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Scientific Capacity Building and Enhancement for Sustainable Development in Developing Countries

An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas

Final Report for APN CAPaBLE Project: 2004-CB01NSY-Dutta

Asian Institute of Technology

An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas

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Final Report submitted to APN

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ISBN

www.apn-gcr.org

Overview of project work and outcomes

Non-technical Summary

Annual flood events in Asia have tripled with economic losses and human casualties increased by more than five folds in the last 30 years. Majority of the events are concentrated in South Asia (39%) and South-east Asia (30%). High rate of urbanization and population growth in these regions are likely to aggravate the situation, especially in low-lying large cities, which are affected by sea water intrusion. Based on the 2001 study, Intergovernmental Panel on Climate Change (IPCC) predicts that global mean sea level (msl) may rise as much as 88 cm by the end of the 21st century. The coastal zone is expected to be home to nearly 75% of the Asian population by 2025. Large coastal cities like Bangkok and Dhaka have already been facing severe problems due to lower elevation, some parts of which being tens of centimeters below msl. Potentially, sea level rise will have the greatest impacts in these large coastal cities and very few countries have planned the ways to deal with these problems. The project was aimed to assess socio-economic impacts of flooding under climate change conditions in low-lying large coastal cities in South and South-east Asia to assist the policy makers of the region to better understand the vulnerability of fast developing coastal cities under climate variability and socio-economic changes. The major recommendation of this project is the need for a single organization/agency dealing with flood mitigation and which can simultaneously address climate change issues. The need for delineating flood mitigation and management policies from disaster management policy is also suggested.

Objectives

The main objectives of the project were: i) to gather and analyze existing data and information for developing a GIS database of hydrologic characteristics and socio-economic conditions of the selected cities; ii) to adapt and apply existing tools and methodologies to simulate and assess flooding under long-term climatic change and rise in sea-level; iii) to assess socio-economic impacts and vulnerability using developed tools; iv) to study the links among policy, socio-economic factors and floods and their impacts in the region for urban flood risk management and identify gaps in existing government polices; v) to establish a network of researchers and institutions engaged in research and policy analysis related to flood risk management; and vi) to build capacity and raise public awareness on climate change and its impacts.

The project involved contributions from six countries of South and South-east Asia: Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam and received technical assistance from Japan. Selection of urban coastal cities was based on the size, population and social and economic importance, frequency and duration of flooding, tidal effects on flooding and availability of data and information. The selected areas were Meghna Delta (Bangladesh), Mahanadi Delta (India), Karachi (Pakistan), Matara (Sri Lanka), Bangkok (Thailand), and Hue City (Vietnam).

Amount received and number of years supported

The grant awarded to this project by the APN CAPaBLE Programme was US$ 45,000 for one year period (2004-2005). The project team received supplementary in-kind support equivalent to US$35,000 from the host institute.

Work undertaken

The following activities were carried out to fulfill the project objectives:

Activity I: Establishment of a network of communication: A network of scientists and institutions was established by means of webpage, web-based discussion forum and mailing list from Japan and the six participating countries in the project**.** This network was used for communication among researchers involved in this project and others for sharing data, information and exchange of know-how.

Activity II: Synthesis of existing data and information and development of GIS database: Existing databases of present hydrological characteristics and socio-economic conditions and their future predictions from various regional and global sources like USGS (DEM and land use), IGBP (soil resources), LUCC (land use changes), UNHABITAT, UNSD (urban development), IPCC, GFDL, MRI, and CCSR (simulated results of GCM) were collected for the selected case study areas. Together with the existing and compiled information through this project at country level, a comprehensive GIS and temporal database was developed.

Activity III: Scenario analyses of floods and its socio-economic impacts: The scenario analysis and socio-economic impact analysis for the case study areas were carried out at AIT with the following three steps:

i) Flood inundation simulation: Flood inundation simulations in the case study areas were carried out using UFRA (Urban Flood Risk Analysis model), IISDHM (Institute of Industrial Science Distributed Hydrological Model) and hydrodynamic model developed by the Public Work Research Institute (PWRI) of Japan for analyzing several scenarios for potential sea level rise conditions in 2025, 2050, 2075 and 2100. The other hydro-meteorological datasets were selected from the recorded worst flood event occurred during the past three decades.
ii) Estimation of potential growth of urbanization: The spatial distribution of present urban indicators (population, buildings, transportation network etc.) and their projected growth in the selected periods of the case analysis were modeled using the AGENT-LUC model.
iii) Socio-economic impacts: Three main sectors (population, buildings, transportation network) were considered for socio-economic impacts. A set of qualitative indices were developed based on questionnaire survey for impact assessment. Utilizing these indices, the impacts of floods on the selected socio-economic sectors were assessed using the results of steps i) and ii) above.

A 2-week long brainstorming workshop was held at AIT during 20-31 March 2005 among the collaborators for deliberation and discussion of country based scenario analyses. It provided an opportunity for cross-country interaction and exchange of initial ideas on development of relevant policies and strategies for implementation.

Activity IV: Workshop for discussing outcomes and relating them to policy development: A 3 day international symposium was organized at AIT during 23-25 June 2005 for the major collaborators and policy makers of the participating countries to discuss among the participants the outputs of the study and how these can be incorporated into the existing flood disaster mitigation policies and strategies in respective countries for better flood risk management. A full day workshop as part of the symposium was carried out to develop guidelines for incorporating climate change in flood risk management policies and strategies. The symposium proceedings has been published and sent to all the relevant agencies in South and South-east Asia to make them aware of the findings and recommended guidelines for consideration in developing relevant government policies.

Activity V: Dissemination of outcomes for raising awareness: Posters on climate change and its impacts on coastal cities have been produced based on the findings of the project and have been distributed to various relevant organizations of the member countries for raising awareness and dissemination of respective case study results. The collaborators have organized pubic fora at local level, where the case study findings have been presented to the stakeholders.

Results

The results obtained from the scenario analysis of socio-economic impacts of floods due to sea level rise in 2025, 2050, 2075 and 2100 in the selected case study areas provided a comprehensive picture of the vulnerability of the population, buildings and transportation networks of these urbanized areas. Comparative analyses of the outcomes of the scenario analysis in the individual case study areas are made. For the present (2005) situation, it has been found that the Meghna Delta is highly vulnerable, with 83% of the total population and buildings being affected. This is followed by the Hue City, where about 44% of the population and buildings are affected. Whereas the Mahanadi Delta, Karachi and Matara City, having more than 86% of the population and 82% of the buildings in the unaffected zone, are not in the high risk domain. In this extreme flood scenario, the damage on road network is very meager, except in Meghna Delta where whole road system is affected.

In 2025, it is observed that about 43% of the population and 77% buildings in Bangkok will be affected by flood. There is little effect on Karachi as 88%

population and buildings will remain unaffected, and no noticeable impact is seen in case of Mahanadi Delta. While a small impact on road network is observed in Mahanadi Delta area in India, in other cities it remains almost unaffected. For the projected scenario of 2050, the coastal cities of Meghna Delta will be significantly affected with majority of impact falling in less affected category. About 45-50% of the population will be affected in Bangkok and Hue City. Projected damage is less severe in case of coastal cities in the Mahanadi Delta with 25% of population, and in Karachi and Matara cities with about 15% of population, under the affected category. A large number of buildings will be affected in Meghna Delta, Bangkok and Hue City. Coastal cities of Mahanadi Delta are expected to experience a significant impact on road network of about 43% of the total length. However, in other cities the effect is negligible. Projected scenario of 2075 is carried out for the coastal cities of India, Pakistan, Thailand and Vietnam. In this case, the degree of effect on population and buildings is about the same as the 2050 scenario. However, the extent of damage caused to road network is high in this case. About 75% of the road will be affected in Mahanadi Delta. Road system in Karachi is also expected to undergo a damage of about 8%. For 2100 scenario, the coastal cities of Bangladesh will be significantly affected with 80% of the population and buildings falling in moderately and highly affected index category. Other cities show little deviation in the extent of damage, in comparison to previous scenario. Road network in the coastal cities in Mahanadi Delta show the same estimated damage index of 75% as in the 2075 scenario. However, in Karachi the damage to road is increased by three folds. There is no major impact on railway system in any of the scenarios considered in this study.

It can be concluded that the coastal cities in Meghna Delta is highly vulnerable to floods under climate change conditions as far as the high priority categories, viz. population and buildings, are concerned. For the cities of Bangkok and Hue, the extent of effect imposed by climate change on population is considerable, albeit lower in comparison to Meghna Delta. A large number of buildings in Bangkok are affected. Cities located in the Mahanadi Delta of India are found to be more sensitive as far as the damage on road network is concerned.

The study found that Bangladesh has addressed climate change issues as far as relevant policy making is concerned. However, the existing policies and strategies of other countries lack any vivid section pertaining to climate change, which may aggravate the future vulnerability situation, and need to be looked upon substantially and immediately.

Relevance to the APN CAPaBLE Programme and its Objectives

The project was highly relevant to the APN research framework. It falls under the APN research areas of: climate change and variability, changes in coastal zones and inland waters, integration of the findings of natural science with social and economic factors and input policy making and implementation. The project and its outcomes are particularly relevant to the three main objectives of the CAPaBLE Programme. It helped in building capacity of one young researcher of the region by direct engagement in the project activities and of several others through their involvement in case study analysis. The project enhanced the capacities of six leading researchers of the six countries of South and South-east Asia through their direct involvement in the project activities and participation in the brain-storming workshop and through sharing of knowledge, experience, scientific information and data collection on climate change impacts, and vulnerabilities. The project contribute in the decision-making in the six developing countries by involving decision makers in identifying gaps in existing government polices through the international symposium and by dissemination of the outcomes of research to policy-makers and civil society.

Self evaluation

The project was successfully implemented. The outcomes of the project were highly satisfactory and it met all the objectives of the projects. The particular highlights of the project were the outcomes of the scenario analyses that are comprehensive and useful for the decision making process in the study areas. The collaborative work in the project with the involvement of a number of researchers and decision-makers of six countries of South and South-east Asia helped developing a network that will lead to expansion of much needed work in other coastal cities of the region. The successful implementation of the methodology developed in scenario analysis for six developing countries has contributed towards enhancing adaptive capacity of the region to climate change and reduce adverse effects in coastal cities. The proceedings of the international symposium organized under the project documenting all the case studies will be a valuable reference to any future related project. Through the international symposium and public fora organized under the project and information dissemination based on the outcomes of the case studies, the project has contributed in raising public awareness on climate change and its impacts on coastal regions. The project has contributed in identifying the existing gaps in knowledge, awareness and policies for adaptation and mitigation of climate impacts on coastal cities of the region.

The project dealt with practical difficulties of obtaining reliable data and information for conducting detailed case studies. The limited availability of high resolution spatial and temporal data for modeling floods, urban landuse changes and socio-economic impact analysis have affected the case studies to some extent. The time span of the project was a critical issue, and it was recognized that the 3rd Activity of the project was ambitious for the given duration and funding of the project.

Potential for future work

One of the potential future scientific works is to expand the studies to other major coastal cities of the region. The further research should consider other related issues of impacts of sea level rise to coastal environment, ecosystem, tourism and other coastal industries by involving various stakeholders. Based on the outcomes of the impact studies adaptation and mitigation strategies should be developed for different sectors of economy and society.

Publications

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Acknowledgments

The project team gratefully acknowledges the financial and human resources contribution of the Regional Network Office of Urban Safety (RNUS) and Water Engineering and Management (WEM) Field of Study of AIT in successful completion of the Project.

Technical Report

Preface

The present trend of rapid urbanization of coastal zones in most developing countries puts an increasing number of people and property at risk due to climate change triggered sea-level rise. The consequent flooding is expected to affect most low lying coastal cities. A series of case studies has been conducted to assess socio-economic impacts of flooding under climate change conditions in low-lying large coastal cities in South and South-east Asia. The highly vulnerable coastal cities of Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam have been selected. The study was aimed at raising the awareness among policy makers on the socio-economic vulnerability of coastal cities under climate change, and assisting them in developing and implementing policies towards betterment of future flood management measures. We sincerely hope that the public awareness created through the dissemination of these findings would play a key role towards reducing the vulnerability of coastal cities to sea-level rise. The project team is grateful to Regional Network Office of Urban Safety (RNUS) and Water Engineering and Management (WEM) Field of Study of AIT for the significant contributions towards the successful completion of the project.

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1.0 Introduction

Background

Annual flood events in Asia have tripled with economic losses and human casualties increased by more than five folds in the last 30 years. Majority of the events are concentrated in South Asia (39%) and South-east Asia (30%) (Dutta *et al.*, 2004). High rate of the urbanization and population growth in South and South-east Asia are likely to aggravate the situation, especially in low-lying large cities, which are affected by sea water intrusion. Based on the 2001 study, Intergovernmental Panel on Climate Change (IPCC) predicts that global mean sea level (msl) may rise as much as 88 cm by the end of the 21st century (IPCC, 2001). The coastal zone is expected to be home to nearly 75% of the Asian population by 2025. Large coastal cities like Bangkok and Dhaka have already been facing severe problems due to lower elevation, some parts of which being tens of centimeters below msl. Potentially, sea level rise will have the greatest impacts in these large coastal cities and very few countries have planned the ways to deal with these problems. It is therefore necessary to assess socio-economic impacts of flooding under climate change conditions in low-lying large cities in South and South-east Asia. This will assist the policy markers to better understand the vulnerability of developing coastal cities under climate variability and change and socio-economic changes.

Scope of the project

The project focuses on understanding the flooding characteristics under projected climatic and socio-economic scenarios. It integrates and analyzes existing data, information and results and use existing tools for simulating the flood behavior and impacts. The project scope is limited to selected low-lying large cities of the participating countries: Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam. The most vulnerable coastal cities from each country are identified based on their representativeness for the study. The research also emphasizes on identifying critical gaps in information and policy and a set of recommendations are made for better decision making to improve the livelihood of the local people.

Objectives

The objectives of the project are as follows:

- To gather and analyze existing data and information for developing a GIS database of hydrologic characteristics and socio-economic conditions of the selected cities;
- To adapt and apply existing tools and methodologies to simulate and assess flooding under long-term climatic change and rise in sea-level;
- To assess socio-economic impacts and vulnerability using developed tools;
- To study the links among policy, socio-economic factors and floods and their impacts in the region for urban flood risk management and identify gaps in existing government polices;
- To establish a network of researchers and institutions engaged in research and policy analysis related to flood risk management; and
- To build capacity and raise public awareness on climate change and its impacts.

Implementation of the project activities

The project consists of five major activities: 1) Establishment of a network for seamless communication among researchers; 2) Synthesis of existing data and information and development of a GIS database; 3) Scenario analysis of floods and its socio-economic impacts; 4) Organization of workshop for discussing outcomes and relating them to policy development; and 5) Organization of open forum for raising awareness among stakeholders.

The project is executed by the following organizations:

- Bangladesh University of Engineering and Technology, Bangladesh
- Andhra University, India
- University of Engineering and Technology, Pakistan
- University of Peradeniya, Sri Lanka
- Asian Institute of Technology (AIT), Thailand (Host Institute)
- Department for Dyke Management, Flood and Storm Control, Vietnam
- University of Tokyo, Japan

Selected study areas

The selection of the coastal cities for case studies is based on the following criteria:

- Size, population and social and economic importance for the country
- Frequency and duration of flooding
- Tidal effects on flooding
- Availability of data and information

Based on the above criteria, the project collaborators finalized the case study cities of their countries as follows. (Figure 1.1):

- Barisal and Patuakhali in Meghna Delta of Bangladesh
- Bhubaneswar, Cuttack and Puri in Mahanadi Delta of India
- Karachi in Pakistan
- Matara in Sri Lanka
- Bangkok in Thailand
- Hue City in Vietnam

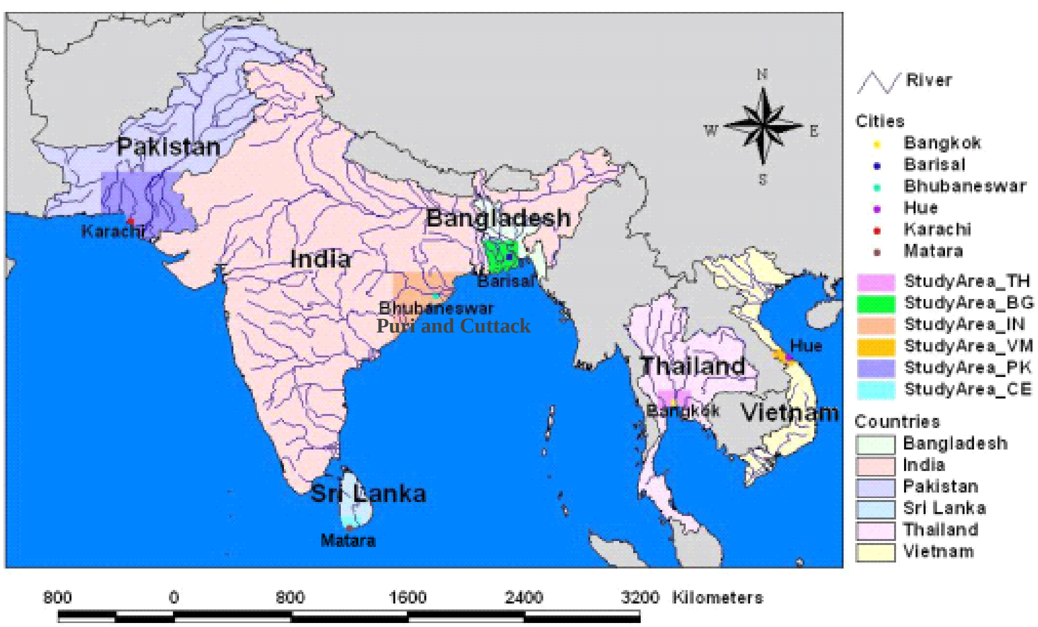


Figure 1.1: Project participating countries and case study areas

Organization of the report

Chapter 2 summarizes the methodology followed to achieve the project objectives including the estimation of future flood inundation due to rise in sea level and the computation of consequent socio- economic losses. Chapter 3 presents the project results and describes the comparative analysis of the case studies. The degree of vulnerability of different categories to flood has been estimated and compared with similar categories of all the coastal cities of the project. Chapter 4 illustrates the summary of the entire research work including the project aims and important findings. The recommendations for future work are included in Chapter 5. Details on the modeling tools used for analysis are presented in Appendix A. The description of the case study areas, hydro-meteorological characteristics, datasets used and analyzed for computation and model output obtained are presented in Appendices B, C, D, E, F and G for Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam respectively. Appendices H, I and J deal with the symposium agenda and participant details, brainstorming on case studies and policy analysis and the open forum particulars respectively. Appendix K provides information on funding sources outside APN. Appendix L details the abbreviations used in the report.

2.0 Methodology

The overall approach and methodology followed to carry out the project is presented in Figure 2.1 which follows logically the objectives of the project.

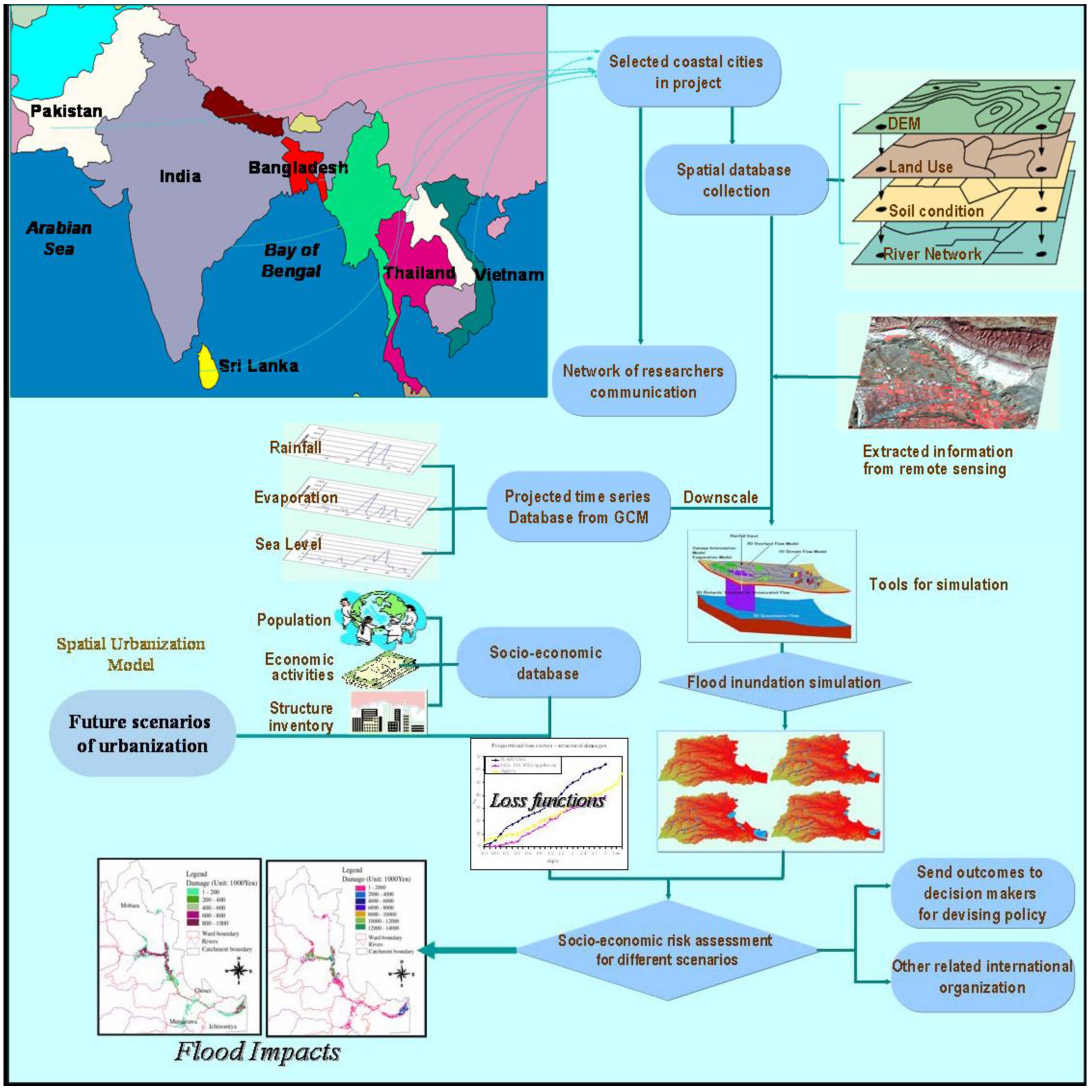


Figure 2.1: Project framework and expected outcomes

Data collection and database development

The data and information required for flood simulations by the modeling tools were collected from various existing sources including the relevant departments of respective countries, regional and global databases produced by various international organizations. The major temporal datasets collected for the simulation include hourly rainfall data, water level data for the upstream and downstream boundaries, evaporation data etc. The spatial datasets required are land use, topography (USGS, 2003), soil (FAO Soil Map, 2003) and river cross-section data. The sources of these data are indicated in the individual case study reports given in Appendices B to G.

Secondary data relevant for socio-economic analysis is collected from respective departments and then colligated with model outputs for present scenario analysis. Due to limited availability of data, the socio-economic impact analysis is conducted only for three main and highly vulnerable sectors:

buildings, population and transportation network. The analysis on building category is concentrated on residential buildings in most of the case studies. Moreover, where the data pertaining to residential buildings is also not available, the count of residential buildings is estimated based on population data with an assumption of four persons per residential building. Transportation category incorporated only main roads and railway networks laid within the study area boundary. A GIS database with the spatial and temporal data collected is developed.

Tools for analysis

Two kinds of physically based mathematical models were used in this study for simulating flood inundation. One is a physically based distributed hydrologic model integrating the overland flow and open channel flow components of IISDHM (Institute of Industrial Science Distributed Hydrological Model) (Dutta *et al.,* 2000). The governing equations for the river flow and overland flow are 1-D St. Venant's equation and 2-D St. Venant's equations with diffusive wave approximation. Fully-implicit finite difference schemes were used to solve the governing equations of open channel and overland flow. This model was applied in the case of converging river network. The second was a hydrodynamic model developed by the Public Work Research Institute (PWRI) (Dutta *et al.,* 2004). Water level and discharge in river and flood plain are calculated using explicit solution scheme. This model was applied in case of diverging river network system.

Socio-economic projections under land use change conditions are computed using Antropogenically Engineered Transformations of Land Use and Land Cover (AGENT-LUC) Model, developed by Rajan and Shibasaki (2000). This model assesses land use and land cover changes as a result of human activities. It consists of four models: the biophysical crop yield model, the rural income model, the urban land use model and the agent decision model; and a sub-model for migration. For obtaining a reasonable estimation of the change in the land use patterns, this model considers demographic condition and the land use history, in addition to the economic factor. The population projection techniques followed in this project are country specific and are detailed in specific appendix. Refer to Appendix A for details on tools used for analysis in the project.

Impacts and vulnerability assessment

Only highly vulnerable socio-economic categories were considered in this study, which are population, buildings and transportation. Analysis was focused on present (2005) and future (2025, 2050, 2075, 2100) scenarios. Present scenario analysis was carried out using primary and secondary data gathered from relevant departments. For future scenario analysis, appropriate projection techniques of socio-economic data were followed and then interpretation was derived in relation with model output.

A questionnaire survey was conducted to develop a set of qualitative impact indices for analysis of socio-economic impacts of floods for the selected categories. The methodology followed for developing the indices are summarized in Appendix A and the country specific details are provided in Appendices B to G.

Linkage among policy, socio-economic factors and floods

Relevant documents on flood mitigation and management, disaster risk management and other policies were collected from the departments and/or ministries by the project collaborators. These policies were reviewed to assess whether or not they address the climate change issues. Apart from this, a 2-week long brainstorming workshop was conducted aiming at assessing the current policies and strategies and for identifying gaps in them. A 3-day international symposium was organized, of which one full day was dedicated to developing guidelines for incorporating climate change in flood risk management policies of participating countries. Appendix H provides the symposium agenda and participant details.

