti Bunder and Munara differing from each other on the basis of climate; which is widening the gap further with the passage of time. Keti Bunder is headquarter division as it is near the coast and attracts the fishermen being their landing site. Ghorabari division is away from the coast, therefore caters fresh water; confining most of the agriculture to its geographical boundary. Whereas Manara divisions mostly consists of islands, where sea intrusion enhances the islands formation process.

Socioeconomic Characteristics

Thatta among all the 23 districts of Sindh stands lowest in terms of economic development and Keti Bunder Tehsil ranks lowest among the administrative divisions. Among the administrative divisions of Keti Bunder, the Munara catering island represents the least privileged population of the Keti Bunder.

The main source of income in Keti Bunder is fishing, followed by agriculture; which is confined mostly to Ghorabari as it receives fresh water supplies from Indus. Cattle including camel, sheep and buffaloes are raised to meet the milk needs, however, lack of fresh water in island doesn't support the cattle. Due to increasing poverty and limited sources of income, people have added catching mud crabs as their additional source of income.

Around 500 fishing vessels of which 50% are small, while 15% are medium and 35% are large, that are operating in Keti Bunder. Around 10-15% fishermen have their own boats, while other boat owners hire the fishermen, which are given share on total catch. Fishermen, remains entangled with the boat owners, because of loans taken for domestic purposes.

Non-agricultural occupations in Keti Bunder are as low as 2 to 3 percent due to lack of development planning and absence of infrastructure. According to the statistics of Pakistan Fisher Folk Forum, 50 poultry farms are running in the area, however, there are only 1 flour mill and 2 ice factories in the entire Tehsil. Unavailability of water, followed by poor infrastructure and human resource capital are the reasons behind stagnant development of the area.

Mangroves Species Distribution in the Study Area

Around eight species of mangroves flourished in the study area in the past but only four species presently exist. Among the existing four species, that is Avicennia marina, Ceriops tagal, Aegiceras corniculatum and Rizophora mucronata, the former is dominating by 95%. Rhizpophora mucronata naturally occurs at Miani Hor in Baluchistan only but it has been introduced at Keti Bunder during re-plantation initiatives.

DPSIR Framework Analysis

According to the studies conducted by SUPARCO, the mangroves cover in Indus Delta reduced from 260,000 ha in 1978 to 81,684 ha in 2003, while the mangroves cover increased to 106,480 ha in 2008 respectively. The increased witness was due to the rehabilitation interventions for mangroves initiated by international NGOs and government departments.

DPSIR framework of analysis using cause-effect relationship while triangulating social, economic and environmental components involved is deployed as site characterization method. The framework will explain the environmental and societal causes of mangroves degradation, the socioeconomic status of mangroves dependent society, the ability of community to address the problem caused and the response that is practically observed either by the society or the other groups (like government departments and NGOs) working in the study area.

DPSIR framework discusses the situation at five stages that is identifying drivers and pressures, defining the current state, the impact on the society and the response generated in reaction to the prevailing issue. The DPSIR framework for Keti Bandar site is discussed as follows.

Drivers

- Unavailability of fresh water, increase in salinity levels and sea water intrusion
- Industrial Pollution
- Limited livelihood options and overdependence on fishing

Pressure

- Over harvesting and overgrazing of mangroves

State

- Reduction in mangroves species diversity
- Reduction in fish species and diversity

Impact

- Increased socio-economic stress on society
- Decreased adaptive capacity

Response

- Re-plantation effort by government departments and non-governmental agencies
- Integrated projects on social and environmental vulnerability assessment

Dependence on River Indus

Pakistan is an agriculture depended country which consumes about 98 % of its water for agriculture. Indus River is the major contributor for the irrigation system of Pakistan (having Sutlej, Chenab, Jhelum, Beas and Ravi as its major tributaries). About 40.0 Mac (million acres) of irrigation is provided by the river Indus covering an area of 73% productive land which is the source of 90% of agriculture output. The imperative river Indus originates from the Tibetan plateau which runs through Jammu Kashmir and enters into Pakistan in the north and runs all along the length of Pakistan towards the south ending up falling in Arabian Sea. Its total length is 3,180 kilometers.

According to the PWSS (2002) from 152 MAF (Million Acre Feet) annual water supply of Indus River 104 MAF is diverted for irrigation, with 38 MAF flowing in the sea and about 10 MAF is wasted in the system. This accounts that around 70% of its water is being consumed for the irrigation purpose. This supply rate is expected to reduce due to increasing water demand for other sectors such as industrial and domestic use due to rapid increase in population and reduced river flow.

The agriculture system of Pakistan depends upon the 5 months of summer river water flow. Dealing with this unsteady flow three main reservoirs were constructed namely Tarbela, Chasma on river Indus and Mangla on river Jhelum.

Water Availability Scenario

Planning commission of Pakistan elaborated in the ten-year perspective Development plan for the year 2001-11 that the shortfall of the water availability will increase from 11 to 31 MAF in year 2004 to 2025 respectively.

According to the Pakistan Institute of Legislative Development and Transparency this shortfall will be due to the increase in the undeniable population growth putting considerable pressure on sectors such as agriculture, urbanization and industrialization. Comparison of past and future demand for different sectors is as followed

According to Indus River System Authority (IRSA) the gap between water demand and water supply is projected to reach around 31MAF by 2025. It should be noted that the gap between demand and supply widens in the summer (Kharif) season and towards the end of the watercourses.

Population Trend

According to the Environment report 2005, the estimated population growth for Pakistan in 2025 will be 221 million. For this the per capita water availability will fall below 1000 m3. This situation will be even worse for the areas which are remote of Indus basin where the average water availability is already below 1000-meter cube annually. The projected water availability for the year 2025 is expected to fall below 700 m3 (Pak-SCEA 2006). The ever increasing demographic trend will cause its serious implication on already scarce water resources in future. This calls for immediate adaptation strategies for the water resources in terms of new water reservoirs and efficient irrigation and agricultural practices.

3.2.2 Hydrological Analysis of Keti Bandar of Indus Delta

The study was conducted on the temporal Landsat TM/ETM+ images for the five selected instances during last 25 years using Object based image analysis technique. The results and discussion presented in the following subsections focus on analyzing the estimated areas for different land-use/land cover categories specially of mangroves at the five selected time instances and corresponding hydrological conditions in terms of river flow availability and recorded rainfall in the study region.

Land Use/ Land Cover (LULC)

Based on Landsat images of year 1992, 1998, 2002, 2010, and 2011 analysis shows the total mangroves cover in the area. On the basis of density and canopy cover, the mangroves were classified as dense, medium, and sparse mangroves cover. (Figure 5).

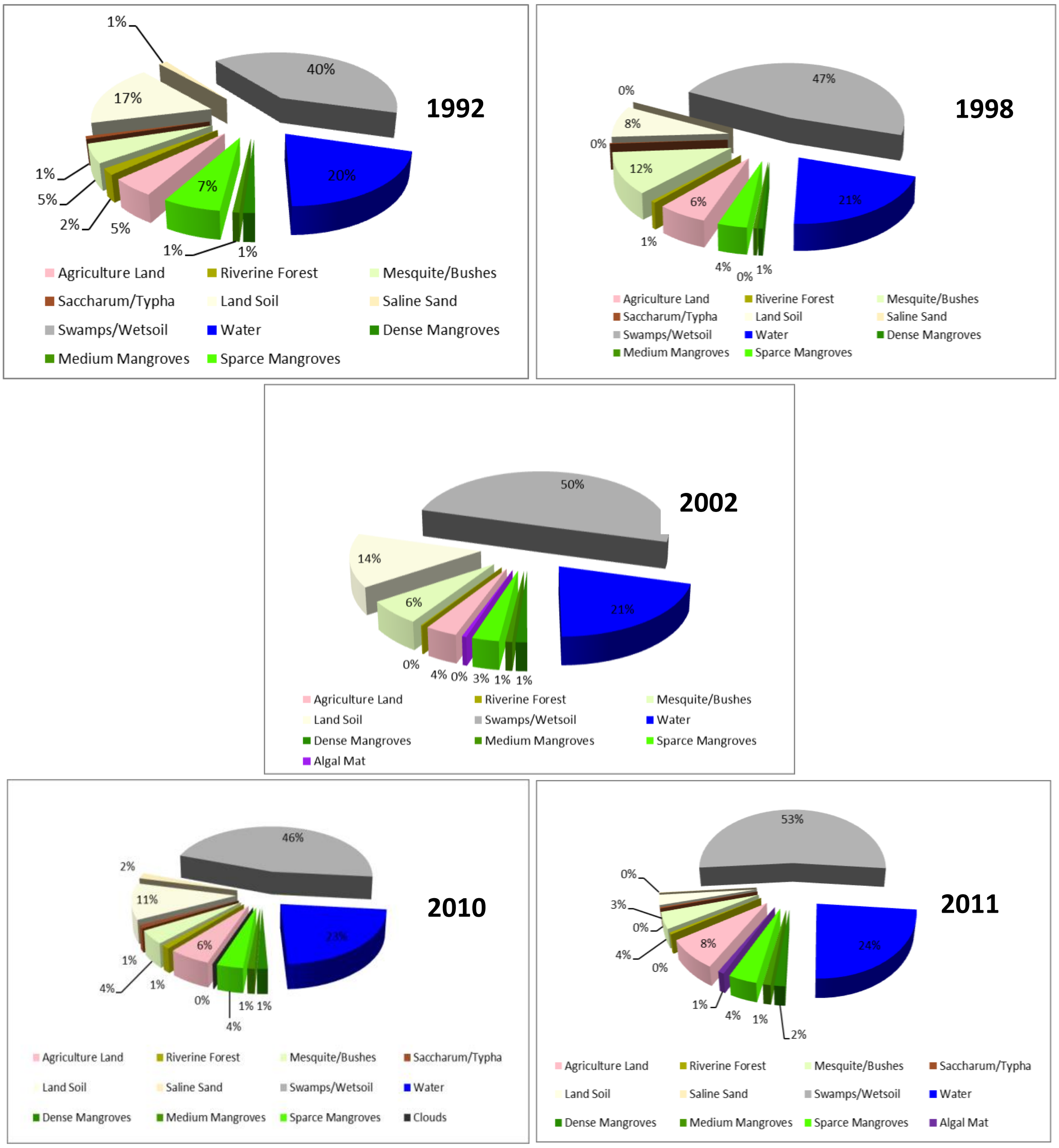


Figure 5: LULC Analysis over last two decades

LULC maps comparison

Based on the image analysis performed in this study, three types of comparisons were made to detect any significant changes in different land cover classes: i) Wet hydrologic regime vs start of drought conditions; ii) Start of drought vs end of drought; and iii) Before vs after a major flood event.

a. Wet hydrologic regime vs start of drought conditions

Figure 6 presents a comparison of the LULC for year 1992 that represents a wet hydrologic regime and year 1998 that represents start of the worst hydrologic drought in Pakistan. Examination of this figure shows that mangrove vegetation of different classes (green patches as per the figure legend) reduced between these two years especially the dense canopy class and it is evident more in the southern part than in the northern part of the study area. Similarly, a marked reduction (~70%) in the area of the riverine forests is detected partially as a result of its conversion to agricultural land due to availability of water in the closest creeks during 1992 to 1997-98 periods.

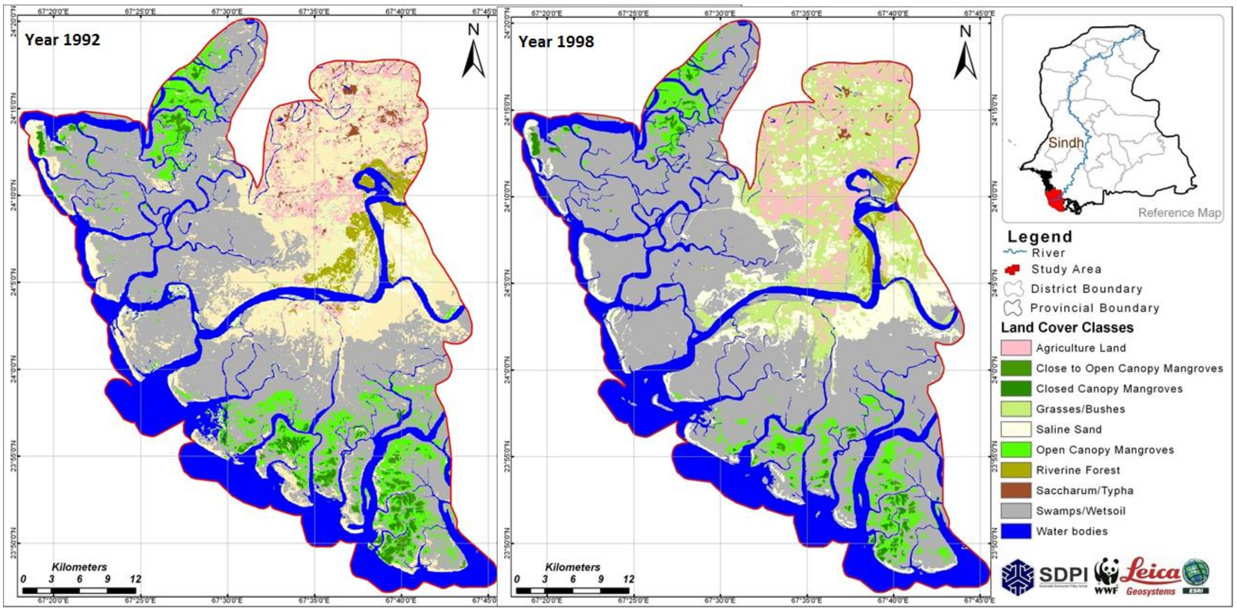


Figure 6: LCLU maps for years 1992 vs 1998

b. Start of drought vs end of drought

As it is evident from Fig. 7, Pakistan faced an intense drought during 1998 to 2002 period and Fig. 7 is an attempt to depict and assess its effects on the LULC of our study area. In Fig. 7, the LULC status shown for the year 1998 represents the conditions in the very early part of this year while the same shown for 2002 depicts the condition near the end of this year when the drought conditions were already eased and more fresh water was available then earlier. For this reason, if the mangrove covered area of each of the three classes only is analyzed using Fig.7, we find an increase in Dense and Medium mangroves while a decrease in sparse mangroves. On the other hand, agricultural land is seen as much reduced due to very low agricultural activities during the drought period and there is a marked reduction in riverine forest area as well.

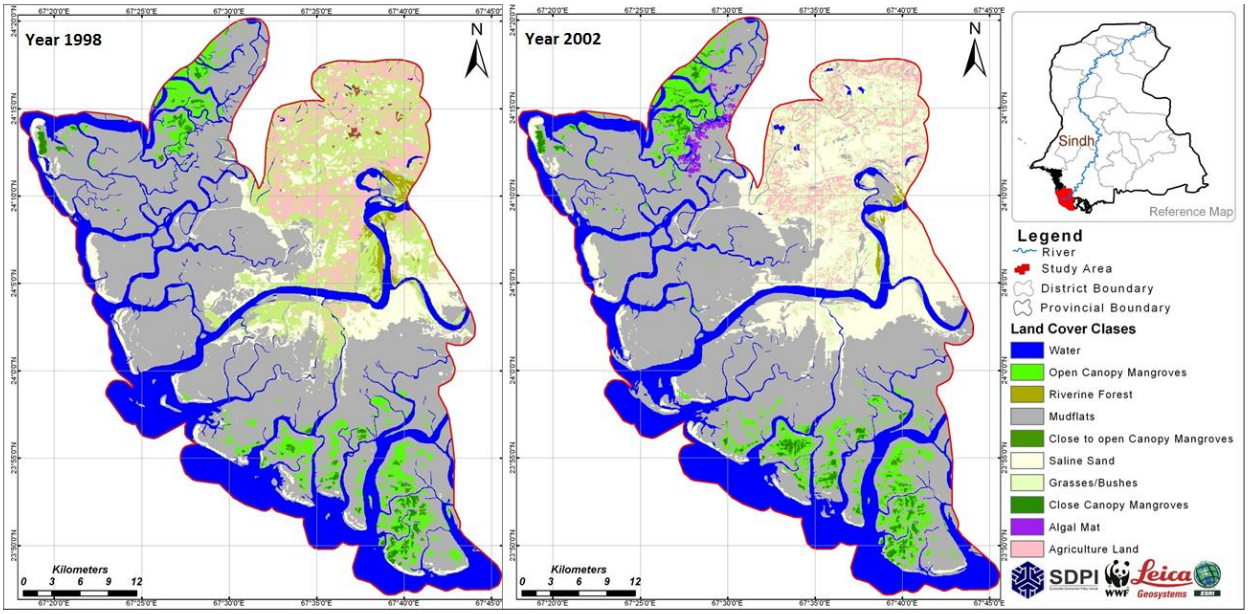


Figure 7: LCLU map – years 1998 vs 2002 (period representing the worst drought of recent history)

c. Before vs after a major flood event

To analyze the effect of flooding and high water event on the land cover conditions in our study area, pre- (year 2010) and post-flood (year 2011) land cover mapping was done and a comparison is presented in Fig. 8. A careful examination of this figure reveals some interesting facts such as washing away of some major patches of riverine forests replaced by grasses and bushes later on, increase in agricultural area due to availability of more water and deposition of nutrient-rich soil brought by flood water, increase in area of all three types (Dense, Medium and Sparse) of mangrove covers, much more wet soil fraction resulting in appearance of algal mat. It is pertinent to mention here that the satellite image used for analyzing year 2010 was not fully cloud-free so there may be a slight underestimation in the land cover area calculated for different classes.

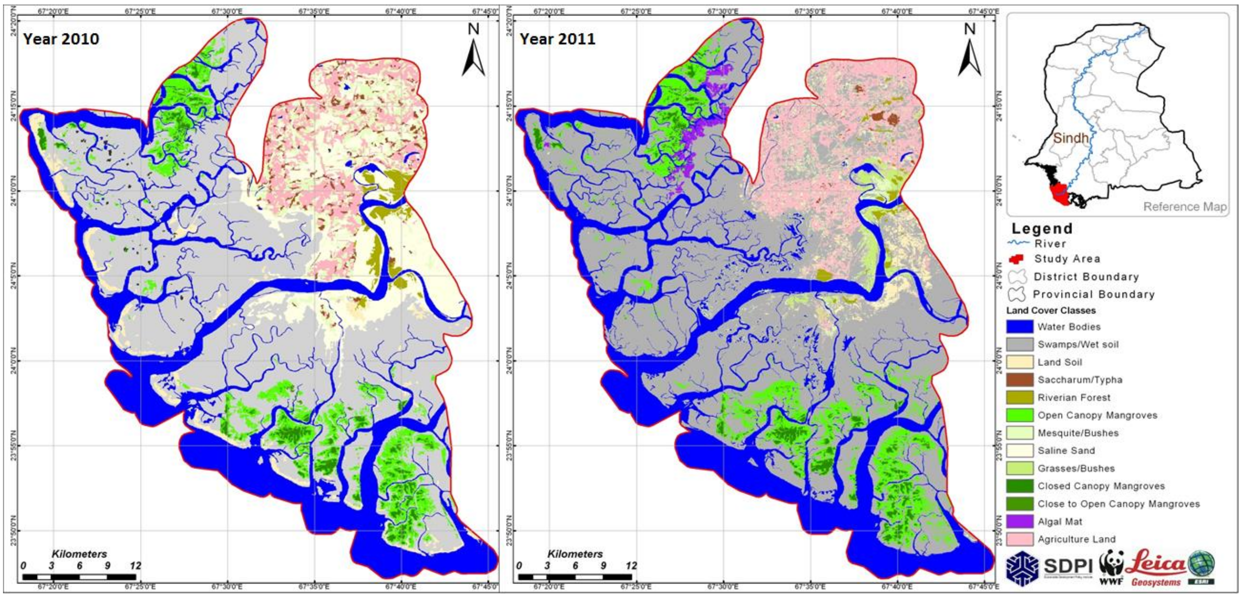


Figure 8: LCLU map – years 2010 vs 2011 (representing conditions before and after a major flood)

Discussion on Effect of Hydrologic Regime on Mangrove Cover

The dash-dot line in Fig. 9 is representing overall trend of the hydrologic regime of the study area for the analyzed period of 1987-88 to 2010-11 and the variation in the estimated total areas of the three major land cover classes are almost following the same trend which shows a strong positive correlation between fresh water availability and land cover (especially mangrove cover) variation.

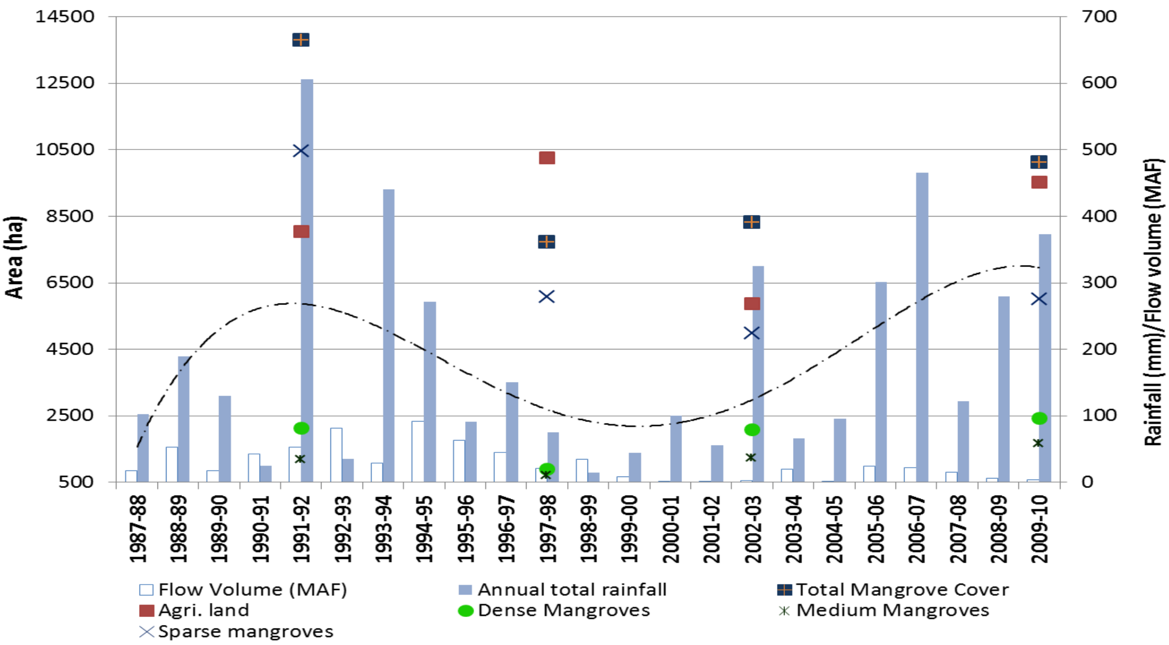


Figure 9: Changes in Mangrove Cover in Relation to Changes in Hydrologic Condition

Conclusion and Recommendations

Results reveal that there is a decrease of 6,072.30 ha of mangroves from 1992 to 1998. High forest consumption and degradation rate show that approx. 6,000 ha of mangroves present in 1992 totally vanished in 1998. The major decrease in the mangrove forest seems to be the pre effect of drought season, which was maximum in the year 1998 and 1999. On the other hand, a relatively sustainable trend of mangroves from 2002 to 2011 is analyzed. Whereas, an increase of about 1,000 ha from 2010 to 2011 in the mangrove forest is due to the post effects of the major flood of 2010.

Large mangrove forest clusters towards open sea are relatively intact with no variation in their middle regions. However, their peripheries are subject to the negative change due to the dynamic geomorphology of the area. Mangroves forest in the northern part of project area (Chann creek area closer to the inland) is comparatively in stable condition. The main reason of this positive situation seems to be the result of the efforts of the Forest Department.

It is also recommended to develop a predictive model by using current and historic (if available) data with different temporal ranges from 1950 - 2011. The developed model could be used to define change trend patterns more precisely and in detail. This will lead to plan and manage plantation activities and community awareness programmes.

It is also suggested to use remotely sensed data (landcover and soil classification maps) for the definition of suitable mangroves plantation sites. Temporal high resolution images can also be used to monitor plantation areas for the assessment of positive and negative trends of young seedlings.

3.2.3 Environmental Flow Requirements Assessment

This study provides an assessment of ecological conditions and its corresponding environmental flows (e-flows) of the Indus delta under climate change scenario. Being located in an arid climatic zone and lack of awareness toward the importance of E-Flows downstream to Indus Delta, the ecological health of river and its associated ecosystems are deteriorating. Therefore, we assessed the existing state of deltaic ecology and categorized it into an arbitrary environmental management class (EMC). Then, using the Global Environmental Flow Calculator (GEF), an initial assessment of current e-flows required for the Indus delta was carried out. Our analysis of the prevailing flows shows that due to no E-Flows allocation for Indus River that reaches downstream to Korti barrage, there is zero or close to zero flow during the most part of the year. Our analysis reveals that under climate change Scenario 1, more flows will be available that may help close to natural E-Flows. This may impose high risks of flood damages to the highly vulnerable deltaic communities. Under Scenario 2 there will be a reduction in flow availability to the extent that E-Flows required under prevailing conditions would not be possible. Consequently, it will aid in the deterioration of the deltaic ecosystems and socio-economic condition of the communities therein. In the case, a viable solution would be to bridge gaps by interlinking economic and development needs of communities with environmental flows needs of Indus delta.

a. Ecological Assessment

The Indus delta is home to a moderate number of *endangered aquatic biota*, where up to 42 species of fish, reptile, mammal and bird in the area are classified as endangered (GoP, WWF and IUCN 2000). The rich and *unique aquatic biota* includes endemic species such as the Indus dolphin, Indus baril (*Barilius modestus)*, Indus garua (*Clupisoma naziri*), and Rita catfish (*Rita rita)* and a number of snakenhead fish like the giant snakehead (*Channa marulius*) (Miththapala 2008).The Indus delta is highly *diverse in habitats*, which range from riverine forests, coastal lagoons and coral reefs, to tidal marshes, mangrove swamps, freshwater lakes, brackish and salt lakes and estuaries (IUCN 2005). The delta has a large number of *protected areas* which include a forest covers of 344,845 ha under the Sindh Forest Department (Qureshi 1985), and various RAMSAR sites. *The delta's aquatic ecosystems are highly sensitive to flow reduction.* Upstream dams have significantly altered downstream water flows, which has led to reduction in fish diversity and catch (Boon and Raven 2012). Studies report a 47% decline in shrimp catch over the last 10 years (Qamar 2009). Additionally, there are reports that obstructions such as reservoirs and dams further hinder natural flows especially during dry seasons when water is regulated and diverted to irrigated lands.

The present condition of the Indus river and *the percentage of delta remaining under natural vegetation* has changed to somewhat extend, compared to a reference condition in the past. In 1980, the mangrove cover in delta region was approximately 345000 ha (FAO and UNEP 1981), whereas recent studies point to intense reduction in natural vegetation covering an area of 158000 ha (PFI 2004). This is a drastic reduction of 46% from that of the original natural vegetation. This means that while the disappearance of Indus mangroves signifies increased fragmentation and degradation of the coastal ecosystems, this also implies that livelihoods of dependent communities are also eroding. *The degree of flow regulation* was relatively low (Mustafa 2004; Ali *et al*. 2007). Major structures along the Indus River, such as Tarbela dam in the upper riparian Indus and Kotri in lower riparian, have greatly obstructed connectivity of aquatic biota in the delta (WCD 2000; WAPDA 2014).

Percentage of delta closed to movement of aquatic biota by structures is also declining adversely.