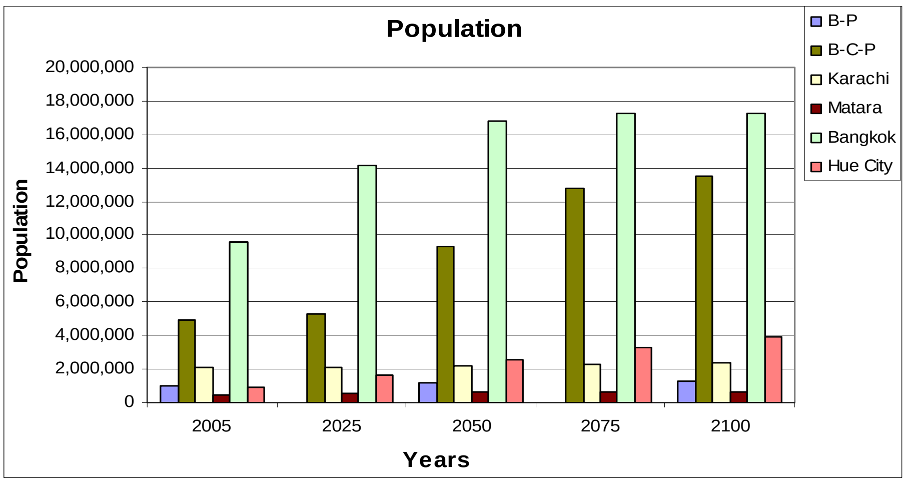
Networking and capacity building

A network of researchers and institutions was established through web-based discussion forum. This was meant for data sharing and exchange of information among researchers working at different institutions. Collaborators of the participating countries were brought together and discussions were held on policy issues through brainstorming workshops. A 3-day international symposium was conducted to bring in a more wide perspective of the issue. Further, the research findings were disseminated through open fora at case study areas. These activities helped in making networks and developing capacities of parties involved.

3.0 Results and Discussion

Projections and impacts

In this part of the report, the results of the six case studies are presented and compared. Figure 3.1 compares of the population of the six study areas of the project. Population trends indicate that the population increase rate will slow down with time. Population projections reveal that the population of Bangkok will approximately double in 100 years from the current level of 9.2 million while the population in Mahanadi Delta containing Bhuwaneshwor, Cuttack and Puri Cities will be 13.7 million by the year 2100, a three-fold increase from the population in 2005. Similarly, the population of Hue City will increase by four folds, from about 1 million to 4 million, in this century. The rates of population increase in Karachi and Matara are lower compared to the other four study areas.



B-P: Barisal – Patuakhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

Figure 3.1: Projected population of the case study cities

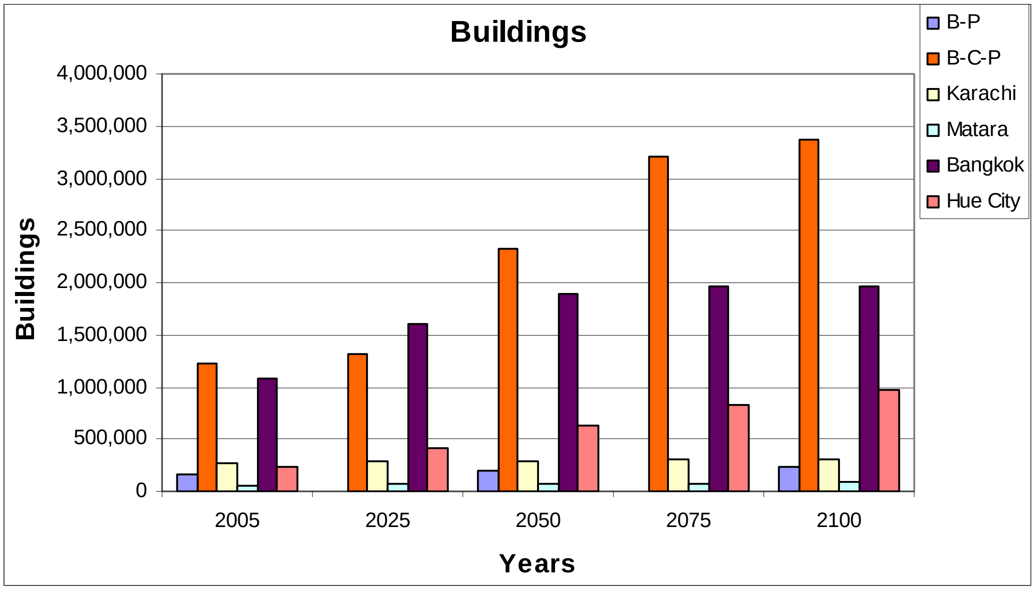
Figure 3.2 presents and compares the projected number of buildings in the study areas. As number of buildings is directly related to population, the increase in the number of buildings also follows similar trend as population. The number of buildings in Bangkok will double to 1.98 million in 100 years while in Bhubaneswar, Cuttack and Puri Cities, the number of buildings will triple by 2100. Similarly, number of buildings in Hue City will increase by four folds in this century. The rates of increase in number of buildings in Karachi and Matara City are lower compared to the other four study areas.

Present scenario

Table 3.1 presents the effect of flooding on population for present as well as future cases considering climate change conditions. Under the present condition, there is not much impact of flooding in Mahanadi Delta area in India. Similarly, people in Karachi (Pakistan) and Matara (Sri Lanka) are also not much affected by the present flooding condition as more than 85% population is unaffected. More than half the population of Hue City is unaffected where as in Barisal - Patuakhali Cities in Bangladesh, only 17% population is unaffected by flooding under the current condition scenario.

Similarly, Table 3.2 presents the effect of flooding on number of buildings for the present and future cases considering climate change impacts. Under the present condition, there is not much impact of flooding on buildings in

Mahanadi Delta in India. Similarly, buildings in Karachi (Pakistan) and Matara (Sri Lanka) are also not much affected by the present flooding condition as more than 80% buildings are unaffected by flooding. More than half of total houses in Hue City is unaffected by present flooding scenario whereas in Barisal - Patuakhali Cities in Bangladesh, only 17% houses are unaffected and 73% are in less affected category in the current scenario. In the present extreme flood scenario, roads and railway network are not affected at all. Tables 3.3 and 3.4 present the effect of flooding on road and railway network in present and future conditions with climate change.



B-P: Barisal – Patuakhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

Figure 3.2: Projected number of buildings in the case study cities

2025 Scenario

In case of the 2025 projected scenario, there is insignificant impact of flooding on population in Mahanadi Delta area in India as 99% population remains unaffected. There is little effect on Karachi with 88% population unaffected. However, about 57% population in Bangkok will be affected by flood under this scenario (Table 3.1).

In case of buildings, there is no significant impact of flooding in Mahanadi Delta as 99% buildings remain unaffected. There is little effect on Karachi with 88% buildings remaining unaffected but more than half buildings in Bangkok will be affected by flood (Table 3.2).

Little impact on road is projected in Mahanadi Delta in India while roads in the other cities will mostly remain unaffected (Table 3.3). Similarly, railway system will not be affected at all in case of the 2025 projected scenario for the cities considered in this project (Table 3.4).

2050 Scenario

For the 2050 projected scenario, more than half population will be affected in Bangkok and Hue City. Barisal - Patuakhali Cities in Bangladesh will be highly affected by projected flooding scenario due to sea level rise but majority of impact falls in less affected category (Table 3.1). There will be little impact of flooding on population in Karachi and Matara Cities as about 86% population will not be affected due to projected flooding scenario of sea level rise. In case of Mahanadi Delta area in India which includes Bhubaneswar - Cuttack - Puri Cities, three fourth of projected population will remain unaffected.

Almost half of total projected buildings will be affected in Hue City. In case of Barisal - Patuakhali Cities in Bangladesh and Bangkok, the buildings will be highly affected by projected flooding scenario due to sea level rise but majority (75%) of them falls in less affected category (Table 3.2). The impact of projected flooding is less significant for the buildings in Karachi and Matara Cities as only 13 and 18% buildings will be affected to some extent due to sea level rise. There is no big impact of flooding in Mahanadi Delta area as about 74% buildings will remain unaffected.

There will be a significant impact on road system in Mahanadi Delta area in India as about 57% of the roads will be affected by projected flooding scenario. In other project cities, roads will remain almost unaffected, except Barisal-Pathukhali Cities in Bangladesh where 95% of the road network will be affected to lesser extent (Table 3.3). No impact on railway system for this scenario is expected (Table 3.4).

2075 Scenario

For the 2075 projected scenario, about half of total projected population will be affected in Bangkok (52%) and Hue City (53%) (Table 3.1). There is minor impact of flooding on population in Karachi as 87% population will remain unaffected. About 73% of population in the Mahanadi Delta area in India which includes Bhubaneswar - Cuttack - Puri Cities will be unaffected.

About 47% of the total projected buildings will be affected due to flooding in Hue City. In case of Bangkok, the buildings will be highly affected by projected flooding scenario but majority (83%) of them falls in less affected category (Table 3.2). The impact of projected flooding is less significant for the buildings in Karachi as 87% buildings will remain unaffected due to sea level rise, and the remaining 13% will have different degree of impacts. There is not big impact of flooding in Mahanadi Delta area in India as 73% buildings will remain unaffected.

There will be significant impact on roads in Mahanadi Delta area in India as about 75% of the road network will be affected. In other cities, roads will remain almost unaffected except Karachi where some impact of flooding is estimated, about 9% of the roads will be affected by the projected flooding scenario (Table 3.3). However, there will be no impact on railway system under this projected scenario also (Table 3.4).

2100 Scenario

In case of the 2100 projected scenario, about 56% of the total projected population will be affected in Bangkok and and about 46% in Hue City. Barisal - Patuakhali Cities in Bangladesh will be highly affected by projected flooding scenario due to sea level rise and the majority of impact (70%) falls in moderately affected category (Table 3.1). The impact of flooding on population in Karachi and Matara Cities will be minimal as about 87 and 86% population respectively will remain unaffected. In case of Mahanadi Delta area in India which includes Bhubaneswar - Cuttack - Puri Cities, about 27% of the projected population will be affected due to sea level rise scenario.

About 48% of the total projected buildings will be affected due to flooding in Hue City. The buildings in Bangkok will be highly affected by this projected flooding scenario; however the most (about 91%) of them fall in less affected category (Table 3.2). In case of buildings, the impact of projected flooding is less significant in Karachi and Matara as about 87 and 82% buildings respectively will remain unaffected due to sea level rise. No severe impact of flooding in Mahanadi Delta area in India is expected as about 73% buildings will remain unaffected.

There will be significant impacts on roads in Barisal-Pathukhali in Bangladesh with all the roads being moderately and highly affected. Similar is the case of Mahanadi Delta area as about 74% of the roads will be affected at different levels (57% less affected, 10% moderately affected and 7% highly affected) by projected flooding scenario. In other cities, roads will remain almost unaffected except Karachi about 25% of the roads will be affected with about 2% road network very highly affected under the scenario (Table 3.3). Similarly, there will be almost no impact on railway system for the 2100 projected scenario like in previous scenarios (Table 3.4).

Existing policies and gaps

Reviewing the existing policies of different member countries of the project, it is observed that most of the countries have flood and disaster management polices but they do not include the issue of climate change and its impact and how to deal with them. For example, in case of Thailand, the Basin Management and Flood Management Plans do exist but there is no mention of climate change in them. Similarly, in case of India, the National Water Policy, National Disaster Management bill, Disaster Risk Management program exist but do not mention climate change issue. In Pakistan, Water Policy, The Pakistan Water Sector Strategy, Sindh Katchi Abadis (unauthorized dwelling) Act exist but again there is no reference to climate change. Similarly, National Disaster Management Plan, Flood Protection Ordinance, Coastal Management Policy, Watershed Management Policy are there in Sri Lanka but the issue of climate change impact remains untouched in these policy documents. The situation is not different in case of Vietnam also. They also have many policies related to flood management and disaster mitigation but the climate change has not included in the policies. However, in case of Bangladesh, the issue of climate change impacts has been considered and included in the National Water Policy, which recognizes climate change induced flood as one of the factors determining future water supply and demand. Similarly, National Water Management Plan (NWMP) also addresses the issues of coastal flooding due to sea level rise. The outcomes of the brainstorming sessions on policy review and identification of gaps are summarized in Appendix I.

Networking and capacity building

Through this project several young researchers were able to enhance their capacities by means of gaining scientific experience and conducting case study analysis. The collaborators from the member countries gained detailed know-how of the modeling tools used in the project through their participation in the intensive brainstorming workshop and that led to capacity building of their respective institutes for future expansion of case studies to other vulnerable coastal cities of the country. The findings of this project were disseminated to the policy makers and to the stakeholders through the respective country collaborators, which will help them in formulating the relevant policies to cope with the climate change. A report on the open forum organized at Bangkok is presented in Appendix J.

Table 3.1: Percentage of population affected under different scenarios

City	2005				
	Degree of effect				
	No	Less	Moderate	High	Very high
B - P	17.4	72.9	0.0	9.7	0.0
B - C - P	98.7	0.6	0.7	0.0	0.0
Karachi	87.8	11.7	0.2	0.3	0.0
Matara	86.4	12.1	1.5	0.0	0.0
Bangkok	n.a.	n.a.	n.a.	n.a.	n.a.
Hue City	56.3	15.6	26.1	2.0	0.0
City	**2025**				
	Degree of effect				
	No	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	98.7	0.5	0.8	0.0	0.0
Karachi	87.5	12.0	0.2	0.2	0.1
Matara	n.a.	n.a.	n.a.	n.a.	n.a.
Bangkok	56.5	40.4	1.0	2.1	0.0
Hue City	n.a.	n.a.	n.a.	n.a.	n.a.
City	**2050**				
	Degree of effect				
	No	Less	Moderate	High	Very high
B - P	17.4	72.9	0.0	9.7	0.0
B - C - P	74.3	22.3	3.4	0.0	0.0
Karachi	87.4	11.5	0.8	0.2	0.1
Matara	85.6	13.4	1.0	0.0	0.0
Bangkok	56.2	40.6	1.3	1.9	0.0
Hue City	52.9	14.6	27.5	5.0	0.0
City	**2075**				
	Degree of effect				
	No	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	N/A
B - C - P	73.0	24.4	2.6	0.0	0.0
Karachi	87.2	11.5	0.9	0.2	0.2
Matara	n.a.	n.a.	n.a.	n.a.	N/A
Bangkok	52.0	44.2	2.0	1.8	0.0
Hue City	53.2	14.1	26.4	6.3	0.0
City	**2100**				
	Degree of effect				
	No	Less	Moderate	High	Very high
B - P	19.3	0.0	69.5	11.2	0.0
B - C - P	72.8	24.7	2.5	0.0	0.0
Karachi	87.0	9.7	1.8	1.2	0.3
Matara	86.1	13.0	0.9	0.0	0.0
Bangkok	43.6	51.9	2.6	1.9	0.0
Hue City	54.5	12.6	24.5	8.4	0.0

B-P: Barisal – Pathukhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

The criteria for degree of effect (No effect, Less effect etc.) are country specific, and are described in country case study reports in Appendices B to G.

Table 3.2: Percentage of buildings affected under different scenarios

City	No	Less	Moderate	High	Very high
	2005				
	Degree of effect				
City	*No*	*Less*	*Moderate*	*High*	*Very high*
B - P	*17.4*	*72.9*	*0.0*	*9.7*	*0.0*
B - C - P	*98.7*	*0.6*	*0.7*	*0.0*	*0.0*
Karachi	*87.9*	*11.8*	*0.3*	*0.0*	*0.0*
Matara	*81.7*	*15.9*	*0.5*	*1.9*	*0.0*
Bangkok	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Hue City	*56.2*	*15.6*	*26.2*	*2.0*	*0.0*
	2025				
	Degree of effect				
City	*No*	*Less*	*Moderate*	*High*	*Very high*
B - P	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
B - C - P	*98.7*	*0.5*	*0.8*	*0.0*	*0.0*
Karachi	*87.6*	*11.9*	*0.4*	*0.1*	*0.0*
Matara	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Bangkok	*23.4*	*71.5*	*5.1*	*0.0*	*0.0*
Hue City	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
	2050				
	Degree of effect				
City	*No*	*Less*	*Moderate*	*High*	*Very high*
B - P	*17.4*	*72.9*	*0.0*	*9.7*	*0.0*
B - C - P	*74.3*	*22.3*	*3.4*	*0.0*	*0.0*
Karachi	*87.3*	*11.9*	*0.7*	*0.1*	*0.0*
Matara	*81.5*	*16.1*	*0.5*	*1.9*	*0.0*
Bangkok	*18.4*	*76.5*	*5.1*	*0.0*	*0.0*
Hue City	*52.9*	*14.6*	*27.5*	*5.0*	*0.0*
	2075				
	Degree of effect				
City	*No*	*Less*	*Moderate*	*High*	*Very high*
B - P	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
B - C - P	*73.0*	*24.4*	*2.6*		*0.0*
Karachi	*86.9*	*12.4*	*0.5*	*0.2*	*0.0*
Matara	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Bangkok	*11.5*	*83.1*	*5.4*	*0.0*	*0.0*
Hue City	*53.2*	*14.1*	*26.4*	*6.3*	*0.0*
	2100				
	Degree of effect				
City	*No*	*Less*	*Moderate*	*High*	*Very high*
B - P	*17.2*	*0.0*	*72.9*	*9.9*	*0.0*
B - C - P	*72.8*	*24.7*	*2.5*	*0.0*	*0.0*
Karachi	*87.0*	*11.5*	*1.2*	*0.3*	*0.0*
Matara	*81.6*	*16.0*	*0.5*	*1.9*	*0.0*
Bangkok	*3.1*	*91.3*	*5.6*	*0.0*	*0.0*
Hue City	*54.5*	*12.6*	*24.5*	*8.4*	*0.0*

B-P: Barisal – Pathukhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

The criteria for degree of effect (No effect, Less effect etc.) are country specific, and are described in country case study reports in Appendices B to G.

Table 3.3: Percentage of roadway affected under different scenarios

City	2005				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	0.0	94.6	0.0	5.4	0.0
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	n.a.	n.a.	n.a.	n.a.	n.a.
Hue City	100.0	0.0	0.0	0.0	0.0
City	**2025**				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	90.0	10.0	0.0	0.0	0.0
Karachi	97.1	1.0	1.6	0.3	0.0
Matara	n.a.	n.a.	n.a.	n.a.	n.a.
Bangkok	99.9	0.0	0.1	0.0	0.0
Hue City	n.a.	n.a.	n.a.	n.a.	n.a.
City	**2050**				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	0.0	94.6	0.0	5.4	0.0
B - C - P	56.9	39.3	3.8	0.0	0.0
Karachi	94.5	3.9	1.3	0.3	0.0
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0
City	**2075**				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	24.3	54.7	12.0	9.0	0.0
Karachi	91.3	5.8	1.6	1.3	0.0
Matara	n.a.	n.a.	n.a.	n.a.	n.a.
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0
City	**2100**				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	0.0	0.0	94.6	5.4	0.0
B - C - P	25.8	56.8	10.1	7.3	0.0
Karachi	75.3	13.8	7.4	1.6	1.9
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0

B-P: Barisal – Pathukhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

The criteria for degree of effect (No effect, Less effect etc.) are country specific, and are described in country case study reports in Appendices B to G.

Table 3.4: Percentage of railway affected under different scenarios

City	2005				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	n.a.	n.a.	n.a.	n.a.	n.a.
Hue City	100.0	0.0	0.0	0.0	0.0
City	2025				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	n.a.	n.a.	n.a.	n.a.	n.a.
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	n.a.	n.a.	n.a.	n.a.	n.a.
City	2050				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0
City	2075				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	n.a.	n.a.	n.a.	n.a.	n.a.
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0
City	2100				
	Degree of effect				
	No affect	Less	Moderate	High	Very high
B - P	n.a.	n.a.	n.a.	n.a.	n.a.
B - C - P	100.0	0.0	0.0	0.0	0.0
Karachi	100.0	0.0	0.0	0.0	0.0
Matara	100.0	0.0	0.0	0.0	0.0
Bangkok	99.9	0.1	0.0	0.0	0.0
Hue City	100.0	0.0	0.0	0.0	0.0

B-P: Barisal – Pathukhali (Bangladesh); B-C-P: Bhubaneswar – Cuttack – Puri (India).

The criteria for degree of effect (No effect, Less effect etc.) are country specific, and are described in country case study reports in Appendices B to G.

4.0 Conclusions

The aims of the project were to model the changes in flooding characteristics in large coastal cities in South and Southeast Asia under climate change conditions and assess its socio-economic impacts including vulnerability for providing a basis for formulating suitable policies to cope up with the climate change conditions. The project involved contributions from six countries of South and Southeast Asia: Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam. Detailed datasets of hydrologic characteristics, urban development, and socio-economic situation of the six areas covered by the project were gathered and a comprehensive GIS database was developed. Simulations were carried out for present climatic conditions and scenarios of climate change conditions in 2025, 2050, 2075 and 2100 using urban flood risk analysis tools. The socio-economic impacts of the urban flooding due to climate change were analyzed on population, residential buildings and transportation networks based on the simulated results. In case of population, Barisal and Patuakhali Cites in Bangladesh seem most affected by urban flooding compared to other project study areas. About 70% of the population will be moderately affected and 11% highly affected according to the projected 2100 scenario. The people in Bangkok and Hue City will be also affected by the projected future flood scenarios due to climate change but to lesser extent. In terms of number of buildings, again Barisal and Patuakhali Cities in Bangladesh and Bangkok are significantly affected by urban flooding. About 83% of total buildings will be moderately and highly affected in Barisal and Patuakhlai. In Bangkok, almost 90% buildings will be in the category of less affected by flooding under the projected 2100 scenario. In terms of road network, Barisal and Patuakhali Cites in Bangladesh seem most vulnerable to urban flooding compared to other project study areas. Almost 95% of the road system will be moderately and 5% highly affected in these cities in the projected 2100 scenario. The analysis reveals that railway network is the least affected component of the socio-economic factors considered in the project under the present and future climate change scenarios.

The review of existing policies and strategies in the involved countries reveals that polices relating to the flood mitigation and disaster management do exist in all the countries but the issue of climate change impact is not considered while formulating those policies, except Bangladesh where the issue has been included in some of the relevant policies.

The project could develop strong networking among the researchers and policy makers from the six participating countries. It is expected that this networking may emerge as partnership for further work on climate change and variability; its impacts and adaptation. The capacities of several individuals and institutions were developed through the project and the project could raise the awareness among the stakeholders through organization of a symposium and open forum, where case study results were presented and discussed. Distribution of posters depicting climate change and its impacts and case study results further added to the awareness raising of the stakeholders and public at large.

5.0 Future Directions

The detailed country specific recommendations are made in the country case study reports presented in Appendices. The following recommendations were made during the brainstorming session of the workshop of this project:

Bangladesh

- There is a need for more understanding of social and policy processes such that the future study should emphasize on this issue.
- The results of the case study should be disseminated to the concerned individuals and agencies in the study areas, although it was pointed out that this is already in the project agenda.
- There is a need for the incorporation of coastal city issues in the broader Integrated Coastal Zone Management (ICZM) approach, and external factors (climate change) and their impacts should be the responsibility of one organization/agency.

India

- The flood mitigation and management policies must be different from disaster management policy, such that it has its own identity, and hence, its own resources.

Pakistan

- The Sindh Katchi Abadis (unauthorized dwelling) Act (1992) pertains to zoning and construction of building type only. The Katchi Abadis Act should be extended to other building areas.
- Furthermore, climate change impacts should be addressed, and the Coastal Development Authority Act should incorporate climate change impacts.

Sri Lanka

- There should be a single authority to coordinate other agencies because there are currently several organizations responsible for flood mitigation/control in the country. The Disaster Management Center may be such authority.
- There should be a clear demarcation of the roles and responsibilities of different authorities with respect to flood mitigation.
- The policies must consider alternative solutions and livelihood options for disadvantaged groups.

Thailand

- The existing policies should be revisited and updated to incorporate climate change and its impacts, mitigation and adaptation measures.
- There should be the revision of obsolete policies; promotion of regional cooperation; enhancement of technology transfer; and involvement of non-governmental organizations in capacity building.

Vietnam

- There is a need for improved/better forecasts for hydrologic parameters, closer cooperation among different agencies involved, database and knowledge management, community participation, and operation and maintenance of existing infrastructure in urban areas.

Based on the major recommendations derived from the project, one of the potential future scientific research is to expand the studies to other major coastal cities of the region for comprehensive analysis of possible impacts of climate changes including extreme events and sea level rise. The further research should consider other related issues of impacts of sea level rise to coastal environment, ecosystem, tourism and other coastal industries by involving various stakeholders. Based on the outcomes of the impact studies, adaptation and mitigation strategies and policies should be developed for different sectors of economy and society. It is also highly recommended that a high-level meeting in each of the countries involving policy makers and stakeholders is organized to discuss the outcomes of the specific case study and the recommendations of the project to initiate the process of formulating suitable policies and strategies to deal with climate change impacts.

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Appendices

Appendix A: Tools for analysis

Appendix A: Tools for analysis

For the case study analyses for different kinds of mathematical tools have been used. The tools are; 1) IISDHM (Institute of Industrial Science Distributed Hydrological Model), 2) PWRI Hydrodynamic Model, 3) AGENT-LUC Model and 4) Methodology for developing socio-economic impact indices. The first two tools were used for flood inundation modeling, of which IISDHM being used in the case of converging river network and PWRI for diverging river network. The third model was used for socio-economic projection under land use change conditions and the fourth one was used for assessment of socio-economic impacts of floods. Brief descriptions of these tools are presented in the following sections.

A.1 Institute of Industrial Science Distributed Hydrological Model

The Institute of Industrial Science Distributed Hydrological Model (IISDHM) is a physically based distributed hydrologic model based on physical governing equations that can be used to simulate movement of water in different components of hydrologic cycle in a river basin (Jha *et al.*, 1997). There are five major components of a distributed hydrologic model such as, i) Interception and Evapo-transpiration, ii) Surface flow, iii) River flow, iv) Subsurface flow and v) Ground water flow.

The surface and river components of the IISDHM, a physically based distributed hydrological model (Jha, et al, [6]), were used for flood inundation simulation. In this model, 1D Saint-Venant's equations of continuity and momentum equations (Eqs. 1 and 2) are used for river network flow simulation and 2D form of the equations for surface flow routing.

Mass conservation equation (continuity equation)

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

And the momentum equation;

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\left(\frac{\partial z}{\partial x}+S_f\right)=0 \tag{2}$$

Where, t = time; x = distance along the longitudinal axis of the water course; A = cross-sectional area; Q = discharge through A; q = lateral inflow or outflow distributed along the x-axis of the watercourse; g = gravity acceleration constant; z = water surface level with reference to datum; and Sf = friction slope.

The governing equations for 2D gradually varied unsteady flow can be derived from conservation of mass and momentum equations. Overland flow equations are the 2D expansion of 1D open channel flow Saint-Venant`s equations, which are written as:

Mass conservation equation (continuity equation):

$$\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}+\frac{\partial h}{\partial t}=q \tag{3}$$

Momentum Equations;
In X-direction:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g(\frac{\partial Z}{\partial x}+S_{fx})=0 \tag{4}$$

In Y-direction:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g(\frac{\partial Z}{\partial y}+S_{fy})=0 \tag{5}$$

Where, u and v are velocities of flow in X- and Y-directions, and Sfx and Sfy are friction slopes in X- and Y-directions.

Diffusive approximations of the 1D and 2D Saint-Venant's equations are used river and surface flow routing by solving implicitly using finite difference schemes with a uniform network of square grids.

The exchange of flow between the channel network and flood plains is simulated using the floodplain compartment concept. The floodplain compartments are surface grids along the river channels, which are considered as boundary conditions in overland flow routing. Flow transfer between floodplain compartment and river is assumed to occur along Δx reaches which adjoin the river and floodplain compartments; this flow is assumed to be broad-crested weir with submergence correction. Flow can be either away from the river or into the river, depending on the relative water surface elevations of the river and the floodplain compartment. The river elevations are computed using 1D diffusive wave model solution for channel network and the floodplain elevations are computed by 2D diffusive wave model for overland flow. The exchange of flow between flood compartment and river reach in time step Δt is computed by a simple storage routing relation, i.e.,

$$V_l^{t+1}=V_l^{t}+(I^{t+1}-O^{t+1})\Delta t \tag{6}$$

In which, Vl = volume of water in the floodplain compartment at time t+1 or t depending on the water elevation, I = inflow from the river grids to adjacent floodplain compartments, and O = outflow from the floodplain compartments to adjacent river grids (Dutta, et al., 1997).

A.2 PWRI Hydrodynamic Model

The Public Work Research Institute (PWRI) hydrodynamic model is an unsteady river-surface flow model combining 1-D and 2-D flow equations using an explicit solution scheme to reproduce the flood inundation on the floodplain (Yoshimoto et al., 1992). The model has major two components – river flow component and surface flow part, and the main characteristic of the model is the link between unsteady calculation in river channel and calculation of flow on the floodplain. The relation between stage in river channel and height of levee decides the points and scale of flood levee failure with unsteady calculation in river channel. Explicit solution scheme for calculation of water level and discharge in river and flood plain as well. The outline of the model is shown in Figure 1.

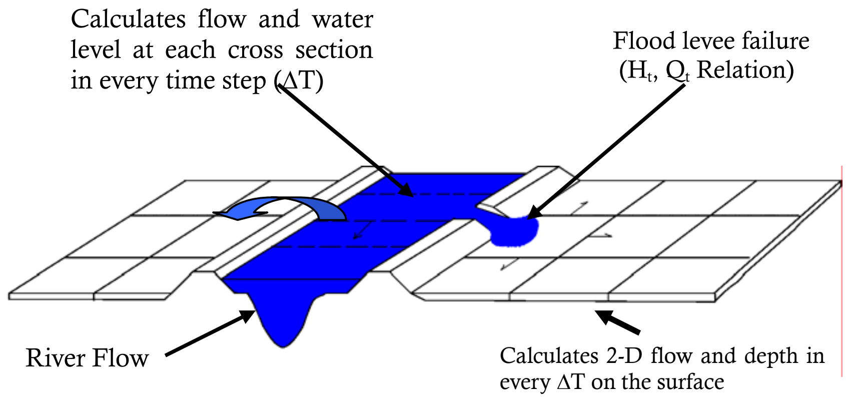

Figure 1: Outline of the model

Governing Equations in Hydrodynamic Model

The surface and river flow component of the surface and river flow model (SRFM), a physically based distributed hydrological model and socio-economic impact assessment utilizing qualitative simulation of flood hazard parameters and qualitative impact indices were used in this study.

The flood simulation model, SRFM simulates the impacts of sea level rising on flooding characteristics. In the model, the unsteady equations for one and two dimensional flows are derived from Saint-Venant's continuity and momentum equations. For river flow component, the finite difference equation for one dimensional channel flow is solved in every grid of the channel for water level and discharge. The model uses explicit solution scheme for river flow calculation. The form of momentum equation is as follows (Dutta et al., 2004).

$$A\frac{dQ}{dt}+Q^2\frac{d\beta}{dx}-2\beta Q\frac{dA}{dt}-\frac{\beta Q^2}{A}\frac{dA}{dx}+gA^2\frac{dH}{dx}+\frac{A}{\rho}T_r=0 \qquad (7)$$

$$T_r=\rho g A\frac{Q^2}{[\sum\frac{A}{n}R^{2/3}]^2}$$

where, A = cross-section area of river; Q = river discharge; Tr = river bottom shear; H = water level; and R = hydraulic radius.

For overland flow component, fundamental equations of two dimensional unsteady flows are constructed from continuity equation and equation of motion. Equation 8 represents the continuity equation and equations 9 and 10 represent the equation of motion in X and Y directions respectively (Dutta *et al.*, 2004).

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \qquad (8)$$

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y}+gh\frac{\partial H}{\partial x}+\frac{1}{\rho}\tau_x(b)=0 \qquad (9)$$

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y}+gh\frac{\partial H}{\partial y}+\frac{1}{\rho}\tau_y(b)=0 \qquad (10)$$

where, H = water level above msl; h = depth of water; u = flow velocity in X direction; v = flow velocity in Y direction; g = gravitational acceleration; ρ = density of water; M = discharge flux in X direction (M = uh); N = discharge flux in Y direction (N = vh); $\tau_x(b)$ = bottom shear stress in X direction; $\tau_y(b)$ = bottom shear stress in y direction.

The bottom shear stress can be calculated using Manning roughness coefficient.

$$\tau_x(b) = \frac{\rho g n^2 \bar{u}\sqrt{u^2 + v^2}}{h^{1/3}}$$

$$\tau_t(b) = \frac{\rho g n^2 \bar{v}\sqrt{u^2 + v^2}}{h^{1/3}}$$

where, $\bar{u}$, $\bar{v}$ = average velocity of present time step and before time step (steady calculation)

A square grid system is adopted to simulate the surface flood inundation. For flow interaction between unsteady calculation in river channel and calculation of flood in river basin a link is established between these two components. The relationship between stages in river channel and heights of levee decides the points and scale of flood levee overflow with unsteady calculation in a river channel.

A.3 AGENT-LUC Model

Socio-economic projections under land use change conditions are computed using Anthropogenically Engineered Transformations of Land Use and Land Cover (AGENT-LUC) Model, developed by Rajan and Shibasaki (2000). This model is a national scale, integrated, dynamic time-series simulation model for assessing the land use and land cover changes as result of the human activities. The overall framework of the model is shown in Figure 2. It consists of four models: the biophysical crop yield model, the rural income model, the urban land use model and the agent decision model; and a sub-model for migration. All these models and the sub-model interact and have feedback loops, to determine the new course of action by the agent at the next time step. The model structure is sequential. The biophysical crop yield model calculates the potential productivity of the land unit for the given conditions of soil, topography, water availability and climatic parameters. The distribution of water availability takes into account the soil conditions, amount of rain-received, and the existence of irrigation facilities. The main assumption of this model is that there is a strong linkage between the climate and crop distributions (Leemans and Solomon, 1993). The crop yield estimates are derived by modifying the approach as described in the EPIC model (Sharpley and Williams, 1990). The central concept of this approach is the growing period and the photosynthetic efficiency of the crops. "The term agent refers to an individual or a group of individuals who exist in a given area (referred to as grid) and are capable of making decisions for themselves (or the given area). The agent also acts as an interface in helping to assimilate the broader macro-information into the decision-making process at the grid level, thereby creating an action in response to the natural and economic stimuli.'

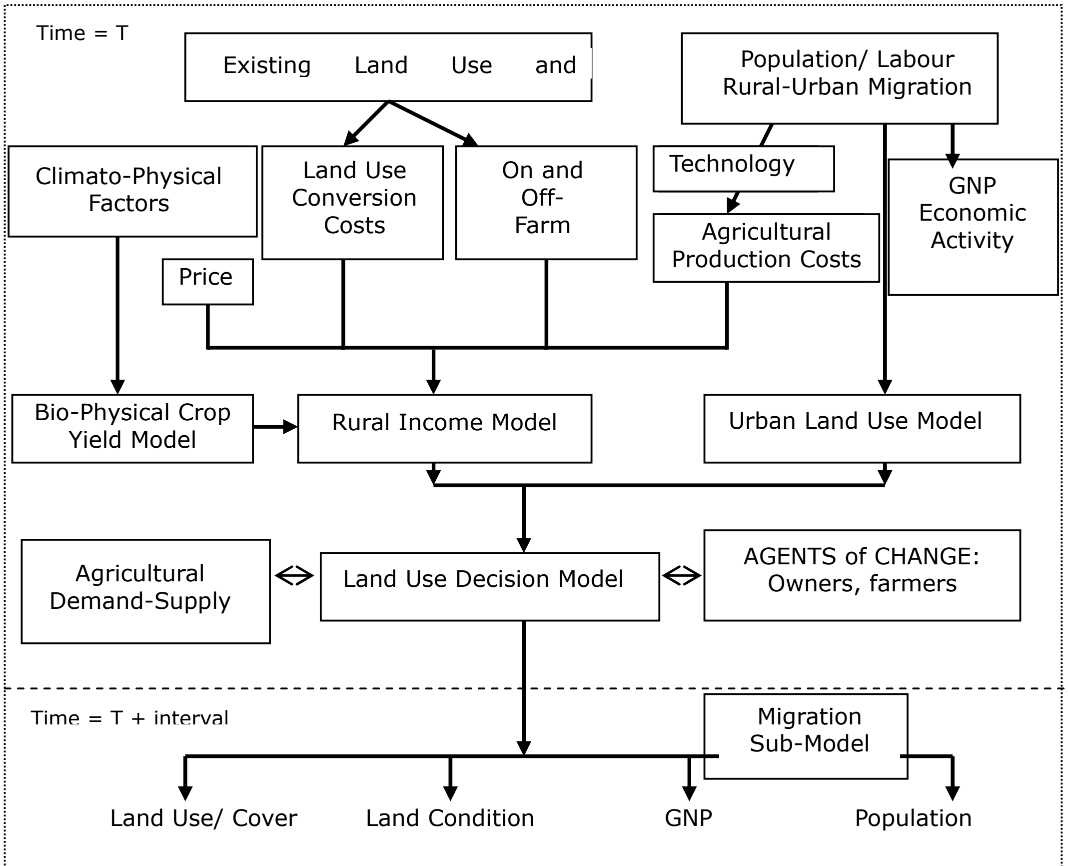

Figure 2: Framework of the AGENT-LUC model

The rural income model calculates the economic potential of the land unit, based on both the agricultural and non-agricultural revenues and expenditures. It also takes into account the accessibility, terrain conditions and current land use in calculating the costs. Urban land use is the other major land use that is primarily influenced by the activities of the human beings. The urban land requirement is estimated as it competes with the agricultural areas due to increasing population pressures and the rise in the economic levels of the region. The model takes into account the locational value – neighborhood and accessibility of the land unit in assessing the new areas that will be urbanized.

The final step in the simulation is the agent decision model, which uses the estimated income, urban land needs and the existing land use in the land unit under consideration as its input to predict the land use. The agent is the decision maker in this model, where the agent arrives at a decision taking into account the prevailing conditions in the respective grids. In addition to the economic factor, the demographic condition (age distribution and educational levels) and the land use history are considered to help in arriving at a reasonable estimate for the change in the land use patterns. In addition to the land use change decision, the model has a migration sub-model that simulates the changes in the population of each grid as consequence of the changes in the economic welfare and the demographic distribution that exists in the grid after the changes in the land use/cover patterns.

A.4 Socio-Economic Flood Impact Assessment

Socio-economic Impact Assessment here is the measurement of the potential loss from a flood event by assessing the vulnerability of population, buildings and infrastructure to this hazard. It identifies the characteristics and potential consequences of flood, how much of the community could be affected by it, and the impact on community assets.

The lack of an accepted method for carrying out assessments that could determine the socio-economic impact of floods has greatly limited the capacity to present a comprehensive picture in this study. Current assessment relies on the total number of people and buildings, and the length of roads affected by floods due to sea level rise.

The impact indices for different categories have been computed by conducting a questionnaire survey in six participating countries, Bangladesh, India, Pakistan, Sri Lanka, Thailand and Vietnam. The responded are the project collaborators, experts in floods and students at the Asian Institute of Technology (AIT). The categories considered are: residential buildings, non-residential buildings, roads, railways, persons less than 6 years, persons between 6 to 65 years, persons above 65 years, income less than 100 US$, income level from US$ 100 to 400 and income level above US$ 400. Classification criteria are also based on different impact indices.

In the present study five different flood hazard categories were selected. Four critical values of flood depths (0.1, 0.6, 1.0 and 3.5 m) were used to categorize the flood hazard. Based on the depth of flood, hazard intensity is assigned. The lower hazard intensity was assigned for lower depth and it indicates low hazard while greater hazard intensity indicates higher hazard. Typical hazard index values for different categories of flood depth are prepared. For the duration of flooding, again five different categories were used for the flood hazards. The categories are: less than 1 day, 1 to 2 days, 3 to 4 day, 5 to 7 days and more than 7 days. For this study and based on the flood duration, only duration category more than 7 days is considered for the six countries.

Impact indices were prepared based on the percentage of damage. The details of the impact indices for different depth category are given in Table 1.

Table 1: Impact indices for different damage category of floods

Percentage of damage	**Impact index**
0%	No impact
0-25%	Less impact
25-50%	Moderate impact
50-75%	High impact
75-100%	Highest impact

For the computation of impact on people, less than 25% damage indicates that there will be a minor health problem, if it is more than 25% but less than 50% then there will be major problem in health, less than 75% damage cause irretrievable illness. There will be a loss of life when the damage exceeds 75%.

To compute the flood impact on buildings, less than 25% damage means less damage to contents, structure and outside property, then if it exceeds the range but below 50% which indicates medium damage, less than 75% damage means high damage. There will be a severe damage if the percentage of damage is more than 75%.

For roads and railway, less than 25% damage indicates that there will be a transportation interruption for few hours, if it is more than 25% but less than 50% then there will be a minor road damage, less than 75% damage cause minor road damage and transportation interruption for few days. Severe to complete collapse of transportation system and need for rehabilitation of road and railway lines are needed when the damage exceeds 75%.

Based on the depth and duration of floods and depending on the percentage of damage impact indices are prepared. A sample based on questionnaire survey results is presented in Table 2.

Table 2: Flood impact assessment for a particular category

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Moderate
0.60-1.00	Less	Less	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	High	High	High
> 3.50	High	High	High	High	High

From the questionnaire survey in Bangladesh, it was found that the people with income less than US$ 100 are most vulnerable compared to high income group. Those who have income level more than US$ 400 are less affected. Residential buildings show higher vulnerability than non-residential buildings. For the impact on transportation, roads and railways both have the same effect. For different age group people, those with age less than 6 years and more than 65 years are much more vulnerable than others.

In case of India, residential buildings are more impacted than the non-residential buildings. For transportation, same degree of impact is found for both roads and railways. People with ages less than 6 years and more than 65 years have same impact and more vulnerable compared to the other age groups. Here again the impact is higher for people with less income. In comparison with Bangladesh, India shows higher impact on buildings and transportation but less impact on people with different age and income groups.

For Pakistan, both residential and non-residential buildings show same impact. Impact on roads is higher than in railways. Same as for other country, the most vulnerable age groups of people are those less than 6 years and more than 65 years. Less income people are more vulnerable as it restricts them to come out of their houses.

In Sri Lanka, same level of impact is found for both residential and non-residential buildings. People within age limit 6 to 65 years are less vulnerable compared to others. For transportation, the impact is same for roads and railway but the impact is higher even for a small depth of flood. Low income people have highest impact even for a flood depth of 10 cm.

In Thailand, the impact on residential buildings is higher than the non-residential buildings. Railway is more vulnerable than road network. The impact on people of all age groups is found same. People with less than US$ 100 are more vulnerable than those with higher income.

From the survey in Vietnam, the impact on residential building is higher than the non-residential buildings. Roads and railways show same impact except if the depth of flooding is higher than 3.5 m, in that case the roads show highest impact whereas it is higher in case of railways. Variation is found for different age group people, highest for those with age less than 6 years and than for age above 65 years. People within these two groups are less affected. Like all other countries, the lower income group people are highly affected in Vietnam.

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Appendix B: Bangladesh Case Study

Appendix B: Bangladesh Case Study

B.1 Coastal zones and floods in Bangladesh

B.1.1 Coastal zones

Bangladesh has a 710,000 m long coastal line and its coastal zone is formed by the estuarine sediments of the Ganges, Brahmaputra and Meghna rivers. Marked by a vast network of river systems, an ever dynamic estuary, a drainage path of a huge basin, and a saline waterfront penetrating inland from the sea it is complex tapestry of landscape. Its western part is a moribund delta (containing Sundarbans mangrove forests) while the middle part (the Meghna estuary area) is an active delta and the eastern part (Chittagong coast) is a stable landmass.

Administratively, the coastal zone includes 19 districts (comprising 147 sub-districts) out of total 64 districts of Bangladesh, and is full of diversity with respect to geo-physical characteristics and livelihoods (Fig 1) (PDO-ICZMP, 2003). Islam (2004) further divided 147 sub-districts into two groups – exposed coast and interior coasts. In addition to the coastal plains, there are a number of small islands that are subject to strong wind and tidal interactions throughout the year, and are inhabited by a large number of people. However, the sea area of the coastal zone is not demarcated. This zone may cover the whole of Extended Economic Zone (EEZ) of 70,000 km^2. Effective fishing areas for marine fish and shrimp have been estimated at about 10,000 Mm^2 and 5,000 Mm^2, respectively.

Demographically, 35 million people live in the coastal region representing 28 percent of the population of Bangladesh. Twenty per cent of the coastal population directly depends on the coastal and marine resources for their livelihood (BBS, 2003). They live exclusively on fishing of wild fish, along with crabs, prawns and shrimps. In addition, the mangrove ecosystem provides living support to nearly 300,000 coastal people through fishing, honey collection, wax and timber, and hunting.

The coastal zone is more dominated by agrarian economy compared to rest of the country, as agriculture's contribution to GDP is 29% compared to 26% nationally. On the other hand, the share of industrial sector is less (22%) compared to Bangladesh (25%). However, the coastal resource base allows other than agricultural activities, provides a significant and increasing contribution to the country's gross domestic product (GDP). These other sectors are inland and marine fisheries, shrimp and salt cultivation, forestry, ports, exports, export processing zones, ship-breaking industry and tourism; Livelihood of coastal people is largely dependent on these sectors.

Being located at the apex of the Bay of Bengal, the geo-morphological and other conditions which have been responsible for the structure of the coastal zone are:

- Topographic position
- Freshwater flushing
- Drainage lines
- Sedimentation
- Proximity to the sea
- Temperature
- Salinity
- Humidity
- Tidal periodicity
- Land use in upland watersheds

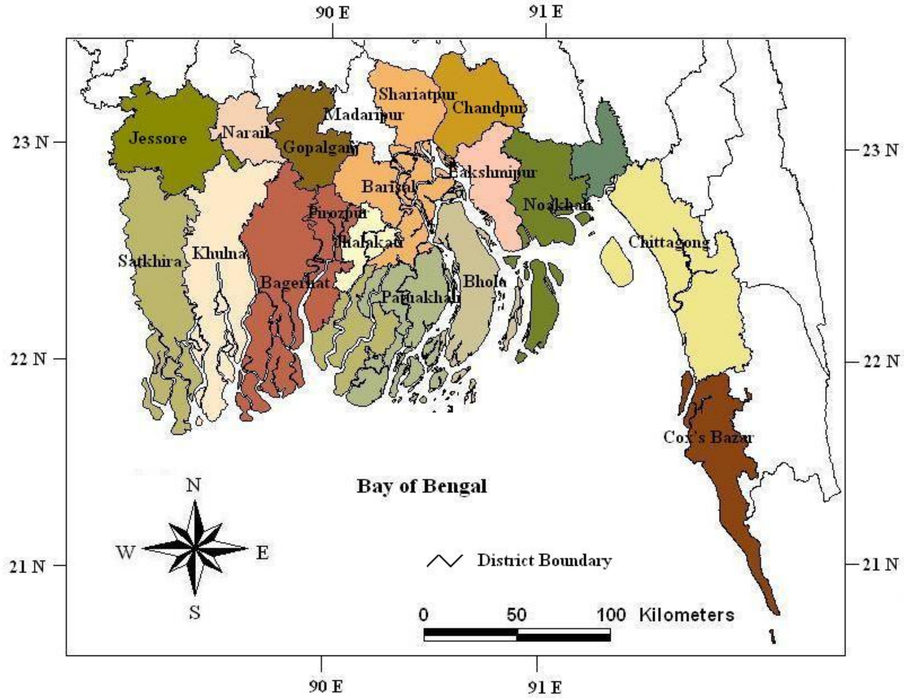

Figure 1: Coastal zone of Bangladesh

B.1.2 Floods

Floodplains of the major rivers, and their tributaries and distributaries cover around 80% of Bangladesh. As a result of very flat topography, 20% of the lands are inundated due to spilling of the rivers each year during the monsoon period (June-September). Rainfall of high intensity and long duration in the river catchments causes drainage congestion within the country due to inadequate conveyance capacity of the rivers and unfavorable tail water situation. The situation becomes severe when peak flow in the rivers synchronizes with high rainfall. The nation experiences around 37% inundation due to floods every 10 years. In 1988 and 1998 more than 60% land was inundated for about three months.

Of the four types of floods common in Bangladesh (rainfall flood, flash flood, monsoon flood and tidal flood) tidal and rainfall floods, are typical for the coastal zone and are generally associated with spring high tide, tidal and cyclonic storm surges. During extreme monsoon storms freshwater runoff from the big rivers, combined with wind and wave set-up caused by strong southern winds, raises the sea surface in the Bay of Bengal and the maximum water levels are higher than the predicted tides. This causes inland tidal flooding with saline tidal waters damaging the standing crops and infrastructure.

In September-October 2000, southwestern district of Satkhira experienced an unusual flooding over a prolonged period of time. Drainage capacities of regional rivers proved to be too low. Of the 23 rivers flowing through Satkhira district 7 are dead, 5 almost dead, 5 degraded and 6 partially degraded (Ahmad *et.al.*, 2001). Also in West Bengal, India the runoff was so high that the rivers could not drain out; this was further hindered by 5-day high tides in the Hoogly River. Backwater effects of the tides and the continuous rainfall increased the already huge runoff, which eventually found its way into Bangladesh. The same area experienced flood once again during July 2002 (The Independent, 11 July 2002).

B.2 Study area introduction

The study area lies between latitude 21°48' N to 23°15' N and longitude 89°45' E to 91°15' E in southern Bangladesh, with an area of 18,354 Mm^2, and is bound by the Ganges River in the north, the Gorai-Madhumati Rivers in the west, the Dakatia River in the east and the Bay of Bengal in the south (Fig. 2). The area covers 8 districts out of 19 districts in the coastal zone. These are: Barguna, Barisal, Bhola, Jhalokati, Lakhsipur, Noakhali, Patuakhali, and Pirojpur.

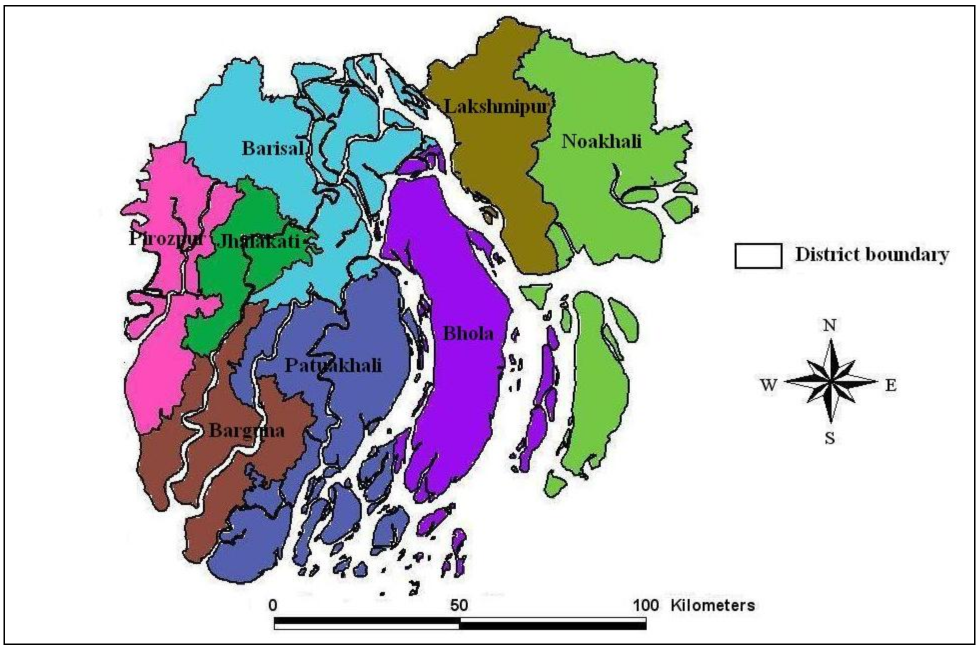

Figure 2: Study area districts

It has a area of 14,755 Mm^2 and its major rivers include: Lower Meghna, Swarupkati, Baleswar, Bishkhali, Buriswar, Ilisha and Tetulia. Table 1 provides a listing of the administrative districts in the coastal zone along with their key characteristics.

Table 1: Key characteristics of the districts in the study area

No.	Name of District	Area (10^6 m^2)	Population	Critical issues		
				Salinity	Tidal fluctuation	Cyclone risk
1	Barguna	1,832	837,955	Yes	yes	yes
2	Barisal	2,791	2,330,960	Yes	yes	
3	Bhola	3,403	1,676,600	Yes	yes	yes
4	Jhalokathi	758	696,055	Yes	yes	
5	Laksmipur	1,458	1,479,371	Yes	yes	yes
6	Patuakhali	3,205	1,444,340	Yes	yes	yes
7	Pirojpur	1,308	1,126,525	Yes	yes	
	Total	14,755	9,591,806			

B.2.1 Hydro meteorological characteristics

Annual rainfall increases from a little over 1,700 mm in the west to over 3,200 mm at Cox's Bazar in the east. Heavy rainfall is most frequent along the East Coast from Feni to Cox's Bazar. The average relative humidity in coastal stations throughout the year shows no specific trends across the coast. Low values are found during January-April and peak values (85-94%) during June-October. The evaporation exceeds rainfall only in the months December and January. In all other months there is an excess of rainfall. The highest excesses occur in the period May-October, and the lowest in February-April and in November.

Mean daily maximum and minimum temperatures, recorded over the period 1995-1999, ranges from 34 to 38 and 10-15 °C, respectively. Temperatures are highest in April and May, decrease slightly during the monsoon and rise slightly in September or October when the rain begins to diminish.