Historically, the Indus dolphin (*Platanista gangetica minor*) was found in tributaries of Sutlej, Beas, Ravi, Chenab and Jhelum rivers. Over the years, habitats have become fragmented, and limited to continuously flowing parts of the Indus, between Chashma and Taunsa, Taunsa and Guddu, and Guddu and Sukkur Barrages (Braulik 2003; Reeves and Chaudhry 1998, Reeves 1998). The flow regulation has resulted in the Indus dolphin being confined to only those parts of the river that are continuously flowing, resulting in its removal from 80% of its former habitat range (WWF-Nepal 2006). Similarly, connectivity of Palla fish (*Tenualosa ilisha)* has been restricted because of which they now travel 170 km to spawn (Qureshi 1968). This means that while water structures play a decisive role in fragmenting aquatic habitats of migratory species, flow regulation also plays a determining role in where the habitats will germinate. This has also had an impact on *relative richness of plant species.* Although the Indus delta has a moderately rich aquatic flora, 4 out of the 8 plant species known to have thrived in the Indus delta have reportedly disappeared (Amjad *et al*. 2007). Presently the Indus mangroves are dominated by highly salt-tolerant *Avicennia marina* (95%) (DasGupta and Shaw 2013). Other plant species include *Ceriops tagal*, *Agiceros corniculatum* and *Rhizophora mucronata* (Amjad *et al*. 2007). Literature points to an increased tendency of introduced and alien species to invade native habitats where water flows significantly diverge from the natural pattern (see Bunn and Arthington 2002), where the most successful introduced/exotic species are those that are adapted to altered water flows (Moyle and Light 1996; Bunn and Arthington 2002). Whereas it is difficult to assess whether and how flow regime alterations may facilitate spread of introduced or alien species in the Indus delta, given the limitation in data availability, it is nevertheless crucial to be mindful of habitat destruction caused elsewhere by biotic changes. For example, the Colorado River of the USA faced severe ecological challenges when river modification facilitated the spread and integration (permanence) of more than 50 exotic fish species (Bunn and Arthington 2002). Such precedents warn of the dire environmental and economic costs of hydro-ecological degradation that follows altered river flows. *The human population density* in the delta is low (102 persons/km^2) and 46% projected population growth by 2015. (WRI 2003; Overeem and Syvitsky 2009). *Water quality* is however poor and only suitable for irrigation and industrial purposes.

b. Ecological Management Classes (EMCs) of the Indus Delta

Based on Smakhtin *et al*.'s model, 6 EMCs are constituted on disproportionately distributed percentages in Table 14. Once indicator scores from ecological assessment are estimated, the sum of indicators is expressed as a percentage of maximum possible sum (Table 15).

Table 13: Indicators selection criteria for Environment Management Class (EMC) of Indus Delta

Indicator	Description / Explanation	Range
Rare and endangered aquatic biota	No. of rare and endangered species as a percentage of total species in the delta/area.	5 =Very high; 4=High; 3=Moderate; 2= Minor; 1=None
Unique aquatic biota	No. of unique and endemic species as a percentage of total species in the delta/area.	5= Very high; 4= High; 3= Moderate 2= Minor; 1= None
Diversity of aquatic habitats	Expert judgement and extensive literature review.	5= Very high; 4= High; 3= Moderate 2= Minor; 1= None

Presence of protected and pristine areas in the river	Smakhtin *et al.* (2007) compose this range based on IUCN's aim of 10% of area to be protected.	5= >10; 4= 5-10%; 3= 3-5% 2= 1-3%; 1= <1%
Sensitivity of aquatic ecosystems to flow reduction	Based on expert judgement and knowledge of the river (type).	5= Very high; 4= High; 3= Moderate 2= Minor; 1= None
Indicators related to River's condition (compared to a reference condition in the past)		
Delta under natural vegetation	Percentage of delta remaining under natural vegetation. Based on literature review.	5= >10; 4= 5-10%; 3= 3-5%; 2 =1-3% 1= <1%
Degree of flow regulation	Total dam storage in a region as a percentage of mean annual flow. Estimated to be 13% here.	1= >100%; 2= 50-100%; 3= 20-50% 4= 10-20%; 5= 0-10%
Delta closed to movement of aquatic biota by structures	Catchment area upstream of dams as a percentage of total catchment areas.	1= 70-100%; 2= 50-70%; 3= 30-50% 4= 10-30%; 5= <10%
Plant species relative richness	Number of individuals of a given species as a percentage of all of the individuals in the community/sample.	5= Very high; 4= High; 3= Moderate 2= Minor; 1= None
Human population density	In the entire river delta as a percentage of population density in the main flood plains	1= <10%; 2= 10-20%; 3= 20-40% 4= 40-60%; 5= >60%
Water quality in the delta	Class A is clean water suitable for drinking; B is for bathing and swimming; C requires conventional treatment and disinfection; D is suitable for wildlife; E is only suitable for irrigation.	5= Class A; 4= Class B; 3= Class C 2= Class D; 1= Class E

Table 14: Environmental Management Classes (c.f. Smakhtin *et al*. 2007)

A sum of actual indicator scores as a percentage of the maximum possible sum	**EMC**	**Most likely ecological condition** (adapted from DWAF 1999)
91-100	A	Natural rivers flows with minor modification and have natural stream flows and riparian habitat
75-90	B	Slightly modified and /or ecologically important rivers with largely intact biodiversity and habitats despite water resources development and/ or basin modifications

A sum of actual indicator scores as a percentage of the maximum possible sum	EMC	Most likely ecological condition (adapted from DWAF 1999)
50-74	C	The habitats and dynamics of biota have been disturbed, but basic ecosystem functions are still intact.
30-49	D	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Lowered presence of intolerant species. Alien species prevail.
15-29	E	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain and no Indigenous species. Invasion of Alien species.
0-14	F	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case the basic ecosystem functions changes are irreversible.

Table 15: EMC assessment of Indus delta regarding Ecological sensitivity and importance

Ecological sensitivity and importance of a Delta		
Indicators	**Range**	**Score**
Endangered aquatic biota	Medium	3
Unique aquatic biota	Very High	5
Diversity of aquatic habitats	Very High	5
Presence of protected areas	>10%	5
Sensitivity of aquatic ecosystem to fresh water flow reduction	Very High	5
Indus River delta looks like at present, compared to a reference condition in the past		
Percentage of Delta remaining under natural vegetation	50-70%	3
Degree of flow regulation	10-20%	4

Percentage of the delta closed to movement of aquatic biota by structures	70-100%	1
Plant species relative richness	Moderate	3
Human population density	Low	2
Overall water quality in delta	Class E	1
Sum of Indicator Score		**38**
Maximum possible Sum of Scores		**55**
Percent of The Maximum		**69%**
Environment Management Class (EMC)		**C**

c. Limitations of EMC estimation

Because the EMC categories are arbitrary, and in experimental stage, further studies and consultations are needed to validate the model. Further justification for the EMC categories needs to be developed (Smakhtin *et al.* 2007), which can be supported by quantifiable indicators that facilitate the definition of comparative quantities such as 'large' and 'small'. Ranges based on expert judgment (qualitative analysis) are subject to human reasoning and local contexts. Hence, it is difficult to compare similar studies carried out across regions by independent researchers. Ambiguity and inadequacy of ecological data in Pakistan remain limiting factors that need to be compensated by finding means to cope with them.

d. E-Flows Assessment

Based on the reference flow provided to the model, first it calculated the mean annual runoff (MAR) for each of the six EMCs as a percentage of natural MAR as given in Table 16.

The results show that Indus River in deltaic region is classified under EMC 'C', on the basis of which e-flow assessment is carried out. Figure 10 shows flow duration curves (FDCs) for all of the EMCs from 'A'-'F' against the reference FDC. The FDCs present a summary of e-flows for each EMC prevailing FDC accounts for post Tarbela Dam period of 1976-2005. Under the prevailing flow conditions (the 'dash-dot' line), high flows are almost similar to that of the reference period; the worrisome part is however that the lower end of the FDC shows zero (or close to zero) flows most of the time (Fig. 10). Comparing the prevailing FDC and the FDC for EMC 'C', the urgency of e-flows allocation for Indus Delta can be easily unpinned.

Table 16: Estimates of long term volumes corresponding to each EMC as % of Natural Mean Annual Runoff (MAR)

Environmental Management Class (EMC)	% Natural Mean Annual Runoff (MAR)
A	71.3
B	47.0
C	29.8
D	18.6
E	11.6
F	7.4

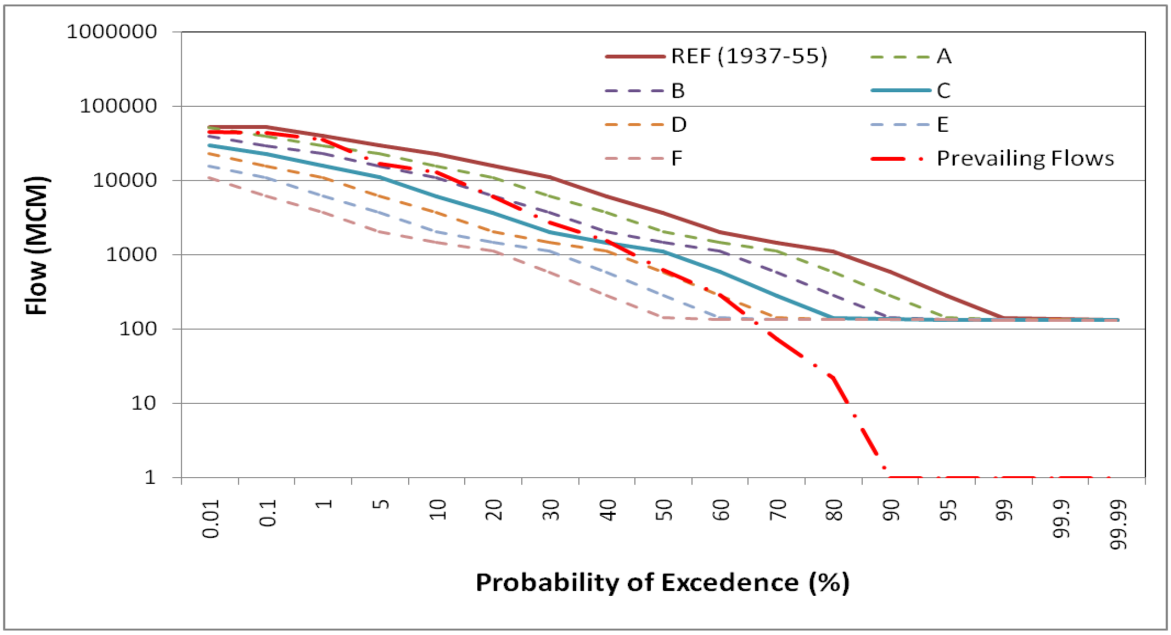


Figure 10: FDC analysis of the reference flow and e-flows corresponding to an EMC

Examination of Fig.11 shows that e-flow time series is fully in phase with the reference flow time series but is reduced in magnitude by a factor calculated through the lateral shifting procedure explained earlier. Thus, e-flow time series is fully representative of the natural flow variability and also taking into account current ecological condition of the river and hence water availability. The e-flows time series suggests an average minimum dry period flow (also known as environmental base flow or EBF) of ~50 m^3/sec while an average maximum wet period flow is ~3000 m^3/sec.

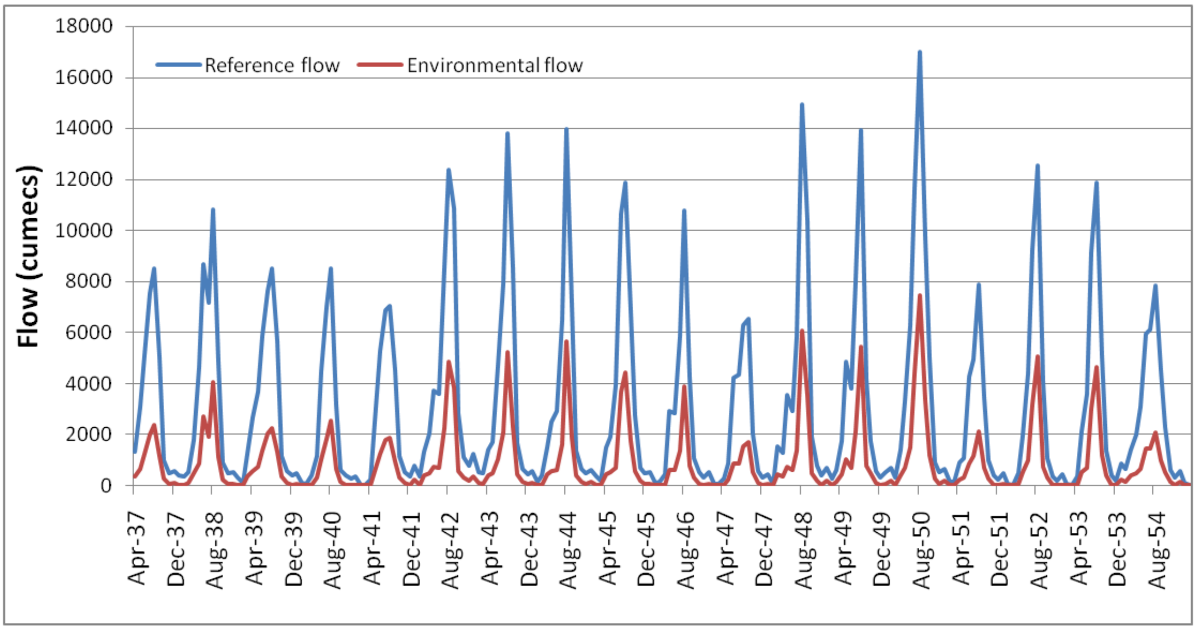


Figure 11: E-flows time series in comparison with the reference flow time series

i. E-Flows under different future flow regimes due to climate change

Scenario 1, described above has been derived from the findings of a very recent study of Immerzeel *et al.* (2013). Based on the projections of the most modern generation of GCMs (CMIP5) and sophisticated glacio-hydrological modelling, this study indicates that no decrease in Indus River flows is expected at least until the end of 21st century. Rather, the likely range of increased river flow they provide is 46% (under RCP45 scenario for the period 2021-2050) to 96% (for RCP85 scenario for the period 2071-2100). Based on this projected range of increased flows in Upper Indus Basin (UIB), we obtained two future reference time series corresponding to 46% and 96% increase. Using the GEFC model we estimated range of future e-flow time series as shown in Fig. 12 and Fig. 13. Examination of these figures shows that projected increase in river flows allows the allocation of more water for e-flows as compared to baseline period. Smakhtin and Eriyagama (2008) reported that according to Hughes and Munster (2000), flexibility in water availability allows to introduce the concept of transitional EMCs e.g., A/B, B/C, C/D, implying that based on available flows we can place a river in two EMCs at a time. For example, the ecological state of Indus river in this study has been worked out to be 'C' but under future scenario of increased flows in can be placed in a transitional EMC of B/C (Fig. 12) due to higher water availability.

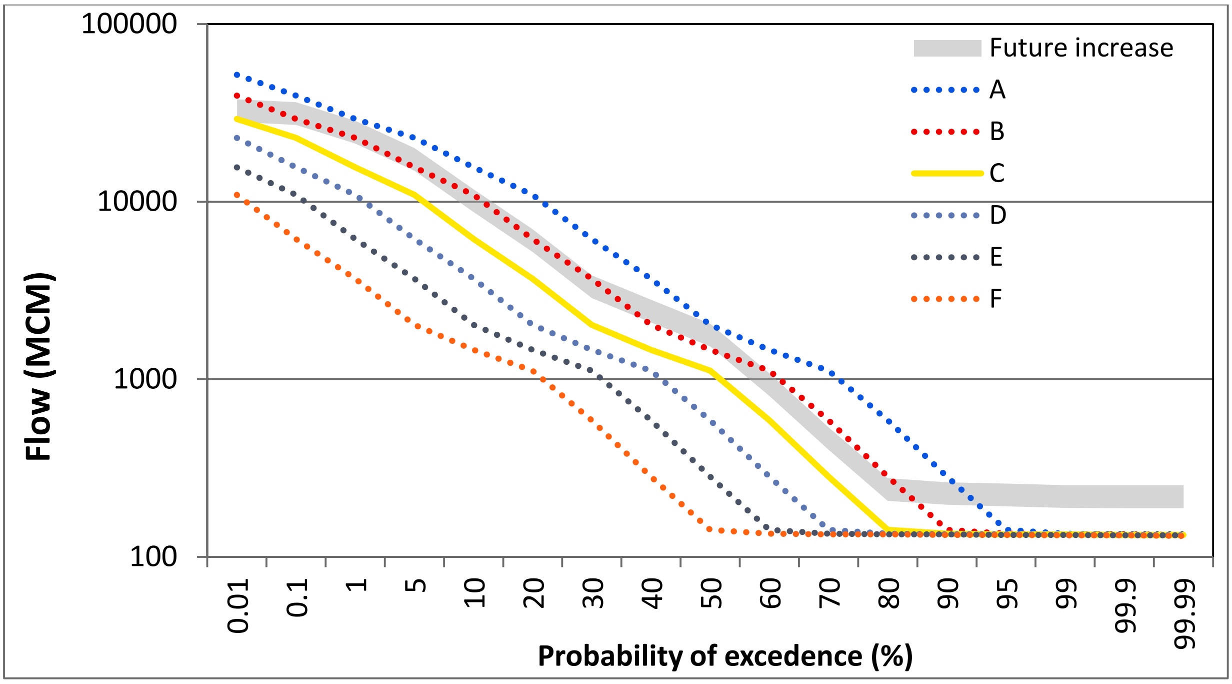


Figure 12: Increase in available E-flows under Scenario 1

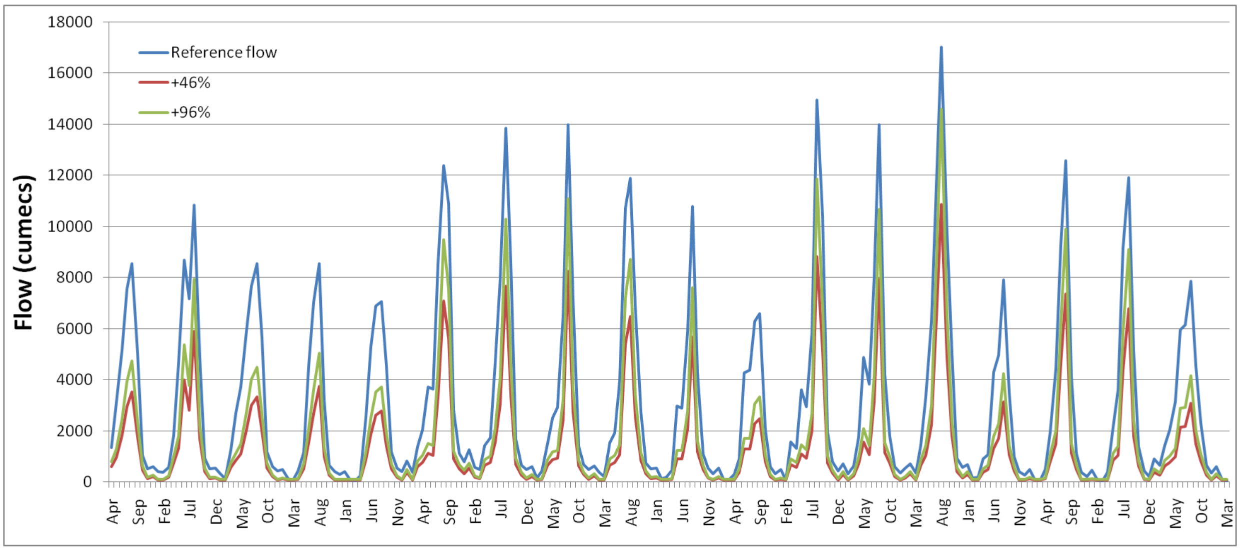


Figure 13: EF assessment under Scenario 1

As far as Scenario 2 is concerned, it has been derived from an earlier study by Rees and Collins (2006) that analysed impact of climate change on Indus River flows. According to this study, flows will rise in the early part of 21st century as a result of rapid melting of Himalayan glaciers under warmer climate and then those will significantly decrease in the later part of the century once glacial ice disappears. It suggests a range of decrease in river flows of -40% to -65%. Similar to Scenario 1, we calculated two future reference time series corresponding to -40% and -65% to obtain range of e-flows under Scenario 2 (Fig. 14 and 15). Examination of these figures suggests that significant reduction in river flows will allow very small amounts to be allocated for e-flows and therefore we will have to put the ecological state of Indus river in a D/E transitional EMC or in a lower than baseline class (‘C’) i.e. D or E (Fig. 14).

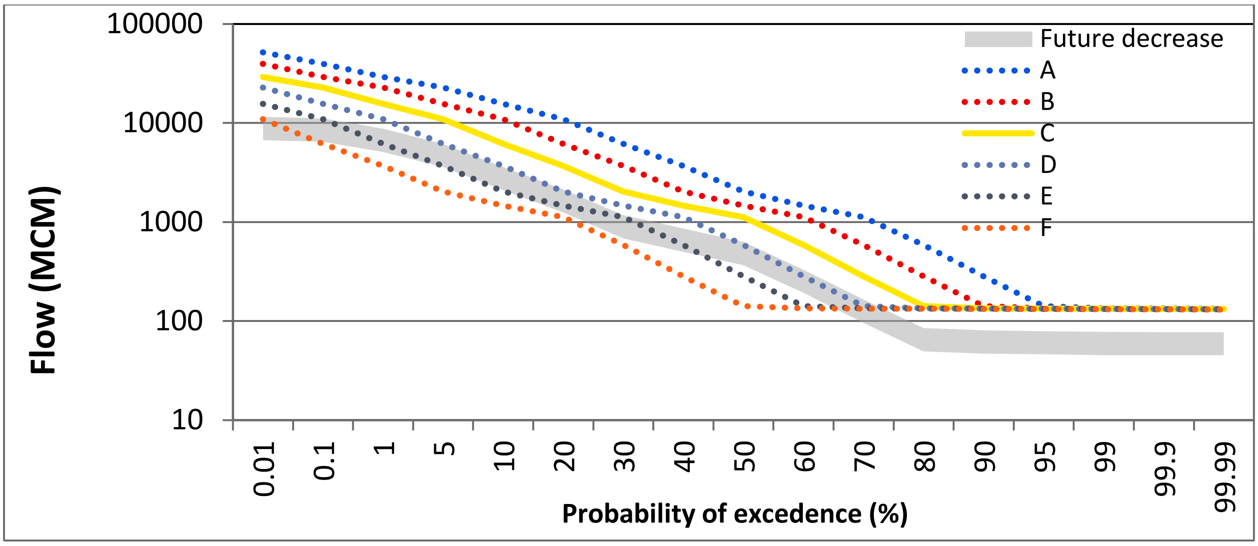


Figure 14: Decrease in available E-flows under Scenario 2

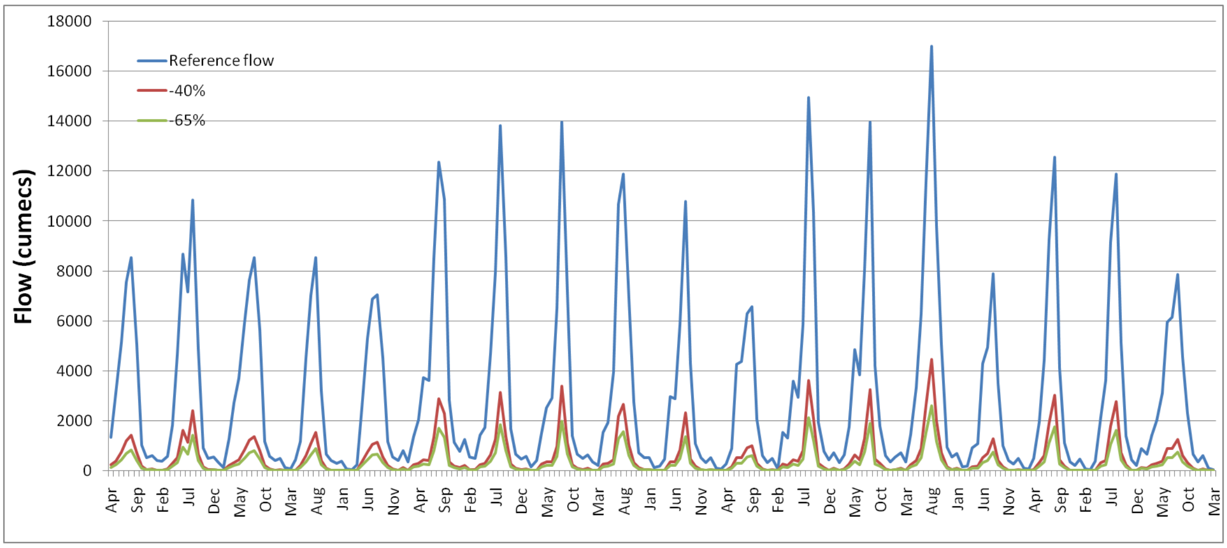


Figure 15: EF assessment under Scenario 2

These changes in river flows under future climate scenarios may have many associated impacts on different important components that comprise the ecosystem of Indus delta. This aspect of our study has been addressed adequately in the following sub-section.

e. Discussion on Likely Impacts of Climate Change Induced Changes in River Flows

Results from this study reveal that current state of Indus Delta is moderately modified (EMC 'C'), meaning that while habitat and aquatic biota of the river have been disturbed by altering river flows and other factors, the basic ecosystem functions are still intact. Competing anthropogenic interests, however, mean that river flows downstream of Kotri Barrage will continue to be altered, while water quality is likely to further decline, thus impacting freshwater ecology in Indus Delta. This is already evident from the reported disappearance of endemic aquatic fauna, and the rapid loss of mangrove cover in the Indus Delta.

Additionally, results from this study support the overwhelming scientific literature which acknowledges that aquatic biodiversity is supported by natural patterns of river flows. Any major alteration is likely to impact the entire freshwater ecosystems (McCartney *et al*. 2001). Conclusions, however, must be arrived at cautiously since the study is riddled with the difficulty of verifying and isolating river flows and deltaic ecosystems as independent variables. Given the complex interrelationship of dynamic systems of flow regime, freshwater ecology, climate change and anthropogenic dependence, it is almost impossible to separate biotic response to flows from other influences that may alter biotic diversity. An aquatic plant species may become rare or endangered, for example, as a result of warmer water temperatures than altered water flows that result from climate change. Similarly, some fish species may disappear from the delta due to unregulated fishing practices, rather than from reduced e-flows. What is certain, however, is that if the current deterioration of aquatic ecology continues, it will be daunting to maintain present, or achieve higher, ecological class, regardless of the changes in river flows in the future.

Periodic river flows (quantity, quality, frequency and timing) determine life histories of associated estuarine and riverine flora and fauna (Arthington *et al.* 2010). The current research simulates future monthly-flow variability and potential ecological response. The study does not consider short-term variability (i.e. daily-time flow variability), due to which we overlook considerations such as whether aquatic biota would evolve gradually, over a longer period of time, to adapt to modified flows, or whether they would behave more sporadically and unpredictably in response to daily fluctuations in river flows. Notwithstanding that, the following section hypothesizes potential impacts of climate change based on the two scenarios explained earlier.

i. Likely impacts of Scenario 1

Increased river flows under extreme variability

There is sufficient scientific evidence to suggest that where river flows may rise, it may through more intense and more frequent extreme weather events. Higher flows may thus signify wide fluctuations in precipitation patterns and glacial melt, which can result in frequent flash floods. In such cases, runoff water and sediment from flooded lands can reduce water quality in deltaic region, thus hindering biological absorption of dissolved nutrients by aquatic biota. It may also mean that the rivers have a reduced ability to provide valued ecosystems services on which local communities depend, such as provision of water, food, waste assimilation and flood control (Anderson *et al.* 2007). Under such circumstances, the worst-affected are the deltaic and coastal communities with poor socioeconomic conditions. In other words, increased water flows in the form of extreme weather events will erode ecological and socioeconomic sustainability of Indus Delta, as deltaic communities are displaced and freshwater ecosystems are degraded. The recent floods of 2010 and 2011 that inundated vast agricultural lands across Pakistan, affected coastal ecosystems and settlements, costing huge financial losses. The agriculture sector alone received a major setback during 2011 floods costing US$ 1840 million, where the total reconstruction cost was estimated to be US$ 2747 million as a result of severe infrastructural demolition (World Bank and ADB 2011).

Therefore, while the EMC of the delta ecology in such a case may be theoretically in a higher category, but practically may be ill-suited to the changed climate conditions.

Increased river flows under normal variability

Notwithstanding that, higher river flows theoretically signify increased water availability which can facilitate the transformation of Indus Delta into a higher EMC. The Indus mangroves are highly salt-tolerant, and the increased water availability (precipitation and/or freshwater) can facilitate runoff of salts from mangroves soils (Jimenez l992). This in turn can spur growth of less salt-tolerant plant species that add to the specie richness of mangroves, thus improving the ecological status of the delta.

Many studies report that millions hectare of land has been affected and degraded due to sea water intrusion (WWF 2012; IUCN 2010). Increased river flows, complemented by well-allocated e-flows, can address problems of soil salinity in deltaic mangroves. Additionally, rain-fed agriculture in Indus Delta could improve, as freshwater flooding rejuvenates deltaic croplands with sediment deposits of fertile alluvium. This would contribute directly to local food security, livelihoods and socioeconomic stability.

ii. Likely impacts of Scenario 2

As stated earlier, Indus River in deltaic region is moderately modified (EMC 'C') under prevailing climatic and ecological conditions. Assuming that climate change will reduce river flows under scenario 2, more e-flows will be required to maintain the existing status of aquatic ecology. However, understanding that competing anthropogenic needs may be catered to first, the provision of reduced river flows would spur a decline in aquatic biota of the delta. Already, studies indicate that mangroves are rapidly disappearing from Pakistan (see DasGupta and Shaw 2013). Reduced inflows from the Himalayas would mean a more aggravated loss of Indus mangroves in Pakistan. Management authorities would thus be faced with the multiple problems of reduced water availability, degrading aquatic habitats, rapidly shrinking mangroves, eroding revenues, and poor livelihood.