The hours of bright sunshine are few during the rainy period in coastal areas, since rain clouds predominate during that period. Fewest hours of bright sunshine (4.0) are recorded in July along the eastern coast (Cox's Bazar), and in June (3.0) in the western coastal areas (Barisal station). The greatest number of bright sunshine hours (10.0) occurs in January along the eastern coast, and in December (7.8) along the western coast. In the coastal zone wind blows mainly from two directions: NE and SE. The NE winds blow mainly in the winter season, and the SE winds during summer.

In the study area has average annual rainfall is around 1,700 mm (Khan, 2002). The major river system of the area - Lower Meghna - receive huge amount of water from the Ganges and Brahmaputra and cause flooding to adjacent areas. The land topography of this area is extremely flat. The land elevation in most of the part is 0 to 5 m above the mean sea level. The northern part is vulnerable to monsoon riverine floods while the southern part is vulnerable to storm surge floods. In the Bay of Bengal during the last 9,000 years, a maximum relative sea level rise rate of 3.65mm/yr has been estimated; the average rate for the Bengal basin, during the Holocene, was 1.07 mm/yr

B.2.2 Socio-economic characteristics

The region has a population of 9.59 million in 2001 (Rahman, 2004). Many large cities, business center, irrigation projects and educational institutions are situated in the area. Major part of the land is used for agricultural and livestock grazing throughout the year productions (Karim, 2000). Fishing is also a major activity, while large scale industrial activity has been constrained by the limited availability of saline-free process water. The eastern coastal plains are also used for salt production, and a few coastal islands are used for drying of fish. Another emerging industry is tourism, with major plans underway to boost the infrastructure to promote both international and domestic tourism.

B.2.3 Flood vulnerability and history

The low lying coastal zone in Bangladesh is located between the extensive drainage network of the Ganges-Brahmaputra-Meghna river system on one side, and tidal and cyclonic activity from the Bay of Bengal on the other. During the 1960s a series of costal embankments were constructed to protect low lying lands from tidal inundation and salinity penetration. Many of these lands have now become high productivity agricultural areas and are valued considerably more than lands outside the embankments. The same coastal embankments paradoxically also tend to block efficient drainage of freshwater on the other (land) side at times of excess rainfall and riverine flooding.

The situation is complicated further under climate change condition. Several factors including enhanced glacier melt in the Himalayas, the possibility of enhanced monsoon precipitation, and the possibility of an increase in intensity of cyclones are likely to contribute to increased (freshwater) flood risk that could be further exacerbated in areas with coastal embankments. At the same time, sea level rise and potentially higher storm surges would result in over-topping of saline water behind the embankments. In other words, climate change could be a double jeopardy for coastal flooding, particularly in areas that are currently protected by embankments and therefore highly valued and home to productive economic activity. Outside the embankment areas, low lying lands will continue to be inundated in any case. But the magnitude and extent of inundation will likely be increased with climate change. Increased sea levels under climate change would also result in saline intrusion further upstream into the river system, which would increase the backwater effect. The whole process is likely to lead to enhanced sedimentation and gradually declining river gradients, increased drainage congestion and increased flood risks for coastal areas (Huq, 2002).

B.2.4 Existing flood disaster mitigation measures

Bangladesh employs coastal embankment towards management of coastal flooding, particularly when it is caused by high tides and storm surges (Fig. 3). However, inadequate drainage infrastructure along an embankment can be counter-productive, and could interact with several aspects of climate change to produce a cascade of adverse consequences. In fact flow regulators incorporated in the design of existing embankments were not built as per design. In other cases, even if the regulators were built, they lacked proper maintenance and consequently failed to serve their intended purpose. The failure of regulators in polders located in the western coastal region has caused saline flooding for over a decade. Therefore building of new drainage regulators along coastal embankments needs to be complemented by an assessment of the need for refurbishing existing regulators, followed by their periodic monitoring and maintenance.

The participation of local communities would be critical for the effective monitoring and maintenance of coastal embankments and flow regulators. The National Water Policy, NWPo (MOWR, 1999) has given a clear mandate for the formation of associations of water users and water managers, and the participation of these local level organizations at all levels of planning and execution of projects, and more importantly, allowing them to take part in operations and maintenance activities. Another coastal flood mitigation measure is enhancement of the drainage and/or conveyance capacity of the coastal rivers. This involves excavation/dredging of silting rivers to unclog their waterways. Controlled flooding to enhance sedimentation and thereby raise the floodplain further upstream is another adaptation measure that has been found to enhance drainage by increasing the flow gradient. Popularly known as the tidal basin concept, this measure has already been tested under the Khulna-Jessore Drainage Rehabilitation Project. Post project appraisals have concluded that this ‘tidal basin’ concept has been accepted by local population.

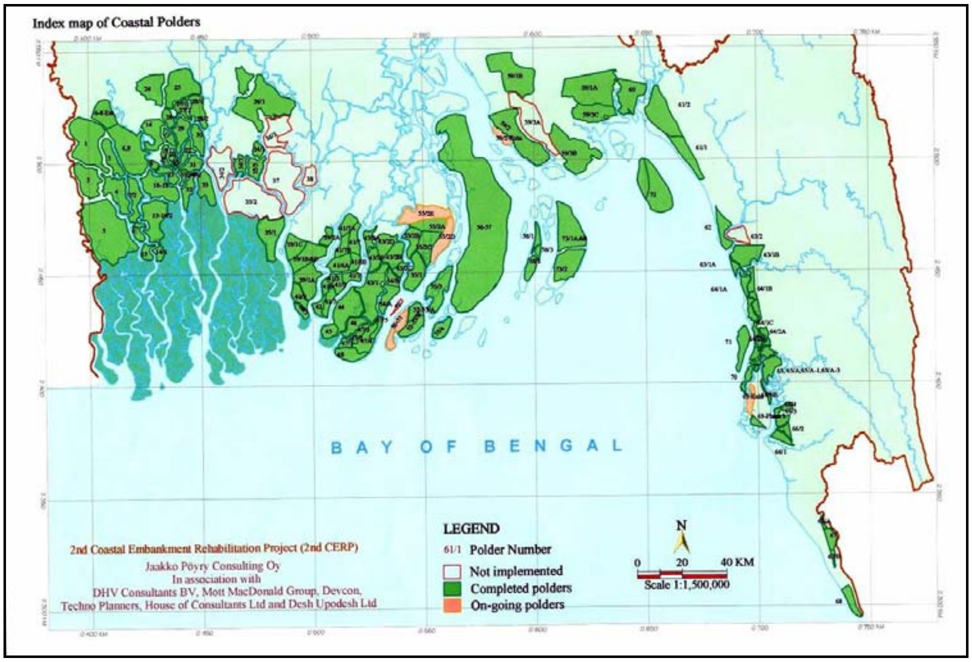

Figure 3: Map of coastal polders

Finally, effective early disaster warning and response in Bangladesh has evolved considerably during the last two decades. The directives given by the Standing Order on Disasters (DMB, 1999) stresses on continuous monitoring of the formation of cyclones in the Bay of Bengal involving satellite-based technology; monitoring the gradual development and track of imminent cyclone; issuance of cyclone warning well ahead of time for the people to take precautionary measures; evacuation from homesteads and relocation in multi-purpose cyclone shelters and concrete buildings. Already such measures have allowed thousands of coastal people to successfully avoid loss of lives during two high intensity cyclonic events: one occurring in 1994 and the other in 1997.

B.2.5 Existing flood risk management policies

Poverty Reduction Strategy Paper (PRSP, 2004) of the Government of Bangladesh (GoB) encapsulates the Government's current policy, strategy and plan for the country's future development. As such, it provides the most currently available comprehensive document setting out the totality of GoB's development plans including management policies to manage flood risk. Apart from PRSP, Bangladesh has put in place a number of sectoral policies and plans that bear upon its ability to cope with current risk of flood, and to some extent the additional risks posed by climate change.

In the context of this study, the following policies and plans that have been published have been consulted and the related inferences drawn for flood risk management.

- Poverty Reduction Strategy Paper (2004)
- National Water Policy (1999)
- National Water Management Plan (2004)

- National Environmental Management Action Plan (1995)
- National Land Use Policy (draft, 1995)
- National Forestry Policy (1994)

Poverty Reduction Strategy Paper (PRSP)

PRSP recognizes the direct links between poverty and vulnerability to natural hazards including floods:

"Given the risk and vulnerability to natural hazards that are likely to continue as a serious threat to national development efforts, macro level policies for disaster risk reduction, mitigation and management must be adopted in view of alleviating disaster-induced poverty".

It notes that the incidence of disasters is likely to increase rather than decrease, particularly due to global climate change. The PRSP proposes a comprehensive and anticipatory approach to reduce Bangladesh's vulnerability. Government in conjunction with Five-Year Strategic Plan for the Comprehensive Disaster Management Programme (2004-2008) envisages:

"...to bring a paradigm shift in disaster management from conventional response and relief practices to a more comprehensive risk reduction culture. The Plan incorporates programmes to strengthen the capacity of the Bangladesh disaster management system in order to reduce unacceptable risk and improve response and recovery management at all levels."

National Water Policy (NWPo)

NWPo recognizes climate change induced flood as one of the factors determining future water supply and demand. The summary section on agriculture and water management states that:

"…..in undertaking these works the potential impacts of climate change and sea- level rise will be factored in".

In relation to the flooding in the coastal zone it is observed that given the breadth of estimates of net sea level rise of 4.5~23 cm in 2025 and 6.5~44 cm by 2050 it is difficult to predict with certainty the impact of climate change induced flooding. Also, the policy is cautious, like the PRSP, about structural interventions to mitigate flooding and emphasizes thorough investigation of important flood control and management issues, such as the efficacy of coastal polders, for guiding future policy on structural interventions.

National Water Management Plan (NWMP)

The NWMP, that looks at implementation and investment responses to address the critical priorities identified in the NWPo, states:

"...the situation is further complicated by an observed trend of increased tidal amplitude associated with reduction of tidal flows due to empolderment in the South West Region. By 1995, the tidal range had increased to about 3.0 m from about 1.8 m in 1960. It is improbable that a new equilibrium has been reached, and the tidal range is expected to continue to increase. The combined effect of both sea level rise and increased tidal range will have a substantial impact over much of the coastal area".

There is thus considerable internalization of climate change induced flooding risks within this document which is expected to guide the implementation of the NWPo. Some examples of priorities that are synergistic with adaptation responses include:

(i) the recommendation in NWPo to develop "early warning and flood-proofing systems to manage the (alternating cycles) of flood and drought";

(ii) the NWPo recommendation for "comprehensive development and management of the main rivers through a system of barrages", which the NWMP has followed up with a plan to construct a barrage on the Ganges to help sustain dry season flows and regulate monsoon flooding. This may enhance their resilience under climate change and sea level rise.

National Environmental Management Action Plan (NEMAP)

NEMAP published in 1995 add a cautionary note on the environmental damages that may result from structural flood control measures – which might highlight some conflicts with structural adaptation responses (such as the construction of barrages) highlighted under the NWPo.

National Land Use Policy (NLUPo) and National Forestry Policy (NFoPo)

NLUPo aims to bring 25% of the land under forest cover and highlights mangrove plantations in char lands, and coastal green belts more generally as a priority. These priorities of NLUPo are also echoed in the National Forest Policy (NFoPo) revised in 1994 – although the goal of NFoP is to bring 20% (as opposed to 25% in NLUPo) of the total land under forest cover. Forest conservation priorities in NFoPo and NLUPo would be a good "no-regrets" adaptation response to reduce the vulnerability of the coastline to cyclones and storm surges, both under existing conditions as well as under climate change.

Consultation of those national policies that has bearing on flood risk management it is found that current thinking on vulnerability to flood disaster is being integrated, at a slow pace, into national and donor planning documents. A significant shift is from a focus on flood control to flood proofing, that is, to a less interventionist stance that takes into account livelihood strategies of the affected population. Floods are also being viewed as part of the development continuum, rather than as discrete geographical events.

B.3 Development of GIS database

The GIS database of the study area contains:

Digital elevation model – 1km resolution obtained from USGS (Fig. 4)
Land use pattern – obtained from USGS (Fig. 5)

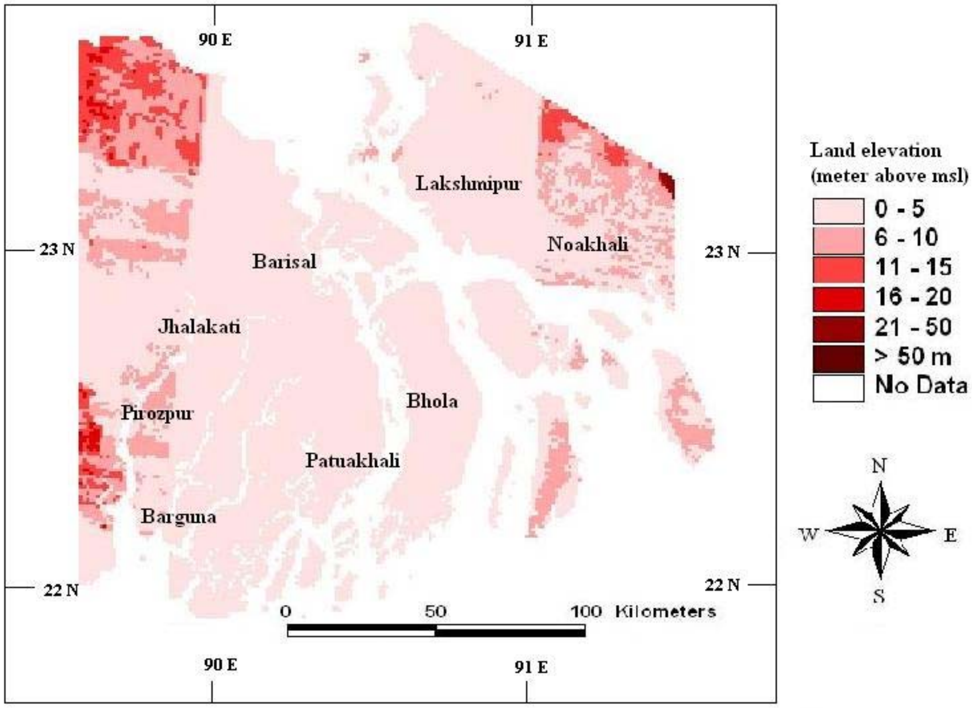

Figure 4.: Digital Elevation Model of the southern part of Bangladesh in 1000m resolution extracted from Hydro1k DEM

The digital elevation model is taken originally from Hydro1k DEM, which is 1km resolution. HYDRO1k is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets derived from the USGS 30 arc-second digital elevation model of the world (GTOPO30). For the land use type, most of the area is found as irrigated land. Grassland covers a large part of the study area. And in the west side of the study area there is some forest area. The detail of the land use map is shown in Fig.5. The rainfall data is collected for 20 rainfall stations inside the study area from the Institute of Water Modeling and Bangladesh Meteorological Department. From those observed data, the spatial distribution of rainfall data is generated.

For the population distribution, the present population data is collected from Barisal City Corporation and the Patuakhali Municipality. The information on population for the past year and for the trend of population increase is taken from the Bangladesh Bureau of Statistics. The availability of population is from 1911 to 2001. Based on the past data and using Gibb's method the present population is projected for the future scenario.

The river system in the area is very complex. The major river system is the Lower Meghna with all of its tributaries. For the simplicity of the model, only 5 channels are considered including Lower Meghna River.

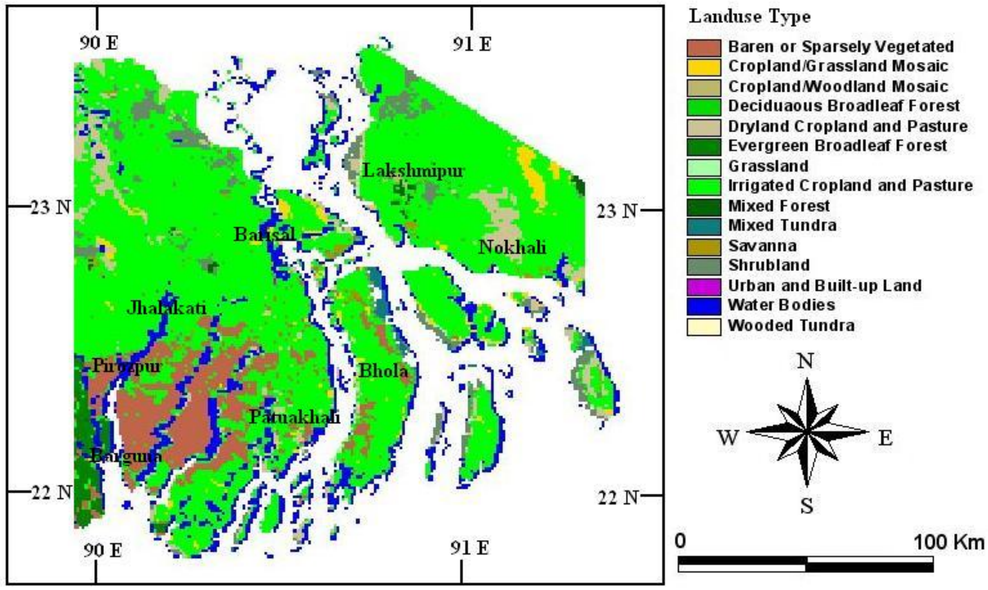

Figure 5: Land use map of the southern part of Bangladesh (Source: USGS)

B.4 Modeling flood characteristics under climate change condition

A one-dimensional Surface River Flow Model (SRFM) has been used to assess flood situation under climate change condition. The study area is first discretized into square grids. The total number of grids is 30,162 with 1km resolution. For river network, only Lower Meghna and its tributaries are considered. The daily discharge at Chandpur is used as upstream boundary and the daily water level data at Chitalkhali, Chardoani, Patherghata, Chotobogi and Dasmunia are used as downstream boundaries (Fig 6). Daily rainfall at 20 gauging stations is used as internal runoff. No lateral overland flow is considered. Existing polders were not incorporated. The unsteady equations are derived from continuity and momentum equations for one dimensional as well as two dimensional flows. For river flow component, the finite difference equation for one dimensional channel flow is solved in every grid of the channel for water level and discharge. The model uses explicit solution scheme for river flow calculation (Dutta *et.al.* 2004).

The flood depths at different locations are calculated using the flood level data and the digital elevation model. The area of flooding under each depth category is computed using Arc View GIS. The flooded area in 1988 is shown in Fig. 7. It is found that major part of the study area was under flood depth category 0.6 to 1.0m. Highest flood level was 3.5m. The results also indicate that the rate of rise in water level is slow, so that the flood water can spread over large area with time and consequently the water level does not increase too much. The higher flooding areas are located in between the Bishkhali and the Tetulia River. This is due to continuous flow from both of the rivers and low land elevation.

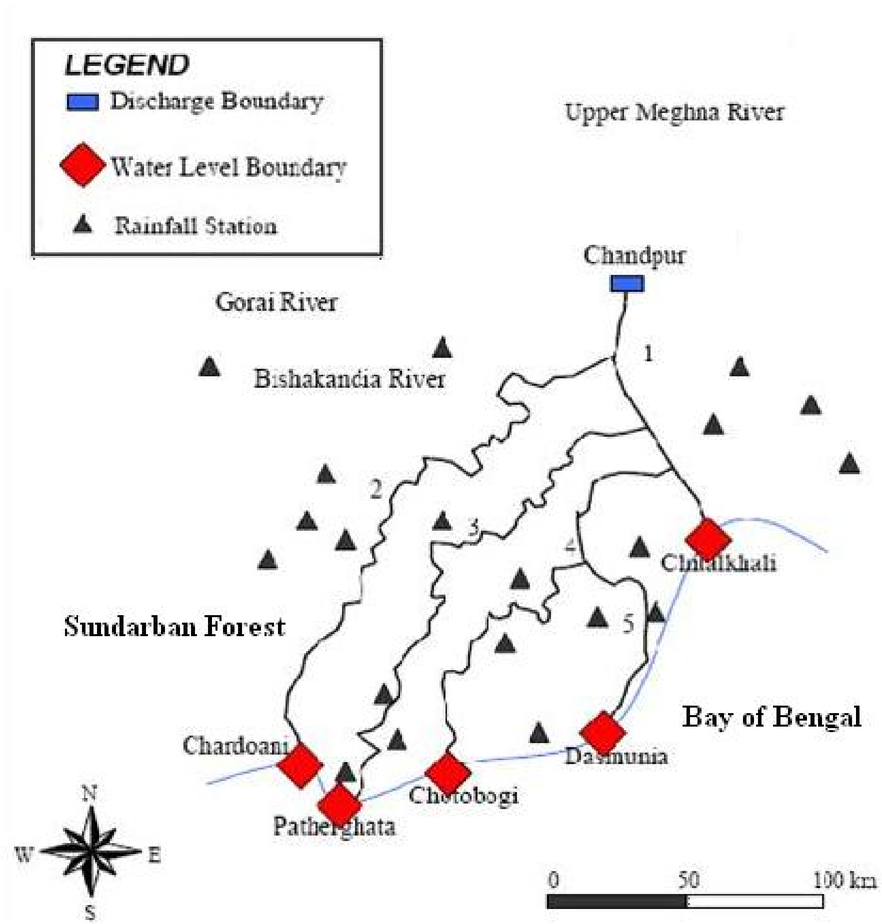

Figure 6: River network system in the study area

To analyze the effects of sea level rise, two scenarios are considered. For the year 2050 and 2100, the sea level is raised by 26 cm and 86 cm respectively in the flood simulation model as per IPCC Third Assessment (IPCC, 2001). The

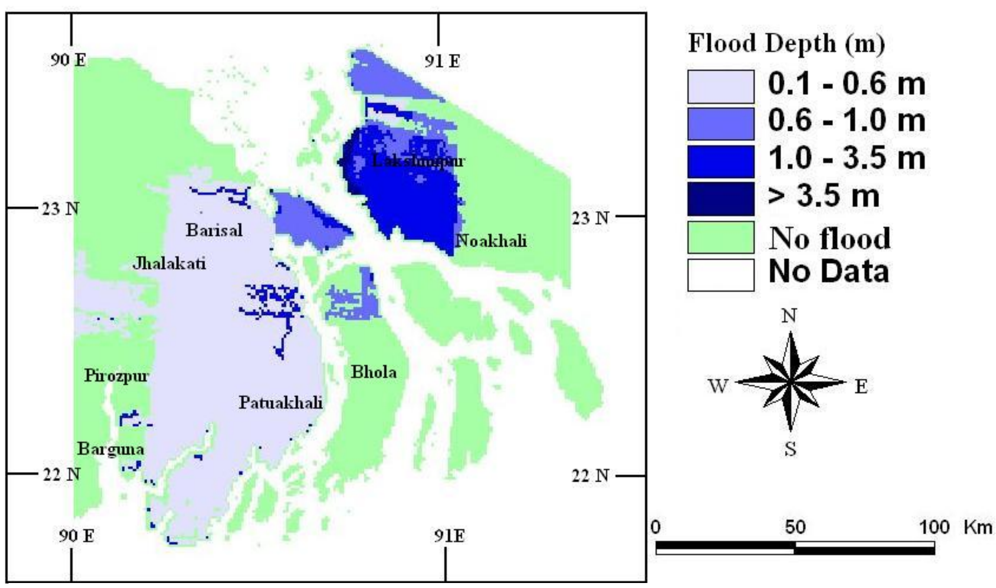

Figure 7: Simulated floods in 1988

rainfall data is taken same as in the present condition. The discharge at

Chandpur station in the year 1988 is considered as the upstream boundary condition.

The simulated maximum flood inundation maps of two large coastal cities - Barisal and Patuakhali - under the two selected scenarios are shown in Figs. 8 to 11. The simulated results show that about 65% and 40% area will be flooded in Barisal and Patuakhali districts in 2050 condition. Compared with the 1988 condition, the maximum flood depth increases by 5cm and 40cm in Barisal 9cm and 53cm in Patuakhali in the year 2050 and 2100 condition respectively.

Extent of flooding under different depth categories (Chowdhury, 1996) for the year 2050 and 2100 have been computed and is presented in Table 2.

Table 2: Extent of flooding for 1988, 2050 and 2100

District	Year	Extent of flooding (%)				Total computed flood area (%)
		0.1-0.6m	0.6-1.0m	1.0-3.5m	>3.5m	
Barisal	1988	49.8	9.8	5.3	0	64.9
	2050	49.3	10.2	5.4	0	64.9
	2100	0	57.5	7.5	0	65.0
Patuakhali	1988	39.8	0	0.2	0	40.0
	2050	39.8	0	0.2	0	40.0
	2100	0	39.8	0.2	0	40.0

Table 2 indicates that total extent of flooding remains unchanged between 1988 and 2050 in Barisal while registers 0.1% increase in 2100. In Patuakhali District, the total extent of flooding remains unchanged even in 2100 compared to 1988. However, only 9.8% area witness 0.6-1.0m flooding in 1988 which increases to 57.5% in 2100 in Barisal district. In Patuakhali district, very little land (0.2%) is flooded beyond 0.6m in both 1988 and 2050 while in 2100 39.8% area will be flooded in the range of 0.6-1.0m. Note that the results presented here are indicative only since embankment around the coastal areas has not been included in the model setup; DEM used is coarse in resolution; and land accretion/erosion is not considered.

B.5 Assessment of socio-economic impacts and vulnerability

The lack of an accepted methodology for carrying out assessments that could determine the socio-economic impact of floods has greatly limited the capacity to present a comprehensive picture in this study. Current assessment relies on the total number of people affected by floods under sea level rise condition. Table 3 presents the total number of affected people in Barisal and Patuakhali districts.

Based on the information of projected number of urban people, household, road network and the area of flooding, the number of affected people, flooded buildings and affected road length in two large coastal cities – Barisal and Patuakhali - have been calculated which are presented in Table 4.

Table 3: Estimated affected people in district with projected population

District	Year	Number of affected people				Total affected people
		0.1-0.6m	0.6-1.0m	1.0-3.5m	>3.5m	
Barisal	1988	1,038,300	204,300	110,500	0	1,353,100
	2050	2,136,900	442,100	234,100	0	2,813,100
	2100	0	4,130,800	538,800	0	4,669,600
Patuakhali	1988	517,900	0	2,600	0	520,500
	2050	1,024,300	0	5,100	0	1,029,400
	2100	0	1,771,800	8,900	0	1,780,700

Table 4 Estimated Affected Urban Population, Buildings and Road in Barisal and Patuakhali

Criteria	Year	Depth category				Total
		0.1-0.6m	0.6-1.0m	1.0-3.5m	>3.5m	
No. of population	2001	708,138	0	94,319	0	802,457
	2050	851,400	0	113,400	0	964,800
	2100	0	872,706	140,160	0	1,012,866
No. of buildings	2001	120,025	0	15,986	0	136,011
	2050	144,307	0	19,220	0	163,527
	2100	0	174,284	23,756	0	198,040
Length of road (km)	2001	35.0	0	1.5	0	36.5
	2050	35.0	0	1.5	0	36.5
	2100	0	35.0	1.5	0	36.5

The impact indices for different categories have been computed. The categories are: residential building, non-residential building, roads, railways, person less than 6 years, person between 6 to 65 years, person above 65 years, income less than 100 US$, income level 100 US$ to 400 US$ and income level above 400 US$.