Ecological Management Classes of the Indus Delta

The results are based on the extensive review of available literature and interviews with relevant experts (selected from academic and scientific institutions, INGOs, and NGOs, civil society and community organizations, etc.).

After estimating the scores for each indicator, their sum is calculated and transformed as the percentage of the total maximum possible sum of all indicators i.e., 64 percent. This percentage is then converted into the destined Environmental Management Class (EMC) that decides the sustainable quantity of water (environmental flows) to be budgeted for environmental aspiration in respective river delta. Low scores of indicators like 'percentage of the basin closed to movement of aquatic biota by structures', 'water quality' and 'human population density' in entire delta proposes the basin into class 'C'.

This EMC assessment also encounters some limitations such as the unavailability of site-specific threshold levels for different ecological and hydrological indicators needed for more precise and accurate estimation. Similarly, the lack of updated scientific information on vulnerability of indicators and its impacts have been a limiting factor for the assessment of ecological sensitivity of rivers and deltas in Pakistan.

E-Flows Assessment

Based on the reference flow provided to the model, first it calculated the mean annual runoff (MAR) for each of the six EMCs as a percentage of natural MAR. Built on the aggregate score of EMC, the study Indus delta falls under 'C' ecological management class. Therefore, further environmental flow analysis was focused to only class 'C'. Figure 11 shows FDCs for all of the EMCs from 'A'-'F' as offset of the reference flow FDC and also the FDC of the prevailing flows for post-Tarbela Dam period of 1976-2005. As shown in Fig. 11 under the prevailing flow conditions (the 'dash-dot' line), the high flows are almost similar to that of the reference period but the most worrisome part is the lower end of the FDC, which shows zero (or close to zero) flows most of the time. Comparing the prevailing flows FDC and the FDC for EMC 'C', the urgency of E-Flows allocation for Indus delta can be easily realized. Further examination of this figure shows a systematic decrease of low and high flows for each of the EMCs in comparison to reference flow resulting from the lateral shifting explained in the Methodology section.

After estimating the EFDC for category 'C', the model was used to generate corresponding EF time series (Fig. 12) along with reference flow time series. Examination of Figure 12 shows that EF time series is fully in phase to the reference flow time series, but is reduced in magnitude by a factor calculated through the lateral shifting procedure explained earlier. Thus, EF time series is fully representing the natural flow variability and also taking into account current ecological condition of the river and hence water availability.

E-Flows under different future flow regimes due to climate change

After determining EF requirement under present conditions of the Indus delta, assessment of changes in river flows under likely climate change was carried.

Two types of future scenarios were analysed elaborated as under:

- Scenario 1: Increase in river flows due to more glacier melt under warmer climate and also increase in precipitation in the UIB and downstream catchments.
- Scenario 2: Decrease in river flows due to no glacier melt contribution following the vanishing of glaciers in the UIB accompanied by reduced precipitation the UIB and downstream catchments.

Scenario 1 has been derived from the findings of a very recent study of Immerzeel et al. (2013). Based on the projections of the most modern generation of GCMs (CMIP5) and sophisticated glaciohydrological modeling, this study indicates no decrease in Indus River flows is expected at least by the end of 21st century. The likely range of increase of river flow they provide is 46% (under RCP45 scenario for the period 2021-2050) to 96% (for RCP85 scenario for the period 2071-2100). Based on this projected range of increased flows in UIB, we obtained two future reference time series corresponding to 46% and 96% increase and the using GEFC model we estimated range of future EF time series (Fig. 13 and Fig. 14). Figures show that projected increase in river flows allows the allocation of more water for E-Flows as compared to baseline period. Smakhtin and Eriyagama (2008) reported that according to Hughes and Munster (2000), flexibility in water availability allows introducing the concept of transitional EMCs e.g. A/B, B/C, C/D, i.e. based on available flows we can place a river in two EMCs at a time. For example, the ecological state of the river of this specific study has been worked out to be 'C', but under future scenario of increased flows it can be placed in a transitional EMC of B/C (Fig. 13) due to the availability of more water.

As far as Scenario 2 is concerned it has been derived from an earlier study by Rees (2005) that analysed impact of climate change on Indus River flows. According to this study, flows will rise in the early part of 21st century as a result of rapid melting of glaciers under warmer climate and then those will significantly decrease in the later part of the century once contribution from the glacier melt is not available due to vanishing glacier ice. It suggests a range of decrease in river flows of -40% to -65%. Similar to Scenario 1, we calculated two future reference time series corresponding to -40% and -65% to obtain range of E-flows under Scenario 2 (Figure. 15 and 16). These figures suggest that significant reduction in river flows will allow very small amounts to be allocated for E-flows, therefore, we will have to put the ecological state of the river of this specific study in a D/E transitional EMC or even in a lower than baseline class (‘C’) i.e. D or E (Fig. 15).

These changes in river flows under future climate scenarios may have many associated impacts on different important components that comprise the ecosystem of Indus delta. This aspect of our study has been addressed adequately in the following sub-section.

Discussion on Likely Impacts of Climate Change Induced Changes in River Flows

a. Likely impacts of Scenario 1

Though, the current EMC of Indus delta has been estimated to class ‘C’, which described ecological condition as ‘the habitats and dynamics of biota, have been disturbed, basic ecosystem functions are still intact’. Therefore, under increased water flow scenarios, the biodiversity would likely to be more ecologically sustainable i.e. reduction in species extinction, strengthen of food web, productive soils, etc. The arid climate of Indus delta and the adequate amount of freshwater flows would also help in reducing soil salinity and erosion, reducing pollution, and increase of sediment deposition etc. (Jimenez, l992) and hence improving fish diversity, distribution and abundance. This would greatly improve the socioeconomic conditions of communities of Indus delta mainly dependent on fishing and contributed to economy through export of fish and fish products.

In addition to ecology, the agriculture in Indus delta has mainly based on flooding of river and fresh alluvium that would rejuvenate soil and crop yields, which otherwise is declining. The cultivation of crops like red rice, banana, papaya, guava, dates, etc. which has been vanishing from the area could be sustainable and commercially viable only if increased fresh flows be managed and distributed judiciously.

Further, it has been reported in many studies (Rasul, 2012; IUCN, 2007) that millions of hectare of land has been affected and degraded due to sea water intrusion. The increased flows would help sediment flows in to the delta and reduced soil erosion.

Increased flows in the form of extreme climatic events like floods and extreme rainfall would cause some potential threats to the delta in the form of mega floods. Coastal communities became economically vulnerable through displacement, migration, damages to property and life, etc. For example, in Thatta district, around 14 thousand hectares of geographical area and 11.7 thousand hectares of agricultural area were affected due to floods of 2011 (FAO and SUPARCO 2011). The agriculture sector received a major setback during 2011 floods costing US$ 1840 million, where the total reconstruction cost was estimated to be US$ 2747 million followed by housing and education infrastructure that was badly demolished (World Bank and ADB 2011).

b. Likely impact of Scenario 2

A decrease in freshwater flows scenarios in later part of this century would likely to create devastating impact on delta. The far-reaching and foremost impact would be the more increase in salinity in Indus delta, which has been recently reported to 42,750 ppm against 1,500ppm of World Health Organization limit (Memon, 2005). The increased salinity with low precipitation and decrease freshwater flows can adversely impact the mangroves growth and extent; soil properties and productivity and hence reduction in livelihood options and opportunities (Amjad et al. 2007). These conditions significantly change the agricultural productivity and fish reproductive cycle along with other commercially important species of shrimps, crabs, etc. therefore, increasing the socio-economic and ecosystem vulnerabilities.

If this decreasing flow scenario persists longer, then EMC of Indus delta might move to transitional class ‘C/D’, if not completely to class ‘D’. Consequently, it would largely degrade the ecological conditions of natural habitat, biota, and result in decline in species’ richness (table 10).

Conclusions and Recommendations

The primary objective of this study was to assess the ecological state of the Indus River delta and on the basis of this, estimate permissible environmental flows downstream of Kotri barrage in the current and future climate change induced water availability scenarios. To decide about which EMC Indus delta can possibly be maintained by allowing E-Flows in the Indus River reach under study, extensive review of available literature and interviews with experts were conducted and it was placed in EMC ‘C’. In the next stage, we used desktop environmental flow estimation method to calculate required E-Flows required for the EMC of the Indus delta. This method estimated flow duration curves for the reference flow i.e. downstream Kotri releases and then derived FDCs for six EMCs (i.e. A to F) from the reference FDC. Two types of climate change induced river flow ‘change scenarios’ have been derived namely anticipated increase in river flows (Scenario 1) and anticipated decrease in river flows (Scenario 2). Analysis (FDC) of the prevailing flows in the study show that due to no E-Flow allocation for Indus River reach downstream of Korti barrage, there is zero or close to zero flow during low flow season that has deteriorated the state of ecosystems in the delta to a large extent. Based on our analysis, the ecosystems in the delta can benefit a lot if E-Flows, similar to recommendations of this study, are allowed in the study reach. Climate change impacts analysis reveals that under Scenario 1, more flows will be available that may help close to natural (reference) E-Flows that may result in a number of socioeconomic benefits along with increased risk of flood damages to the highly vulnerable delta communities. On the other hand, Scenario 2 will cause reduction in flow availability to the extent that E-Flows required under prevailing conditions would not be possible. Consequently, it will add to the deterioration of the deltaic ecosystems and hence the socio-economic condition of the communities therein.

This study aims to attract the attention of national policy makers to adopt and implement the concept of E-Flows that does not prevail in the country, especially at the implementation level. Moreover, this study can serve as an important scientific base for a more detailed study involving a combination of modeling techniques, field surveys and a multidisciplinary team of experts.

3.2.4 Socio-economic Vulnerability Assessment

This study aims to understand climate change induced socio-economic vulnerability of mangrove-dependent communities in the Indus Delta. We evaluate the linkages between vulnerability indicators by relating a community's perceptions with observed and projected climate change scenarios. In evaluating these linkages, some key questions are considered such as: what are the likely socio-economic drivers contributing to community's sensitivity? Are these drivers impacting the communities and how much is the community's coping potential to climate change? What are key adaptation options necessary for increasing community's resilience? This study has been carried out in a coastal town (Keti Bandar) located in Indus delta. This region is highly sensitive to declining fresh water flows, changing climate and poor socio-economic conditions of local population. We have used the Composite Vulnerability Index (CVI) approach in order to draw a general picture of community vulnerability under a changing climate in the Keti Bandar. The data for three CVI components (exposure, sensitivity and adaptive capacity) were collected at household level through questionnaire-based survey in six villages, however for exposure, secondary data were also acquired.

Selection of indicators and their criteria for justification:

Exposure indicators:

Air Temperature

Mangrove forests are dependent on optimal temperatures, which impact their biophysical processes such as photosynthesis, leaf formation, root development, flowering and fruiting etc. (Nicholls *et al.,* 2008; Belkin, 2009; Bardach, 1989). Salinity is also directly related to increase in temperature that can trigger changes in the composition and distribution of the mangroves species, favoring only high salt tolerant species (Lovelock *et al.,* 2010; Cohen *et al.,* 2009). Further, fish distribution and size has been altered by changing temperature coupled with precipitation patterns (Ayub, 2010). This is specifically true for the Keti Bandar area, where communities are highly dependent on key natural resources like fish, shrimp and crab for their livelihood and trade.

Precipitation

The mangroves growth and extent in arid climate are highly dependent on precipitation patterns within and outside the ecosystem (McLeod and Salim, 2006). Low precipitation level increase salinity in seawater leading to anaerobic conditions which in turn adversely impact the mangroves growth and reproduction cycles of the existing fauna (Rogers *et al.,* 2005; Brander, 2007). The erratic patterns of rain and flooding are likely to reduce ecosystem productivity due to soil erosion, phytoplankton displacement, less sedimentation deposit and reduction in agricultural yields (Keller *et al.* 2009).

Sea Surface Temperature (SST)

An average warming of 0.3±0.1^{0}C per decade was observed in the coastal areas of Pakistan; while projected increase in the global mean SST under IPCC SERS A2 scenario is around 2.6^{o}C by the end of 21st century (Singh and Sarker, 2002; Khan*et al.,* 2004, 2008; Belkin, 2009; IPCC, 2007). This would significantly impact the intensity of cyclone, evolution of monsoons, sea level rise, and sea water intrusion; thus changing the salinity levels and land use patterns, (Krishna and Roa, 2010; Khan *et al.,* 2008; Chowdhury *et al.,* 2010). Similarly, fish diversity, distribution, abundance, phenology and its spawning season all are closely related to SST variability (William *et al.,* 2013).

Sensitivity Indicators:

Mangrove degradation

The mangrove ecosystems provide a very diverse set of goods and services (Hossain, 2009). It provides a protection belt against storms and super cyclones by breaking and dissipating the wind energy (WWF, 2005); thus protecting the communities from the severity of natural disasters (McLeod and Salim, 2006). Overexploitation of some of the services provided by mangroves led to its degradation however, making it one of the highly sensitive ecosystems in Pakistan. Almost 70% reduction in mangrove forest cover has been witnessed in the past three decades; which is mainly associated with the cutting for fuel wood and clearing land for agriculture, housing and industrial purposes.

Water and Sanitation

The availability of clean and safe drinking water and sanitation facilities is an important factor and being strongly linked to health status of the local population (Adger *et al.,* 2004). It has been reported by the World Water Assessment Program (2009) that unavailability of safe drinking water and sanitation facility causes three million pre-mature deaths in rural areas of developing countries. The floods and droughts damage water and sanitation infrastructure and make the dependent population more prone to diseases, pathogens, agriculture runoff like pesticides and industrial effluents **(**Bates *et al.,* 2008).

Fresh Water Flows

The fresh water availability is an important factor, not only for growth of mangrove forests but also for agricultural and fish production (Amjad *et al.,* 2007). According to Salman (2010), observed decrease in fresh water flows from 140 to 40 million-acre feet is disastrous for mangroves' growth and sediment deposition. The freshwater availability for the Indus basin will decrease further by the end of 21st and 22nd centuries as projected by CMIP3 general circulation models under IPCC's SRES A1B scenario (Hasson *et al.*, 2013a; Hasson *et al.*, 2014). The decrease in freshwater availability causes a decrease in soil productivity and change in land use pattern consequently affecting the economic activities in the area (Hai and Khursheed, 2011).

Cost of Climatic Disasters

The climate or weather induced disasters causes 80% more damages than non-climatic one. (Costello *et al.,* 2009Frequencies of climate disaster possess more cost to vulnerable communities of coastal areas (FAO and SUPARCO 2011). For example, agriculture sector received a major setback during 2011 flood costing to US$ 1840 million, where the total reconstruction cost was estimated to be US$ 2747 million followed by housing and education infrastructure that have been badly demolished (World Bank and ADB 2011). The worst cyclone in the year 1999 brought the huge economic cost of more than a thousand million rupees (Memon, 2010).

Adaptive Capacity Indicators

Consumption Patterns

Consumption pattern become less diversified with the increased deterioration rate of natural resources, such as fish. Therefore, communities have to improve their coping capacity and adapt to some resilience mechanisms. During emergency situation or a disaster, food production and access is the first thing being compromised in coastal areas (World Bank, 2005). Household saving in coastal areas is very meager, and thus owing to a limited income resources and high outflows in terms of expenditures.

Income diversification

The major income sources in the coastal areas are fishing and agriculture; where the latter is under severe threat with decreasing fresh water flows in the coastal areas. Livestock is considered as the most valuable commodity as well as an addition for consumptive needs (WWF, 2005). If income is diversified, especially in case of off-farm income, 20-35% of additional income can be augmented to primary income (Azhar, 1995). Relying solely on the natural resources for the income can make the environment vulnerable, due to high resource dependency on nature.

Dependency Ratio

The dependency is negatively related to the adaptive capacity, as higher the dependency ratio, low is the adaptive capacity (World Bank, 2007). The adaptive capacity increases when communities have access to vocational trainings, as it not only decreases the dependency ratio but also the dependence on the natural sources for income. The linkage between adaptive capacity and dependency ratio is reported to be getting worse at the times of shocks or disasters (Joshi, 2012).

Schooling or Education Level

Factors that contribute to poor coping capacity due to climate change include low literacy rate and education level, weak institutions, low skills sets, and limited infrastructure (UNDP, 2006). There are no updated and authentic estimates of literacy level in this study area so far, but a general agreement is on a much lower level than the recorded ones. (Hai and Khurshid, 2011).

Infrastructure

Sensitivity and adaptive capacity of local communities are linked to development of the area and its infrastructure (Wilbanks *et al.,* 2007). Infrastructure status is a crucial variable in determining the adaptive capacity of any vulnerable population (Satterthwaite *et al.,* 2007). It includes all kinds of basic human needs including transportation, coastal defense work, access to clean water and sanitation. General civic facilities in both rural and urban areas are crucial in order to reduce its vulnerability (Assaf, 2009).

Household Assets holdings

For enhanced adaptive capacity, ownership of diversified, surplus and interchangeable assets plays a critical role (Ospina and Heek, 2010; Daze *et al.,* 2009). Among physical assets, nature of houses (already considered under infrastructure), number and size of boats, and livestock are important, while for human and natural assets, qualification (and trainings) and land owned by households are considered of vital importance for assessing the adaptive capacity (Joshi, 2012).

Family Networks

The coping capacity of a community dealing with the climate change associated risks is highly dependent upon social factors like, social values, networks, customs as well as the social capital. Social networks either within a family or community are very effective tool for ascertaining the adaptive capacity (Sutherland *et al.,* 2005). Particularly, during time of stress, kinship or good relationships between family members and members of the communities and networks can help to better cope with sudden environmental changes (Adger, 1999).

Migration

Migration is a socially embedded process, which is mostly perceived for bringing low adaptive capacity to the individuals or the communities coping with stressful changes in the environment (Adger, 1999; Brooks *et al.*, 2005). However, considering the broader perspective of migration, it can be established that migrations enhance adaptive capacity of any community to cope with climate change (Barnett and Webber, 2009).

Results and Discussion

Exposure Index Trends

The analysis of observed temperature record from Karachi-AP station and temperature change over the study area from Climate Research Unit (CRU) shows a consistent increase in mean annual air temperature (Figure 16a & 16b). Similarly, the index values for ‘monthly variability of temperature’ and ‘monthly average diurnal temperature range’ rank high. It shows increased incidence of abrupt changes which can trigger many bio-physical processes in coastal areas such as its adverse impact (mostly negative due to abrupt decline in temperature) on mangrove ecosystems.

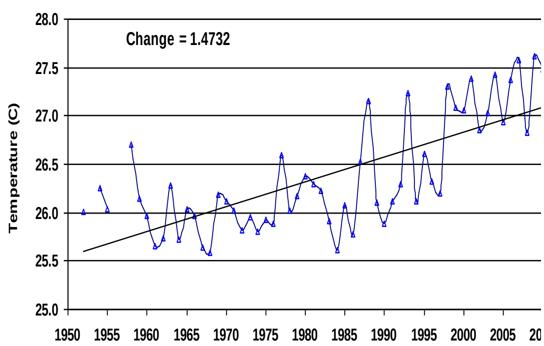


Figure 16a- Annual temperature trend of nearby meteorological station (Karachi-AP) for the period 1951-2010

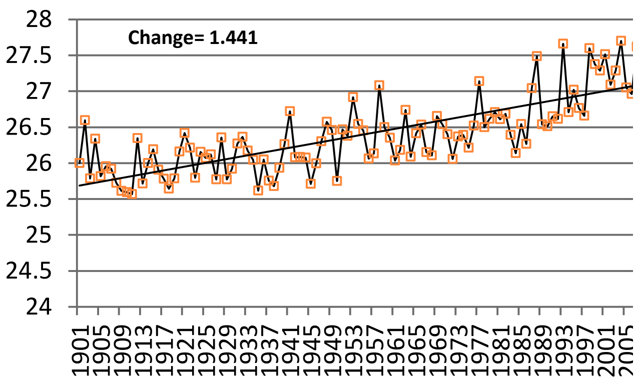


Figure 16b: Mean annual temperature trend over the study area between 1901-2011 taken from CRU TS gridded observational dataset

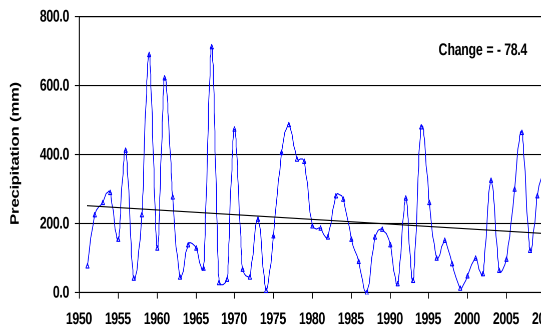


Figure 17a: Annual total precipitation trend taken from the nearby meteorological station (Karachi-AP) for the period 1951-2010

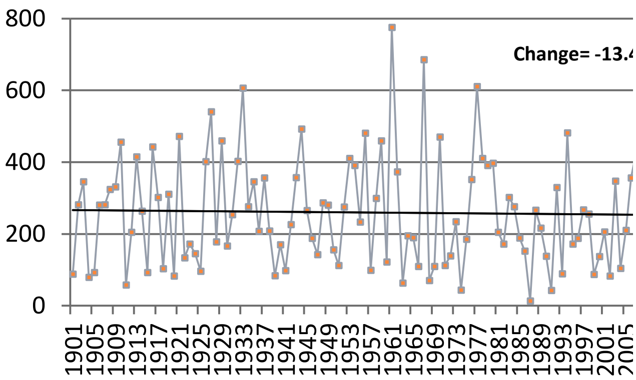


Figure 17b: Annual total precipitation trend over the study area between 1901-2011 taken from CRU TS gridded observational dataset

Annual total precipitation trend change has been estimated over the period 1951-2010 from a nearby meteorological observatory (Karachi-AP) and CRU TS 3.2 dataset over the study area for the period 1901-2011 (Figure 17a & 17b). As the frequency of extreme dry months in summer and spring seasons is high, the sensitivity of mangroves to precipitation exposure can therefore be moderate to highly sensitive and vulnerable.

Future Climate Change Scenarios for Keti Bander

While considering the index approach applied on observed climate parameters, we develop climate change scenarios for looking into possible future vulnerabilities. This provides us the best-available means of exploring how human activities and the observed environmental changes may change the future composition of the atmosphere (Fig. 18).

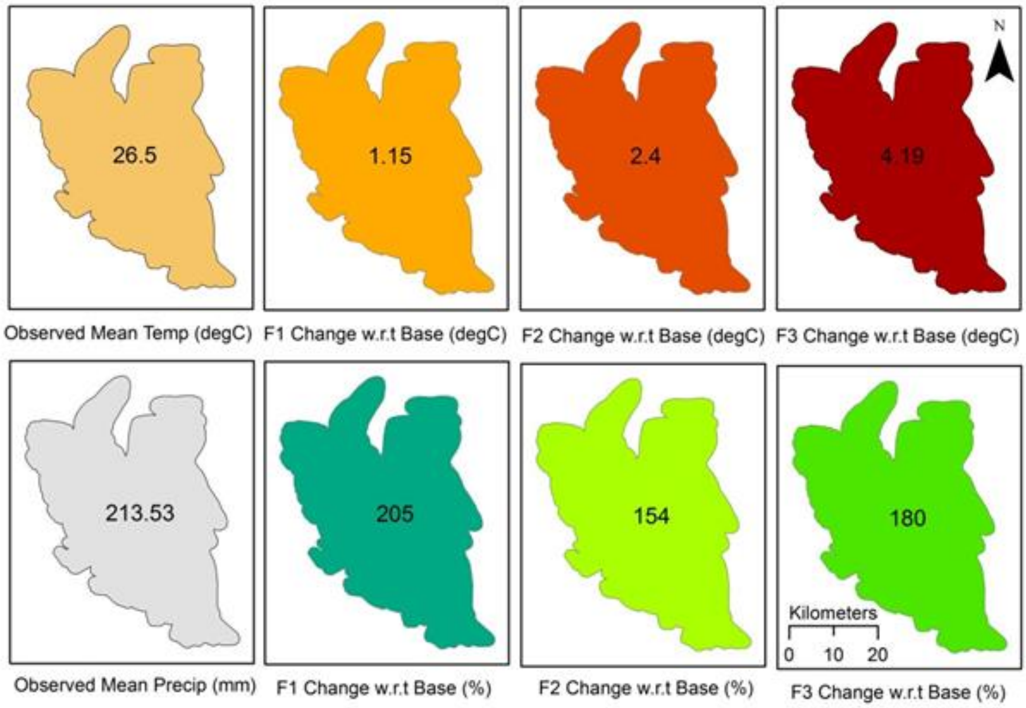


Figure 18: Observed Temperature (°C) and Precipitation (mm) Climatology along with the absolute projected changes in Temperature (°C) and relatively change in Precipitation (%) for the three future climates (F1, F2, F3) with respect to base for the study area.

Sensitivity Index Trends

The statistical results for exposure indicators and criteria show direct linkages with the sensitivity indicators. Scores of all sensitivity indicators for the Keti Bandar fall in the category of extremely sensitive/vulnerable, except for two variables i.e. 'mangroves used per month as a fuel' and 'estimated per capita economic cost of disasters'. The low values for these variables are mainly due to consistently shrinking mangrove cover; rendering low accessibility to mangroves for the local communities and high rate of migration during disasters as shown in table 17.

Table 17: Sub-indices of CVI assessment, their indicators, related variables and their computed values

Sub-Indices and their Indicators	Variable	Variable Description	Index overall	Index for Agriculture	Index for Fisheries
Exposure (E)			**0.521**	**0.521**	**0.521**
Air Temperature	E1	Monthly Variability of Temperatures during	0.677	0.677	0.677
	E2	Monthly Average Diurnal Temperature	0.549	0.549	0.549
	E5	Frequency of extreme hot months (above	0.41	0.41	0.41
	E6	Frequency of extreme cold months (below -			
Precipitation (P)	E7	No of extreme dry days: Spring (P<5mm)	0.555	0.555	0.555
	E3	Monthly Variability of total precipitation	0.394	0.394	0.394
Sea Surface	E4	Monthly variability of Sea Surface Temp.	0.542	0.542	0.542
Sensitivity (S)			**0.652**	**0.638**	**0.669**
Mangrove Forests	S1	Sensitivity of mangroves in Keti Bandar	0.808	0.845	0.769
	S2	Accessibility to Mangroves	0.371	0.269	0.444
	S3	Mangroves used per month as fuel	0.024	0.001	0.050
Water and sanitation	S4	Share of households relying on unprotected	0.908	0.787	0.758
	S5	Population deprived of sanitation Facility	0.967	0.938	1
Fresh Water Flows	S6	Change in Fresh Water flows	0.815	0.742	0.913
	S7	Effect of unavailability of Fresh water on	0.804	0.935	-
	S8	Effect of unavailability of Fresh Water on Fish	0.848	-	1
	S9	Frequency of sea intrusion or inundation	0.649	0.610	0.692
Climatic Disasters	S10	Frequency of Natural Climatic Disasters	0.959	0.924	1
	S11	Intensity of Natural Climatic Disasters	0.881	0.903	0.857
	S12	Estimated per capita economic costs of these	0.062	0.066	0.058
	S13	Percentage of population financially aided by	0.817	0.781	0.857
Lack of Adaptive Capacity (1-A)			**0.564**	**0.581**	**0.546**
Consumption	A1	Household Consumption per Capita	0.081	0.057	0.105
Income	A2	Herfindahl index of income diversification	0.141	0.161	0.122
Dependency	A3	Ratio of total number of people and number	0.214	0.236	0.189
Education Level	A4	People educated above secondary level	0.017	0.031	0
	A5	Percentage Share of Literate People	0.195	0.307	0.067
Infrastructure	A6	Access to Basic Services	0.196	0.234	0.152
Assets	A7	Nature of Dwellings	0.85	0.875	0.821
	A8	Number of the Assets owned by the	0.65	0.453	0.875
Family Networks	A9	Level of cooperation within the family	0.983	0.969	1
	A10	Level of cooperation within the family	0.883	0.844	0.929
Migrations	A11	Extent of Migration due to natural Disasters	0.8	0.844	0.75
	A12	Extent of Migration because of material	0.783	0.719	0.857
CVI			**0.580**	**0.579**	**0.580**

Moreover, inadequate and non-regulated release of fresh water flows from the Indus River below Kotri barrage allows sea water intrusion (Ali *et al*. 2009); decreasing agriculture and fisheries production in Keti Bandar. Frequency of sea water intrusion or inundation is recorded as high. If an individual variable of 'effects of unavailability of fresh water for fish' is considered for fishing community, the index value is 1. This value reflects a very high impact on the economy of community that depends entirely on fisheries.

Considering the relation between the exposure and cost of climatic disasters, the respective variables showed a high index values; referring to the fact that climatic disasters are quite frequent in Keti Bandar, and the area has been hit worst by the floods of 2010 and 2011. The situation of drinking water and sanitation in the study area is also worse. Almost none of the households in fishing community have access to the sanitation facility.

Potential Impacts and Adaptive Capacity

Migrations in the Keti Bandar were recorded as high, depicting high adaptive capacity of the community, owing to the reasons that people were capable enough to migrate at the times of natural disasters to seek shelter and job opportunities. According to the perception survey (Figure 20 & 21), decreasing trend of livelihood, unavailability of civic facilities, and seeking better job opportunities are the typical non-climatic factors triggering migration. However, among the climatic factors, the floods and heavy rainfalls are the main causes of migration.

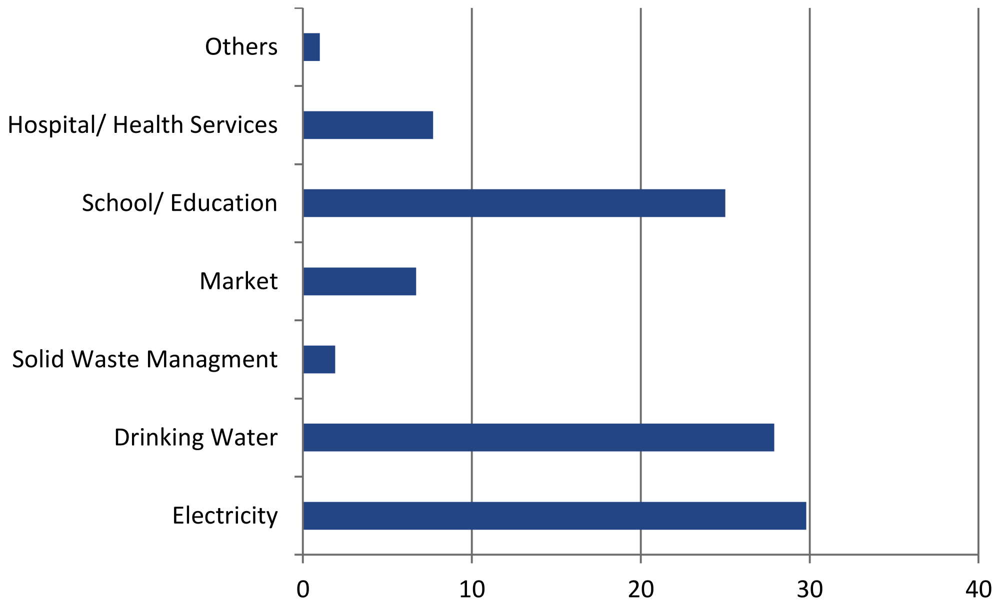
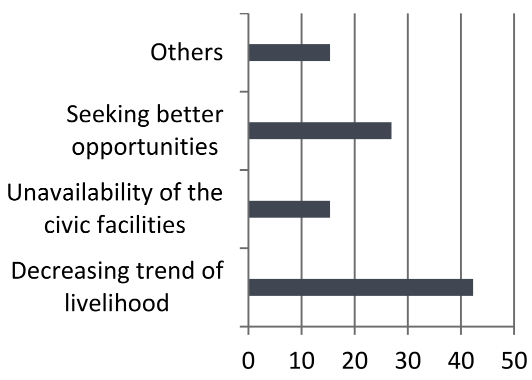


Figure 19: Access (%) to basic services



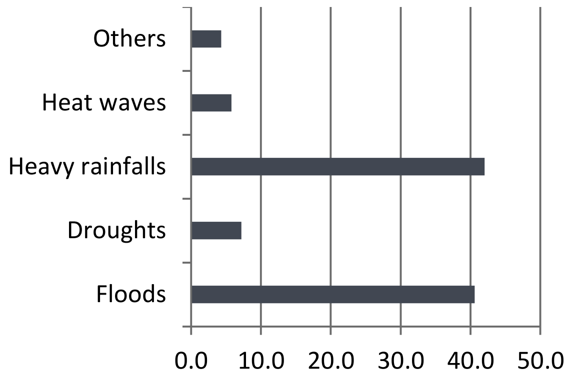


Figure 20: General reasons (%) for migration

Figure 21: Climatic reasons (%) for migration

It can be ascertained that the consumption patterns, income diversification, dependency ratio, schooling or education level and infrastructure (access to basic facilities) are the indicators reflecting low adaptive capacity/ very high vulnerability in the community of Keti Bandar (table 17). There are many reasons for these circumstances but low or nearly insignificant literacy rate (worst among the fishing community with an index value of 0) and poorly diversified and intervallic sources of income are the most significant reasons behind low adaptive capacity.

Over all, infrastructure (nature of dwellings), family networks, and migration are the indicators which enhance the adaptive capacity of the community and balance the adaptive capacity sub index when considered collectively.

Adaptation options and recommendations

The purpose of this vulnerability assessment is to identify different possible adaptation options that can feed into on-going national efforts for the development and action plans in the light of recently approved National climate change policy in 2012. Below are some of the key adaptation options deducted from this study that could provide useful intervention strategies to tackle climate change consequences and impacts in the Indus Delta region:

1. **Provision of safe drinking water and sanitation facilities:** Lack of access to safe and clean water for drinking and sanitation is a major cause of poor health status among the Indus Deltaic communities. The ground water in the Indus delta is saline and unsuitable for drinking; and as a substitute communities have to drink untreated water from the irrigation canals, which are contaminated with industrial and agricultural effluents. The situation becomes critical when water is not available in irrigation canals due to seasonal flows or application to agriculture fields. Hence, proper water storage and its treatment facilities for the coastal areas can enable them to better adapt to risks and shocks related to climate change.

2. **Ensuring environmental flows:** Decreased fresh water flows in the past have greatly contributed in the degradation of the Indus delta ecology. The resultant decrease in coastal ecosystem resources and services has shrunk the livelihood opportunities, causing widespread poverty and migration in the coastal areas. This is mainly linked with extensive irrigation developments upstream. In Water Accord enacted in 1991, provinces were agreed on to allocate 10 million acre feet water as environmental flows to protect the low riparian

ecosystem. The accord is waiting to be implemented successfully. It is, therefore, highly recommended to ensure the water availability as 'environmental flows' for the sustainable ecosystem which can also be taken as an important adaptation strategy in devising the National Climate Change action plans for this area.

3. **Safeguard from climatic disasters and settlements in high-risk areas:** The impact of climate change is projected to play a major role particularly in the coastal areas, given the potential of increasing extreme climate events due to sea level rise. Recent floods and sea storms have provided reliable indications of this. There is a need to enhance both scientific and local knowledge base on climate change impacts over the Indus Delta to better integrate such information into planning processes for disaster risk reduction and community development strategies. Since these communities dwell in small and scattered settlements usually around fringes of creeks that are highly vulnerable to natural calamities and even prone to medium level floods/storms, there is a need to develop proper and safe settlements in order to protect life and property as well as provision of civic facilities.

4. **Improving education access:** Education is a key to enhance the resilience of local communities both in pre and post-disaster situations. The investment in education sector can greatly enhance the adaptive capacity and resilience of an individual or a community to respond to these climate change risks and vulnerabilities. Therefore, allocation of funds and facilities for improving literacy rate in the coastal areas of Pakistan can greatly improve the livelihood options, which can help not only in alleviating poverty but also in increasing adaptive capacity to respond to climate change.

5. **Capacity development for climate preparedness and innovations:** The incapacities of institutions and professional's networks have led to poor management of coastal resources particularly in the wake of rapidly changing environmental indicators and climate extremes. There is a widespread lack of the governmental framework or action plans for raising awareness to the local communities living and working in such vulnerable areas. Thus, it is recommended that the capacities related to public sector departments should be enhanced by re-organization and improving their inter-departmental coordination. Further, new approaches should be devised, tested and implemented such as new building and settlement codes, insurance coverage for the vulnerable fishing and farmers' communities, rapid evacuation drills for hazard preparedness of the coastal communities, etc.

Conclusion

In this study we attempted to answer some key research questions by relating community's perceptions with observed and projected climate change scenarios. We tried to develop linkages between likely drivers of community's sensitivity, impacts and coping potential due to climate change. Composite Vulnerability Index (CVI) approach has been used in order to draw a general picture of vulnerable communities under changing climate in Keti Bandar area of the Indus Delta. It is found that these marginalized coastal communities, either engaged with fishery or agriculture sector, are highly sensitive and exposed to the climate change driven threats. Further, there is lack of adaptive capacity mainly due to the poor consumption patterns, less income diversification, high dependency ratio and lack of education. Therefore, we recommend some key adaptation options that can be incorporated into ongoing national efforts for developing climate change action plans at the local levels. The recommendations focus on provision of safe drinking water and sanitation facilities, ensuring the environmental flows to the Indus delta, provision of safeguards from the climatic disaster, enhanced access to education, and adoption to the innovative livelihoods options in order to enhance the community's resilience to climate change in coastal areas of Pakistan.

3.2.5 Institutional Analysis

Over the past 50 years, changes in the ecosystems have been rapid and widespread by human activities in comparison to any period of time in the human history (MA 2005). Even though alterations to the ecosystem have provided considerable gains in the economic development and well-being of man, have come at a price in degrading many ecosystem services and have amplified the risk nonlinear changes in the ecosystems (Garmestani, AS & Benson, MH, 2013). Ostrom (2009) states that, the budding losses of water resources, fisheries and forests are a major crisis worldwide. There is limited understanding of the processes that facilitate improvements of natural resources or their deterioration, which is due to different concepts and languages used in the scientific disciplines to express and describe the complex social-ecological systems (SES). The absence of a general framework that could be used to organize findings, the isolated knowledge does not cumulate. The accepted theory, until recently was that governments must enforce solutions for maintaining resources as resource-users will never self-organize to sustain it. Many natural resources are currently under threat of damaging or loss of resources, including fisheries, water resources and forests, at the same time facing decline of biodiversity due to the impending threat of climate change. Resources used by man are rooted in complex social-ecological systems (SES). It is a challenge to analyze how some SESs are sustainable whereas others fail. The complex systems require identification and investigation of the multiple levels at various spatial and temporal scales (F. Berkes et al, 1998; J. Norberg & Cumming, 2008).

North (1990), describes institutions as having formal rules such as laws, political systems, contracts etc, and informal rules such as norms, customs, traditions religious beliefs etc. that assist in individual or group coordination and administration. Kherallah and Kirsten (2001) state that institutions are responsible in influencing human behavior which affects the economic outcome such as economic growth and development and economic efficiency which often results in jointly in changes in the institutions.

When considering institutional environment, a difference is ofter set between formal and informal institutions. Formal institutions are "embodied in constitutions, laws, the structure of state decision (the number of veto players and their mode of selection) and regulations enforced by judges, courts, police, bureaucracy, and the like" whereas informal institutions are "norms of conduct, perhaps historical traditions or religious precepts" enforced by custom or habit (Keefer and Shirley, 2000; cited in Williamson, 2002). Eaton *et al*. (2008) stated that a well operated institutional environment is significant for economic development. The institutional environment comprises of extensive socio-economic structure within which various institutional arrangements transpire, such as market dealings (agreements to exchange goods and services), or organizations (formal groups involving individuals working towards a common purpose).

Developing countries have underdeveloped institutions, issues such as when countries develop which institutions function effectively and how institution can be developed by the countries (Shirley, 2003).

Livelihood strategies created and adapted by individuals and households are formed by integrating policies, institutions and processes. The sustainability of natural resources can be impacted the institutionally shaped livelihood approach. In Pakistan, a forest policy that is workable, research-based, sustainable and people-friendly needs to be formulated that can accommodate the requirements of the stakeholders including the government. Until the sustainability of the stakeholder's livelihood is not addressed, the objectives of the policy initiatives cannot be accomplished (Shahbaz et al. 2006). The socioeconomic aspects of many developing countries include the composition of village communities, gender issues, inequality of economic levels, infrastructure development, participation level, inadequate policies and systems, poor awareness and weakness of the institutions (Mishra et al. 2005).

In response to 'institutional failure' concerning sustainable forest resource management, decentralized or participatory forest policies have been constructed in many developing countries (Dupar and Badenoch 2002; Siry et al. 2005). The inefficiency of the top-down system of forest management of Pakistan has been brought about by the failure of the forest authorities in decreasing deforestation and has brought about conflicts between the local people and the state (Iqbal 2000; Khattak 2002).

Many international communities have implemented and been supporters of integrated coastal area management principles, though in practice integrated coastal management has been less successful and in many localities disagreement over resource use still exists (Brugere, 2006).

Pakistan's fishing sector employ 125,000 citizens with family dependents numbering nearly one million. Above 15,000 diverse fishing vessels of assorted sizes are engaged in fishing, ranging from small and medium-sized boats to large launches and trawlers of which one-third are shrimp trawlers mostly owned by shareholders outside the community. Boat and shore fishing is done in creeks and within the 12-mile territorial limit which falls under provincial jurisdiction, whereas, larger launches have the opportunity in going to deeper waters off chore extending up to the Somalian coast (Khan at al., 2005). Pakistan's domestic population has a small consumption of fish, thus is ranked one of the lowest consumers of

fish per capita; the majority of the fish catch is exported to Europe, the USA, the Far East and the Middle East (SMEDA, 1998).

Institutional Performance against NGOs

The boundaries and property rights of mangroves areas under the jurisdictions of these institutions SFD, PQA and BoR were clearly drawn mostly following creeks in the deltaic landscape. Moreover, the official staffs of these agencies were familiar with the boundaries and land rights in mangrove areas. But PQA and BoR were not concerned about the access and rights as they are not accountable for the management of mangrove forests. Regarding the analysis of organizations such as WWF, IUCN for the management of mangroves have noticeably described the boundaries, land rights issues and awareness of official staffs in mangrove areas. On the other hand, Pakistan Fisher-folk Forum (PFF) is community based organization which is fairly familiar with boundaries and land rights in mangrove areas. All three organizations had a facility of official staffs but only those hired by SFD were legally accountable for monitoring the local use of mangroves. Moreover, monitoring mangroves by SFD could not be so effective because of inadequate logistics and field staffs. There were legal fines and sanctions for illegal use of mangroves but seemingly the cases of prosecutions and detention against rule violators were very exceptional. In case of PQA, nobody was legally assigned such a duty but PQA guards were monitoring the use and status of mangroves as a part of their routine watch on the properties and infrastructure of the port. Again BoR had not specified any set of rules and regulations for the monitoring of mangroves. International agencies WWF, IUCN has no any department for the monitoring of mangroves and they evaluate mangroves by considering either external, internal or third party with respect to their projects.

Regarding the conservation and restoration of mangroves, SFD has replanted about 20,000 hectares of mangrove in discrete localities and has made significant efforts to restore the exotic mangrove species in the Indus Delta. For the plantation of mangroves, SFD has in-house expertise but still staff availability is an issue for plantation and restoration. Similarly, WWF and IUCN also have in-house expertise including human resources with good experience for the conservation and restoration of mangroves but PFF have not. However, most of the mangroves planted by PQA were in replacement of those cleared for the improvement in port facilities. BoR had not commenced any mangrove plantation in their region, as they did not consider it as their duty. Nearly all mangrove plantations in the Indus Delta had been accomplished through the partnerships with regional and international agencies such as the World Bank, IUCN and WWF. In this regard, SFD doesn't realize such need to establish partnership with foresaid agencies as lack of required financial resources. According to SFD, the growth of mangroves in their local area is average due to geographical variation but their department is excellently managing the plantation of mangroves and their conservation decisions are based on scientific evidence. Moreover, conservation and management decisions of international agencies are based on both scientific and traditional knowledge.

SFD considers the communities for the better management of mangroves and conduct quarterly based meetings for the engagement of local people in mangrove plantation. As viewed by Shah (1998) SFD had organized a list of mangrove dependent communities for the whole Indus Delta but the list was never utilized for any significant purpose and is now outdated. In short, these institutions had no formal mandate or any specific mechanism through which local people could be mobilized to participate in restoration and management of mangroves. On the other hand, WWF, IUCN and PFF also consider the local people participation for the management off mangroves. They conduct meetings on monthly basis and response of local people towards participation is good.

Changing National Forest Policy Concerns

Policies for forest management have been in practice in the Sub-continent since the British Asia. The need to retreat policy objectives of British Asia for generating maximum revenues and foreign exchange for national economic development, motivated colonial forestry agency to design silvicultural management systems in mangrove forests of Sunderban in the British-India and Matang of Malaysia. Although, mangrove covered areas of the Indus Delta, in Pakistan, were characterized as 'wastelands' and Board of Revenue (BoR) was the decision-making authority. Lacking managerial and technical skills, the Sindh forest department (SFD) established a management system for the mangroves owing to the organization's primary mandate. The first forest policy (1955) of Pakistan intended to increase forest cover of the country; SFD took this as an opportunity to increase mangrove cover even though declared as wastelands till that time. In 1958, with the updating of the policy the Forestry Section of Food and Agriculture Department of West Pakistan declared these mangroves as 'Protected Forests' under the control of the SFD. The first working plan (1963-1983) for the management of mangroves was formulated inspired by the Sunderban management plan in East Pakistan. The plan failed to achieve its objects to sustain the domestic agriculture, conserving healthy mangrove cover for the shelter of coastline and effects of the ocean. In 1973, thousand hectares of mangrove trees were removed to accommodate the Port Muhammad Bin Qasim to increase international trade. As a result SFD had to allocate about 46,000 hectares covered by mangrove forests for Port Qasim Authority (PQA).

According to the National Policy on Forestry and Wildlife 1980, that recognized the importance of involvement of local people in tree plantation and establishment of national parks, the SFD established a Coastal Zone Afforestation Division in 1985. The CZAD focused on three main tasks, firstly to *take over the control of mangroves*, which were sources of firewood and fodder for the local communities. The local communities accepted SFD's ownership of mangroves and as agreed to compensate a minimum payment for the collection of materials from these forests. The second task was plantation *of mangroves on fallow mudflats.* However, the most significant task was to *gather all mandatory information* required for the provision of a working plan for the silvicultural management of mangroves as compulsory by the forest policies.

Not much struggle was made for the management of mangroves until 1985 when SFD organized their second working plan (1985–2005) for the remaining mangroves under its authority. This working plan predicted that through better understanding of the value of mangroves, the anticipated objective of making significant involvement to the forest wealth of the country would be attained. While, the main objectives of this plan were alike to the previous plan, it also correlated the protective value of mangroves with their fruitful value (SFD 1985). In addition, consideration was also paid on raising public attentiveness about the intangible benefits. The strategy was also concerned with the maintainable source of firewood and fodder to the local communities.

National Forest Policy 2010

National Forest Policy 2010 provides a framework for sustainable management of forests and associated natural resources including wildlife, watersheds, rangelands and allied biodiversity. The Policy strives for initiating the process of addressing essential causes of forest depletion through

active contribution of all local communities to sustain and expand ecosystem functions. The main aim of this policy is to provide guiding principle to the federal and provincial agencies for improvement, maintenance, restoration and sustainable management of forests and associated natural resources to make sure sustainability of ecosystem functions, facilities and benefits for existing and future generations of Pakistan.

National Forest Policy 2010 stands out from previous policies by ensuring financial and technical aid on Geographical Information System (GIS) and Remote Sensing for Research and Development (R & D) institutions and provincial forest departments, to effectively monitor the forest cover on public and private land. The policy could ensure the protection and afforestation of mangrove forests but failed to make proper arrangements to control marine pollution, allowing sufficient water to flow down the Indus River for sustainability of these forests. Stakeholder involvement by incentive-based programs for forests and natural resources protection, which ultimately benefits downstream communities, has yet to be initiated. Since the 18th amendment denouncement, umbrella policy is still awaiting, the responsibilities and priming the actions proposed in the policy to be fulfilled by provincial governments including Federally Administered Tribal Area (FATA), Azad Jammu and Kashmir (AJK) and Gilgit-Baltistan (GB).

Discussion

Regarding the concept of "*participation*" and "*sustainable livelihoods*", forest policies of Pakistan were aimed at forest conservation. However, in practice these policies are not only duplication of previously top-down, autocratic and non-participatory forest polices but also the conservation aspect of those policies failed to play an effective role in systematic monitoring and implementation. The analysis of previous policies was associated with government's political objectives, overlooking ground realities and local people participation. In practice, unequal power relations and social conflicts are quite common e.g., forest resources are difficult to get for the poor and vulnerable communities. Consequently, asymmetry of power created a sense "lack of rights" encouraging the vulnerable communities to adapt illegal ways for better livelihoods from the forest resources (Shackleton *et al*. 2002).

Changing trends and learned experiences are leading the world towards a new approach "*conservation and development*" replacing with "*conservation versus development*". The proponents of this approach including governments, international donors and international lending agencies are recalibrating their vision and mission statements to organize themselves towards development without distorting the conservation. However, good governance is the key to pro-poor efforts for any development in the country. Certainly, vulnerable coastal communities engaged with fishery (90%) or agriculture sector (8%), are already highly sensitive and exposed to the climate change driven threats. Furthermore, there is lack of adaptive capacity mainly due to the poor consumption patterns, less income diversification, high dependency ratio and lack of education.

Following key policy recommendations are needed to be considered seriously;

- Since the first policy, it has been observed that Sindh Board of Revenue (BoR) being the major authority has no technical expertise and intensions in the mangrove forest management. It is recommended to transfer the authoritative ownership and powers to Sindh Forest Department (SFD) for improved management practices. Nevertheless, the main purpose for mangrove forest management should be well-defined and prioritized.

- An inter-institutional committee, comprising of representatives from formal and informal institutions, research institutions, local communities, NGO's and INGO's, should be formed to enlighten the scientific and indigenous knowledge base, and management practices in the mangrove ecosystems. Where feasible, multiple-use management should be taken into consideration for the ultimate goal of sustainable management and development.

3.3 Srilanka- Puttalam lagoon- Result and Discussion

3.3.1 Site Selection and Characterization

The distribution of mangroves in the world is limited to the tropical and sub-tropical regions with best development between 25°N and 25°S. Mangrove ecosystems are found as discontinuous patches all around the coastal area of Sri Lanka, which lies 5°N and 10°N. The largest patch in Sri Lanka has been identified as the one that occurs in Puttalam Lagoon-Dutch Bay-Portuguese bay complex, extending over about 4000 hectares. Because of their high productivity mangrove ecosystems provide resources for household activities and livelihoods for coastal communities, who are usually marginalized in terms of economy. During the past decade most of this mangrove ecosystem in the Puttalam lagoon area has been exploited. Expansion of shrimp farming, urbanization, tourism, industries and climate change driven factors are affecting mangrove ecosystems (McLeod and Salm, 2006; IUCN2012).

Location and characteristics

The Puttalam Lagoon, located at 7.959213 - 8.544330 North and 790 48'25 - 79049'17, is one of the largest lagoons in Sri Lanka which extends over 32,750 ha (ADB and IUCN, 2003). The Lagoon is open naturally to the sea at the northern end, while the southern end is connected to the Dutch canal. The Lagoon system is very shallow with a depth of 1-2 m. However the deep channels within the Lagoon are much deeper with depths of 4-5 m. The northern part of the lagoon consists of water with normal oceanic salinity whereas the southern past is hyper-saline due to high evaporation.

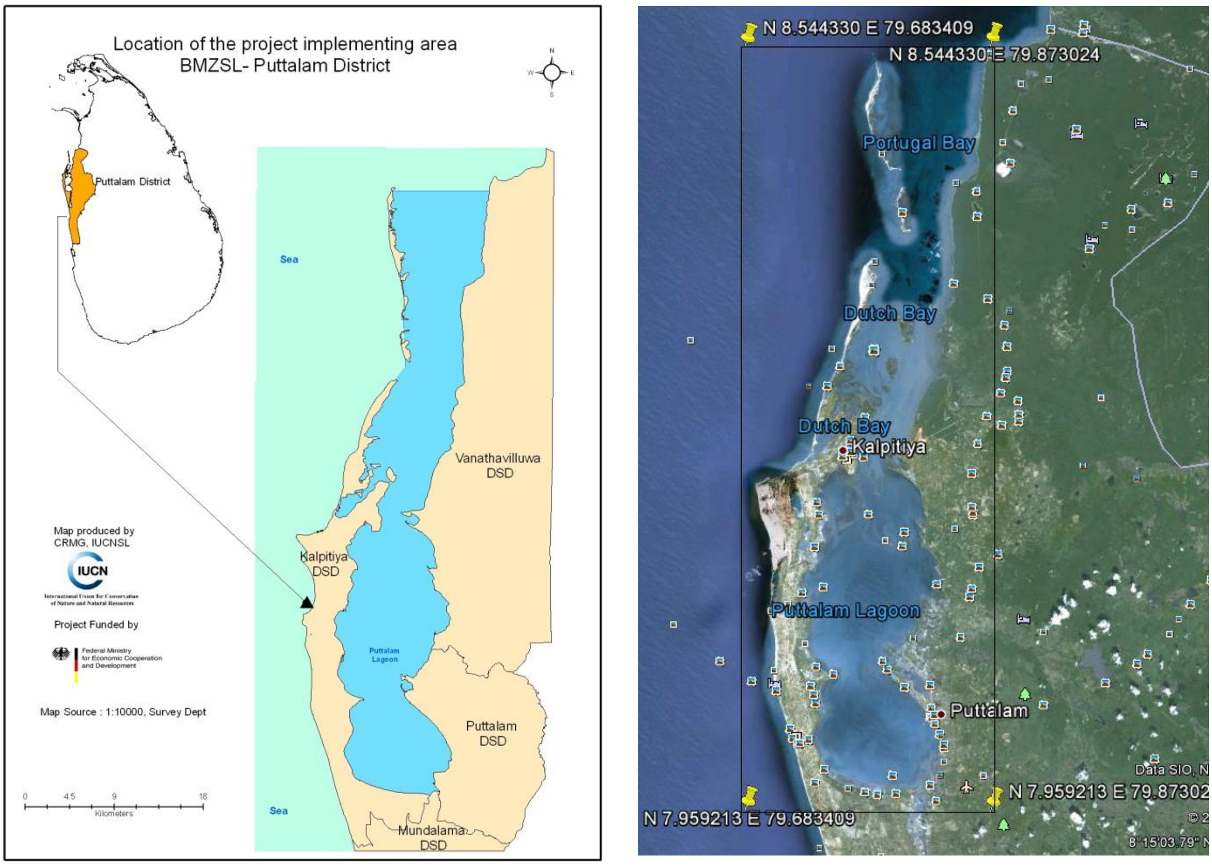


Figure 23: Location of the Puttalam Lagoon

(Source: Weragodatenna, 2010)

The Lagoon is one of the most productive estuaries in the country and has been an economically important area in terms of fisheries, tourism, agriculture and industries. On the other hand, this sensitive coastal ecosystem is an assert of Sri Lankan biodiversity as it harbours a number of floral and faunal species in distinct habitats such as mangroves, coral reefs, salt marshes, sand dunes, mudflats, etc. A total of 512 species of flora, including 406 native species, nine endemic, eight threatened species, 108 exotic and 13 invasive alien species and a total of 308 faunal species belonging to 112 families with seven endemic and 12 Nationally Threatened species have been identified in the Puttalam Lagoon area. Furthermore, the largest National Park of Sri Lanka - Wilpattu National Park is situated to the NorthEast of the lagoon and the Bar Reef Marine Sanctuary to the NorthWest. The Bar Reef Marine Sanctuary is the largest marine protected area in Sri Lanka. It has an extent of 306.7 km^2 and is located parallel to the coast from the northern ending of the Kalpitiya peninsula to the islands which separate Portugal Bay from the Gulf of Mannar. It has high ecological, biological and aesthetic significance, being the home of 156 species of coral and 283 species of reef fish.

Puttalam Lagoon is located in the dry zone of the island. The annual average rainfall varies between 1,000 and 1,100 mm and derived mainly from the northeast monsoon. Because of the distinct seasonality in the rainfall the area experiences a prolonged dry season of 4-7 months from March to September. Apart from the low seasonal rainfall the prominent climatic characteristics of the Lagoon are intense sunlight and strong seasonal winds. The average temperature of the area is 28.2 º C with a peak of 29.7 ºC in May and a lowest of 21.7 ºC in January. The average monthly surface temperatures in the Puttalam Lagoon vary from 27.6 ºC to 30.8 ºC (Durairatnam, 1963). Coastal wind speed is highest during the southwest monsoon (from May to September) with peak monthly average wind speed of 12 km/ in August. The lowest wind speed in observed in November (5.2 km/h).