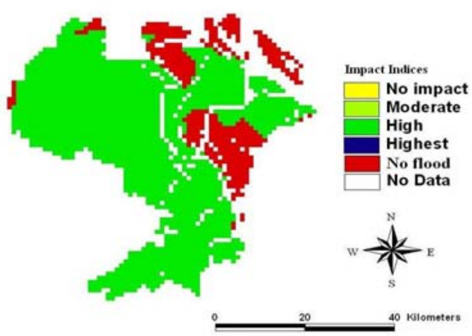

Figure 12: Impact map for residential buildings in Barisal in 2100

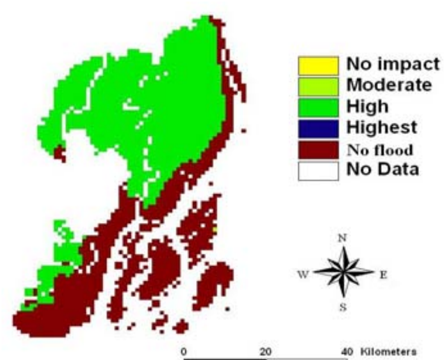

Figure 13: Impact map for residential buildings in Patuakhali

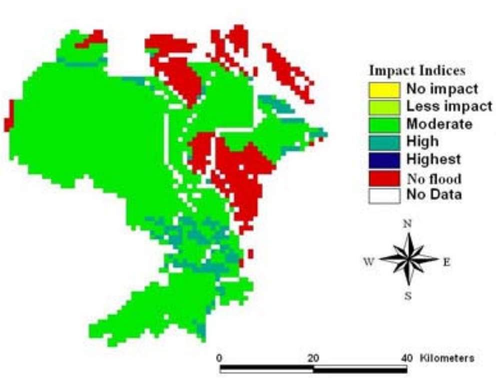

Figure 14: Impact map for non-residential buildings in Barisal buildings

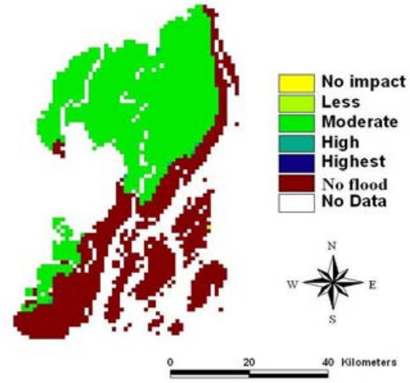

Figure 15: Impact map for non-residential buildings in Patuakhali in

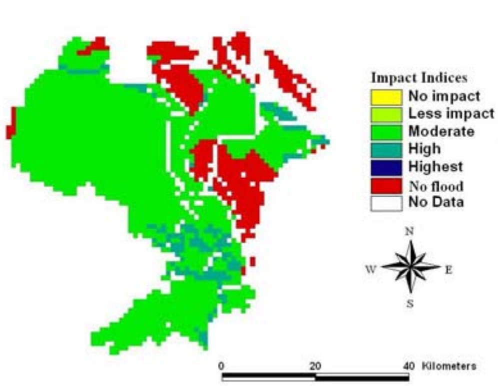

Figure 16: Impact map for roads in Barisal in 2100

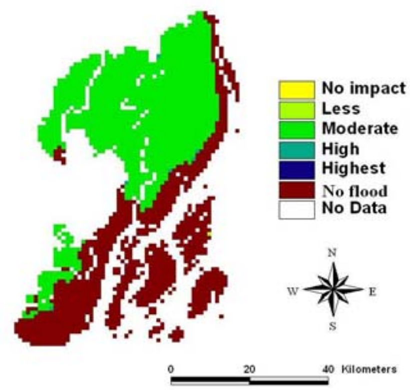

Figure 17: Impact map for roads in Patuakhali in 2100

B.6 Links among policy, socio-economic factors, floods and impacts

There is an extensive framework of policy statements in Bangladesh that has a bearing on the socio-economic factors and flooding in the coastal zone. These are:

- Coastal Zone Policy, CZPo, (2005)
- National Environment Policy, NEPo (1992)
- National Forestry Policy, NFoPo (1994)
- National Water Policy, NWPo (1999)

An attempt has been made to analyze policy environment on the following issues which have relevance to socio-economic factors and flooding in the coastal zone:

- Integrated coastal zone
- management Land use planning
- Disaster preparedness
- Environmental issues

The analysis presented here has been made based on only readily available documents.

Integrated coastal zone management

Government of Bangladesh has declared Integrated Coastal Zone Management (ICZM) as the key to development in the coastal zone through approval of the Coastal Zone Policy (CZPo) in the Cabinet in March 2005 (MOWR, 2005). Subsequent Coastal Zone Strategy (CDS), which links CZPo with concrete interventions, takes into account "..visible climate change impacts" among other emerging trends in the coastal zone. While reviewing the challenges in the coastal zone the same document states that "…..Livelihoods affected by natural system processes in the coastal zone are salinity intrusion, flooding and drainage congestion, cyclones and heavy storms (8 million people at risk) and erosion and accretion. These are all expected to be further adversely affected by the impacts of climate change and sea level rise". As an effective step towards reducing the vulnerability of climate change, CDS plans to establish linkage with the newly activated 'Climate Change Cell' of Government of Bangladesh and participate in the formulation and implementation processes of the 'National Adaptation Plan of Action (NAPA) for climate change.'

Land use planning

The NEPo (1992) encourages land use depending on eco-system prevailing at different parts of the country.

The NWPo (1999) emphasizes that 'activity for planning and management of the nation's river systems is undertaken within the context of hydrological regions' and states that The Water Resources Planning Organization (WARPO) will delineate the hydrological regions of the country, based on appropriate natural features, for planning the development of their water resources. The WARPO has delineated 7 hydrological regions whereby the coastal zone is spread over 3 different regions.

The NAPo (1999) states 'special development programmes will be taken with a view to increasing production of potential crops suitable for the coastal area' and 'suitable projects will be taken up for building water reservoir to capture tidal water and thereby expanding mechanized irrigation facilities in the coastal areas'.

In general, there is agreement between different policy documents on land use planning. However, the conflict between different uses of coastal land for paddy cultivation, for salt production, for shrimp cultivation, for coastal afforestation or mangroves should be resolved. A consensus is important to find formula to determine proper land use.

Disaster preparedness

The NFoPo (1994) recognizes the role of massive and planned tree plantation in the coastal areas to reduce the velocity and intensity of cyclone, tornado and tidal bore.

The NWPo (1999) suggests that the Government, through its responsible organization, will 'develop early warning and flood-proofing systems to manage natural disasters like flood and drought'. The NWPo (1999) did not mention about disasters like tidal surge, cyclone etc, more relevant to the coastal zone. For disaster preparedness, the NWPo suggests 'designation of flood risk zones' and elaborates that 'Regions of economic importance such as metropolitan areas, sea and air ports, and export processing zones will be fully protected against floods as a matter of first priority'.

The draft Land Use Policy mentions 'due to global warming, rise in the sea water level with the consequent threat of a significant part of the country going under water looms large over Bangladesh. Appropriate steps should be taken so that land in the coastal zones is used in a manner which could reduce the adverse effects of natural calamities. For this purpose, growth of mangroves and coastal afforestation in an appropriate degree and manner could play a useful role in this regard'.

A 'Comprehensive Disaster Management Plan' is being prepared. There is need that issues of disaster prone coastal zone are fully incorporated in the CDMP. The WB (2000) has also prepared a document 'Bangladesh: Climatic Change and Sustainable Development' recommending possible adaptive measures.

Environmental Issues

The NWPo (1999) recognizes some of the coastal issues such as 'excessive soil erosion and sedimentation, water logging and Stalinization of agricultural land, groundwater depletion, watershed degradation and deforestation, reduction of biodiversity, wetland loss, saltwater intrusion, and coastal zone habitat loss' as environmental problems. The policy emphasizes, among others, two aspects that have bearing on the socio-economics of the coastal zone:

- Ensure adequate upland flow in water channels to preserve the coastal estuary eco-system threatened by intrusion of salinity from the sea.
- Stop unplanned construction on riverbanks and indiscriminate clearance of vegetation on newly accreted land.

The NEPo (1992) states:

- Ensure environment friendly conservation and development of resources available in the coastal and marine eco-systems.
- Ban all activities resulting in pollution of coastal and marine areas
- Strengthen research in conservation and development of coastal and marine resources and environment
- Ensure fish harvest from coastal and marine area at maximum tolerable limit
- Although environment related policies are elaborated and specific on issues related to marine environment, yet there is wide gap in translating these policies into concrete actions.

B.7 Issues, challenges and recommendations

The low lying coastal zone of Bangladesh is critically vulnerable to climate induced floods, but the core elements of its vulnerability are primarily contextual. Nonetheless, the societal exposure to this vulnerability is very high due to high population and population density, with close to 800 persons per square kilometer in the coastal zones. Very low levels of development and high levels of poverty (between 33 and 40%) add to the social sensitivity to any external hazards including climate change induced flood.

This case study, though limited by a number of technical issues including the poor resolution of DEM, exclusion of coastal polders and rate of natural coastal accretion, highlights extent and impact of coastal flooding under climate change scenario. Drawing on comprehensive review of existing flood mitigation measures, relevant policies and strategies, gaps in state-of-the-affair and issues have been explored.

It has been found that many actions undertaken to address the baseline stresses in Bangladesh (e.g. poverty reduction) are also synergistic with the so called adaptations that might be required as climate change impacts manifest themselves. Yet, there is a need to clearly address whether climate change impacts are simply one more reason to lower contextual vulnerability via business as usual economic development activity, or whether adaptation to climate change might require suitable modifications of development policies and priorities. For example, policies to encourage tourism and build tourism infrastructure in vulnerable areas of the coastal zone, particularly the Khulna region, might need to take into account the projected impacts of climate change to reduce the risk of mal-adaptation. Thus far there is a clear lack of articulation on this important issue.

With regard to structural adaptations such as coastal embankments or polders and salinity reduction, even though it is true that many of these measures have already been integrated in development policies and projects, there remains an ongoing challenge with regard to their durability and sustainability. For example, given the high influx of sediments from upstream each year, measures such as dredging of waterways are not a one time response but require periodic repetition and must ensure operation of a system of continuous monitoring and updating. This should not only be considered as a mere value addition to the existing pool of knowledge but also be an integrated part of the policy and strategy and would requires continued government and donor interest as well as participation of the local population far beyond the original lifetime of the intervention. Structural adaptations therefore need to be matched by efforts to facilitate financial and institutional adaptation – sustained interest on the part of the government and development partners, and the participation of local populations to help monitor and maintain the intervention.

Finally, this case study indicates a general lack of explicit attention to “climate change” in many government plans and policy documents in Bangladesh. At the same time this report also highlights the necessity of through in-depth analysis of linkage between climate changes induced flooding, societal response and policy environment in the coastal zone of Bangladesh.

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Appendix C: India Case Study

Appendix C: India Case Study

C.1 Coastal zones and floods in India

India is one of the most densely populated countries in the world with over one billion people. Indian coastline stretches about 5700 km on the mainland and about 7500 km including the two island territories (about half of the Indian boundary) and exhibits most of the known geomorphological features of coastal zones. Western coastline has a wide continental shelf having an area of about 0.31 million km^2 which is marked by backwaters and mud flats. East coast consists of Tamil Nadu coast, Andhra coast, Orissa coast and West Bengal coast, which is flat and deltaic and rich in mangrove forests covering an area of about 1430 km^2. A total number of 11 major and 130 minor sea ports located in coastal zones are economic engines of International and National Trade and Commerce in India. Approximately 40% of total population lives within 100 km ocean coast (Hua et. al. 2002). The people living in the coastal regions of India are highly vulnerable to natural hazards such as cyclones and resulting floods as well as man-made hazards like water pollution. The natural hazards take millions of lives, damage properties and natural resources in coastal areas. For example, a cyclone in the year 1999 killed over 10,000 people in Orissa state and millions of people became vulnerable (CNN, 1999). The total loss on account of flood damage in India is estimated as Rs. 526600 million during the period from 1953 to 1998 and thus the yearly average works out to be Rs. 11550 million (Choudhari and Rajan, 2000).

The climate change over the globe may have its impact on increase in wavelength and amplitude of the ocean waves and also increase in sea water level resulting in the inundation of several low lying areas of the world as well as India. India has been identified as one amongst 27 countries which are most vulnerable to the impacts of global warming related accelerated sea level rise (UNEP, 1989). Indian coastline is facing increasing stresses like population growth, urbanization, industrial development, trade, etc., and human pressures like overexploitation of marine resources, dumping of industrial and toxic wastes, oil spills and leaks. The impact of global warming-induced sea level rise has great significance to India due to its extensive low-lying densely populated coastal zone. Sea level rise is likely to result in loss of land due to submergence of coastal areas, inland extension of sea water intrusion and groundwater contamination and may have wide economic, cultural and ecological repercussions over India.

Observations suggest that the sea level has risen at a rate of 2.5 mm per year along the Indian coastline since 1950 (Lal and Aggarwal, 2000). A mean sea level rise is projected to be between 15 to 38 cm by the mid 21st century along Indian coast. Simulation studies based on ensemble of four AOGCM outputs indicate that the oceanic region adjoining the Indian subcontinent is likely to warm up at its surface by about 1.5 – 2.0 °C by the middle of century and by about 2.5 – 3.5 °C by the end of the century. This simulated a rise in sea level by 46 to 59 cm along Indian coastline which is comparable with the projected global mean sea level rise of 50 cm by the end of this century and may have significant impact on Indian coastal zone (South Asian Media Net Report). Recent studies on the potential impact of one meter sea level rise along Indian coast provide an idea about the land which could be inundated and the population that would be affected provided no protective measures are taken. It has been suggested that the total area of 5763 km^2 along the coastal states of India i.e. 0.41% could be inundated and almost 7.1 million i.e. 4.6% of coastal population could be directly affected (TERI, 1996).

In addition to this the occurrence of tropical cyclones would significantly enhance the vulnerability of populations living in cyclone prone coastal regions of India. During the last hundred years (1891-1990), eastern coast was hit by 262 cyclones of which 92 were severe. The west coast of India was hit by only 33 cyclones of lesser intensity during the same period. In 19 cases on the East coast, the death toll exceeded 10,000 lives.

Global warming may result in an increase in sea surface temperatures as a result of which changes in the frequency, intensity or tracks in cyclones hitting the coastal zones may take place. India is frequently affected by tropical cyclones and storms particularly during or around monsoon season. About 6.5% of worlds 80 tropical storms are formed annually in the Indian Ocean. Frequency of formation of cyclones is 5–6 times more in Bay of Bengal as compared to Arabian Sea. Therefore, the east coast of India in general and the states of Orissa, Andhra Pradesh and West Bengal in particular are more vulnerable to the fury of cyclones and resulting floods causing damage to life and property almost every year.

There have been a number of studies on the likelihood of changes in the tropical storms in the event of global warming (Knutson *et al.,* 1999; Henderson-Sellers *et al.,* 1998; Royer *et al.,* 1998 and Krishnamurti *et al.,* 1998). Some recent global climate model experiments suggest a future decline in tropical cyclone frequency (Royer *et al.,* 1998). The east coast of India receives rainfall from cyclones during southwest monsoon (June – September) and northeast monsoon (October – December). The number of cyclonic disturbances over the Bay of Bengal during southwest monsoon has come down sharply over the years. The fall seems steep according to the numbers for the last three decades since 1971. However, there was no such steep fall in the number of cyclones during the northeast monsoon in the same period. The major difference between cyclonic systems of the southwest monsoon and those of the northeast monsoon relates to their impact. While the former causes copious rainfall, the latter led to large scale destruction.

Storm surges are generated by the winds and the atmospheric pressure changes associated with cyclones. India and its neighborhood are threatened by the possibility of storm surge floods whenever a tropical cyclone approaches. The Andhra Cyclone devastated the eastern coast of India, killing about 10,000 persons in November 1977. More recently the Orissa coast of India was struck by a severe cyclonic storm in October 1999 killing more than 15,000 people besides enormous loss to the property in the region (WMO, 2004). These and most of the worlds greatest human disasters associated with tropical cyclones have been directly attributed to storm surges. These disasters cause heavy loss of life and property, damage to the coastal structures and the losses of agriculture, which lead to annual economic losses in these countries.

Table 1 illustrates the 20 states affected by the tropical cyclones and resulting floods in India and also presents the vulnerable population in different states living in different storm risk zone (Hossain and Singh, 2002). It can be observed that the people of Andhra Pradesh, Tamilnadu, West Bengal and Orissa states are being severely affected by the storm risk and resulting floods because of flat and deltaic coasts. The storm risk increases from category 1 to category 4 and the population of Orissa are highly vulnerable for floods under category. Hence, Orissa that is frequently subjected to storms and floods and having poor socio-economic condition has been selected for the present study.

C.2 Study area introduction

Orissa State located on the east coast of India lies between 17°49'N to 22°34' N latitude and 81° 29' E to 87°29' E longitude. It has thirty districts (Figure 1) which covers an area of 155,707 km^2, which is 4.74% of the total Indian land mass. The State has a 480 kms long coastline, lagoons and offshore islands on the eastern part along the Bay of Bengal, while on the western part it has large areas of hilly forests. The coastal plains of the state extend from Subarnarekha River in the north to the Rushikulya in the south and are narrow in the north. Mahanadi and Subarnarekha are the major estuaries, while Rushikulya, Bahuda, Devi, Balijhori, Ghalia, Kharnasi, Jambu, etc are the minor estuaries. Chilka Lake is the largest brackish water lagoon in Asia, stretches over an area of 1100 km². Bhitarkanika is the second largest mangrove ecosystem of India, next to Sundarbans mangroves. Gahirmatha is the largest breeding ground for Olive Ridley Sea Turtles in the world.

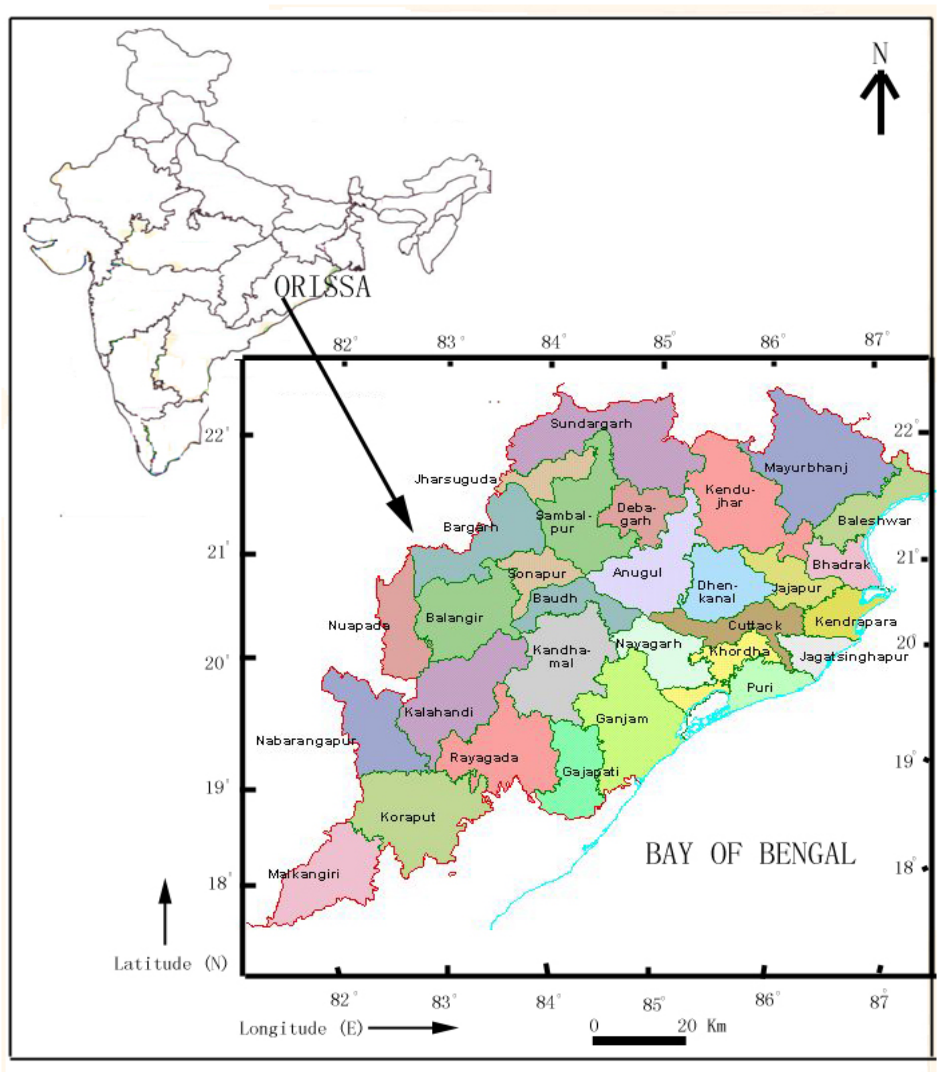


Figure 1: Various districts in Orissa

The state of Orissa comprises 11 major river basins in covering a geographical area of 1,50,460 km^2 and minor river basins draining directly to the Bay of Bengal from an area of 5247 km^2. The catchment area of all river basins is given in Table 2.

Heavy and intensive rains in the hilly areas and tidal surges along the coast during the cyclones inundate the coastal areas of Orissa state. Due to lack of systematic upper catchment treatment, high degree of siltation takes place in the rivers traversing through the coasts. In addition poor drainage in the coastal belts, breaching and spilling over the embankments cause severe floods in the delta areas. Damage due to floods is caused mainly by the Mahanadi, the Brahmani and the Baitarani rivers which have common delta where flood waters intermingle and when in spate simultaneously, wreak considerable havoc. The problem is accentuated when the flood synchronizes with high tide. The silt deposited constantly by these rivers in the delta area raises the flood level and the rivers often overflow their banks or break through new channels causing heavy damages. Floods and drainage congestion also affect the lower reaches along Subarnarekha river. River Rushikulya, Vamsadhara and Budha Balang also cause occasional floods. In the present study the Mahanadi basin has been taken flood inundation modeling under the sea-level rise condition.

Table 1: Vulnerable populations of various states of India in storm risk zone (Hossain and Singh, 2002)

Name of the State and UT	Per capita income (Rs) 1996-1997	% of total population	Vulnerable population in the storm risk			
			1	2	3	4
Andaman and Nicobar Islands	*12,653*	*0.03*	-	*568*	*78,617*	*237,656*
Andhra Pradesh	*10,590*	*7.91*	-	*6,945,353*	*44,798,612*	*25,421,168*
Arunachal Pradesh	*13,424*	*0.10*	*990,125*	-	-	-
Assam	*7,335*	*2.66*	*22,016,898*	*3,771,457*	*191,885*	-
Bihar	*4,654*	*10.29*	*24,212,092*	*63,566,239*	*12,599,841*	-
Chandigarh	-	*0.07*	*725,329*	-	-	-
Dadra and Nagar Haveli	-	*0.02*	-	*107,844*	*52,420*	-
Daman and Diu	-	*0.01*	-	*94,019*	*31,481*	-
Delhi	*22,687*	*1.09*	*10,659,296*	-	-	-
Goa	*23,482*	*0.14*	-	*1,355,597*	-	-
Gujarat	*16,251*	*4.91*	*11,306,950*	*27,787,558*	*8,779,782*	-
Haryana	*17,626*	*2.00*	*19,467,310*	-	-	-
Himachal	*7,355*	*0.61*	*5,919,175*	-	-	-

Pradesh						
Jammu and Kashmir	*6,658*	*0.71*	*6,932,431*	-	-	-
Karnataka	*11,693*	*5.36*	-	*15,482,877*	*36,763,203*	-
Kerala	*11,936*	*3.46*	-	*3,141,365*	*30,566,568*	-
Lakshadweep	-	*0.00*	-	*11,511*	*25,580*	-
Madhya Pradesh	*8,114*	*7.89*	*49,812,172*	*25,054,153*	*2,091,106*	-
Maharashtra	*18,365*	*9.39*	*4,065,310*	*69,488,861*	*18,050,222*	-
Manipur	*8,194*	*0.22*	-	*2,118,531*	*7,040*	-
Meghalaya	*8,474*	*0.21*	*362,144*	*1,714,280*	-	-
Mizoram	*13,360*	*0.08*	-	*13,631*	*779,805*	*7*
Nagaland	*11,174*	*0.14*	*970,138*	*423,483*	-	-
Orissa	*6,767*	*3.77*	-	*3,202,679*	*28,635,942*	*4,934,940*
Pondicherry	*11,677*	*0.09*	-	-	*18,463*	*859,034*
Punjab	*19,500*	*1.95*	*18,980,768*	-	-	-
Rajasthan	*9,356*	*5.24*	*51,120,072*	-	-	-
Sikkim	*7,416*	*0.05*	*466,761*	-	-	-
Tamil Nadu	*12,989*	-	-	*2,918,748*	*46,145,579*	*15,823,653*
Tripura	*5,569*	*0.33*	-	*26,720*	*3,168,470*	-
Uttar Pradesh	*7,263*	*16.54*	*147,750,382*	*13,572,370*	-	-
West Bengal	*10,636*	*8.09*	*12,726,756*	*13,412,395*	*45,313,980*	*7,503,504*
Total population in different risk zone			*388,484,109*	*25,420,239*	*278,098,596*	*5,477,996*
Total 32 states						*975,572,906*

The Mahanadi is one of the largest Indian peninsular rivers that drain into the Bay of Bengal (Figure 2). The 857 km long river originates in Raipur district of the central Indian state of Madhya Pradesh and flows through the eastern state of Orissa before meeting the Bay of Bengal. Mahanadi Basin extends over an area of 141,589 km^2 which is nearly 4.3% of total geographical area of the country. The basin lies in the states of Madhya Pradesh (75,136 km^2), Orissa (65,580 km^2), Bihar (635 km^2) and Maharashtra (238 km^2). Its main tributaries are the Seonth, the Jonk, the Hasdeo, the Mand, the Ib, the Ong and the Tel. Physiographically, the basin can be divided into four regions, namely, the Northern Plateau, the Eastern Ghats, the Coastal Plain and the Erosional Plains of Central Table Land. The first two are hilly regions. The coastal plain is the central interior region of the basin, traversed by the river and its tributaries. The main soil types found in the basin are red and yellow soils, mixed red and black soils, laterite soils and deltaic soils. The Mahanadi basin can be divided into two distinct reaches for flood management purposes. They are Upper Mahanadi and Mahanadi Delta. The area upstream of Mundali Barrage, the head of delta, intercepting a catchment area of about 132,100 km^2 is called the

Upper Mahanadi and the rest 9034 km^2 is called the Mahanadi Delta.