The Lagoon is connected to outflows of three river basins, namely Kala Oya, Mi Oya and Moongil Aru. The extents of the catchments are: Kala Oya 2,772 km^2, Mi Oya 1,516 km^2 and Moongil Ara 44 km^2 (IUCN, 2010). Kala Oya provides the largest freshwater volume to the Lagoon, however its effect is reduced as the stream flows closer to the mouth of the Lagoon. Apart from the water from local rainfall Kala Oya receives water from the largest river in Sri Lanka via trans-basin diversion. This diversion project was initiated in 1973 in order to supply water for paddy cultivation in the dry zone of the country. Therefore, the most dominant water use of the Kala Oya basin is irrigated agriculture, predominantly paddy cultivation (De Alwis, undated). Cascade tank system is a prominent feature of the dry zone of the country. Kala Oya basin alone has about 600 ancient minor irrigation tanks which holds and reuses water mainly for irrigation and other water uses.

The Puttalam Lagoon supports a range of inter-connected and inter-dependent natural habitats that form a mosaic in a larger landscape. Mangroves, salt marshes, coral reefs, beach front vegetation, tropical dry-mix evergreen forests, grasslands, mud flats, marsh lands, rivers and other water bodies, riverine wetlands and some of the major habitats found in the Puttalam lagoon.

DPSIR FRAMEWORK:

After the end of civil war in Sri Lanka there has been a rapid growth in the tourism sector in the area. The number of tourist arrivals for this area has increased by 447,890 in 2008, 438,475 in 2009 and 654,476 in 2010. Large scale development of resort, related infrastructure and services is one of the drivers identified in this assessment.

Another driver is expansion of salt pans. In 2010 there was 1,363 ha of slatterns in the Puttalam Lagoon area (Weragodatenna, 2010) whereas in the 1990's, there was only one slattern close to Puttalam town. Currently there are many large-scale salterns in the area. These provide casual employment.

For example, a family engaged in the industry can earn about LKR 3,000-5,000 (~26.4-44 USD) per month from a 0.135 ha salt pan (Fernando, 2010) therefore, it had been becoming an emerging livelihood of the area.

The lagoon receives freshwater from Kala Oya, the Mi Oya and the Moongil Ara. The catchments of these freshwater sources as well as the land around the Lagoon are under intensive crop cultivation such as paddy, coconut, vegetables and fruit. Heavy use of agro-chemicals and chemical fertilizers are being used by the farmers in these sensitive catchment areas in order to receive high crop yields. This has led to pollution of Lagoon water and surrounding freshwater and groundwater by agro chemicals and plant nutrients. Furthermore, the soil from the agricultural fields wash into the Lagoon causing increased turbidity, sedimentation and nutrient accumulation.

Climatic variability is an emerging threat to the environment, economy and the communities associated with the Lagoon and surrounding area. A 7% decrease in average rainfall has been observed in the Puttalam area in between 1961-1990 compared to 1931-1960. Moreover, there has been an increasing trend in the average air temperature of 0.016 ºC per year between 1961-1990, with a maximum rate of increase of 0.02 ºC per year in the Puttalam area (Survey Dept. 2007). The effect on freshwater by the rising sea level and salt water intrusion, effect of increasing temperature and also the effect of change of rainfall patter are the drivers associated with climate change which affect the mangroves.

Based on these drivers a DPSIR framework has been developed for the Puttalam lagoon (Figure 24)

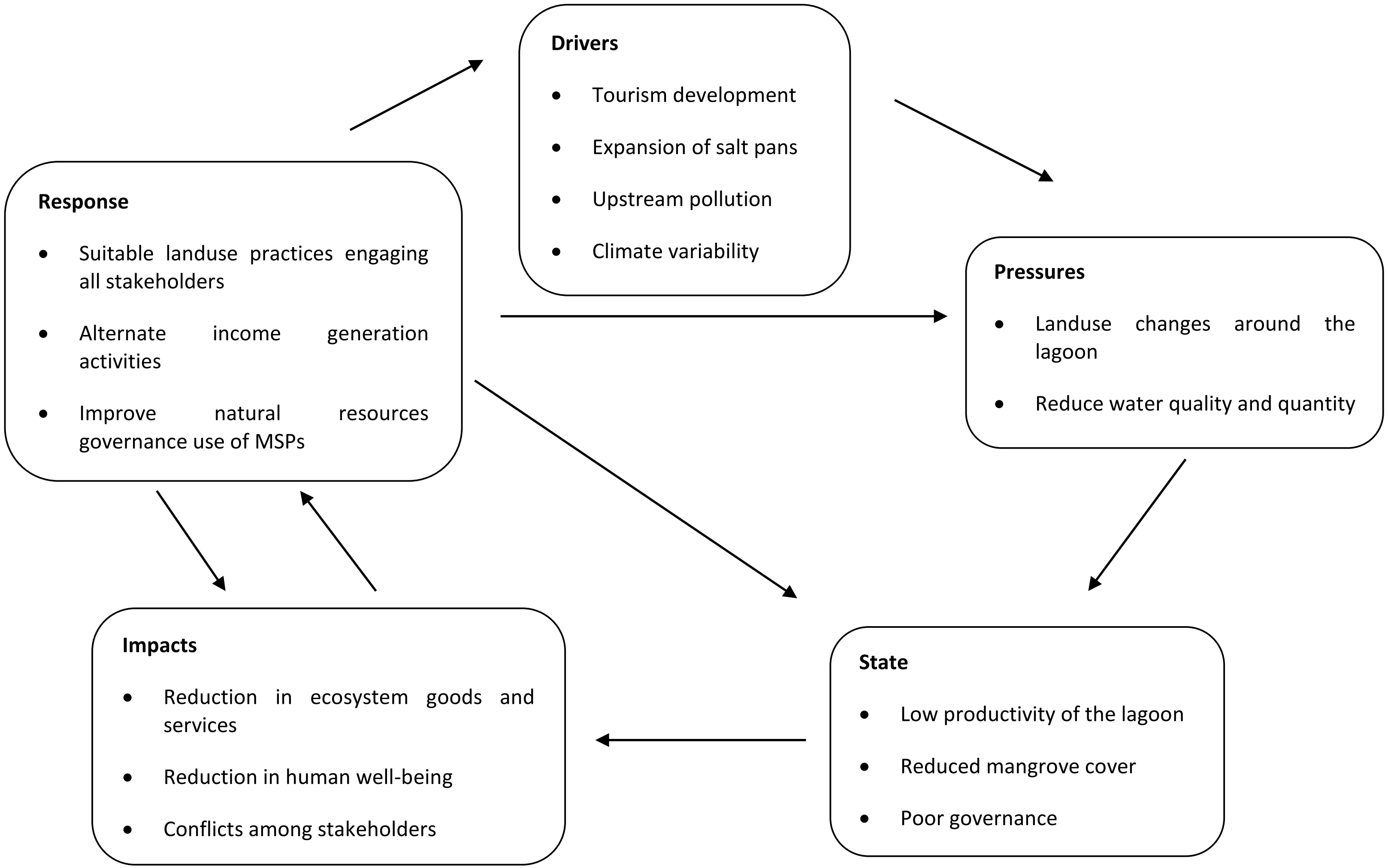


Figure 24: DPSIR Framework for Puttalam Lagoon, Sri Lanka

Mangroves of the Puttalam Lagoon

Mangroves are found along sheltered lagoon and estuarine area and the islands in the Puttalam lagoon. It can be considered as the most extensively distributed habitat in the Puttalam Lagoon area.

Two types of mangrove communities are recorded in the Lagoon area, namely riverine mangroves and fringing mangroves. Riverine mangroves are more structurally complex than fringing mangroves. Riverine mangroves occur along rivers and streams, particularly in the estuaries of the Mi Oya and Kala Oya, and are flooded daily by the tides. They receive nutrients from both inland and estuarine sources, and frequent flushing with freshwater reduces the salt stress. Because of these favourable conditions riverine mangroves are very productive. Fringing mangroves can be found along protected coastlines, islands and the exposed waters of bays and lagoons (Amarasinghe and Balasubramanium, 1992). These mangroves are mostly found on alluvial deposits (dominant with silt and fine clay particles) but also occur on sandy soils (Jayasuriya et al., 2006). Fringing mangroves are flooded periodically by tides.

Mangroves are highly productive ecosystems. They recycle nutrients and serve as nursery grounds for commercially important species. Mangroves provide firewood, timber, construction materials, fishing, agriculture, and forage for livestock, medicines, dyes and food items to communities. Apart from those they provide critical environmental services such as physical barrier against extreme weather events control the inflow of fresh water into the Lagoon, prevent sedimentation and filtering the water.

Diversity of mangroves in Puttalam lagoon

The Lagoon and the Dutch bay mainly comprises of *Rhizophora mucronata* and *Avicennia marina*. Monospecific stands of *A. marina* are ordinary in the Lagoon and *R. mucronata* dominates the water-front areas of the riverine mangroves of Kala Oya and Mi Oya. *Rhizophora mucronata* is the most dominant large shrub in the Lagoon area; while *Avicennia marina* (a small tree) and *Excoecaria agallocha* (a large tree) are also dominant within their stratum. *Excoecaria agallocha* and *Sonneratia alba* also were recorded as the other dominant species in the area. These species are ideal for future restoration of degraded mangrove habitats.

Exploitation of mangroves and associate vegetation in the Puttalam lagoon

Mangroves are closely linked with many household activities and small industries in the Puttalam lagoon. About 55% of the households around the Lagoon use mangrove plants as firewood (Dayaratne et al., 1995). In the western parts of the Lagoon *Sonneratia alba* and *Thespesia populnea* are used as fodder for goats. The bark of *Rhizopora mucronata* and a few other mangrove species is collected for tannin extraction in a few islands associated with Lagoon. This tannin is used for preservation and colouring of nets and other fishing equipment. In the Seguwanthivu area *Cynometra iripa* seeds are used traditionally instead of Areca nut. A few species, such as *Acrostichum aureum* and *Suaeda maritime* are used as leafy vegetables. As a consequence of the rapid expansion of the shrimp farm industry the mangrove vegetation of the Puttalam lagoon has been affected severely in the last few decades. Currently, the expansion of shrimp farms and salterns has affected mangroves in Seguwantivu, Tirikkapallama, Palavi, Mampuriya and Anawasala.

Expansions of salterns and shrimp farming, as well as encroachment for human settlement, are serious threats to salt marsh habitat.

Climate Change in the Puttalam Lagoon

Climate change impacts are being observed in Sri Lanka: average rainfall has decreased by 144 mm (7%) between 1961-1990 compared to 1931-1960; average air temperature has shown increasing trends (0.016 ºC per year between 1961-1990), with a maximum rate of increase of 0.02 ºC per year in the Puttalam area (Survey Dept. 2007). Figure 5.13 below shows the changes in climate in Puttalam district.

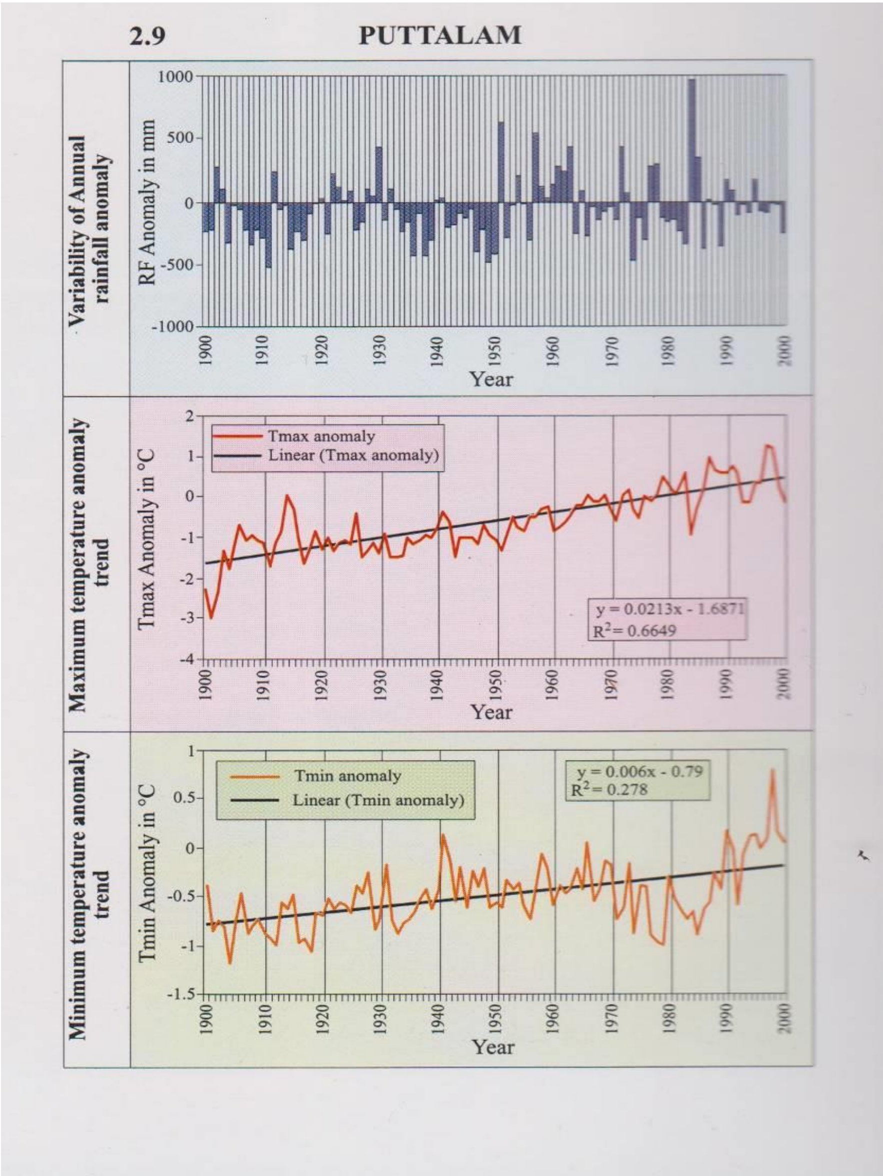


Figure 25: Climate change in Puttalam
(Source: Survey Dept., 2007)

Fisheries

With a surface area/ water area of 32,700 ha, and famous for good quality fish, the Puttalam Lagoon harbours marine, brackish and freshwater species, and is considered one of the most productive 'basin estuaries' in Sri Lanka (Dayaratne et al., 1997). There are about 165,000 people directly or indirectly dependent on the Puttalam Lagoon, out of which about 15,546 are active fishers. About 5,938 of them are fishing directly in the Lagoon, 5,501 on full time and 425 are part time. There are 108 fishing villages in the District (88 around the Lagoon) and 12,680 households engage in fisheries (Department of Census and Statistics, 2009; Fernando, 2010). The total fishing population of the area is 44,380, fishing both in the lagoon and associated coastal waters. Fishing is the sole income of 67.4%, the main income of 21.4% and the secondary income of 9.5% of lagoon fishers (Fernando, 2010).

A total of 4,633 fishing crafts are operational in the district for both coastal and lagoon fisheries. The type of fishing craft varies – there are traditional non-motorized boats, traditional motorized boats and boats with out-board motors. Out-board FRP boats are the most prevalent (57%).

With respect to Lagoon fisheries, there are 2,145 registered boats, and the most commonly used type of boat is the traditional non-mechanised boat (56%) - such as outrigger canoes (*oru*), and log rafts (*theppam* and *wallam).* Fishing in the area is seasonal, with more crafts operating in the Lagoon during the southwest monsoon. In Mundel Lake there are 40 boats and 100 fishers. Various fishing gears are used in the capture fishery of the Puttalam Lagoon. The most commonly used method of capture is the gill net, used to catch both fin and shellfish. Bottom-set nets and trammel nets are used for the crab fishery.

In coastal areas, there is shrimp trawling, small-meshed gill net fishery, flying fish fishery and beach seine fishery targeting various species, carried out at various times of the year. About 127 species of ornamental fish are also harvested. The abundance of several ornamental species has decreased Indian Chanks (*Turbinella pyrum*), found in the area, are valued ornamentals for the export industry. With respect to fishery resources, a recent study reported a total of 69 species belonging to 27 families (mainly Carangids and Clupeids) harvested from the Puttalam Lagoon.

Commercial shrimp farming in the northwest coast of Sri Lanka immerged in 1980s and 1990s. Some 900 shrimp farms mushroomed in the region, but only about 50% were legal and only a few had carried out the environmental impact assessment required by the law. Recent data indicate the total area of shrimp farms in the Puttalam Lagoon area in 2009 was 1,817 ha, of which 1,167 ha (64%) were unproductive, abandoned farms. The shrimp that is cultured is *Penaeus monodon*, which are reared in earthen ponds. *Penaeus semisulcatus* and *P. indicus* are the main commercially important shrimp species. The coastal shrimp fishery of Puttalam focuses on two species, the Green tiger prawn (*Penaeus semisulcatus*) and Moyebi shrimp (*Metapenaeus moyebi*).

Six species of edible bivalves have been recorded in Puttalam Lagoon: *Crassosstrea madrasensis, Madiolus auriculatus, Gafrarium timudum, Andara antiquate, Marcia opima* and *M. hiantina.* Eight species of sea cucumbers are collected from the Dutch Bay. There are concerns that without proper regulation this fishery will not be sustainable. Sea horses caught from seagrass meadows are either sold live for the aquarium trade or exported dried. Research is currently on-going to estimate the extent of this exploitation.

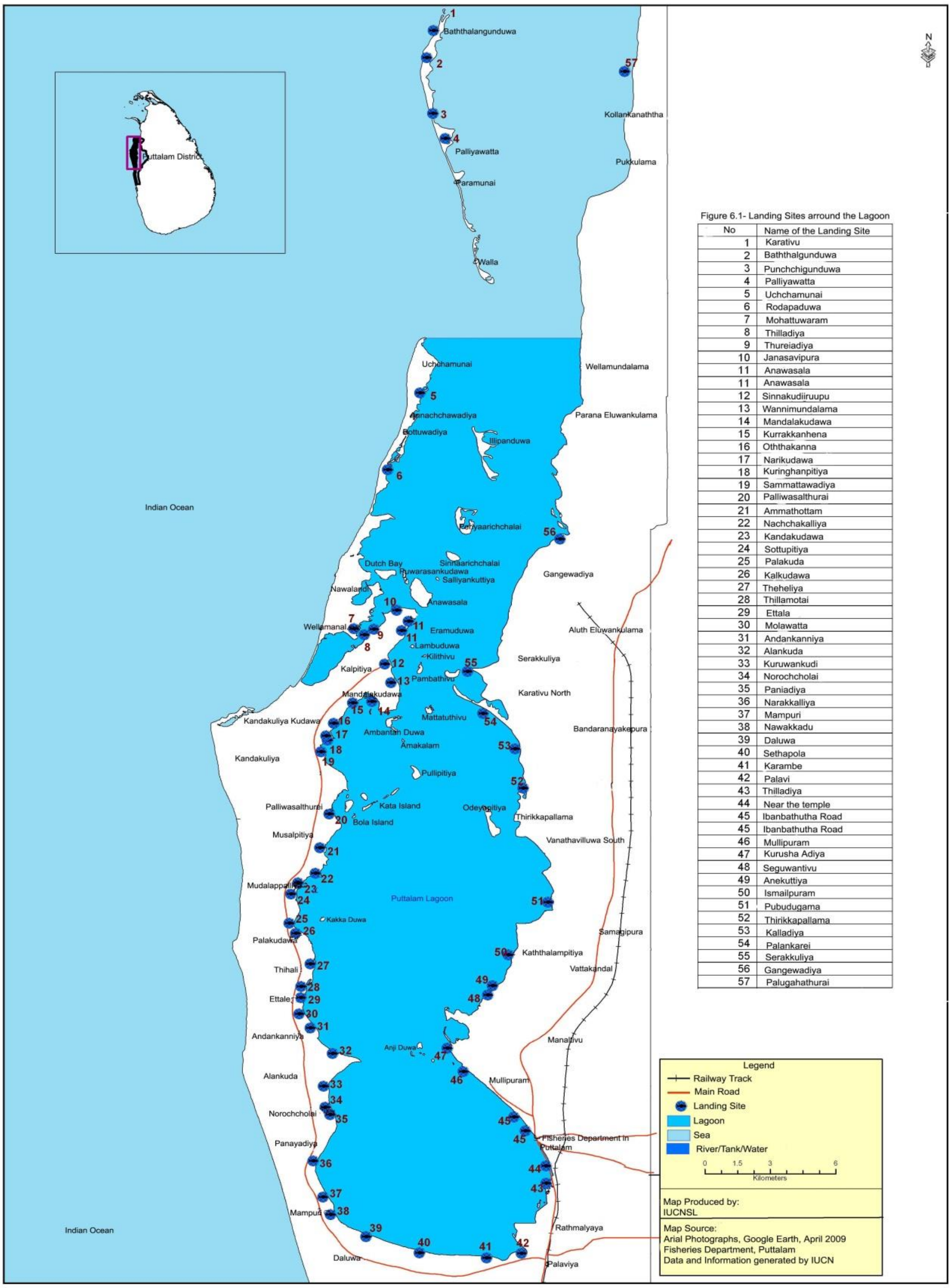


Figure 26: Fish landing sites around Puttalam Lagoon
(Source: Weragodatenna, 2010)

Four species of red algae - *Gracilaria edulis, Laurencia* spp., *Geldim* spp. and *Hypnea musciformi,* two species of green algae (*Ulva* spp. and *Enteromorpha* spp.) and two species of brown algae (*Sargassum* spp. and *Padina* spp.) have been recorded in the area. *Gracilaria edulis* collected from Puttalam Lagoon is dried and sold to the traders, however, it has been noted that *Glacilaria* has not been harvested from the Lagoon in the last three years.

Estimates for 2009 and 2010 from the Puttalam Department of Fisheries show that annual fish production for lagoon fisheries was already 1.2 times and 1.5 Maximum Sustainable Yield respectively.

Other industries

Agriculture is the second most important economic activity of the district, with 29.3% of the population engaged in it. Coconut, paddy, cashew, vegetable crops, and fruit crops are the main crops cultivated around the Lagoon area. Small scale home gardens are quite common. There are 5195.8 ha of home gardens within a 5 km radius of the Lagoon.

In addition to the fishing and agriculture, animal husbandry plays an important livelihood option in the area. It is practiced by both fishers and farmers to provide supplemental income. At present there are 1,363 ha of salterns in the Puttalam Lagoon area. Like shrimp farming, salterns provide casual employment.

Holcim Lanka Limited operates a cement manufacturing plant in the Puttalam district. Limestone is extracted by blasting and the use of heavy earth-moving equipment. A thermal coal fired power plant with infrastructure for 300 MW (with the plan to expand up to 900 MW), has been constructed in the Kalpitiya peninsula. Two wind farms with the capacity of 10 MW of electricity are being cited in the Kalpitiya area.

Kalpitiya has been identified by the tourism sector as one of several new areas to revitalize the tourist industry after the cessation of the war. Five thousand new rooms are planned in this area. A considerable number of SMEs are also found in the area.

Important Stakeholders related to Mangroves

Several organizations have direct jurisdiction over the Lagoon Area. These include the Department of Fisheries, the Forest Department, the Department of Wildlife Conservation, the Coast Conservation and Coastal Resources Management Department, the Department of Archaeology, the Tourism Development Authority, the Urban Development Authority and the North Western Provincial Environmental Authority. There are other organizations such as the Department of Fisheries, the National Aquaculture Development Authority (NAQDA), the Provincial Ministry of Fisheries, the Regional Resource Development Authority (RRDA), the Urban Council and *Pradeshiya Sabha* (Local Councils) which have developmental functions. There is also a suite of laws that impact on the Lagoon.

Apart from the Government institutions there are number of other important stakeholders such as fisher folks, NGOs, INGOs, community based organizations (CBOs) as well as saltern owners, aquaculture owners, tourist hoteliers, etc.

All these stakeholders have different levels of interests and impacts on the mangrove ecosystems. Previous work carried out by IUCN Sri Lanka in Puttalam lagoon confirms the willingness of these stakeholders in natural resources and ecosystems management and conservation.

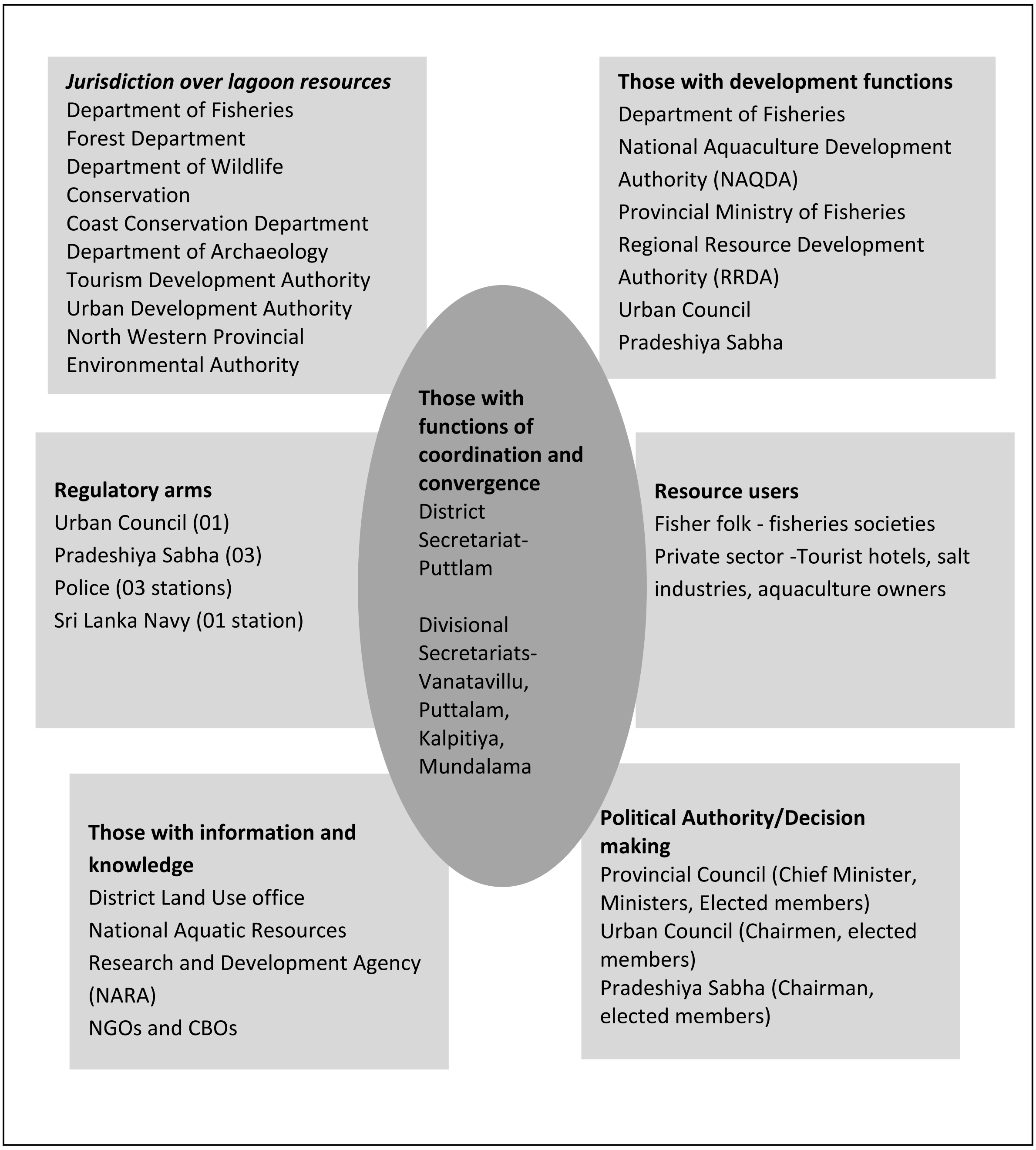


Figure 27: Institutional Mapping of a lagoon management system in Puttalam Lagoon Area (Source: IUCN, 2010b)

3.3.2 Hydrological Analysis

Assessment of causes of fluctuation in river flows

Stream water from Kala Oya, Mi Oya and Moongil Ara and, groundwater are the freshwater contributing sources for the Puttalam lagoon. The annual discharges from the three rivers are 587 MCM, 338 MCM and 9 MCM respectively, which corresponds to roughly about 15% of the annual precipitation received at each catchment (CEA, 1994).

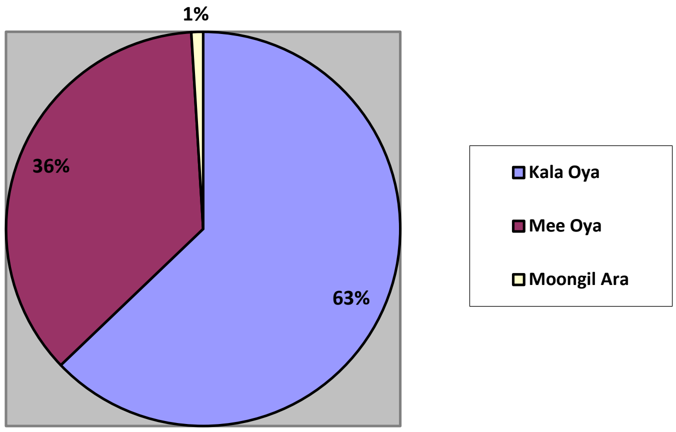


Figure 28: Contribution of Stream Flow to the Lagoon by the Three Major Streams

Seasonality of rainfall

Seasonality of rainfall is the most prominent cause of fluctuation of stream flow in the Puttalam lagoon area. Most parts of the country receive highest rainfalls during the second inter-monsoon, which prevails from October to early December. Apart from that the Northwest monsoons prevailing from December to mid-January also brings rain to the Dry zone of the country. Therefore, the stream flow received by the Puttalam lagoon area is generally higher during the period from October to December.

Groundwater aquifers

The Puttalam lagoon area has a rich density of groundwater aquifers. However, there is a great demand for groundwater in Puttalam district where more than 90% of users depend upon groundwater. Records in 2005 shows that the surface water and ground water supply to urban, rural and industrial sectors is estimated to be 270 m^3 per day and 8,424 m^3 per day, respectively (Panabokke and Perera, 2005) that is the groundwater is used about 30 times of the amount of the surface water used in these sectors.

Therefore, groundwater can be considered as the water source for urban, industrial, livestock and domestic purposes while surface water use in the associated basins is predominantly used for irrigated agriculture. However, groundwater is the major source of all the water uses in Kalpitiya peninsula and extensive irrigated agriculture is carried out using groundwater.

Drastic changes in land use, particularly clearing of watershed areas decreases groundwater recharge by rapid removal of storm water. Furthermore, increased groundwater abstraction for industrial, domestic and agricultural purposes pose a threat on depletion of groundwater table.

Existence of water storing structures/water regulating structures

Kala Oya and Mi oya are major streams which supplies water to dry zone irrigated agriculture. Multiple irrigation schemes consisting of a number of dams and anicuts are involved with the two streams. Kandalama, Kala wewa, Usgala siyamblngamuwa and Rajangana are the four major reservoirs associated with Kala Oya while Inginimitiya and Thabbowa wewa are the two reservoirs associated with Mi Oya. These storage and regulatory structures influence the natural flow to the lagoon system. The following table gives the details of these major reservoirs.

Table 18: Details of the Major Reservoirs Associated with Kala Oya and Mi Oya

Stream	Major reservoirs	Catchment area (km^2)	Length of the dam (m)	Height of the dam (m)	Storage capacity (MCM)
Kala Oya	Kandalama wewa	264	1600	21	33.3
	Kala wewa	842	6880	14.8	123.4
	Siyambalangamuwa	182.4	1433	16.8	27.3
	Rajangana	760	4000	18.3	101
Mi Oya	Inginimitiya	550	4632	18	73
	Thabbowa tank	384	1542	10	19

Source: Ministry of Irrigation and Water Resource Management: http://www.damsafety.lk/Information/Dams/Dams/Kandalama%20Reservoir.html

Irrigation water issue and abstract

Apart from the natural fluctuation of the stream flow due to rainfall the surrounding inlands may receive a small contribution from irrigation water from reservoirs through crop fields. Other than the major reservoirs listed above there are hundreds of small tanks spread all over the two catchment areas. Water retained by all these structures are mainly used for irrigated agriculture, mainly paddy. In major irrigation schemes paddy is grown in two seasons a year; from October to March of the following year (called Maha season) and May to August (Yala season). The amount of irrigation water required for paddy is expressed as depth of water per unit area. In Mahaweli irrigation schemes water allocation is generally calculated considering the depth of water required for paddy cultivation as one meter per season. Therefore, dry zone paddy cultivation can be considered as the largest water consumer affecting the volume and the timing of water flow in Kala Oya and Mi Oya basins.

The following graph shows the average sluice issues (from 2001 to 2010) of two major reservoirs which are built across the major tributaries of the Kala Oya. Rajangana is located downstream to the Kala wewa reservoir. As the graph shows irrigation water issue is done in the two paddy growing seasons. When it is overlaid with annual rainfall graph of the DL_3 agro-ecological zone it shows that irrigation water issue is a source of water to the area during the dry spells. Return waters from the Rajangana Irrigation Scheme provide a year-round flow in Kala Oya, while major increases in stream flow observed during and after the monsoons (ADB, 2008).

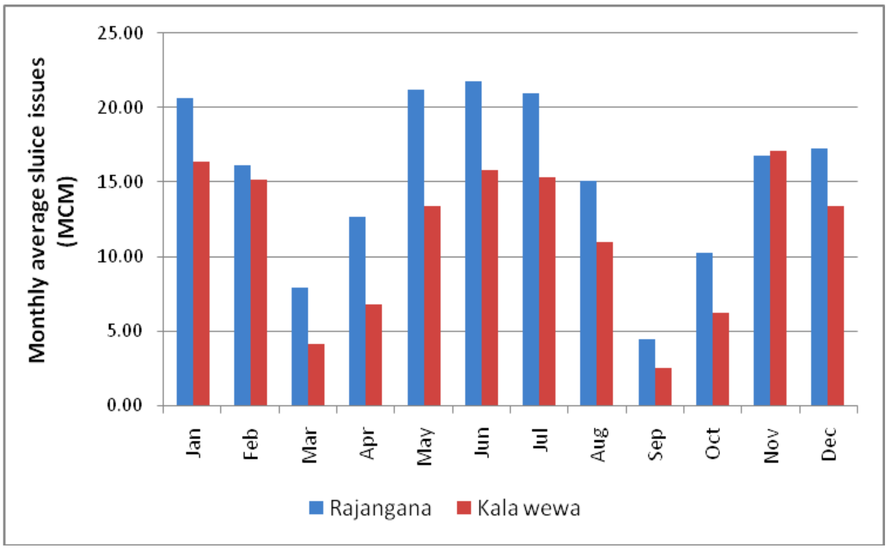


Figure 29: Monthly average sluice issue from Kala wewa and Rajangana reservoirs
Source of data: Mahaweli Authority od Sri Lanka, Seasonal Summary Reports

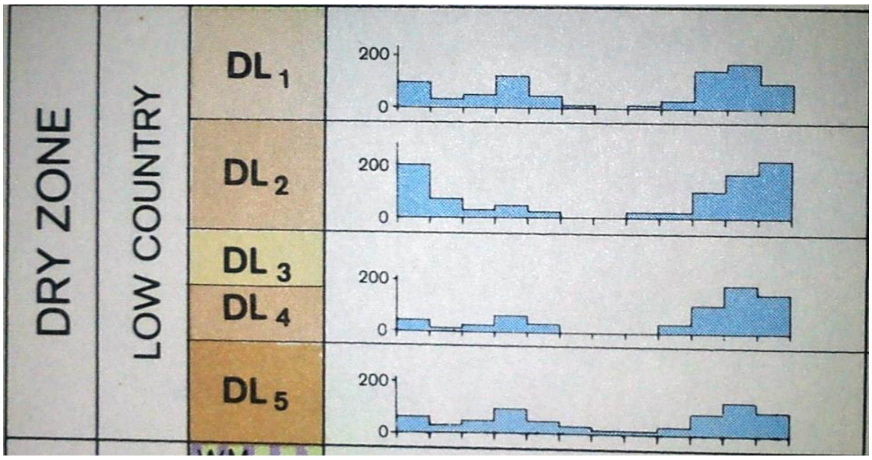


Figure 30: Annual rainfall distribution graphs of the Dry Zone Sri Lanka (vertical axis shows rainfall in mm and horizontal axis shows the months of the year)
Source: From agro-ecological map of Sri Lanka

Increase demand for urban and industrial water

Urbanization and industrialization of the dry zone area, particularly with the returning population after ending the civil war, have increased the water requirement. With the new resettlements both domestic and livelihood water requirements have been increased. Currently many development projects are being carried out in Puttalam district, which also demand for water. Therefore, extraction of both surface and groundwater for these purposes would reduce the amount of freshwater reaching the lagoon. However, there has not been any estimation done for these extraction levels and its impact on the flow reaching the lagoon.

Water quality of Puttalam Lagoon and surrounding area

The lagoon receives freshwater from Kala Oya and Mee Oya basins which are predominantly with agricultural land, cultivated with paddy most of the time in the year and also with vegetables, fruits and coconuts. Heavy use of inorganic fertilizers and other agrochemicals in these sensitive areas have a tendency to cause water pollution, particularly towards the lower basin where those get concentrated. The following tables show the reservoir water quality, surface water quality and ground water quality of attributing to the water quality of the Puttalam lagoon.

Even though Kala wewa and Rajangana reservoirs are located towards the inland of the dry zone because of the size of the reservoirs and the land use of their catchments they are significant in controlling the water quality and the quantity flowing to the lagoon.

Table 19: Water Quality Parameters of Kala wewa and Rajangana

Author	Year of publication	Study period	Kala wewa		Rajangana	
			pH range	EC range (µS/cm)	pH range	EC range (µS/cm)
Silva E.I.L	1996	1980-1981	7.5 – 8.5	175 - 300	7.8 – 8.8	450 - 660
Amarasiri S.	2008	Unknown	7.1 – 8.7	82 - 400	7.5 – 8.6	278 - 650

Surface water quality at Eluwankulama in 2003 is given in following table. Eluwankulama is located about 10 km towards the inland from Puttalam lagoon.

Table 20: Water Quality of Kala Oya at Eluwankulama in 2003 (monthly average)

Parameter	Unit	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov
Turbidity	NTU	7.0	2.8	8.0	15.0	6.0	7.8	6.3		5.1	17.0
Conductivity	µs/cm	431	602	483	499	526	510	546	98	607	564
pH	mg/L		7.7	8.3	7.6	7.8	9.4	7.8	8.3	7.9	8.4
Total Alkalinity	mg/L	190	240	238	211	257	251	255	286	249	263
Dissolved	mg/L	6.9	5.6	5.7	5.8	6.4	6.0	6.6	5.0	6.0	5.9
COD	mg/L	27.9	27.3	15.2	23.5	36.6	12.4	35.1	22.4		
Sodium	mg/L	128	182	150	196	174	368	231	220	211	155
Potassium	mg/L	4.6	2.5	3.4	5.4	2.4	2.9	4.2	0.0	6.6	5.2
Calcium	mg/L	35.1	39.5	41.5	32.8	40.4	38.9	35.3	39.6	56.9	40.3
Magnesium	mg/L	18.0	21.0	15.8	16.3	19.4	21.5	19.3	25.8	7.2	21.2
Fluoride	mg/L	0.7	0.9	1.0	0.8	0.9	1.0	1.0	1.2	1.0	1.6
Chloride	mg/L	61.6		51.6	66.7	84.4	66.5	120.	75.2	112.	89.2
Nitrate	mg/L	7.5	11.7	18.0	16.7	18.6	27.3	33.6	43.8	86.2	57.3
Phosphate	mg/L	3.6	2.0	3.0	2.0	2.8	1.2	2.2	3.0	0.7	0.9
Sulphate	mg/L	7.1	13.4	2.4	0.0	4.3	0.0	19.4	17.7	0.6	10.3

Source: Sri Lanka Mahaveli Authority (2003), Kala Oya Basin Study, (Extracted from ADB, 2008)

The general groundwater quality data are compared against the drinking water standards of Sri Lanka in the following table. Even though the considered parameters are within the maximum permissible levels for drinking water it is observed that the groundwater is more polluted closer to the townships and suburbs. High iron content, hardness and sometimes salinity causes poor water quality and is caused mainly by the geological condition of the area (ADB, 2008).

Table 21: General Groundwater Quality in Puttalam

Parameter	Range (ppm)	Sri Lanka drinking water standard		Location
		Max desirable	Max permissible	
Total dissolved solids	200-500			
Total hardness	500-850	250	600	
Nitrate	5-10		10	Puttalam Town
	1-5		10	In the suburbs
Nitrite	<0.05		0.01	
Ammonium	>1.0			In the town
	0.5-1.0			Town perimeter
	0.3-0.5			Outside the town
Chloride	500-1000	200	1200	At the coast
Fluoride	0.1-0.5	0.6	1.5	In the town
	0.5-1.0			Outside the town
Silica	20-50			
Total iron	0.75	0.3	1.0	Increases in areas of red beds and ferruginous gravel
Manganese	0.10-0.16	0.05	0.5	
Chromium	0.009-0.015		0.05	
Cobalt	<0.02			
Copper	<0.03	0.05	1.5	
Zinc	0.025-1.0	5	15	

Source: Institute of Fundamental Studies (1986): Hydro-geological Atlas of Sri Lanka, (Extracted from ADB, 2008)

3.3.3. Socio-economic and Ecological Vulnerability Assessment

Assessment of Ecological Health of Delta and Mangrove Ecosystem

During its work on ecosystem restoration in 2008, IUCN conducted a site sampling to determine the ecosystem services provided by the coastal ecosystems and to prioritize locations for ecological restoration. In this study 15 sampling sites from the coastal area of the Puttalam lagoon were subjected for this assessment. The value of ecosystem services provided by each natural habitat was determined by the approximate extent of the habitat and its quality. Therefore, this valuation system is used here to assess the ecological health in terms of extent and quality along the Puttalam lagoon area. Furthermore, direct and indirect drivers causing changes in the ecosystems were also highlighted and the sites are also being ranked. The sites selected for the assessments are shown in the map below (Figure 31) and the results of the analysis are given in Tables 22 and 23.

Based on the results out of the 15 sites assessed, Gangewadiya, Serakkuliya, Thirikkapallama, Pubudugama and Kurunnampitiya have the highest values for ecosystem services. The high values for ecosystem services in these five sites are attributed to the large extents of mangrove habitats in these areas.

Furthermore, results indicates that regulatory services (such as climate regulation, erosion control, water quality, flood control, and community protection) and supporting services (such as primary production, soil formation, nutrient cycling, fish breeding, and biodiversity protection) provided by these selected habitat sites accounts for almost 60% of the ecosystem services provided by them. This indicates the importance of these systems in maintain the natural ecological conditions of the area.

Figure 31: The 15 sites selected for the assessment of potential coastal sites for ecosystem restoration in Puttalam lagoon
Source: IUCN 2008

Table 22: Site Specific Ranking Table for Ecosystem Services

	Kandakuliya - Kudawa	Serakkuliya	Alaththakanniya	Palaviya	ThilAdiya	Kurinngnapitiya	Mampuriya South	Mampuriya North	Thirikkapallama	Pubudugama	Mullipuram	Soththupitiya	Eththale	Anakuttiya & Sewwantivu	Gangewadiya
Ecosystem Services															
Provisioning															
Food	4	5	4	1	1	4	2	2	2	4	3	3	2	4	5
Water	2	3	3	1	2	3	1	2	1	2	4	2	2	2	3
Fibre	1	1	1	0	0	0	0	0	1	0	0	1	0	1	1
Fuel	2	2	4	1	4	3	1	1	2	2	2	1	4	4	2
Medicinal Plants	0	1	1	1	0	1	1	1	2	1	0	0	1	2	1
Sub Total	**9**	**12**	**13**	**4**	**7**	**11**	**5**	**6**	**8**	**9**	**9**	**7**	**9**	**13**	**12**
Regulatory															
Climate regulation	1	2	1	1	4	4	2	1	3	3	1	3	4	3	2
Erosion control	0	3	1	1	4	3	2	1	3	4	1	4	3	4	3
Water quality	3	3	1	1	3	3	2	2	3	2	2	3	3	4	3
Community Protection	0	2	2	2	3	4	2	1	3	2	1	4	4	4	3
Flood Control	0	3	1	3	4	4	3	1	4	4	2	2	4	4	3
Sub Total	**4**	**13**	**6**	**8**	**18**	**18**	**11**	**6**	**16**	**15**	**7**	**16**	**18**	**19**	**14**
Cultural															
Aesthetic value	3	4	1	3	1	2	1	1	4	3	2	1	3	2	5
Spiritual	2	3	1	2	1	2	1	1	3	3	1	3	1	2	3

	Kandakuliya - Kudawa	Serakkuliya	Alaththakanniya	Palaviya	ThilAdiya	Kurinngnapitiya	Mampuriya South	Mampuriya North	Thirikkapallama	Pubudugama	Mullipuram	Soththupitiya	Eththale	Anakuttiya & Sewwantivu	Gangewadiya
Recreation/Tourism (current/potential)	3	4	1	3	1	2	1	1	4	3	2	1	2	2	5
Education and research (current/potential)	3	5	2	2	1	2	1	1	5	3	2	2	3	2	5
Sub Total	**11**	**16**	**5**	**10**	**4**	**8**	**4**	**4**	**16**	**12**	**7**	**7**	**9**	**8**	**18**
Supporting															
Primary production (photosynthesis)	2	4	2	3	3	4	2	1	3	4	2	2	4	4	4
Soil formation	1	3	0	2	3	3	1	1	3	3	1	1	3	4	4
Nutrient cycling	2	4	2	3	3	4	2	1	3	3	1	2	3	4	4
Fish Breeding	2	4	1	1	2	4	1	1	4	4	2	3	3	4	5
Biodiversity Protection	2	4	3	3	3	3	2	1	5	4	1	2	4	4	5
Sub Total	**9**	**19**	**8**	**12**	**14**	**18**	**8**	**5**	**18**	**18**	**7**	**10**	**17**	**20**	**22**
Grand Total	**33**	**60**	**32**	**34**	**43**	**55**	**28**	**21**	**58**	**54**	**30**	**40**	**53**	**60**	**66**

Scale

0 – No impact, 1 – Very low, 2 – Low, 3 – Moderate, 4 – High, 5 – Very high

Table 23: Site specific ranking table of direct and indirect divers of change

Direct drivers of change	Indicators	Kandakuliya - Kudawa	Serakkuliya	Alaththakanniya	Palaviya	Thiladiya	Kurinngampitiya	MampuriyaSouth	Mampuriya North	Thirikkapallama	Pubudugama	Mullipuram	Soththupitiya	Eththale	Anakuttiya & Sewwanthiu	Gangewadiya
Change of land use	Conversion of land to prawn farms, conversion of land to salt pans, Conversion to settlements, conversion to road and other infrastructure (current and potential)	2	3	3	4	3	4	2	2	2.5	1	2	3	3	4	1
Harvest of ecosystem products for consumption and their impacts	Increase demand for food, Destruction of mangroves for fuel wood	3	3	3	0	2	3	1	1	4	1	1	4	4	2.5	2
Livelihood dependence and impacts -destructive fishing, over harvesting	Use of destructive fishing practices-nylon nets, push nets, cage nets, increase in number of fishermen, increase in fishing number of gears , Directed take of low value species, directed take of high value species, by catch	2	3.5	2	3	2	4	5	5	3	0	5	5	4	2	3
Livelihoods dependence and impacts-chemical pollution, sand mining	Intensive agricultural practices in the area, potential agrochemical water pollution, pollution due to prawn culture	0	4	2	0	2	3	4	4	2	1	4	5	4	4	2
Human security-IDPs and impacts	Pressures on fisheries due to IDPs, Conversion of land for settlements, Destruction of mangroves for fuel wood	4	2	2	0	2	3	3	3	1.5	1	3	4	5	2	2
Sub total		**11**	**15.5**	**12**	**7**	**11**	**17**	**15**	**15**	**13**	**4**	**15**	**21**	**20**	**14.5**	**10**
Indirect drivers of Change	**Indicators**															
Population growth	Current population, growth of population, increase of fishing population	1	3	3	0	2	4	4	4	3	2	4	5	5	4	4

Direct drivers of change	Indicators	Kandakuliya - Kudawa	Serakkuliya	Alaththakanniya	Palaviya	Thiladiya	Kurinngampitiya	MampuriyaSouth	Mampuriya North	Thirikkapallama	Pubudugama	Mullipuram	Soththupitiya	Eththale	Anakuttiya & Sewwanthiu	Gangewadiya
Shifting market	Introduction of prawn industry, Increased economic returns from salt industry and clearance of mangroves, urbanization and resulted destructions	0	0.5	3.5	4	4	3	2	2	3	1	3	3	4	5	1
Economic Freedom and ecosystem impacts	Availability of alternative income generating activities, dependency on ecosystem resources	0	5	3	1	2	3	4	4	2	3	4	4	4	1	4
Social capital	Community organizations, Community groups and theirs relationships, Level of awareness on ecosystem and human wellbeing, Attitude towards ecosystem conservation	4	4	1	1	1	4	1	1	1	4.5	5	5	5	1	1
Sub total		**5**	**12.5**	**10.5**	**6**	**9**	**14**	**11**	**11**	**9**	**10.5**	**16**	**17**	**18**	**11**	**10**

Scale

0 - No impact
1 - Very low
2 - Low
3 - Moderate
4 - High
5 - Very high

Source: IUCN, 2008

Assessing Vulnerability of Socio-economic and Ecological Sectors to Climate Change Scenarios

Climate change impacts are being observed in Sri Lanka: average rainfall has decreased by 144 mm (7%) between 1961-1990 as compared to 1931-1960; average air temperature has shown increasing trends (0.016 ºC per year between 1961-1990), with a maximum rate of increase of 0.02 ºC per year in the Puttalam area (Survey Dept. 2007).

A GIS based assessment on the potential climate change vulnerabilities for Sri Lanka has been carried out and a data book on Climate Change Variability in Sri Lanka has been published by the Ministry of Environment, Sri Lanka in 2011. This is called the Sector Vulnerability Profile (SVP) which is a supplementary document to Sri Lanka's National Climate Change Adaptation Policy. The assessment has considered the potential climate change vulnerability for urban development, human settlements and economic infrastructure, water, agriculture and fisheries, health and, biodiversity and ecosystem services of Sri Lanka at the level of Divisional Secretariat Divisions.

The climate change vulnerability of socio-economic and ecological sectors of the four DS divisions in Puttalam district which comprises the Puttalam lagoon area are given in Table 24.

Table 24: Composite sector vulnerability for climate change for the administrative divisions in Puttalam lagoon area

Sector	Kalpitiya			Mundalama			Puttalam			Vanathavilluwa			Puttalam District
	Drought	Flood	SLR	Drought	Flood	SLR	Drought	Flood	SLR	Drought	Flood	SLR	
Housing	3		1	9		3	49		4	13			
Transport		90	8		37	29		49	23				
Drinking water	20	24	1	18	22	2	68	62	12	27			
Plantations	19			14	14		16						
Livestock	39		1	43		11	30		6				
Fisheries - inland & brackish water	1		1	4		2	8		3	2			
Fisheries - marine			1			2			5				
Health risk - Dengue													1
Health risk - Dysentery													8
Health risk - Leptospirosis													11
Biodiversity													12

High (Rank) Medium (Rank) Low (Rank)

Source: Ministry of Environment, 2011

3.3.4 Institutional Mapping & Analysis

No less than 15 national laws, overlaid with a constitutional amendment that devolves power to the provinces, are operational in this area. Each of these laws confers a different government organisation with a different – sometimes conflicting – mandate. This leaves implementing field officers unsure of their roles and responsibilities.

In-depth analysis of institutions in the Puttalam area was carried out with the objectives of a) Understanding the current institutional setting, mandates, capacities, financial status , issues and constraints in the Puttalam District; b) Mapping selected institutions and identifying key partners for lagoon ecosystem management; c) Identifying networks and information flow, rules and incentives that influence the person performing given activities; d) Identifying the baseline that can be used to monitor, review, adapt and evaluate changes in the Project cycle; and e) Identifying gaps and overlap and identifying the type of institutional mechanism that is most appropriate at successive stages of the development and implementation of a conservation plan (IUCN, 2009)

Key results:

- The main issue from IUCN's analysis was the lack of clarity of laws and jurisdictional and functional overlap among them. For example, there are jurisdictional overlaps among the Coast Conservation Act, the Mines and Minerals Act, the Urban Authority Law causing delays in decision making, incurring costs in terms of resources and time.
- There is also inadequate planning that is integrated in its approach and that leads to a lack of holistic management. Even though various coordinating bodies have been established and are mediated by the District Secretary, communities are not represented adequately and their voice is unheard. Although Special Area Management (under the Coast Conservation Act) and Fisheries Management Areas (under the Fisheries and Aquatic Resources Act) allow for more integrated coastal resource management, the Lagoon does not come under either approach.
- In addition, there is a lack of capacity for management - both among communities and relevant government institutions. Many community organisations lack constitutions, rules and formal procedures for operations as well as proper financial reporting. In the government sector, there is a dearth of adequate skills, as well as human resources. For example, forest areas in the Lagoon surrounds have not been demarcated due to shortage of resources.
- Financing for conservation or incentives for conservation is minimal compared to that for social development. Many of the non-governmental organisations in the Lagoon area focus on the welfare of internally displaced persons. Further, in the public sector, the emphasis is on inputs and

activities, rather than outcomes. A sustainable financing mechanism for conservation is urgently needed.

- Currently, information is scattered and there are no mechanisms for sharing this information, with the result that decisions are not always made on the best available knowledge (IUCN, 2009).

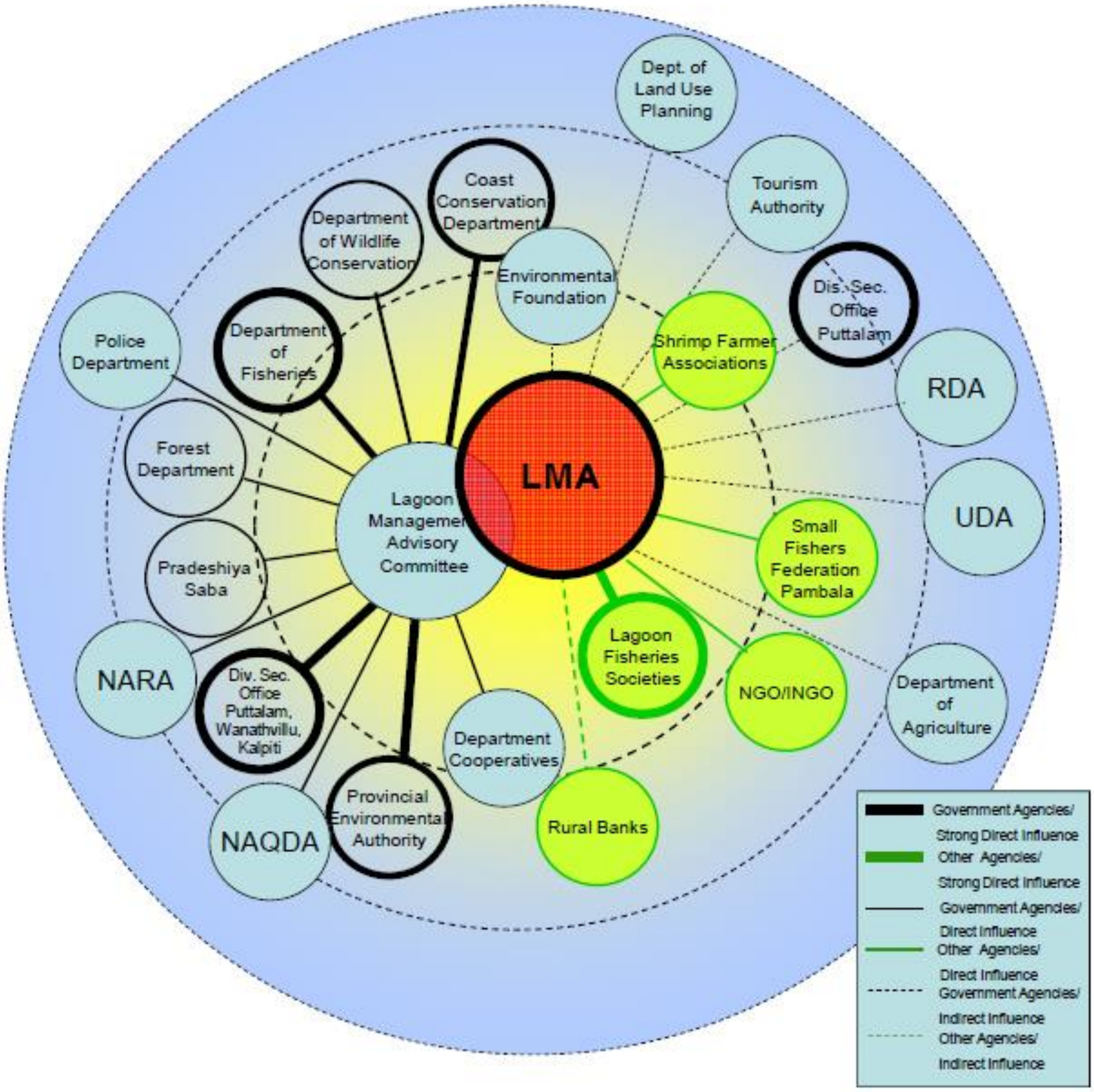


Figure 32: Institutional Mapping
(Source: IUCN, 2010b)

3.4 Bangladesh

3.4.1. Site Selection and Characterization

The Ganges-Brahmaputra delta is one of the world's largest and most populated delta which is located in a low-lying region where it is under threaten of highly vulnerable coastal environment (Delft hydraulics, 1989; Alam, 1996; Kuehl et al., 1997). This Ganges-Brahmaputra delta is also known as Ganges delta (Merriam-Webster, 1997), the Sundarbans Delta, or the Bengalla Delta (Delft, 2009; Wikipedia). The approximate surface area of this delta is about 100,000 km^2 and two-thirds of its area under Bangladesh and the rest constitutes the state of West Bengal, India (Delft, 2009). The tidal range in this delta varies from 3.5m to 5.0m (Choudhuri and choudhury, 1994) and it can be considered as a tide dominated coastal depocenter (Galloway, 1975) as $1060x10^6$ tonnage of sediment comes through the river system in this delta (Milliman and Syvitski, 1992) and falls in the Meghna estury. The Sundarbans, the largest single block of tidal halophytic mangrove forest in the world (Pasha et al. 2003), is situated at the south of this delta. Shared between two neighboring countries, Bangladesh and India, the larger part (62%) is situated in the southwest corner of Bangladesh.