Table 2: Catchment characteristics of various rivers in Orissa State

No.	Name of Basin	Total catchment Area (km^2)	Catchment area within Orissa (km^2)	Catchment area in Orissa to total geographical area of State (%)
1	Subarnarekha	19,277	2,983	1.92
2	Budhabalanga	4,838	4,838	3.11
3	Baitarani	14,218	13,482	8.66
4	Brahmani	39,269	22,516	14.46
5	Mahanadi	141,134	65,628	42.15
6	Rushikulya	8,963	8,963	5.76
7	Bahuda	1,118	890	0.57
8	Vamsadhara	11,377	8,960	5.75
9	Nagavali	9,275	4,500	2.89
10	Kolab	20,427	10,300	6.61
11	Indravati	41,700	7,400	4.75

Rainfall is dominated by the summer monsoon (June-September) with an average annual rainfall in the basin is 1,463 mm. In the region of the Mahanadi River the climate is predominantly sub-tropical with summer temperatures of around 29°C and winter temperatures of 21°C. An average annual surface water potential of 66.9 km^3 has been assessed in this basin. Out of this, 50 km^3 is utilizable water. Culturable area in the basin is about 8.0 Million ha, which is 40% of the total culturable area of the country. Present use of surface water in the basin is 17 km^3. The hydropower potential of the basin has been assessed as 627 MW at 60% load factor.

The population of the Mahanadi basin released by the census organization in May 2001 stands at 16,202,133. The Mahanadi Delta consisting of the district of Cuttack, Puri, Jagatsingpur, Khurda etc. has a population density of 572/ km^2. The mid area along the main river consisting the district of Sambalpur, Bargarh, Sonepur, Boudh, Nayagarh, Dhenkanal etc has a population density of 169/ km^2 and the area consisting the tributaries in the district of Rayagada, Nabarangpur, Kalahandi, Nawaparal Bolangir, Jharsuguda, Sundergarh etc has the population density of 183/ km^2. In short the deltaic region is more populated than the upper reaches.

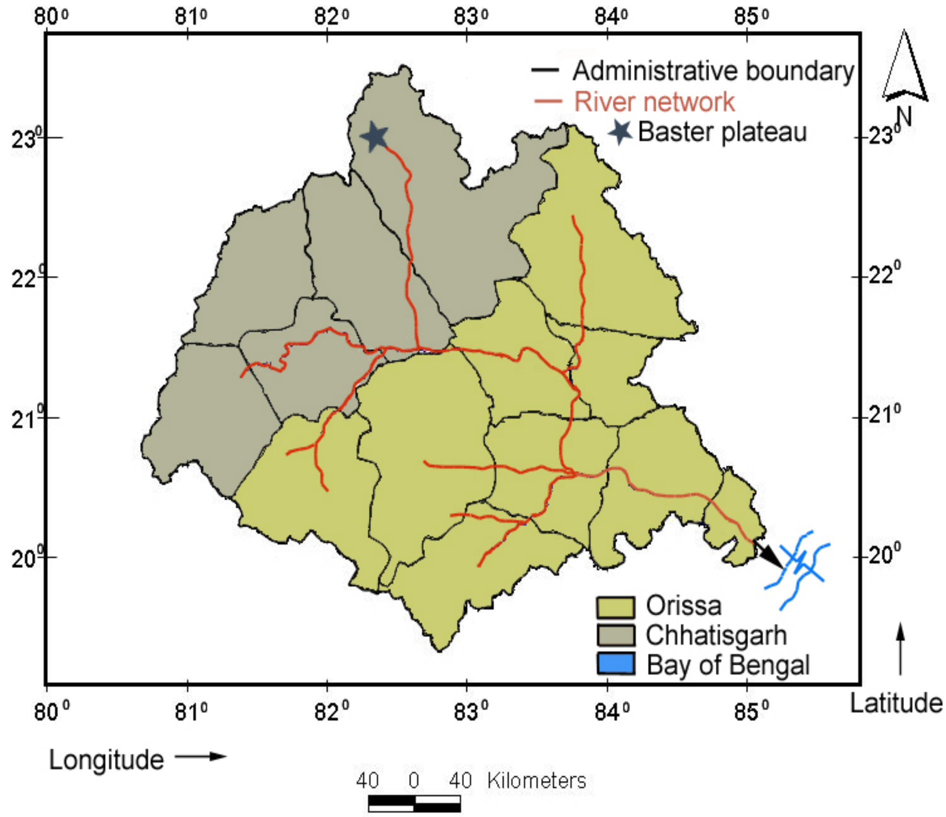


Figure 2: Mahanadi Basin

Low-lying deltas are especially vulnerable to sea-level rise and increasing shoreline wave action. A decrease in river water discharge, as projected under some climate change scenarios, could lead to hindrance of delta progradation and increase the risk of irreversible change for the ecosystem in estuarine-deltaic areas. Tidal rivers and estuaries will become more prone to saltwater intrusion as a result of projected sea-level rise. Sea-level changes associated with global warming would be exacerbated by tectonic submergence, ground subsidence as a result of groundwater withdrawal, rise of water level created by delta progradation, and eustatic sea-level rise. The tidal, estuarine part of the Mahanadi river covers a length of 40 km and a basin area of 9 km^2. This part is being frequently affected by cyclonic storms and resulting floods and storm surges. On the basis of physical characteristics it is classified as partially-mixed coastal plain estuary. Figure 3 shows various rivers in the Mahanadi Delta.

The Mahanadi Delta is bounded by the high land on the right of Kuakhai from Bhubaneswar extending up to Khurda and then to Chilka and on the left bounded by high land of Chaudwar and the hill range parallel to the National Highway. The Mahanadi Delta has entirely been brought under irrigation by canal system, which originates from barrages across river Mahanadi and its branches. This delta having been formed only through metamorphosis of sediment deposits, there exist a medium to thick layer of clay underneath the surface. This makes the infiltration into the ground poor. The obstruction due to alluvial sand dune at the coast, create difficulties for drainage. The situation aggravates with the release from the irrigation canal, poor sub-surface drainage and high tide during the floods and a large part remains waterlogged for weeks together.

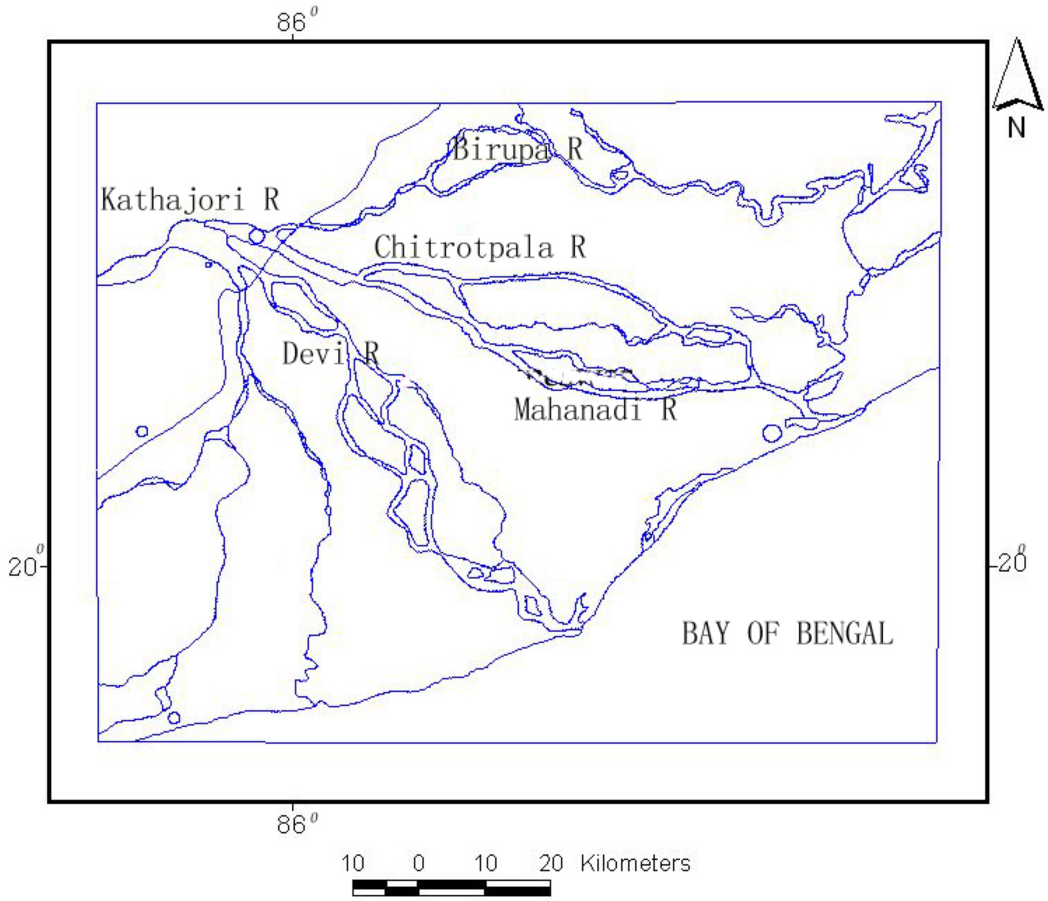


Figure 3: Drainage network of the Mahanadi Delta (Mohanti and Swain,

C.2.1 Hydro meteorological characteristics

Indian monsoon rainfall largely depends on the westward moving low pressure systems developing over the Bay of Bengal and their life time, as low pressure systems like low depression, deep depression and cyclonic storm etc are the major rain bearing systems. Orissa, a meteorological sub-division of India is more dependent on the activity of the monsoon trough and the low pressure systems forming over the Bay of Bengal along the monsoon trough, as it lies close to but south of the eastern end of the monsoon trough over Indian mainland. The monsoon rainfall over Orissa largely depends on frequency of formation, region of formation, intensity and movement etc. of low pressure systems. The coastal plain of Mahanadi basin comprises of Balasore, Cuttack, Puri and coastal areas of Ganjam district. The above zones are more prone for cyclones and resulting floods as well as storm surges.

The State gets most of the precipitation form the southwest monsoon. The climate is characterized by high temperature from March to May and high rainfall from June to September. The State also receives a small quantity of precipitation from the retreating monsoon in the months of October-November. Mostly such rainfall is associated with cyclonic storms. The annual average rainfall is 1482 mm between 1901-2001, out of which 76% is received between June-September. Mayurbhanj district in the northern plateau receives the highest rainfall while the least is received in Ganjam district in the southern coast. The average rainfall of Orissa has decreased considerably over the last fifty years. The average annual rainfall of the state which was about 1502 mm between 1901-1950, has reduced to about 1350 mm between 1951-2001. The western part of the state experiences higher temperatures in comparison to other parts of the state during the summer months. Analysis of the peak temperature during summers in Orissa shows a linear trend of increasing temperatures over the years. The average temperature during summer rose considerably from 37 degree to nearly 41 degrees, over the last four decades. In 1998, more than 2,000 people died due to heat stroke in the State. Similarly, the State has registered a sharp fall in the night temperature of 2 to 4 degrees below normal. In the State, seasonal and spatial variation of humidity is also considerable. Due to the close proximity of the Bay of Bengal, humidity is relatively higher in the coastal tract than in the inland regions of the State. The average humidity percentage in the coastal plains is over 75%, whereas it is only 60% over the vast inland regions.

C.2.2 Socio-economic characteristics

Orissa is economically the second lowest state in India. The chief occupation is fishing and agriculture, chiefly, rice and paddy cultivation. According to the 2001 census, the total population of Orissa is 36.71 million, which is about 3.6% of the population of the country. The decennial growth rate was 15.94% in the state during 1991-2001 while the density of the population is 236/km^2, against 203/ km^2 in 1991. However, the coastal districts are more densely populated than the inland areas with population density well over 450/ km^2. The literacy rate of the state is 63.61%. However, the female literacy rate (50.97%) is much lower than that of the males (75.95%). Out of the total workers, 38.7% are cultivators, 25.1% agricultural labourers, 2.7% engaged in household industries, 3.1% in industries and other than household industries, and 30.4% are other workers.

A well-developed network of transport and communication is prerequisite for rapid economic development. Roads are the major means of transportation in the State. Rural road connectivity of the state is poor with only 40% of villages connected by all weather roads as compared to 60% at the national Level. However, floods cause breaches and damages to the roads, the immediate impact of which is felt in delayed response. The cost of the repair is high.

The participation percentage of women in the workforce is 36.40%, while the proportion of women to total employees in the organized sector is only 8.77%. Women earn lower wages compared to men, especially in the non-organized sectors. Even though women constitute nearly half of the population, they are more vulnerable to disasters like floods because of socio-cultural barriers to various forms of livelihood opportunities. Added to this, women have very few resources over which they have exclusive rights or control. They also have reduced mobility due to existing socio-cultural practices, which make women more vulnerable to flood disaster impacts. Thus, lack of access to better livelihood and education, discrimination in work status and wage earning capacity, lack of alternative employment opportunities coupled with their marginalized social status, make women more vulnerable to flood disasters. This also leads to poor access to information and hence they are discriminated during relief and rehabilitation phases after disasters.

The State is especially vulnerable to stomach related diseases, TB and malaria. Many pockets in the flood plains and the coastal belt become prone to epidemics after floods and cyclones while malaria is endemic in the western and other drought-prone districts of the State. Recent trends indicate that malaria is also spreading to non-endemic areas. The State also has very high infant and maternal mortality rates. Sanitation and safe drinking water coverage is also low.

Urbanization has led to high rates of migration to cities, in search of employment opportunities. The majority of the immigrants usually belong to the lower income strata of population. The increasing influx of poor immigrants to an area adds pressure on the existing infrastructure and land resources. Being poor, these immigrants settle in slums or areas vulnerable to flood disasters and lacking in basic infrastructure like safe drinking water, sanitation and drainage facilities. Lack of spatial urban planning has led to unplanned growth of towns and cities. Majority of the cities have extremely inadequate drainage, waste management and sanitation facilities. This makes the population highly vulnerable to various diseases. Narrow roads, poorly maintained overhead electric and telephone wires, and congested drains make these settlements vulnerable during floods and cyclones.

In Orissa, 78% of the population lives in the villages and most of the houses are kutcha -made of bamboo, mud and thatch. These houses are not only vulnerable to natural disasters, but also require high maintenance costs and periodic replacement of building materials.

The average per capita income of Orissa in 1999-2000 was Rs.9, 162/- which was lower than the national average of Rs.16,047/-. The per capita income of population in Mahanadi Delta is highest among the population in Mahanadi basin. The poverty of people in Mahanadi basin compounded with frequent floods and cyclones in Mahanadi Delta allows neither the population nor the State to progress faster. Even though Mahanadi basin is richest among the river basins of Orissa, the development of the basin is restricted due to financial constraints together with frequent natural calamities.

C.2.3 Flood vulnerability and history

Orissa is a multi-hazard prone state requiring drought proof mitigation in the western parts and mitigation related to floods and cyclone in the eastern deltaic coastal parts of the State. Between 1961 and 2000, the frequency of floods has increased in Orissa. Between 1834 and 1926 the state experienced flood once in four year; which rose to once in two year after 1926.

Mahanadi Delta area gets flooded due to breaches in the embankment during high flood. Flood water entering through the escapes inundate the cultivated land. Besides damaging communication, irrigation system, houses etc., it causes loss of human and animal life. Due to poor drainage conditions of the area the flood water stays on for longer period and damage crops and public and private utilities. The worst flood of the 19th century, one of the first as on record, rolled down the river Mahanadi in October 1834. There was heavy damage in the coastal area including loss of human life and cattle. The flood discharge during 1866 at Naraj IB was computed to be 36,342 m^3/s. An area of about 777 km^2 was submerged in Puri district and 1662 km^2 of area was affected in Cuttack district. About 0.7 million people became homeless. As per the report of Mr. W. A. English, the then Superintending Engineer, Orissa, here was a total devastation in the delta caused by this flood and breaches of about 300 m length with 10 m depth of scour were noticed in the embankments. Besides damages to crops and houses, the communication was greatly affected. During the 1933 flood, the water level in Mahanadi at Naraj I.B. rose to 28 m with a peak flood discharge of 41,711 m^3/s. The flood height at Bellevue and Jobra rose to 25.07 m and 23.03 m respectively. Due to the flood, a large breach occurred on Sirua right bank at Khanditar. Total loss of human life and livestock was 8 and 162 respectively. All together 3,919 houses were ruine and 7,565 houses were damaged in Cuttack district. Crops on 39,172 hectares were completely damaged, while crops in 6,586 hectares were partly damaged. There were in total 75 breaches due to floods in 1937. Crops in 80,531 hectares were damaged in three districts of Cuttack, Puri and Sambalpur. The number of houses damaged either partly or completely were 3,378 in Cuttack and 2,579 in Puri. The number of villages affected were 758 and 556 in Cuttack and Puri districts respectively.

A heavy flood swept Cuttack district in July 1955. The flood discharge in Mahanadi during the flood was about 50992 m^3/s. Cuttack was in a dangerous situation as the flood water overtopped 900 years old stone revetments surrounding the city at many places at a velocity of 7 m/s. There was a major breach of flood embankment at Daleighai for a length of 610 m. A population of 1,415,000 were affected due to this flood. The next flood in the year 1980 resulted 92 major breaches in the river embankments of cuttack district. Amongst these the worst breach occurred at Birabarpatna in the left bank of Biluakhai river to the extent of 400 m. There were about 800 breaches in the canal banks of distribution system. In Puri district another 20 breaches occurred in river embankments. The worst breach occurred in right bank of Devi river at Jharpada for a length of 200 m. Altogether 0.239 million hectares of cropped area was affected due to this flood. The number of houses swept away, collapsed, partly damaged were 135,726. The total population affected by this flood was 2 million.

During the year 1982 the flood devastation extended over an area of 90,000 km^2. More than five million were severely affected. Embankments of Mahanadi and its branches were breached a several places and about 1.2 million hectares of cultivated land was inundated. Bhubaneswar, Cuttack, Boudh, Manmunda, Sambalpur, Puri, Paradeep, Jagtsinghpur, Kendrapara, Nimapara, Pipili, Gop, Kakatpur and other important towns were cut off due to major road breaches. National highway linking Calcutta and Chennai was breached and damaged badly and traffic was disrupted for more than a month. The distribution system in Cuttack, Puri and Sambalpur districts were damaged. The most serious breach occurred in Daleihai, Kantapada and Brabar Patna in the left bank of river Devi each varying from 400 to 400 m in length. Extensive areas of Puri and Cuttack district continued to remain submerged under water for a period of about 30 days. A population of 3.4 million in the Cuttack district and 1.2 million in Puri district are said to have been affected during the flood. The total number of houses affected in Cuttack and Puri districts were 421,511 and cropped area affected was 0.47 lakh hectares.

During the floods in 1991 the river embankments of Mahanadi, Kathjori, Devi, Kandal, Birupa, Luna, Chitrotpala, Paika, Hansua in Cuttack district and Kuakhai, Kushabhadra, Daya, Bhargabi, Kuanria and Brutanga in Puri district were breached affecting cropped area of 0.68 million hectares. There were also wide spread damages to irrigation distribution system, road network, private land, school buildings and public institutions.

In the recent past Orissa was ravaged by several major calamities, For example, the Super cyclone during 29 – 31 October 1999 and the flash floods of 2001 between which there was a drought in 2000. In addition, there were severe floods in the year 2003 as well. The impact of Super cyclone in 1999 was experienced in 14 coastal districts with wind speeds as high as 300 km/h. The damage caused was enormous with a death toll of 8,495 people and about 450,000 cattle. Two million houses were destroyed and 23,000 schools were damaged. Power supply was disrupted in 19,062 villages and all means of communication was paralyzed for a few days. The 1999 cyclone ranks as one of the strongest recorded in this region, but as is often the case, it was the heavy rainfall, storm surge and the associated flooding rather than the wind strength which caused most of the devastation and deaths. There was a storm surge of up to 6 m and inundation up to 20 km in land occurred. It may be interesting to note that just two weeks prior to this cyclone, during 17 – 19 October 1999 another cyclone with winds of near 200 km/h struck a little further down the coast claiming at least 70 lives and making over 40,000 homeless. During 17 – 20 July 2001 very high floods occurred for continuous several days when the flow exceeded 39,000 m^3/s and recorded highest discharge was around 40,868 m^3/s. The state experienced nine bouts of flood within a span of just 15 days in 2001, an all time high, damaging 2.12 million hectares of standing crops (Roy *et al.,* 2002). For a few days in August and September 2003, very high floods occurred and the flow fluctuated between 31,000 to 38,200 m^3/s.

The various factors which contribute to the high degree of vulnerability and damages in the State during floods are:

- Nearly 80% of rainfall in the State occurs within 3 months, which also coincide with the main cropping season
- High population densities in the coastal and delta regions, which are flood prone
- Increased encroachment in the floodplains because of comparatively better livelihood opportunities and development contributing to the increased vulnerability
- Poor socio-economic condition of the majority people living in the floodplains, and the local economy being primarily dependent on the monsoon paddy
- Poor infrastructure and weak mud houses
- Very little or no forest cover in the flood prone areas. For example, the forest cover in Bhadrak district is only 0.1%, Balasore 1.3%, Puri 1.4% and Jagasinghpur 2.3%

C.2.4 Existing flood disaster mitigation measures

Flood disaster mitigation measures can broadly be classified into structural and non-structural measures. The Structural measures aim at preventing or reducing the flow rate of floodwaters from reaching the potential damage centres. The non-structural measurers, on the other hand, aim at reducing the susceptibility to flood damage as well as minimizing the loss burden.

A major contributory factor to increasing damages by floods in the State is the increased encroachment of the flood plains. One of the mitigation measures include proper flood zoning with strict guidelines prescribing the land use in flood plains and other vulnerable areas will be carried out along with all the structural and non-structural measures.

The various structural and non-structural measures being implemented in the State are given below:

Structural Measures	***Non-structural Measures***
Dams and Reservoirs Embankments, flood walls, sea walls Natural detention basin Channel improprement Drainage improprement Diversion of flood waters Flood proofing and elevation Channel alterations High flow diversions Storm water management Coastline protection Watershed management Shelterbelt Plantation and coast afforestation	i) Reducing the susceptibility to flood damages through: Flood plain management Flood proofing Flood forecasting and warning ii) Minimizing the flood loss through: Disaster Relief Flood fighting including Public Health Measures

The other regulations would include:

- Not permitting unrestricted new development in the hazard prone areas
- Anchoring and flood proofing structures to be built in known flood prone areas
- Built in safeguards for new water and sewage systems and utility lines from flooding
- Enforcing risk zone base flood elevation and floodway requirements
- Prohibition on development in wetlands

The Orissa State Disaster Mitigation Authority (OSDMA) was created in December 1999 after the super cycle of 1999. OSDMA has focused its attention to the following measures, where some headway has been achieved (Sanyal, 2005).

Shelter: 94 multi-purpose cyclone shelters have been constructed within 10 Km wide band along the 480 Km long coast line of the State to provide shelter to the vulnerable populace and to use the assets for other community related works during normal times. Shelter Management and Maintenance Committees (CSMMC) comprising both local government officials and village people manage the buildings. Besides NGOs have constructed another 29 shelters and constructing another 30 odd shelters. About 8000 school-cum-shelters were constructed to provide shelter to the people at the time of flood and cyclone.

Awareness and Capacity building: Disaster Risk Management programme is being implemented in 145 blocks under 16 districts of the state covering 3005

Grampanchayats and about 23234 villages. Disaster Management plans are prepared at four different levels i.e. Village, Grampanchayat, Block and District. Village level disaster management committees have been formed and different task forces have been trained to discharge different responsibilities during and after the disaster. Community involvement in disaster preparedness and management at the grass root level has been given the primacy. Public awareness campaigns through media, posters, and short duration films are taken up for dissemination of information to the people regarding disaster management.

Search and Rescue: Well-equipped Orissa Disaster Rapid Action Force (ODRAF) units were created to provide search and rescue assistance in the aftermath of a disaster. The Orissa State Armed Police personnel man the units. Modern search and rescue equipments and high-level skill training have been provided to these units. Five such units are located at different strategic locations in the state with three in the coastal area.

Communication*:* A fully dedicated civil VHF wireless network having 402 base stations covering all district headquarters, all block headquarters, some tahasil headquarters and even some vulnerable gram panchayats was established to provide alternative communication medium to the district administration in the event of a disaster. Satellite Phones have been provided to the district collectors in vulnerable areas and the key disaster managers in the state with a view to enabling them to establish contact in the event of failure of all other means of communication.

Reconstruction: River training works, saline embankments, dredging of river-beds etc. were taken up under various infrastructure reconstruction projects. Pitching of river embankments by boulder-crate technology was also adopted at many vulnerable places.

The main dams in the Orissa state are Hirakud, Balimela, Rengali, Kolab and Indravati. The Balimela, Kolab and Indravati dams are built on the Godavari Basin on the Sileru, Kolab and Indravati rivers respectively. The Rengali Dam is built on Brahmani River and Hirakud on Mahanadi River. The dams are used for flood control, power and Irrigation. The Hirakud dam, the longest dam in the country has a net irrigated area of 35,486 hectares and an installed capacity of 475 MW for power generation. There are also a large number of earthen dams in the state used mainly for irrigation as well as flood control purposes. Flood cushion has been provided in few dams like Rengali dam on river Brahmani and Chandil Dam on river Subernarekha in Orissa.

The Upper Mahanadi mostly passes through mountainous region with steep to moderate slope having very good draining characteristic. It does not have any significant flood problem. In other words flood seldom occurs in this area excepting at a few places where the area has been reclaimed from the river regime in retention basin for human habilitation due to population pressure and agriculture need. Such reclaimed areas are the towns like Sambalpur, Sonepur, Boudh, Kantilo and Banki. The mitigation of flood in these areas has been moderately achieved by constructing flood embankments. Since the ground slope is steep or moderate the flood level falls quite fast and the embankment are not required to retain water for a longer period. Though the adjacent area are neither water logged nor wet lands, yet drainage problem exist during high flood, flooding the low lying area for a small period. The situation is not alarming as it is in the Mahanadi Delta.