Recognizing the importance and uniqueness of the Sundarbans, UNESCO declared part of the Indian portion of the forest as a world heritage site in 1987, and part of the Bangladeshi portion was declared a separate world heritage site in 1997. The total forest coves 10,000 km^2 of which 6,000 km^2 are in Bangladesh (Sundarbans Tiger Projects 2012). Rivers in the Sundarbans are the meeting places of many salt water which comes from sea and fresh water which comes from upstream rivers. As a result, it becomes a region of transition between sweet water of the rivers originating from Ganges and the salt water of the Bay of Bengal (Wahid et al. 2002). The land level of Sundarban varies from 0.9 m to 2.11 m above sea level (Ketabi et al. 1987) and most of the area is higher elevation than low tide but lower than high tide.

Study Area

Dacope Upazilla is located in Khulna district and it is bounded by Batiaghata upazilla on the North, Pussur River on the South, Rampal and Mongla Upazillas on the East, Paikgachha and Koyra Upazillas on the West. Main rivers are Pasur, Sibsa, Manki, Bhadra. The study area is shown in the **Error! Reference source not found.**33. The southern part of this Upazilla is surrounded by Sundarban.

Demography

The total Population of the upazilla is 1,52,316 among them 99.9% people live in households. Male population is 52.25% and female is 47.75%. There are different religious people live in this upazilla among them Muslims are 37%, Hindus are 61%, Christians are 1% and other ethnic groups are 1%. Average literacy rate is only 37.6% and male are more literate (47.8%) than female (26.4%) (Ref: Census 2011).

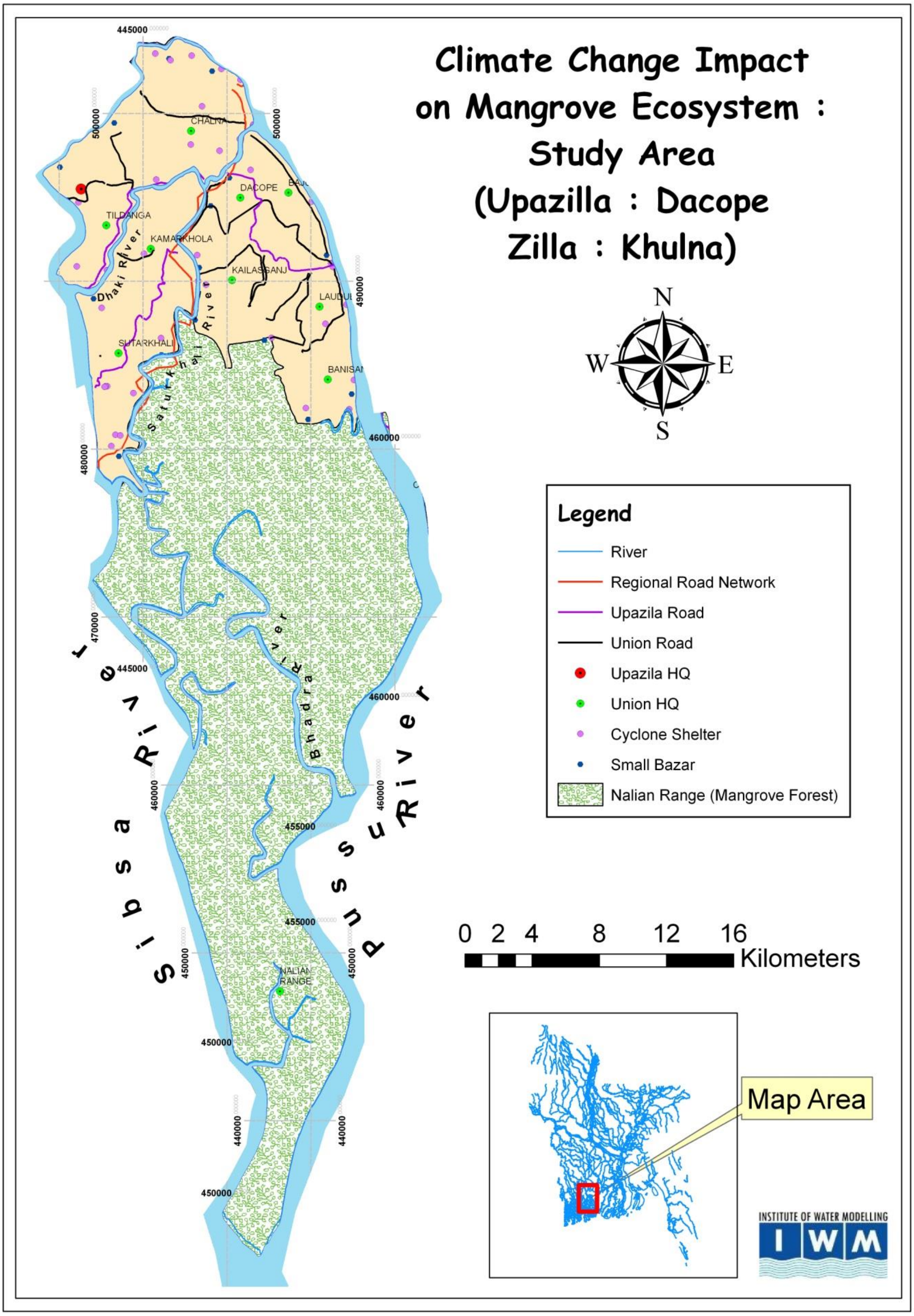


Figure 33: Study Area

Table 25: Union-wise Population in Dacope Upazilla

Serial Number	Paurashava/ Union Name	Area (acres)	Total Households	Population		
				Total	In Households	Floating
1	Chalna Paurashava		3449	14188	14174	14
2	Bajua Union	14054	3577	15753	15702	51
3	Banishanta Union	56749	3398	14606	14589	17
4	Laudubi Union	3613	2042	9222	9222	0
5	Dacope Union	4329	1825	7047	7047	0
6	Kailasganj Union	7744	3443	14516	14473	43
7	Kamarkhola Union	10214	3559	13897	13897	0
8	Pankhali Union	9099	3735	15570	15570	0
9	Sutarkhali Union	112059	7463	30060	30043	17
10	Tildanga Union	24526	4095	17006	17006	0
11	Khulna Range Union (Nalian)	197438	11	451	451	0
Total=	Dacope Upazilla	245020	36597	152316	152174	142

Table 26: Employment Status in Dacope Upazilla

Employment Status	Male	Female
Employed	9360	1280
Looking for Job	83	52
Household Work	159	14189
Do not Work	2373	4810

Table 27: Field of Activity of employed resident in Dacope Upazilla

Field of Activity	Male	Female
Agriculture	7085	365
Industry	297	47
Service	1978	868
Total	9360	1280

Figure 34: Most Common Household in Dacope Upazilla

Climate

It is evident from temperature data that the warmest months are June, July, August and September and the coolest month is January. The maximum average temperature is about 34°C and minimum average temperature is about 18°C. Figure shows monthly maximum and minimum temperature at Dacope upazilla and Figure shows historical annual average temperature which shows an increasing trend over the last fifty years. It is clear from the Figure that total rainfall has increased a lot after the year 1997 and in 2008 it was about 5800mm whereas Figure shows that the 3-day maximum rainfall occurred during the year 1997 (Bangladesh Meteorological Department).

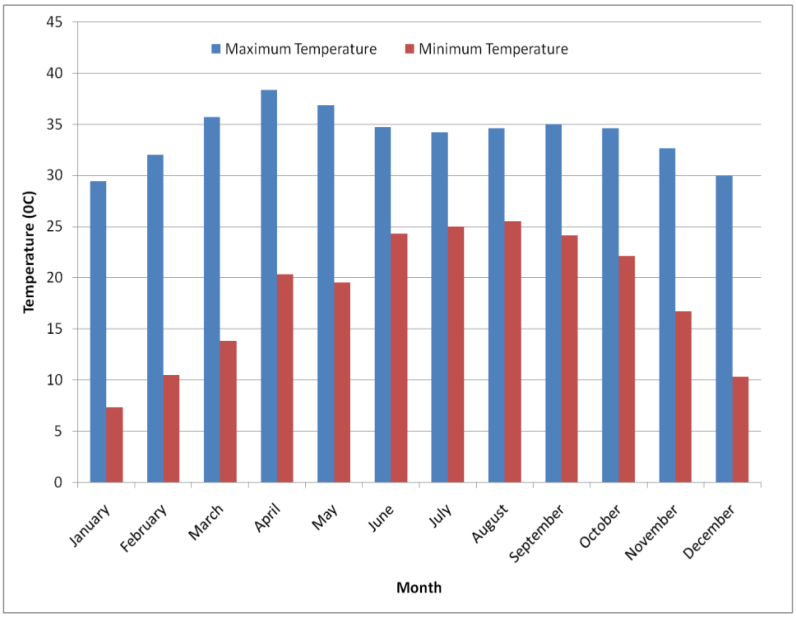


Figure 35: Monthly Maximum and Minimum Temperature

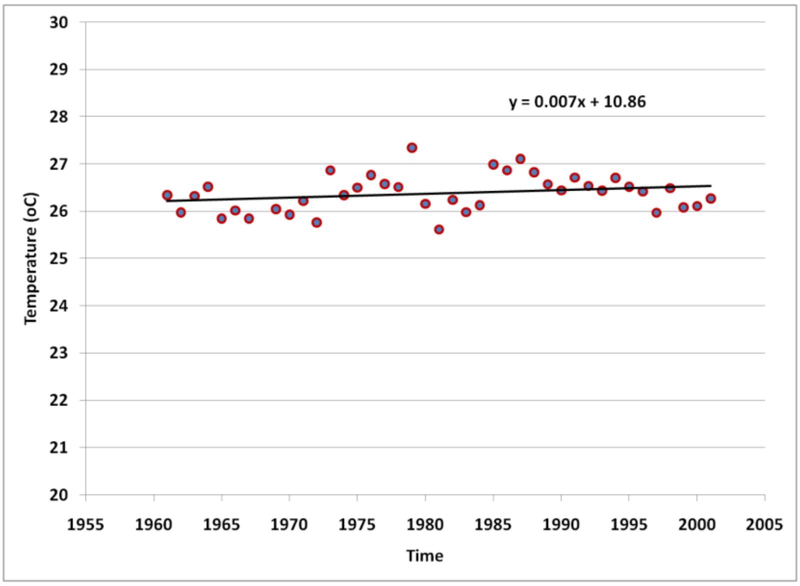


Figure 36: Annual Average Temperature at the Study Area

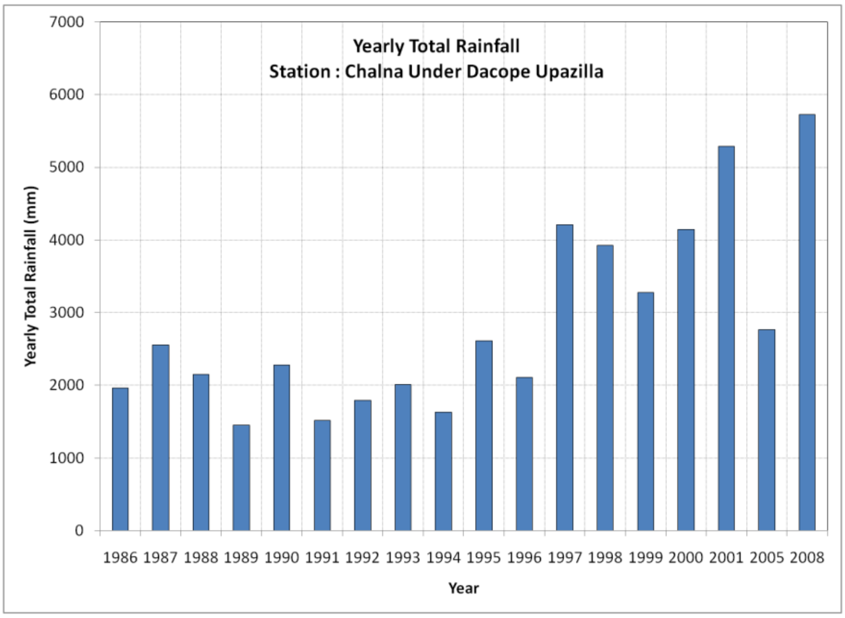


Figure 37: Yearly Total Rainfall in Dacope Upazilla

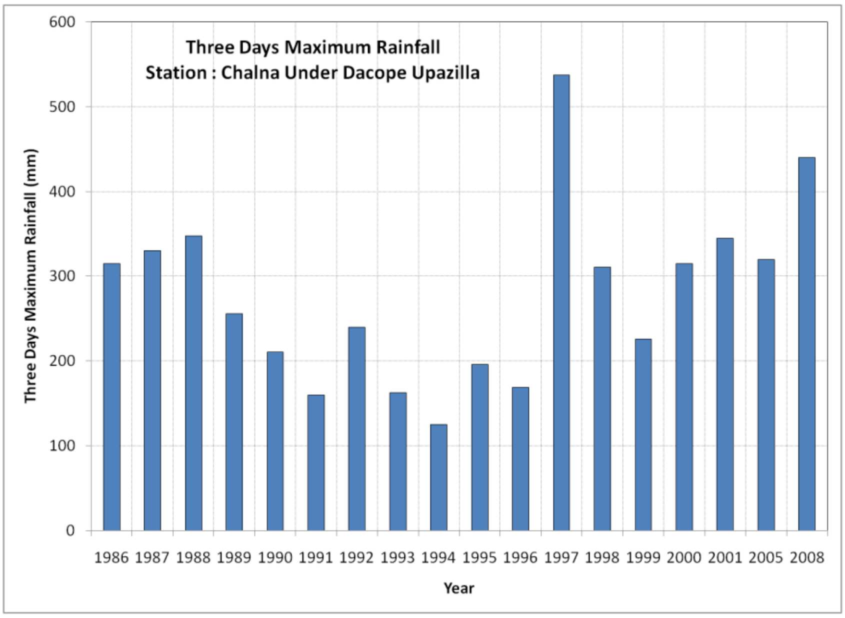


Figure 38: 3-Days Yearly Maximum Rainfall

Tidal Characteristics

It is evident from the measured and simulated water level data near Dacope upazilla that the water level in this area is completely influenced by tide (Model Data). Table shows the tidal characteristics of Pussur River near Dacope.

Table 28: Tidal Characteristics of Dacope Upazilla

Parameters	Pussur	
	Dry Season	Monsoon Season
Maximum Water level (m PWD)	2.63	2.90
Minimum Water level (m PWD)	-1.58	-1.15
Mean Low Water Spring (m PWD)	-1.18	-0.82
Mean High Water Spring (m PWD)	1.75	2.34
Mean Low Water Neap (m PWD)	-0.86	-0.37
Mean High Water Neap (m PWD)	1.75	1.88
Mean Water Level (m PWD)	0.42	0.80

3.4.2 Water Flow and Salinity Modeling

Water level, flow and salinity distribution at and around the study area has been assessed by using two types of salinity model namely Southwest Regional Hydrodynamic and Salinity Model and Bay of Bengal Salinity Hydrodynamic and Model. These two models have been maintained by Institute of Water Modelling for the last 20 years. Under this study, these models were validated with field measurements and to assess the water level, flow and salinity distribution under climate change condition.

The available salinity models for the coastal area of Bangladesh has been developed based on MIKE11 and MIKE 21 FM modeling system and applied for a number of projects over the last 20 years to find the spatial and temporal variation of water level, flow and salinity level over a year and also to examine the effect of climate change on landward movement of salinity front and in assessing the fresh water availability. The models for water flow and salinity for the coastal region of Bangladesh are well calibrated and validated and calibration results showed good agreement with the measured water flow, water level and salinity over the time and space. The models based on MIKE11 modelling system need less time and efforts to update and recalibrate to have quality outputs in comparison of other modelling systems and that is why it is used for river model. On the other hand MIKE 21 modeling system takes quite a long time to simulate and hence it is used for estuary and sea.

Methodology

The main purpose of this salinity model is to assess the spatial and temporal distribution of salinity level in the study area both the in existing condition and in climate change context which will help to calculate the exposure index.

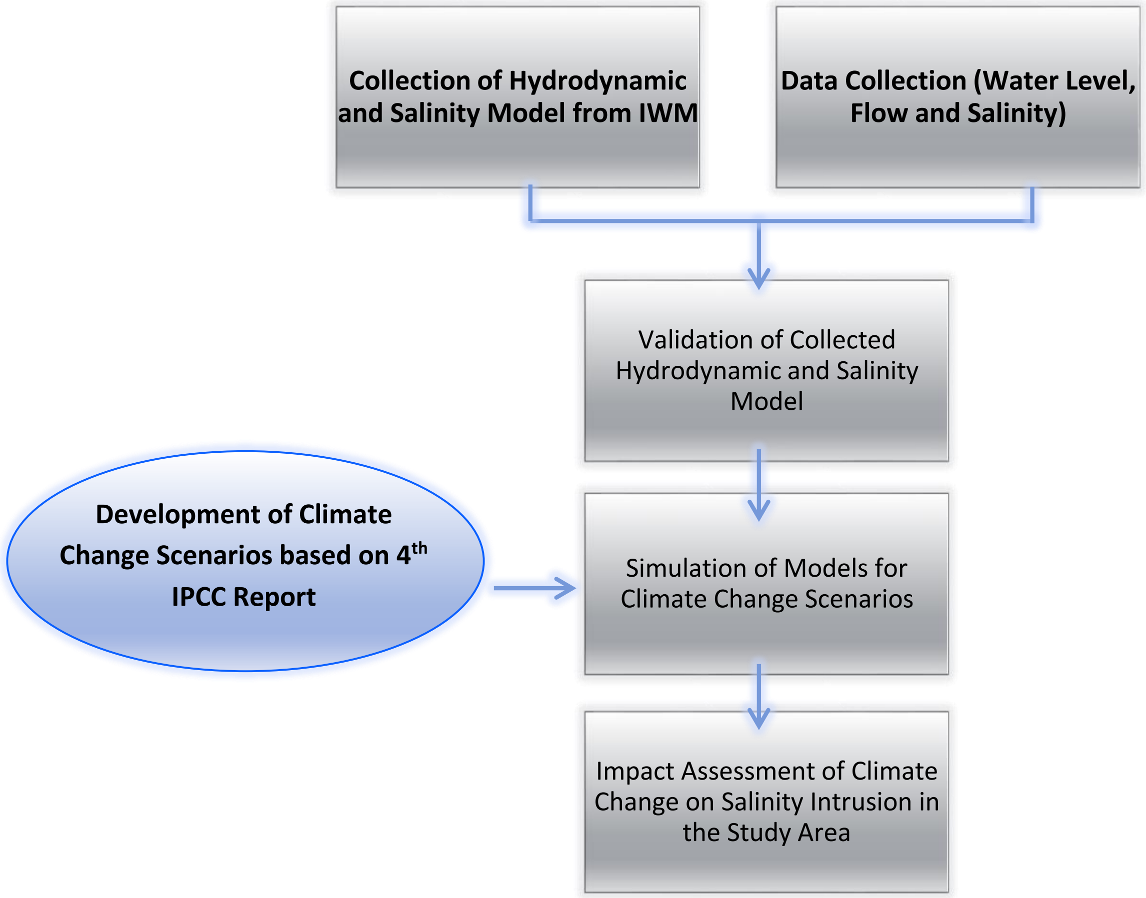


Figure 39: Steps to Assess the Climate Change Impact on Salinity Intrusion

Validation of River and Coastal Salinity Model

Southwest Regional Model

The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. The model region is presented in Figure 40. Total catchment area and length of rivers/channels of the SWRM are around 37,300 km2 and 5,600 km, respectively. The Bay of Bengal and the international border with India form the southern and western boundaries, respectively. The rivers of the southwest region of Bangladesh are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal.

Freshwater inflows originate from the Gorai, an offtake of the Ganges, and from numerous smaller offtakes from the Lower Meghna. In the northern part of the model, the main non-tidal river systems comprise the Gorai, Arial Khan, Jayanti and Upper Meghna. The southern rivers mainly comprise tidal estuary systems, the largest being the Jamuna, Malancha, Pussur-Sibsa, Baleswar, Tentulia and Lower Meghna. Interconnected with these larger rivers are a myriad of smaller tidal channels and drainage canals. The tidal channel network is particularly complex in the Sundarbans Mangrove Forest in the far south west corner of the region.

The SWRM model has 230 river branches and 32 boundaries of which 12 are directly connected to the sea in the downstream. The cross-sections of most of the river branches have been updated with recent data surveyed in 2009-2012. Among the upstream boundaries three are dominant with freshwater flow from the Ganges-Brahmaputra-Meghna basin. These three boundaries are at Gorai Railway Bridge on Gorai River, Baruria on Padma River and Bhairabbazar on Upper Meghna River. At Bhairabbazar, satisfactory rating curves cannot be generated due to scattered data and tidal influence during dry period; as a result water level time series has been used as upstream boundary of Upper Meghna River. At Gorai Railway Bridge and Baruria, rating curves have been updated and the rated discharges have been used for Gorai and Padma boundaries. The downstream water level and salinity boundaries have been generated based on observed data and the Bay of Bengal model results.

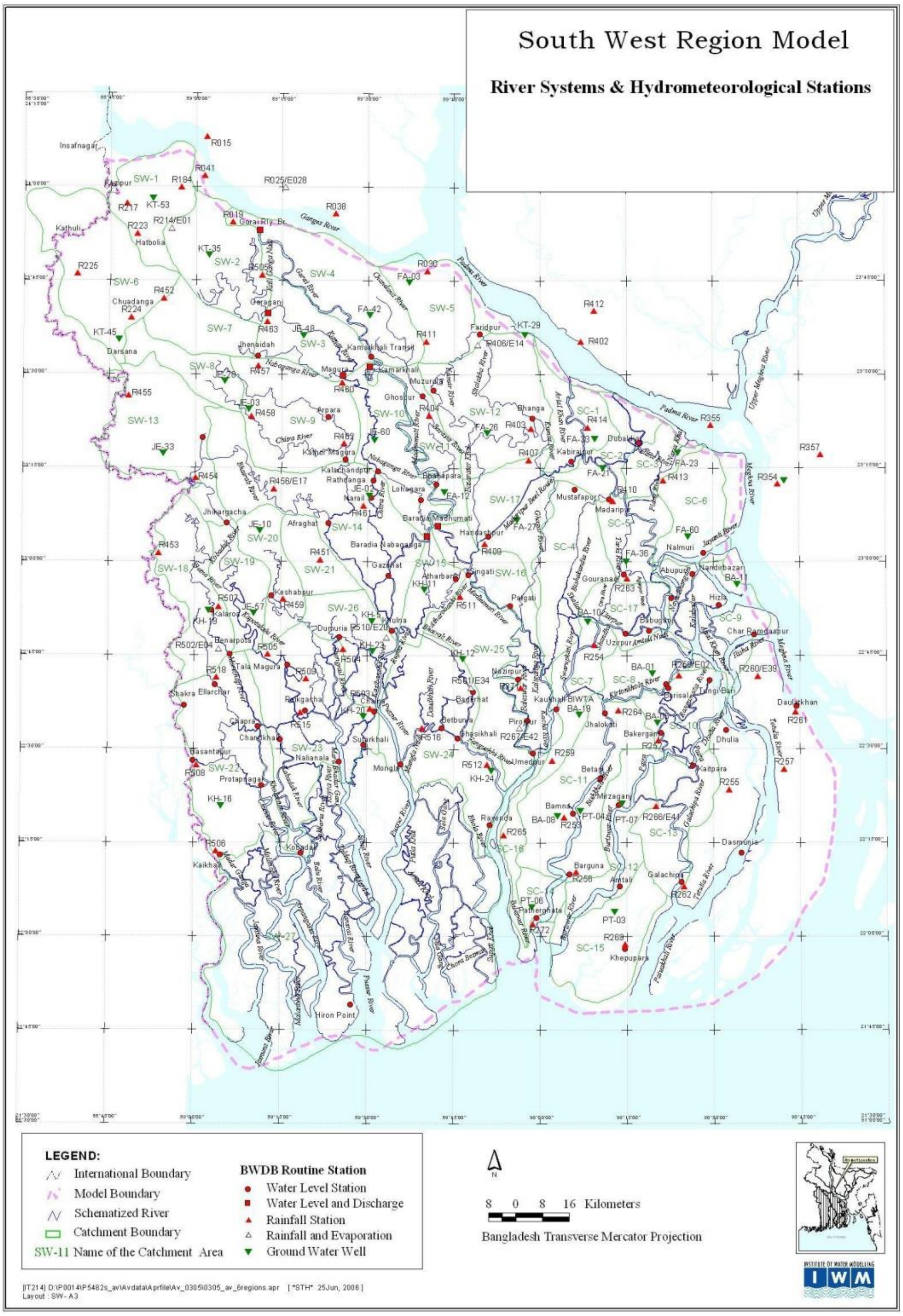


Figure 40: River Network in the Southwest Regional Model

Bay of Bengal Model

The software used for the development of the mathematical model of Bay of Bengal is MIKE21 FM module of DHI Water and Environment. The MIKE 21 FM model system is based on an unstructured flexible mesh consisting of linear triangular elements.

The BoB model domain extends from Chandpur on Lower Meghna River in the north to 16^0 Latitude in the Bay of Bengal in the south. The model applies PWD datum, i.e. level 0.46m is MSL. The grid or mesh size decreases (or the resolution increases) towards coastlines and islands. Inter-tidal areas are flooded and dried during a tidal cycle, both in nature and in the model.

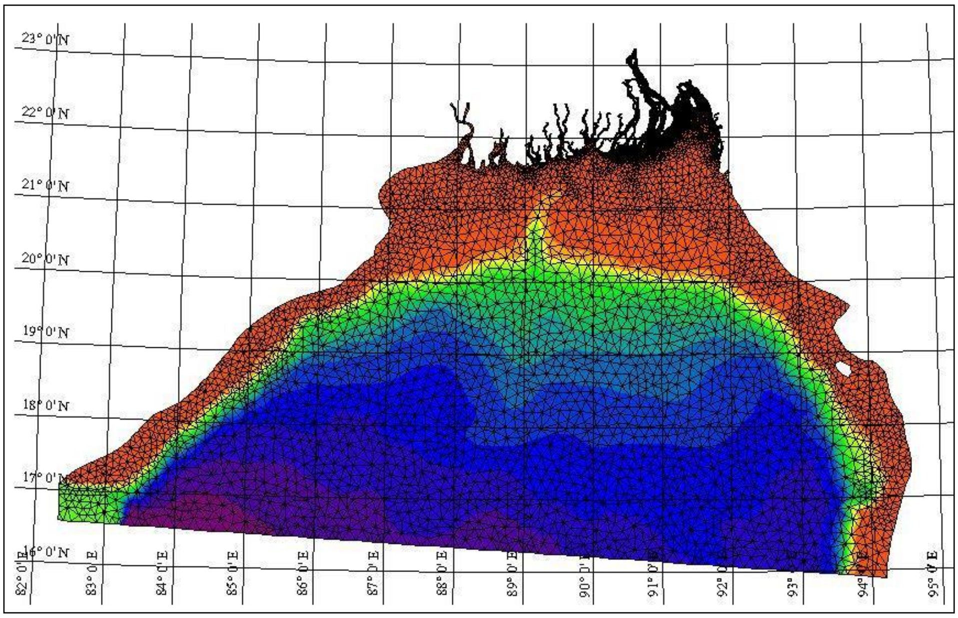


Figure 3.2.51: Computational Mesh and Bathymetry of Bay of Bengal Model

There are two open boundaries in the model, one is in the Lower Meghna River at Chandpur and another one is in the Bay of Bengal. The Bay of Bengal is quite deep and the maximum depth along the southern open boundary is more than 2000 meter. At the southern boundary water level time series is generated from global tide model of DHI and the salinity is constant at 32ppt. The salinity time series at the upstream boundaries are taken from measurements at Nalian (Sibsa River), Mongla (Pussur River), Arpangasia (Kobadak River), Pirozpur (Baleswar River) and Swarupkathi (Kaliganga River).

Validation of Models

Both the models were validated with the flow and salinity data set of 2011. Figure 42 show the validation of Bay of Bengal Model and South Regional Model against flow data and all the comparison shows quite good agreement between measured and simulated flow. On the other hand Figure 43 shows validation plots against measured salinity data for both the models and these validations also show quite good agreement.

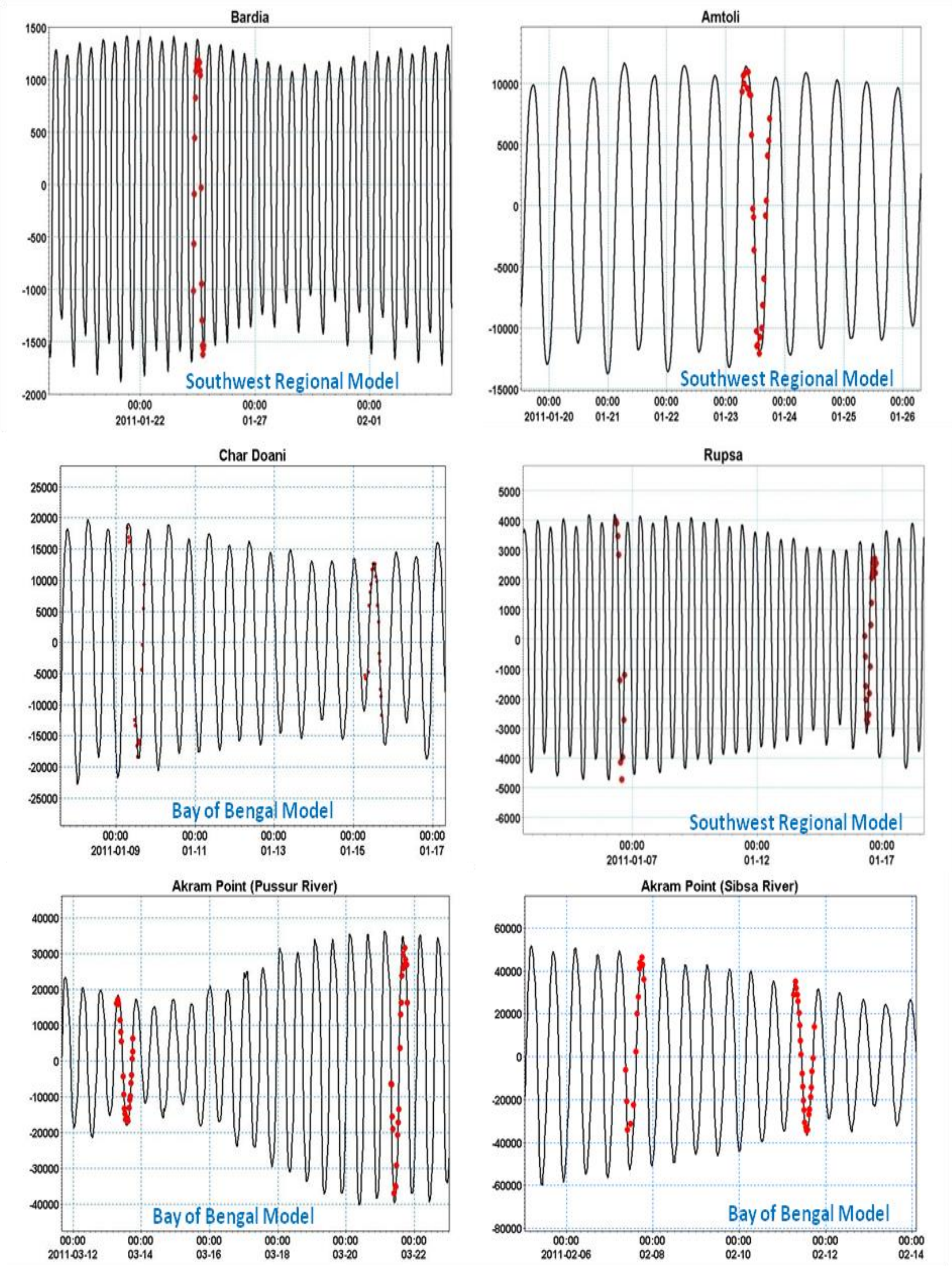


Figure 3.2.52: Validation of Bay Model and River Model against Flow Data

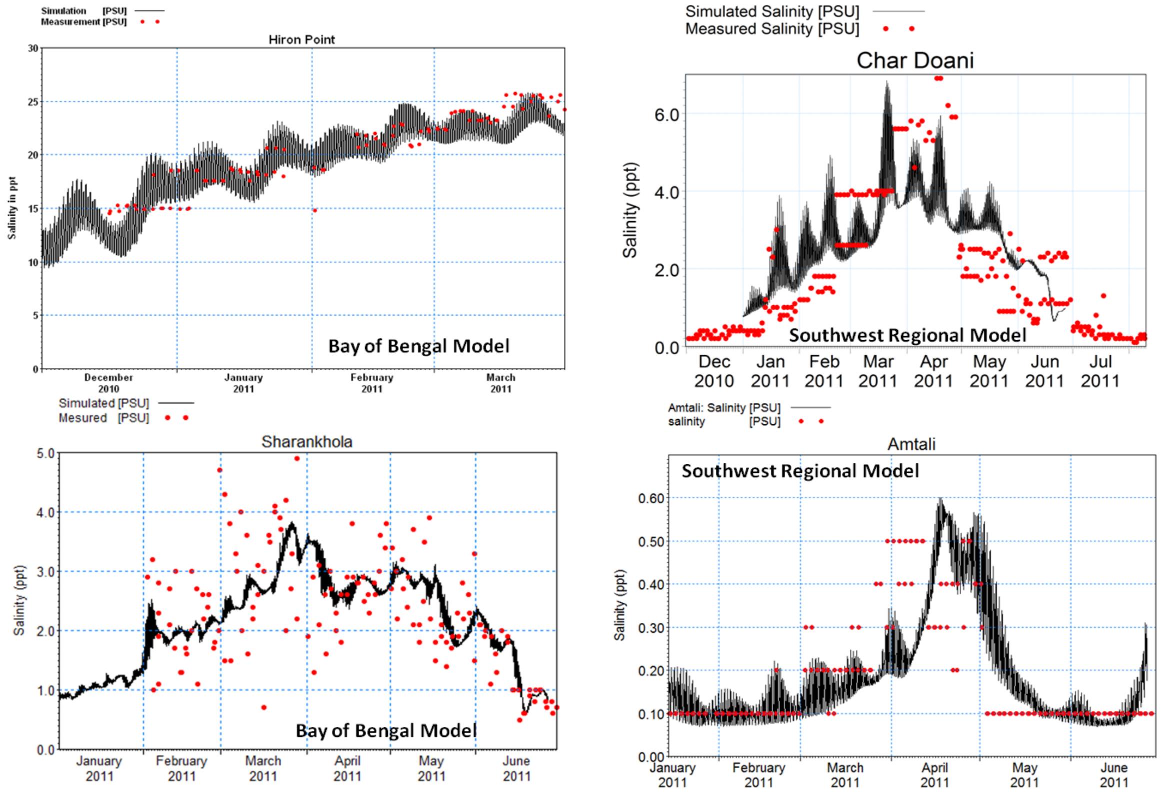


Figure 3.2.53: Validation of Bay Model and River Model against Salinity Data

Development of Climate Change Scenarios

The key variables affected by climate change and their quantification according to 4th IPCC findings and recent studies are discussed below.

Sea Level Rise

Individual scenarios are considered as independent entities in the database. Clearly, in practice, individual scenarios are often related to each other and are not always developed independently. Some are simply variants of others generated for a particular purpose. Many "new" scenarios are designed to track existing benchmark scenarios. A good example is the set of IS92 scenarios, especially the "central" IS92a scenario, which was often used as a reference from which to develop other scenarios.

The 4th IPCC (2007) prediction of the global sea level rise for the IS92a scenario is shown in the Figure 44. From this prediction it has found that the sea level will rise up to 59 cm in 2100.

Sea level rise for different year IS92a scenario calculated from the

Figure **3.2.5** is shown in Table . For this study 2035 has been selected to assess the impact of changing climate and from the Table the sea level rise was selected as 15cm for the selected year.

Table 29: Predicted Sea Level Rise for the Next 100 Years

Year	Sea Level Rise (cm) above year 2000 level
2020	8
2030	12
2035	15
2040	17
2050	23
2060	29
2070	36
2080	43
2090	51
2100	59

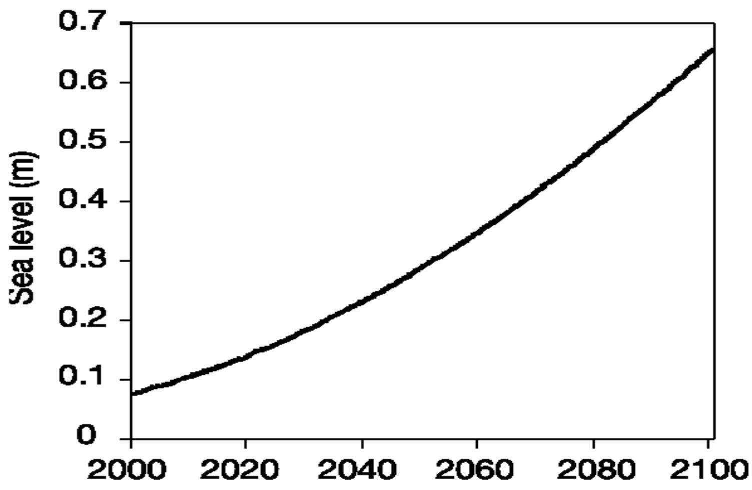


Figure 3.2.54: Prediction of Global Sea Level Rise According to IS92a Scenario (AR4, 2007)

Precipitation

Precipitation data was collected from downscaled results from PRECIS.

Simulation of Models for Base and Changing Climate

Both the models were then simulated for base condition (the year 2011) and for changing climate (the year 2035). All these results were then used to calculate exposure index both for base and changing climate. A maximum salinity map for the month of April was then prepared both for base and changing climate and furnished in the Figure 3.2.5.

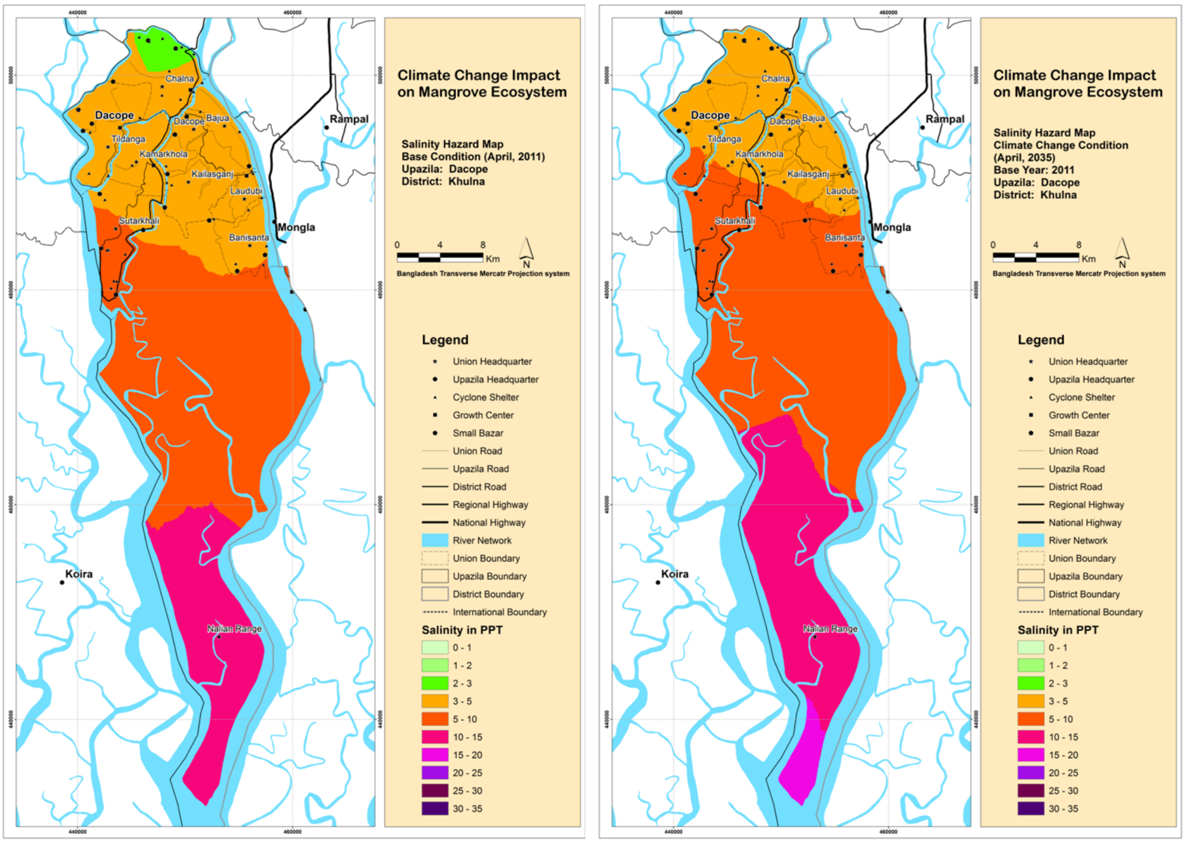


Figure 3.2.55: Maximum Salinity Map for Base and Changing Climate in the Month of April

3.4.4 Socio-economic Vulnerability Assessment

The study intends to understand the socio-economic vulnerability under changing climate for the coastal communities that are dependent on the mangroves ecosystem of Ganges. We, therefore, try to answer some key research questions in this study via relating community's perceptions with observed and projected climate change scenarios. For example, what are the possible drivers of sensitivity, how they are impacting and how much is the coping potential of communities? What should be the key adaptations options for increasing community's resilience? Hence, for an integration study indicators such as exposure (E), sensitivity (S) and adaptive capacity (A) were considered.

Data used

The study relies on a mix of qualitative and quantitative data for parameters exposure E, sensitivity S and adaptive capacity A and their variables listed in Table 2 and 3. Primary data for S and A collected from field surveys (Dacope Upazill, Bangladesh in May, 2013) and is complemented by secondary data that guided the direction and later on analysis of the research process. Data on indicators was collected from national surveys and relevant departments. The data for the sub-index E was obtained from Bangladesh Meteorological Department for the historical period of 1951-2010 and 1986-2008.

Results:

Table 30: Sub-indices of CVI assessment, their indicators, related variables and their computed values for Dacope Upazilla, Bangladesh.

Sub-Indices and their Indicators	Variable Description	Value of Variables	CVI Index for Upazilla
Exposure (E)			**0.44**
Air Temperature	Standard Deviation of Average Temperature during 1989-2008	0.75	0.75
Precipitation (P)	Standard Deviation of Average Precipitation during 1989-2008	0.46	0.46
Temperature range	Range Between Maximum and Minimum Temperature	0.42	0.42
Cyclone	Index representing frequency of Cyclone	0.32	0.32
Drought	Index representing exposure of Drought to the study area	0.25	0.25
Salinity	Frequency of 1ppt salinity beyond which drinking water is not	0.50	0.42
	Frequency of 2ppt salinity beyond which agriculture is not suitable	0.42	
	Frequency of 2ppt salinity beyond which aquaculture is not suitable	0.33	
Sensitivity (S)			**0.44**
Percentage of Children	Share of Population below 5 year of Age	0.075	0.075
Percentage of Aged People	Share of Population above 65 years of Age	0.066	0.066
Fresh water Availability	Percentage of population without access to improved water source	1.00	0.96
	Percentage of population those will be affected due to future water	1.00	
	Percentage of population those are victims of salinity Intrusion	0.89	
Natural Climate Disasters	Frequency of Natural climate disasters	0.54	0.58
	Intensity of Natural Disasters	0.77	
	Estimated per capita economic cost of these disasters	0.12	
	Percentage of population financially aided by different agencies	0.87	
Health relate infrastructure	Percentage of population without access to improved toilet facility	0.326	0.507
	Share of population relying on unprotected water sources	0.687	
Lack of Adaptive Capacity			**0.48**
Employment	Employment rate	0.32	0.32
Literacy	Literacy rate	0.56	0.56
Consumption Pattern	Household consumption	0.55	0.55
Proxy for Access to Health Service Immunization	Percentage of children aged 2-23 month immunized against major	1.00	0.72
	Percentage of births attended by skilled birth attendants	0.43	
Electricity	Percentage of population those have access to electricity	0.28	0.28
Dependency	Ration between earning persons and total person in the family	0.26	0.26
Infrastructure	Nature of dwellings	0.27	0.27
Family Network	Level of cooperation within locality	0.91	0.91
CVI			

4. Conclusions

The aims of the project were to produce scientific information on impacts of climate change on mangrove ecosystems in three countries of South Asia i.e., Bangladesh, Pakistan and Sri Lanka. To attain this aim, we constitute following three objectives of the project:

1. To examine different climatic and hydrological factors under climate change scenarios and assessment of their linkages and interactions on mangrove ecosystems;
2. To carry out vulnerability assessment for socio-economic variable, indicators and processes which are affecting mangrove ecosystem sustainability in South Asia;
3. To provide necessary adaptation/recommendations with respect to for policy and institutional intervention for mangroves sustainability and development for decision makers at local, national and regional level.

As many as six different studies were concluded regarding the socio-economic vulnerabilities of dependent coastal communities, assessment on changing hydrologic conditions and its resultant land cover changes through a temporal GIS/RS analysis, development of climate change scenarios for the study sites, environmental flows assessment, salinity distribution due to sea level rise (SLR) and institutional/policy analysis. Mostly new processes were adopted for the assessment of these studies, which are the combination of both quantitative and qualitative techniques. Our analysis shows that vulnerable coastal communities engaged either with fishery or agriculture sector, are highly sensitive and exposed to the climate change driven threats. There is lack of adaptive capacity mainly due to the poor consumption patterns, less income diversification, high dependency ratio and lack of education. In another study the results shows that the currents state of environmental flows highly deteriorate the state of ecosystems in the deltaic regions to a large extent. Under increased flows scenarios due to climate change impacts our analysis reveals that may result in increased risk of flood damages to the highly vulnerable deltaic communities. On the other hand, under reduced flows there would add to the deterioration of the deltaic ecosystems and hence the socio-economic condition of the communities therein. In the case of Pakistan, Sri-Lanka and Bangladesh, a sustainable solution would be to bridge gaps by interlinking economic and development needs of communities with environmental needs of a river and its associated ecosystems. The option in this case would be to build capacity of locals in generating environmentally sustainable incomes that help in the development, protection and preservation of mangrove ecosystems.

5 Future Directions

The project has successfully developed the effective cooperation and networking among researchers and other important stakeholders regionally as well as at international level. This collaborations is expected to develop in future specifically related to the identification of adaptation needs for vulnerable coastal communities in South Asia. The outcome of this project can help to build capacities and awareness among policy makers, academia, media, etc for sustainable mangrove ecosystems management and conservation. Moreover, this report can also serve as an important scientific base for a more detailed research studies involving a combination of advance modeling techniques, field surveys and a multidisciplinary teams of experts for in-depth analysis of impacts of climate change.

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7 Appendix

Appendix Ia

INSTITUTIONAL ASSESSMENT QUESTIONNAIRE

OBJECTIVE

Role of Institutions towards Socio-Economic Conditions of Community at Keti Bandar; Pros & Constraints (in last 5 years)

SECTION A: STAKEHOLDER BACKGROUND

Name of institution (including address)			
Official mandate			
Role & Responsibilities			
Ongoing activities			
Completed & Planned activities			
Major constraints for these activities			

Q. 1. Number of technical staff available in the Institution?

Q. 2. What are the areas of expertise of staff?

Q. 3. What is the strength of technical/professional staff to address the goals & objective of the institution?

☐Poor ☐Moderate ☐Good ☐Excellent

Q. 4. What are the capacity development programs in the institution?

Q. 5. What is the level of training?

☐In-service ☐Tertiary ☐Technical ☐Community awareness

Q. 6. Does the structure clearly allocate the functions and responsibilities?

☐Yes ☐No

Q. 7. What are the priority issues in order to effectively implement the work projects/programs/activities?

Q. 8. What constraints do you experience relating to your institutional structure in implementing your activities?

____

____

____

Q.9. List other institutions that collaborate with you?

____

____

____

Q.10.What is the type of collaboration with other institutions/organizations?

☐Data sharing ☐Joint ventures ☐Administrative

Q.11.How can be collaboration improved?

____

____

____

Q. 12. Do you consider infrastructure and equipment needs are sufficient to effectively implement your activities?

Building	☐Yes	☐No
Offices	☐Yes	☐No
Vehicles	☐Yes	☐No
Computers	☐Yes	☐No

SECTION B: SWOT ANALYSIS

Q. 1. What are the strengths of your institution to successfully achieve your mandate?

Q. 2. What weaknesses do you face that hinder the progress of your institution with regard to environmental management?

☐ Economic factor

☐ Lack of public interest

☐ Lack of technical assistance

☐ Lack of motivation

Q. 3. What are the external factors that create an enabling environment?

Q. 4. What are the external factors that may threaten the accomplishment of your mandate so far as environmental management is concerned?

SECTION C: MANGROVES STATUS

1	What are the major benefits of mangroves forest in your point of view?	1. 2. 3. 4. 5.
2	What is the trend of mangroves spread in the area?	☐Increased ☐Decreased ☐No Change
3	How many species of mangroves are you familiar with?	a) _________________________ b) _________________________ c) _________________________
4	What is the trend of these species? ☐Increased ☐Decreased ☐No Change	a) _________________________ b) _________________________ c) _________________________
5	Which species of mangroves are used as fuel?	☐ *Avicennia marina* ☐ *Ceriops tagal* ☐ *Aegiceros corniculatum*
6	Is mangrove fuel wood sold in a proper market, or is collected individually?	
7	How far is your office from the mangrove cover?	☐within 1 km. ☐more than 1km ☐2 to 3 km ☐3 to 5 km. ☐further away
8	Are the mangrove species used for construction purposes?	☐Yes ☐No ☐Might have been used, I don't have any idea
9	Do you use mangroves for livestock forage or grazing?	☐Yes ☐ No
10	Is there any allotment or rule for grazing in practice?	☐Yes ☐ No
11	What has been the trend of community's accessibility to the mangroves?	☐ Increased ☐ Decreased ☐ Not changed

12	If increased, what are the reasons attributed to it?	☐The laws doesn't restrict the free use of mangroves for livelihood ☐The reasonable prices of the fuel wood or timber ☐Unavailability of regular fuel, e.g. natural gas ☐Other

*****SECTION D: SITUATION ANALYSIS**

I: Boundaries and property rights in mangrove areas

1	Is there clear delineation of boundaries for area under jurisdiction?	☐ Yes ☐ No
2	Is the managerial staff familiar with the boundaries?	☐ Yes ☐ No
3	Is field staff familiar with the boundaries?	☐ Yes ☐ No
4	Is there clear stipulation of property rights in mangrove areas?	☐ Yes ☐ No
5	Is there stipulation of access and withdrawal rights of local communities?	☐ Yes ☐ No

II: Monitoring Mangroves

6	Is there any department for monitoring of mangrove use?	☐ Yes ☐ No
7	If not then how does the institution monitor & evaluate the mangrove use?	
8	Is there enough provision of field staff for monitoring?	☐ Yes ☐ No
9	How much is the enforcement of laws efficient on the use of mangrove?	☐ Strong ☐ Average ☐ Weak
10	Who has the authority to take legal action against violators?	

III: Restoration & conservation of mangroves

11	Do you have In-house expertise in plantation and restoration?	☐ Yes ☐ No
12	What are In-house expertise in plantation and restoration?	
13	Is the staff capacity enough for plantation and restoration?	☐ Yes ☐ No
14	Do you feel the need of partnership with other agencies for mangrove conservation?	☐ Yes ☐ No
15	How healthy are the mangroves in your local region?	☐Healthy ☐Average ☐Poor ☐Don't know
16	How much these partner agencies/organizations influence the conservation of mangroves?	☐25% ☐50% ☐75% ☐ >75%

17	How well are mangroves managed in your local area?	☐ Excellent ☐Adequate ☐Not well managed ☐No management
18	Conservation & management decision are based on	☐ Scientific evidence ☐ Traditional knowledge ☐ Both ☐ Don't know
19	What are the efforts taken for restoration & conservation of mangroves in last 5 years?	1) 2) 3)
20	How can we ensure mangroves are better protected and maintained in your area?	☐Community Education ☐Major penalties for damage ☐Educating local government ☐Long-term monitoring programs

IV: Community participation initiatives

21	Does the institution consider the communities for better management?	☐ Yes ☐ No
22	Does the institution conduct the local community meetings?	☐ Yes ☐ No
23	How often meetings are conducted?	☐Weekly ☐Monthly ☐Quarterly ☐Annually
24	What is the response of community towards participation?	☐Excellent ☐Very good ☐Good ☐Poor
25	What initiatives have been taken regarding awareness-raising on the importance of mangroves?	1) 2) 3)

Appendix IIb

17th – 22nd March, 2014

Trip Report Karachi

by Waheed ul Zafar Zahdi

Purpose of Travel

The purpose of the field trip was to conduct a study survey "Role of the Institutions towards Protection & Conservation of the Mangrove Forests" from formal & informal institutions for Mangroves ecosystems in Karachi.

Travel Objectives and their Completion

The assigned tasks and status of the achieved tasks are listed below

Sr. No	Tasks to be achieved	Achievement	Status
1	Conduct Training of Enumerator & Team Coordination (2Hrs Session)	Trained the enumerator & team members	Task Achieved
2	Conduct 6 Expert Interviews	6 Expert Interviews	Task Achieved
3	Conduct 4 Focus Group Discussion	4 Focus Group Discussion	Task Achieved

Details of Karachi Field Trip Report

For the project of APN "Impact of Climate Change on Mangrove Ecosystem in South Asia" Mr. Waheed ul Zafar Zahdi, Mr. Abdul Rehman and M. Amjad from Global Change Impact Study Centre (GCISC), visited Karachi for a six day field survey (including survey conduction, focus group discussion and professional expert interviews).

The list of activities during the stay in Karachi is as follows:

Work Days	Activities
Day 1 Monday 17th March, 2014	Travel to Karachi Two hours training sessions held at Regent Plaza Hotel & Convention Centre, Karachi.
Day 2 Tuesday (18th March, 2014)	Conducted 2 FGD's & 2 Professional Expert Interviews with: Muhammad Moazzam khan; Technical Advisor-Marine Fisheries, WWF-Pakistan. (11:00am-2:00pm) Muhammad Tahir Qureshi; Senior Advisor-Coastal Ecosystem, IUCN-Pakistan. (2:30pm-5:30pm)
Day 3 Wednesday (19th March, 2014)	Conducted 2 FGD's & 2 Professional Expert Interviews with: Ali Arsalan (founder) & a senior researcher Jamil Junejo; Pakistan Fisherfolk Forum. (10:00am to 01:00pm) Riaz Ahmed Wagan, Chief Conservator of Forests and Arif Ali Khokhar, DFO coastal forests, Sindh. (1:30pm to 4:00pm)
Day 4 Thursday (20th March, 14)	Interview with: Zulfiqar Zamrani; Project Management Office, Sindh Board of Revenue. (11:00am to 2:00pm)
Day 5 Friday (21st March, 14)	Interview with: Lt (R) Akhtar Javed P.N., Dy. Manager Marine Pollution Control Centre, Port Qasim Authority. (11:00am to 01:30pm)

Day 6 Saturday (22nd March, 14)	Departure from Karachi to Islamabad

List of Young Scientists contributed in this project:

Sr.no	Name	Activity involved	Institution/Email
Pakistan			
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Glossary of Terms

ADB	Asian Development Bank
CEA	Central Environmental Authority
IUCN	International Union for Conservation of Nature
NAQDA	National Aquaculture Development Authority
NGO	Non-governmental Organization
RRDA	Regional Resource Development Authority
ETM	Enhanced Thematic Mapper
GIS	Geographic Information System
RS	Remote Sensing
TM	Thematic Mapper
UNEP	United Nations Environment Programme
WWF	World Wide Fund for Nature
IPCC	Intergovernmental Panel on Climate Change
SWRM	Sustainable Water Resource Management
BBS	Bangladesh Bureau of Statistics
FM	Frequency Modulation
MSL	Mean Sea Level
BMD	Bangladesh Meteorological Model
ICDDRB	International Center for Diarrhea Disease and Research, Bangladesh
BoB	Bay of Bengal
SVP	Sector Vulnerability Profile