Downstream of Mundali, river Mahanadi branches and sub-branches in to a number of rivers forming the Mahanadi Delta. The land below city of Cuttack was formed by river Mahanadi through sediment deposit. The plains of Mahanadi Delta are prone to floods. The land of Mahanadi Delta is very fertile and therefore the area is thickly populated. To protect the villages and agricultural land in different places, flood embankments have been constructed on both sides of Mahanadi and its branches in the delta area. Due to the embankments, the river is restricted to discharge its sediment load within the river bed and consequently the river bed has started rising and presently at most of the places the river Mahanadi and its branches are flowing at higher elevation than the surrounding area. The Mahanadi Delta extends almost for a length of 100 kms from Cuttack up to the mouth. The flood protection measures in Delta are mostly through embankment and levee. Mahanadi and its branches have been embanked through out its length in deltaic plain and is now protected against certain flood magnitude of 25,496 m^3/s at Naraj. However, it is susceptible to flood ravage at higher discharge. Therefore, there is a need for construction of another flood control scheme somewhere in between Hirakud and Mundali to keep outflow below 25,496 m^3/s (Dept. of Water Resources, Govt. of Orissa, 2001).

As structural measures along have not yielded the desired results and flood damages continue to show increasing trend, non-structural measures such as flood forecasting, flood plain zoning, flood proofing of the civil amenities of the affected villages, public participation in flood management works have been given a fair trial (Anil Sinha, 1999). The India Meteorological Department (IMD) has developed an advanced Cyclone Warning System using satellites, advanced computers and communication systems. The Central Water Commission also uses inputs from IMD to issue flood related warnings. The IMD has one of its regional centers at Bhubneshwar which issue cyclone warnings. It has 26 other information centers for dissemination of information. The IMD watches intensity of a cyclone and issues bulletins at frequent intervals. Primarily these bulletins are sent to the State Governments and various ministries at the Centre. They in turn circulate the above information. Cyclone warning is now being issued in 4 stages (i) Pre-Cyclone Watch – when a low pressure area develops and a depression starts to form usually 96-72 hrs in advance (ii) Cyclone Alert – when cyclonic storm has taken shape with gale force winds but exact landfall is not known, usually 48 hrs in advance (iii) Cyclone Warning –giving forecast of exact landfall wind speeds, rain and storm surge, usually 24 hours in advance and (iv) Post Landfall Scenario – giving expected damage over land, usually 12 hrs in advance (Ministry of Railways, Govt. of India, 2004)

The Sea Level Monitoring And Modeling (SELMAM) programme envisages precise measurements of Mean Sea Level (MSL) variations due to global climatic change etc. and assessment of the impact of such variations on the coastal belts of India. The programme has three basic components namely, (i) establishment of accurately measuring tide gauges (ii) preparation of micro level coastal area maps and (iii) development of predictive models. It is proposed to set up 11 modern tide gauge stations at Bombay, Veraval, Goa, Kochi, Tuticorin, Madras, Machilipatnam, Vishakhapatnam, Paradeep, Calcutta and Kavaratti. The tide gauge station at Goa will be the national reference station. In addition, micro level coastal area maps of the stretch between Nellore to Machilipatnam will be made in 1: 25000 scale.

Flood forecasting and warning is an important non-structural measure for flood management In India. About 157 flood forecasting stations are operated by Central Water Commission through field offices for issuing flood forecasts and warnings on all major interstate rivers which includes inflow forecasts for 25 major reservoirs /barrages (Chaudhuri and Rajan, 2000). Collection of hydro meteorological data, transmission of data on real time to control room, formulation of forecasts and dissemination are the main components of the flood forecasting system. Forecast formulation is carried out by adopting techniques suitable for the forecasting work keeping in view the purpose. Modernization of flood forecasting work is being taken up in a continuing way and strict vigilance is kept on accuracy of forecast. Presently flood forecasts and warnings are used to take up a chain of activity for flood fighting and flood damage reduction, to removable property and life using these forecasts. With pre-assessment of the flood disaster scenario to which different regions are exposed to and a comprehensive approach to disaster reduction endeavor, utilization of flood forecasts and warnings can be made more effective. A more analytical and application oriented approach for utilization of flood forecasts from an overall disaster reduction perspective can ensure much better results. There is a scope for improvement in flood management procedures utilizing a more versatile flood forecasting system.

The main considerations of Central Water Commission were to improve the quality and accuracy of the forecasts and increase the warning time of the forecast to make it more meaningful. The works proposed were (i) Automated data collection and transmission system through sensors and data collecting platforms (DCPs) (ii) Use of latest technology for communication through Satellite and (iii) Improvement of the forecast formulation techniques. Under the scheme the head quarters are strengthened with modem equipment, field units are provided with sensors and DCP equipment, and telemetry system is established in Mahanadi basin including installation of Very Small Aperture Terminals (VSAT) facilities at selected locations.

Flood insurance has several advantages as means for modifying the loss burden. Although flood insurance is being provided to cover the flood risk yet it is on a limited and selective scale. This is mainly because of intricacy in the matter of fixing premium and possibility of payment of claims frequently to acutely flood prone areas. As such any flood insurance system has to be carefully drawn up examining all aspects so that the proposals are viable for the insurance companies to sustain themselves.

Existing flood risk management policies

Floods affected vast areas of the country, transcending state boundaries. Floods affect an average area of around 9 million hectares per year. According to the National Commission on floods, the area susceptible to floods is around 40 million hectares. The approach to the management of floods has to be coordinated and guided at the national level. These are the flood control and management policy under *National Water Policy (2002)* of India.

There should be a master plan for flood control and management for each flood prone basin.

Adequate flood-cushion should be provided in water storage projects, wherever feasible, to facilitate better flood management. In highly flood prone areas, flood control should be given overriding consideration in reservoir regulation policy even at the cost of sacrificing some irrigation or power benefits.

While physical flood protection works like embankments and dykes will continue to be necessary, increased emphasis should be laid on non-structural measures such as flood forecasting and warning, flood plain zoning and flood proofing for the minimization of losses and to reduce the recurring expenditure on flood relief.

There should be strict regulation of settlements and economic activity in the flood plain zones along with flood proofing, to minimize the loss of life and property on account of floods.

The flood forecasting activities should be modernized, value added and extended to other uncovered areas. Inflow forecasting to reservoirs should be instituted for their effective regulation

The National Disaster Management bill has been prepared and communicated to all the State governments as a guidance paper for formulation of their own Disaster Management Acts. The National Disaster Management bill provides for creation of disaster management authorities at four levels, National, State, District and Local authority (Gram Panchayat and Urban Local Body). There will be Executive Committees and Advisory Committees at different levels to provide expert opinion to the concerned authorities for effective disaster management. According to the National DM bill, every Ministry / Department is required to prepare a Disaster Management Plan in tandem with the developmental plan of the department. The Major Principles of DM Policy includes:

- Shift from relief and welfare to Rights and Entitlement
- Integrate Disaster Management into Development policy and planning
- Legislation to provide statutory backing to essential DM functions
- Community Based Disaster Preparedness
- Use people's indigenous knowledge and culture in decentralizing DM
- Ensuring Humanitarian assistance to disaster victims
- Capacity Building at all levels
- Making DM part of Educational curriculum

In the State of Orissa OSDMA has facilitated in formulating State Disaster Management Policy, Plan, Bill etc. The State government has approved the State Disaster Management Policy. The State Disaster Management Plan has been prepared. The draft State Disaster Management Bill has been prepared to be laid before the state legislature. Five sub-groups were set up to prepare reports on different types of hazards including flood. 31 types of disasters were identified under these groups. Responsibilities of OSDMA in promoting and strengthening flood management activities are given below:

- Development of Multi-hazard response plan
- Establish and maintain a communication network at all levels for dissemination and collection of information relating to disaster management.
- Institutional capacity building
- Capacity building of the communities and Community Based organizations to handle emergencies

- Preparation of Geographic Information System (GIS) for disaster mitigation and development planning
- Design and development of training programme for decision makers, elected representatives and the Civil Society groups
- Coordination of NGO efforts

The state and central governments normally struggle to rehabilitate the victims of the cyclone. The services of the Indian Army, Navy and Air Force are being utilized in the rescue and relief efforts. The state governments are geared to set up control rooms to coordinate the response to the disaster and to keep the district authorities posted on the latest developments. Evacuating people from low-lying coastal areas is another option that is being implemented from time to time. The Indian Air Force is being used to drop food packets, vaccine, plastic sheets to storm victims.

For example, during October 1999 super cyclone over Orissa rehabilitation programs have been taken up on a wide scale by Government as well as Non-Governmental Organizations in various sectors, including livelihood reconstruction, housing, cyclone shelter construction, water and sanitation, school buildings and health infrastructure. Rehabilitation is being viewed as a long term, phased activity.

For planning and coordination of Disaster Management Activities in India which includes flood disasters, a High Powered Committee (HPC) on Disaster Management was constituted in 1999 with the approval of the Prime Minister under the Chairmanship of Shri J.C. Pant, a former Secretary to the Government of India. The HPC constituted 5 sub-groups to develop detailed history of each type of disaster and the type of plans of actions needed to have the most effective preparedness, response and recovery strategies for each type of disaster. The first sub-group was on: Water and Climate related hazards (floods, cyclones and storm surges).

The disaster risk management (DRM) program, a multi-donor funded project being implemented in 169 most multi-hazard prone districts of 17 selected states, was started with the initial support from the United Nations Development Program (UNDP), which provided the ground work for establishment of the community based disaster risk management framework and formalizing the collaboration between the different stakeholder a various levels for implementing this program. Financial support from the European Commission, the United States Agency for International Development, The Government of Japan through UN Trust Fund and the Australian Agency for International Development (Aus Aid) supported the Government of India driven strategic initiative grow over the years into a dynamic agenda of sustainable disaster management options appropriate to different parts of the country. Assistance is being provided to the States to draw up disaster management plans at the State, District, Block/Taluka and Village levels. Awareness generation campaigns to sensitize all the stakeholders on the need for flood preparedness and mitigation measures. Elected representatives and officials are being trained in flood disaster management under the programme. Orissa is also among the 17 multi-hazard prone States.

India Disaster Resource Network (IDRN) www.idrn.gov.in or http://164.100.4.222/idrn a web portal/centralized data base for collection and compilation of material and human resources inventory from the national to state, district and taluka levels to enable key decision makers at all levels to be informed on the stock of resources available for disaster preparedness and response, to enhance rapid and effective mobilization of equipment and skilled human resources and to respond immediately to emergency situations. About 70,065 records in 557 districts throughout the country have been uploaded.

In the various efforts that have started in the State, strengthening of organizational structures on disaster management and reorienting existing organisational and administrative structures have been the focal points. Involvement of various government departments, legislators and other natural leaders, research, specialised agencies and resource individuals, UN agencies, other bilateral, international and national donors, training institutes, NGOs, CBOs, Panchayats and the community for a concerted and coordinated effort to reduce risks against all forms of hazards has been the primary focus area of this initiative. The ultimate vision is to have a disaster resilient Orissa with total risk reduction as the main monitoring parameter in all developmental investments and initiatives to ensure sustainable development. The State Disaster Management Plan only highlights the activities of the State Government agencies and departments of Prevention, Response and Recovery.

C.3 Development of GIS database

The Distributed Hydrologic Model (DHM) used in this study is Institute of Industrial Science Distributed Hydrologic Model (IISDHM) (Dutta, 2000). It considers five major processes of hydrologic cycle: interception and evapotranspiration, river flow, overland flow, unsaturated zone flow and saturated zone flow. An implicit finite difference scheme is used to solve the governing equations of flow for river network.

C.3.1 Temporal data

The major temporal datasets collected includes hourly rainfall data, water level data.at Hirakud dam outlet and sea level data. Following sections explains them in detail. Figure 4 illustrates the location of rain gauge stations on the map of Mahanadi Delta.

C.3.2 Rainfall Data

Rainfall data of hourly resolution for three rain-gauge stations Bhubaneswar, Cuttack and Puri, was collected from the Indian Meteorological Department, Pune. Hourly rainfall plot of these rain gauge stations for 17th and 18th of October 1999 are illustrated in Figure 5. A super-cyclone crossed Mahanadi Delta during 16th to 20th of October 1999. Within this duration, the maximum precipitation was during 17th and 18th, and hence was selected for model simulation. Maximum rainfall observed was at station Bhubaneswar for both the days.

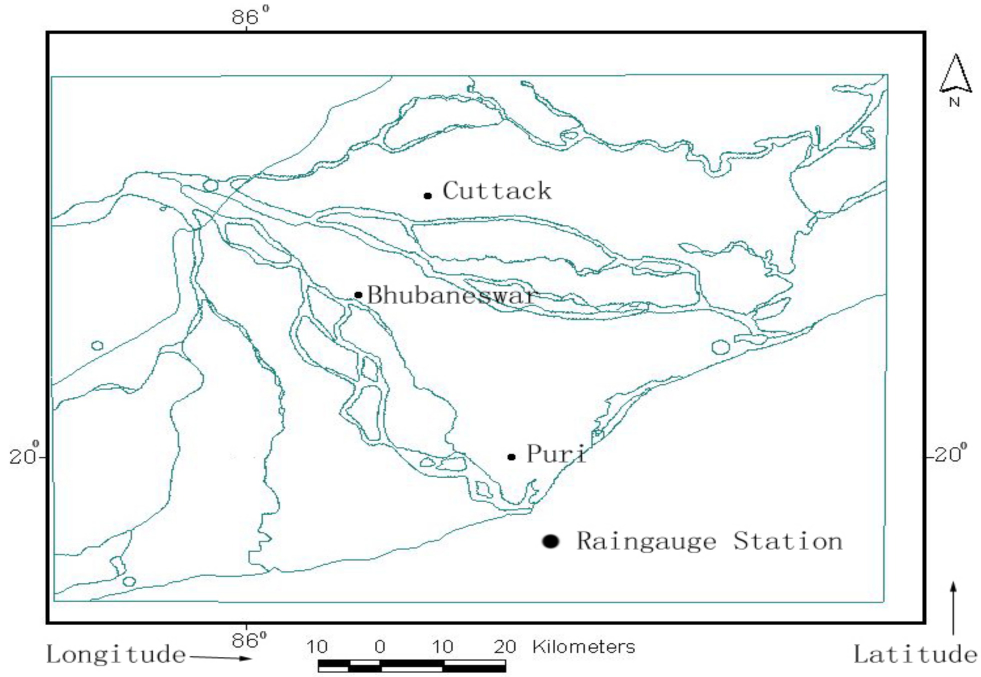


Figure 4: Location map of rain gauge stations

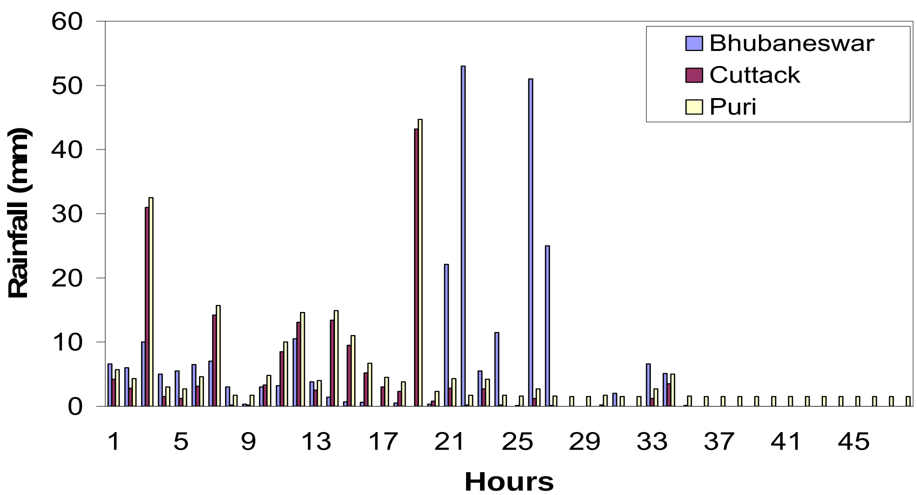


Figure 5: Time Series Plot of Rainfall (17-18 October 1999)

C.3.3 Boundary Conditions

Water level at the downstream of Hirakud dam was considered as the upstream boundary condition and mean sea level was taken as the downstream boundary condition.

C.3.4 Spatial Data

Major spatial datasets required for model simulation includes land use, topography, soil and river cross-section.

C.3.5 Land use data

Landuse map of study area was collected from local source. Ten classes were made for the whole Mahanadi Basin based on the landuse, of which the landuse pattern of delta region is mainly falling under Agricultural Land under Major Irrigation. Figure 6 illustrates land use pattern of Mahanadi basin.

C.3.6 Topography

Hydro1K DEM dataset of 1000m x 1000m horizontal resolution was used in this study. Figure 7 illustrates the DEM of the study area. The maximum elevation of the delta is 4.7 m above m.s.l. At the point where delta merges with the Bay of Bengal the elevation is 0.1 m above m.s.l.

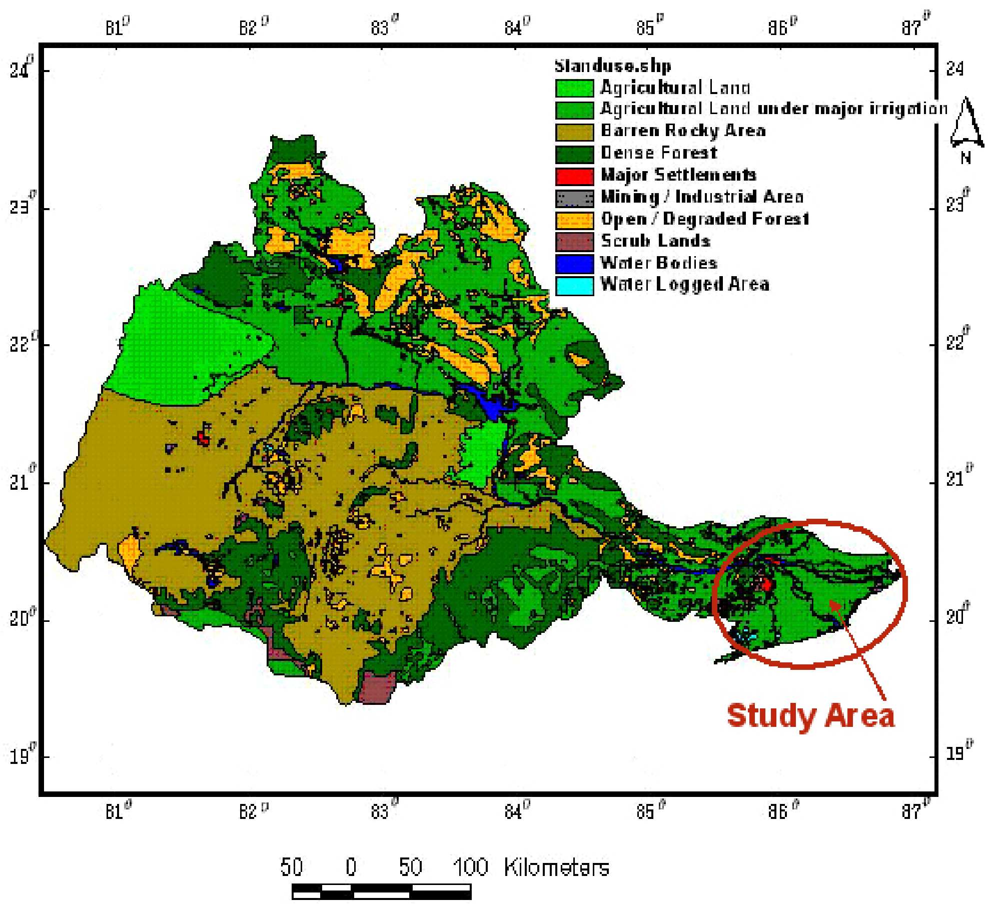


Figure 6: Landuse map of Mahanadi

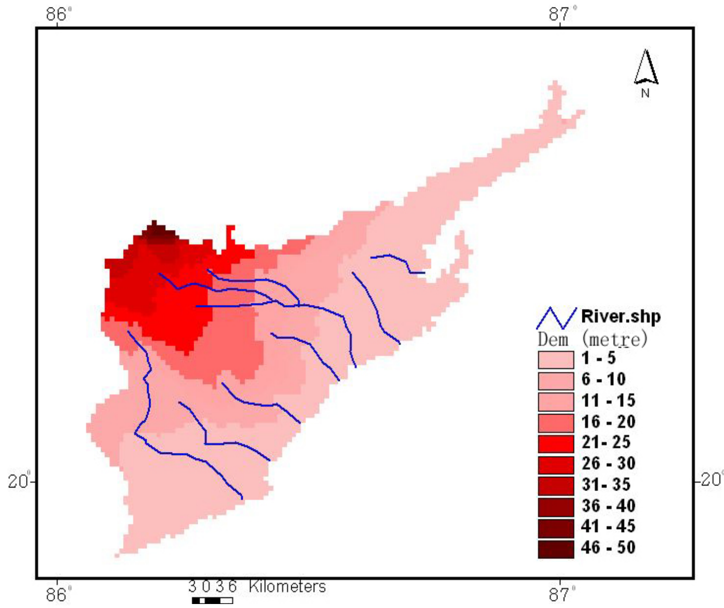


Figure 7: DEM of Mahanadi Delta

C.3.7 Soil Data

Soil map of Peninsular India produced by FAO (Satyanarayana *et al.,* 2003) was utilized in this study. In the delta region the soil type is mainly ferric luvisol.

C.4 Modeling flood characteristics under climate change condition

The model was applied for present and future scenarios. Present scenario was generated for year the 2000, and future scenarios were considered for the year 2025, 2050, 2075 and 2100. According to IPCC, the A1 scenario indicated an increase in water level of 14, 32, 57 and 88 cm for the future years of 2025, 2050, 2075 and 2100 respectively.

For the simulation, the observed m.s.l for the year 2000 was considered as present condition, and the m.s.l. was increased by 14, 32, 57 and 88 cm from the present level to obtain future flood inundation condition in the Mahanadi Delta. Figure 8 illustrates the inundation maps output of the model for the various scenarios considered.Maximum flood inundation depth simulated was 5.68 m, for an increase in m.s.l value of 88 cm for the year 2100. Table. 3 indicate the simulated flood area for the cases analyzed.

Table 3: Simulated flood area (km^2)

Flood Depth (m)	**Year**				
	2000	**2025**	**2050**	**2075**	**2100**
< 0.1 m	1,319	1,430	811	810	811
0.1-0.6 m	174	27	382	380	376
0.6 – 1 m	--	--	--	--	--
1 – 3.5 m	--	--	740	747	787
> 3.5 m	151	149	583	590	612

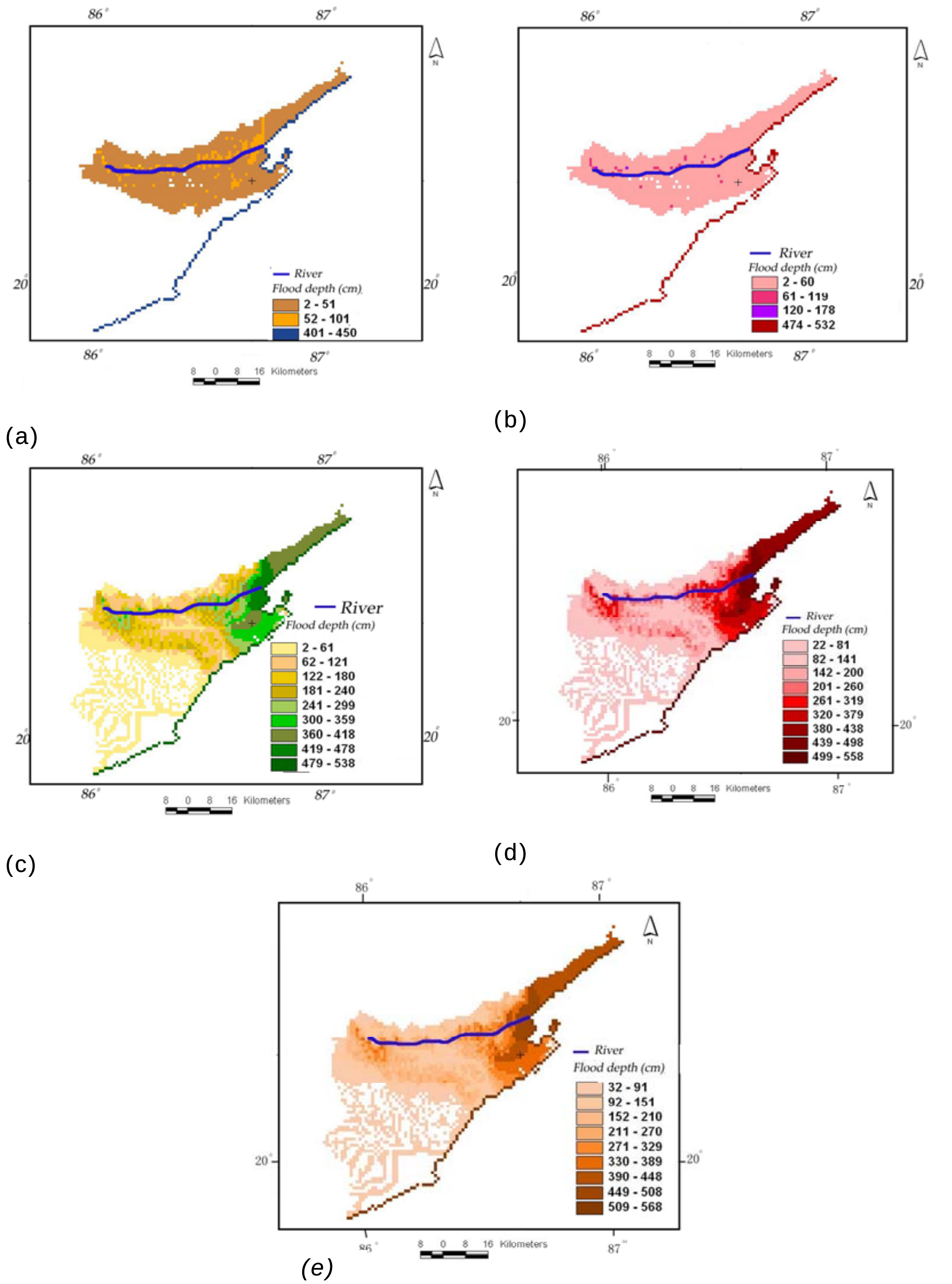


Figure 8 Inundation map generated for the five scenarios (a)2000, (b) 2025, (c) 2050, (d) 2075, (e) 2100

It can be seen that, in the year 2000 and 2025, inundation is caused mainly by flood depth of less than 0.1 m. However, for the years 2050, 2075 and 2100, more area is flooded by inundation depth of 1-3.5 m and more than 3.5 m.

C.5 Assessment of socio-economic impacts and vulnerability

The preliminary information for assessing the socio-economic impact of the flood was obtained by conducting a questionnaire survey. The survey was aimed to develop Flood Impact Indices for various categories such as Population, Buildings and Transportation under different flood depth conditions. Tables 4, 5 and 6 comprehend the indices developed from the questionnaire survey.

Table 4: Flood risk indices generated for population

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Moderate
0.60-1.00	Less	Less	Less	Moderate	Moderate
1.00-3.50	Less	Less	Moderate	Moderate	High
> 3.50	Moderate	Moderate	Moderate	High	High

Table 5: Flood risk indices generated for residential buildings

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Moderate	High
0.60-1.00	Less	Less	Moderate	Moderate	High
1.00-3.50	Less	Moderate	Moderate	High	High
> 3.50	Moderate	High	High	High	Highest

Table 6: Flood risk indices generated for transportation network (roads)

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Moderate	Moderate	Moderate	High
0.60-1.00	Moderate	Moderate	Moderate	High	High
1.00-3.50	Moderate	Moderate	High	Highest	Highest
> 3.50	High	High	High	Highest	Highest

With these indices as the basis, and by knowing the flood depth from the model results, the hazard map for the three categories for the five years are developed. Figure 9, 10 and 11 illustrates the hazard map for the various categories such as population, residential buildings and transportation respectively**.** Table 7, 8 and 9 depicts the estimated damage for population, residential buildings and transportation categories. Present population data was obtained from the Primary Census Abstract of Orissa State (Census of India 2001). Future projection of population was made by following the observed growth rate during 1991 to 2001. The number of residential buildings at present was approximated from the population data with the assumption that four people occupy one residential building.

Table 7: Estimated number of affected population

Impact Index	Year				
	2000	2025	2050	2075	2100
Less	29,688	25,936	2,078,949	3,123,980	3,325,159
Moderate	32,030	43,837	317,726	329,120	331,150

Table 8: Estimated number of affected residential buildings

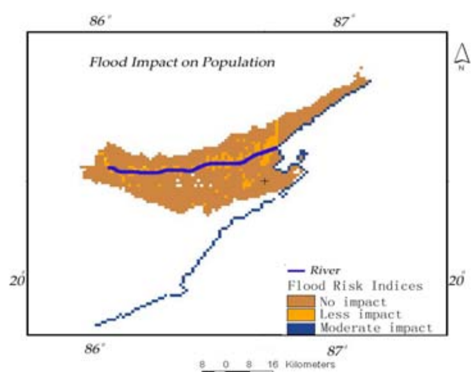
Impact Index	Year				
	2000	2025	2050	2075	2100
Less	7,422	6,484	519,737	780,995	831,289
Moderate	8,008	10,959	79,431	82,280	82,787

The present road network for the study area was obtained from the Global Coverage 'Digital Chart of the World' of ESRI. For the future years the road network is retained the same and the damage caused was estimated.

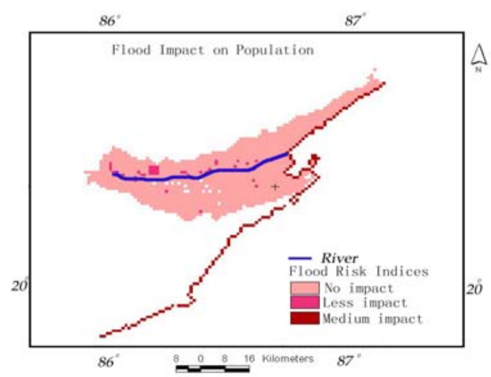
Table 9: Estimated length of affected road (in km)

Impact Index	Year				
	2000	2025	2050	2075	2100
Less	-	92	360	501	520
Moderate	-	-	35	110	92
High	-	-	-	82	67

The loss in this case is less compared to other categories because the length of road network falling in delta region is only to a lesser extent. Railway network was not considered in this study because the railway-line is passing through one side of the delta, outside the study area boundary.



(a)



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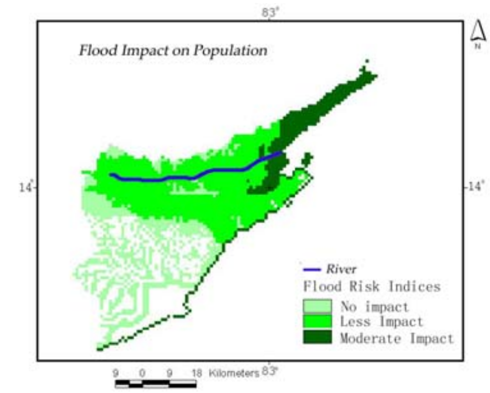

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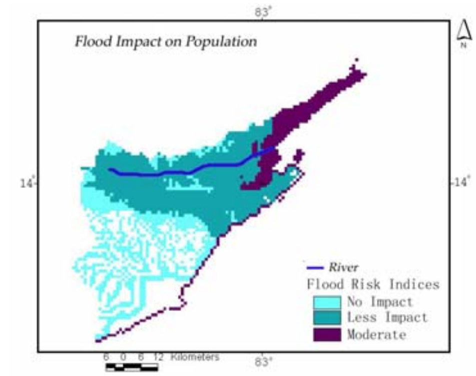

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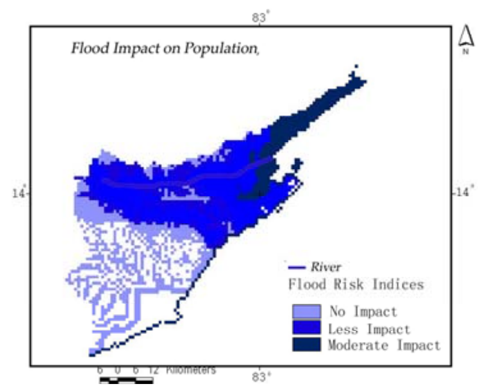
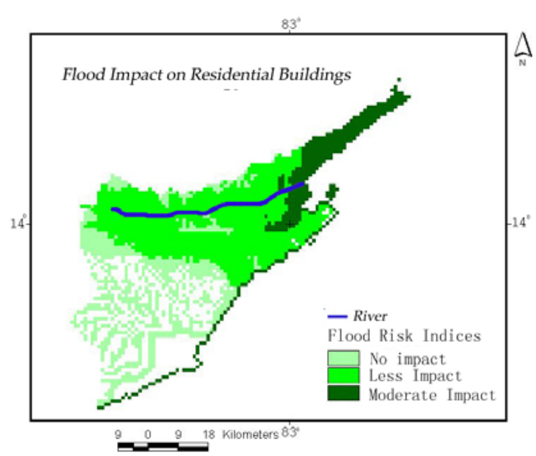
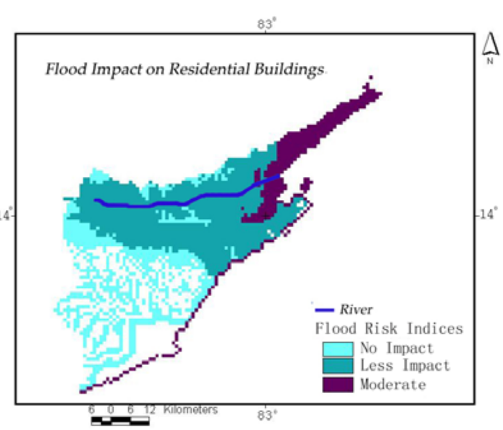


(e)

Figure 9: Hazard map generated for population category (a) 2000, (b 2025, (c) 2050, (d) 2075, (e) 2100



(a)



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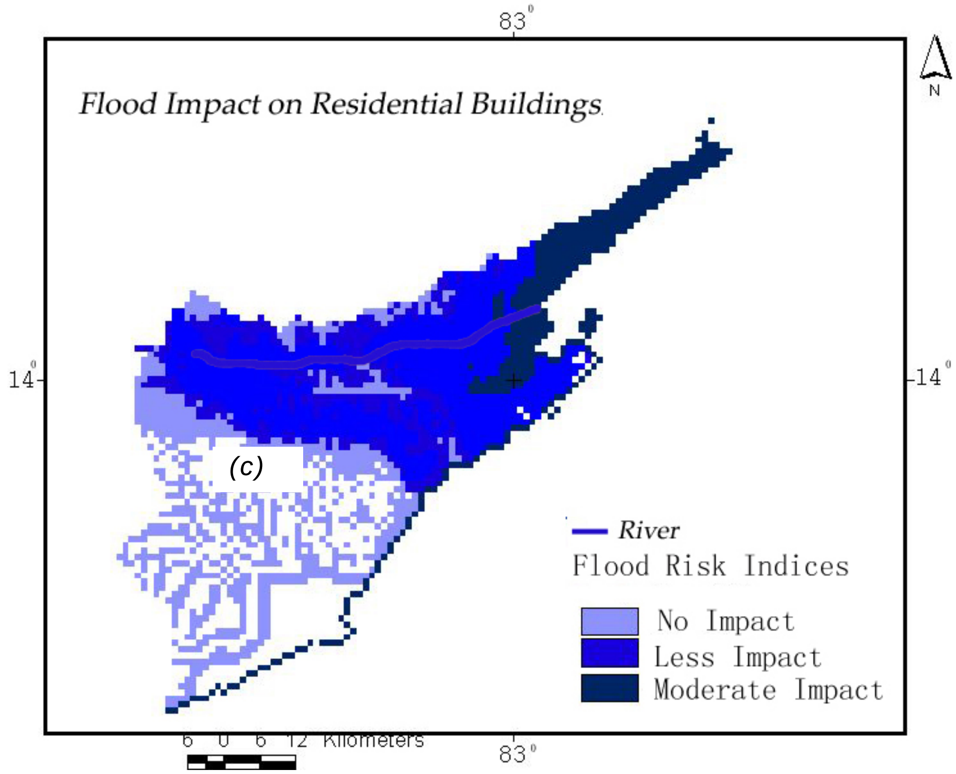
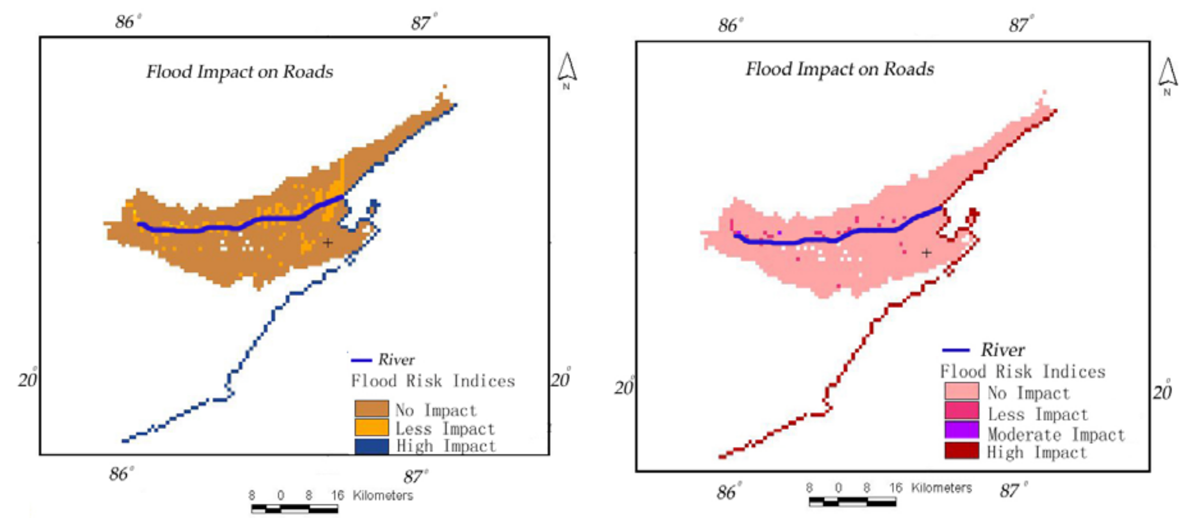
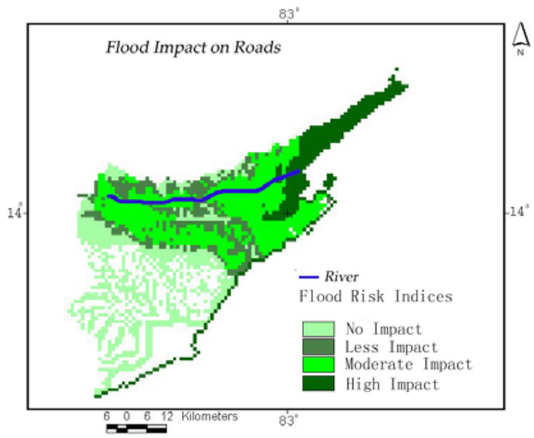


Figure 10: Hazard map generated for residential building category (a) 2000, (b 2025, (c) 2050



(a) (b)



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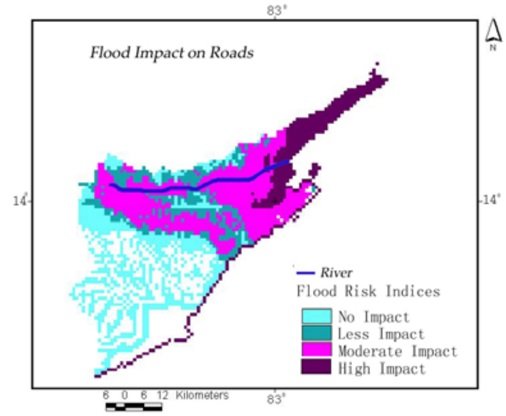

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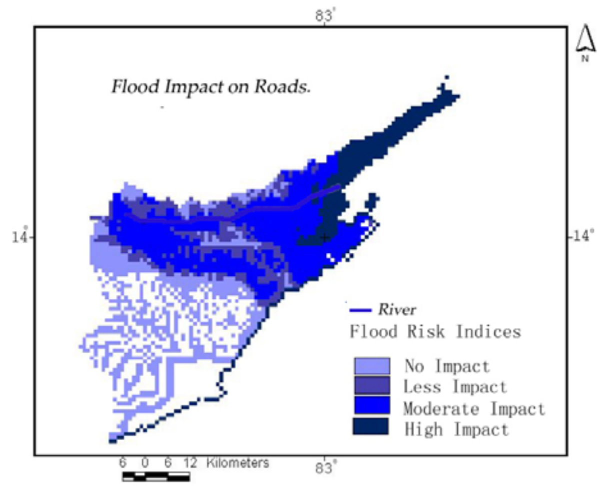

(e)

Figure 11 Hazard map generated for road transportation category (a) 2000, (b 2025, (c) 2050, (d) 2075, (e) 2100

C.6 Links among policy, socio-economic factors, floods and impacts

The policy framework in India that consider the socio-economic and flooding in coastal zone is based on environmental consideration and sustainable development.

The Coastal Regulation Zone notifications and Integrated Coastal Zone Management (ICZM) Plans made under National Environmental Policy (NEP) are responsible for development activities in the coastal areas. In recent years there has been significant degradation of coastal resources, for which the proximate causes include poorly planned human settlements, improper location of industries and infrastructure, pollution from industries and settlements, and overexploitation of living natural resources. In the future, sea level rise due to climate change may have major adverse impacts on the coastal environment. There is need to ensure that the regulations are firmly founded on scientific principles, in order to ensure effective protection to valuable coastal environmental resources, without unnecessarily impeding livelihoods, or legitimate coastal economic activity, or settlements, or infrastructure development. The following actions would be taken for coastal area for environmental conservation and sustainable development in some of the key sectors of development activities. These are:

Revisit the **Coastal Regulation Zone (CRZ) notifications** to make the approach to coastal environmental regulation more holistic, and thereby ensure *protection to coastal ecological systems, coastal waters, and the vulnerability of some coastal areas to potential sea level rise.*

The **Integrated Coastal Zone Management (ICZM)** Plans need to be comprehensive, and prepared on scientific basis, with the participation of the local communities both in formulation and implementation. The ICZM Plans should be reviewed at pre-determined intervals *to take account of changes in geomorphology, economies, and settlement patterns*.

Decentralize the clearance of specific projects to State environmental authorities (up to feasible extent), exempting activities, which do not cause significant environmental impacts, and are consistent with approved ICZM Plans.

Mainstream the sustainable management of mangroves into the **forestry sector** regulatory regime, ensuring that they continue to provide livelihoods to local communities (Forestry).

Disseminate available techniques for **regeneration of coral reefs**, and support activities based on application of such techniques (Biodiversity).

Embody considerations of **sea-level rise in coastal management** plans, as well as **infrastructure planning and construction norms** (Infrastructure development)

Develop a strategy for strengthening regulation, and addressing impacts, of **ship-breaking activities** on coastal and near marine resources (Water Pollution).

Restriction on indiscriminate growth of tourism and strict regulation of the tourist activities in sensitive areas such as islands and coastal stretches (Tourism)

Each coastal State should prepare a comprehensive coastal land management plan, keeping in view the **environmental and ecological impacts**, and regulate the developmental activities accordingly (Coastal land use)

The erosion of land, whether by the sea in coastal areas or by river waters inland, should be minimised by suitable cost-effective measures. The States and Union Territories should also undertake all requisite steps to ensure that indiscriminate occupation and exploitation of coastal strips of land are discouraged and that the location of economic activities in areas adjacent to the sea is regulated (Land degradation).

In view of the need for careful planning of water resources the Government of India adopted the National Water Policy in September 1987 and later updated as draft National Water Policy 1998 which is subsequently approved in 2002 (Dept. of Water Resources, Govt. of Orissa). Some of the salient features are

The water resources planning, development and management will have to be done for a hydrological unit, such as drainage basin as a whole or for a sub-basin multi-sectorally, conjunctively for both surface and groundwater incorporating quantity and quality aspect as well as environmental consideration.

There should be a master plan for flood control and management for each flood prone basin. In highly flood prone area, flood control should be given over riding consideration in reservoir regulation policy sacrificing some irrigation or power benfits.

Water should be made available to water short area by transfer from other area including transfer from one river basin to another based on a National perspective after taking in account the requirement of the areas and basins.

The flood control and management policy under *National Water Policy (2002)* of India is already discussed in section 5.2.5.

In consistence with National Water Policy, the Government of Orissa formulated its State Water Policy of Orissa in the year 1994 so that the state would be able to utilize this renewable resource to its optimal benefit (Dept. of Water Resources, Govt. of Orissa). Some of the objectives of State Water Policy of Orissa (1994) include:

- Provision of flood protection and drainage facilities
- Regulation of land use in flood and drainage prone areas
- There should be a master plan for flood control and management for each flood prone basin. In highly flood prone area, flood control should be given overriding consideration in reservoir regulation policy sacrificing some irrigation or power benefits
- Minimum flow should be ensured in the streams for maintaining ecology and regime of the water course.
- Observance of safety standards in respect of storage dams and other water related structures.
- Formulation of suitable flood and Drainage plan for each Basin

The Ministry of Water resources (MoWR) constituted the National Commission for Water Resources Development in 1996 to prepare an integrated plan for development of water resources based on resource availability and demand patterns and to suggest modalities for transfer of surplus water to water deficit basins. Assessment of groundwater resources and irrigation potential of the country is carried out on a regular basis for different basins. A network of 157 flood forecasting stations covering most of the interstate river systems under the Central Water Commission forecasts the occurrence of floods and inflows. Of the identified 40 million hectares of area susceptible to floods, flood management measures undertaken so far have provided a reasonable degree of protection to about 16.4 million hectares (upto the end of Ninth Five-Year Plan) through measures such as flood embankments and drainage channels. Flood and drought management, and environmental and social impact assessments are an integral part of project formulation and implementation for all water resource planning processes. Recently, the Government of India has launched a research programme in partnership with the UK Department of the Environment, Transport and the Regions, on the impacts of climate change in India. The study seeks to build on India's expertise to assess the sectoral impacts of climate change, reduce uncertainties in the current climate change prediction models and make a valuable contribution to international climate science.

The first manual in the State to manage relief was based on the Famine Commission Report of 1901. It was known as the Bihar and Orissa Famine Code, 1913, having provisions to meet situations arising out of famine conditions and floods. The Code was revised in 1930. The provisions of the Code lost its relevance after independence due to the shift in emphasis from law and order to social welfare and economic development. The Code was further revised in 1996 but there is still scope for improvement (*Chapter 5 –3rd Draft-Disaster management plan, Govt. of India*). There is a need for a more comprehensive approach with focus on risk management and risk reduction for all forms of possible disasters, both natural and man-made.

The provisions of the Orissa Relief Code guide the current arrangements of responses to disasters. Other Acts and codes like Factory Act, Building Code, etc. which guide and provide the necessary statutory powers to various departments/ agencies to plan, implement and enforce various measures which will assist in strengthening the prevention, response and recovery arrangements in the State. The arrangements (particularly in response and recovery) are intended to permit the situation to be assessed, and to provide for the graduated marshalling and utilization of the resources required to deal with it, under systems set up under the relevant overall plan and the participating agencies' own plans.

There are several acts/plans/policies adopted by Govt. of India and subsequently by some of the states which are prone for disasters. The occurrence of floods are almost a regular feature with certain approximate interval in years/months. Whereas other disasters are occasional and may occur by chance. It is not good on the part of the administration to join these disasters under a single organization known as disaster mitigation agency. The steps to be taken in the case of mitigation and management of floods are totally different when compared with other four natural/manmade disasters identified. Hence, there must be a separate policy for flood disaster mitigation and management.

Disaster management policies have taken into account about the importance of climate change and rise in sea level which in turn may have natural disasters. Such phenomena may have strong impact on coastal cities and depending on future projections of the population in the coastal cities, there is every possibility of multiplying impact on human environment. Hence detailed hydrological model studies with distributed data sets must be made and pixel based socio economic losses must be studied in order to have accurate estimation of socio-economic losses that may occur during such climate change devastations.

C.7 Issues, challenges and recommendations

The major issue confronted in achieving the objectives of this study is the difficulty raised due to the lack of availability of temporal, spatial and socio-economic datasets. Moreover, the whole analysis is carried out for the extreme vulnerability condition, i.e., for the future years the analysis has been carried out neglecting the effect of the possible future flood protection measures

The challenges faced at the policy level are stated:

- Lack of awareness among the policy makers about the importance of including global warming in their planning process.
- Inadequate data resource center and unavailability of for assessing coastal vulnerability to climate change.
- Development of adaptation measures which must be consistent with economic development and environmentally and socially sustainable over time.
- Identify the methods of integrating the adaptation policy into national, regional and local development planning and policies.
- Identify the specific adaptation options for dealing with particular climate related hazards which are suitable to the geomorphologic and socio-economic structure of different regions on the Indian coast.
- Development of regional vulnerability indicators for assessing the generic adaptive capacity at particular region based on the finer detail informations (socioeconomic, physiographic, past record of floods, etc.),
- Need to develop scenarios at regional level using regional climate models or downscaling technique which will help policy makers to develop more adequate policies for flood management.
- Need to integrate the diverse scientific assessments and link them with policy-making.

The recommendations emerged out of the symposium are stated:

Restructure the National Policy on flood management reflecting the holistic approach in pre-disaster phase and post-disaster relief and rehabilitation.

Creation of awareness for flood damage reduction is urgently needed amongst policy makers, administrators, professionals, financial institutions, NGOs and voluntary organisations at different levels.

Appropriate amendments in the legislative and regulatory instruments along with strengthening of the enforcement mechanisms at different levels.

Capacity building at local and regional levels for undertaking rapid-assessment surveys and investigations of the nature and extent of damage in post disaster situations.

Preparation of hazard and vulnerability maps of flood prone areas with enhanced community participation at all levels community, panchayat, block and district.

Making mandatory, the use of disaster resistant codes and guidelines related to flood resistant construction/renovation in the houses and buildings in the society by law and through incentives and disincentives with the help of local bodies/panchayats.

To create a suitable institutional mechanism at national/state level to advise and help the existing disaster relief set up in formulation and updating of short and long-range action plans for the preparedness, mitigation and prevention of natural disasters.

To promote the study of natural disaster prevention, mitigation and preparedness as subjects in academic and research institutions.

To create a disaster management database centre with the involvement of multiple disaster management agencies with the prime objective of creating, compiling and updating disaster related database and bringing together experts and expertise of various disaster managers on a common platform.

To develop appropriate policy instrument and funding support for urgent flood disaster preparedness and prevention actions in high risk areas including upgrading the resistance of existing housing and related structures and systems.

More emphasis should be given on Research and Development work in flood management as a thrust area in academic institutions with the help of funding agencies to build on the existing skills and knowledge of communities and other expertise in the field and developing sustainable and cost effective solution.

To develop pre-disaster pro-active approach through Local and Community Based Flood Preparedness and Mitigation Porgrammes.

Inter-district and inter-state coordination need to be developed by each district and coordinated by state disaster management authority i.e. OSDMA.

More emphasis should be given to community health condition (children and women) providing perspectives on long-term solutions.

Extension of case study (general recommendation)

Flood mitigation and management policy must be different from disaster management policy – own identity, own resource.

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Appendix D: Pakistan Case Study

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The Islamic Republic of Pakistan emerged on the map of the world as an independent sovereign state on 14^{th} August 1947. It lies between $23^{0}35'$ to $37^{0}05'$ north latitude and $60^{0}50'$ to $77^{0}50'$ east longitude (Figure 1). Although Pakistan stands sixth in terms of population (159 million, 2005) and 26^{th} in terms of GDP (US$347.3 Billion) [World, 2001], yet it possesses the largest contiguous irrigation system in the world. Agriculture dominates Pakistan's economy; contributing 24% of Pakistan's gross domestic product (GDP), 70% of total exports, and employing 50% of the labour force. Pakistan has a total land area of 796 km^2. About one fourth, 221 km^2, is cultivable, of which about 73% (162,000 km^2) is irrigated [Population, 2005]. The Indus Irrigation System, commanding 63% (140 km^2) of the total cultivable area, generates about 90% of the nation's total value of agricultural output. The water resources availability in the country is depicted in Table1.

Table 1: Average inflows and water use in the Indus Basin [World Bank, 2004]

Inflows into the system from rivers and tributaries	176.54 BCM	100%
Diversion to canals	128.03 BCM	72.5%
Outflow to the sea	36.30 BCM	20.6%
System Losses	12.21 BCM	6.9%

Figure 1: The map of Pakistan showing
Karachi City

Pakistan has been bestowed with the mighty mountains of Hindukush and Himalaya in the north and west, lush green plains in the centre and deep

Arabian Sea in the South. Pakistan is divided into four provinces viz. Sindh, Punjab, North West Frontier Province and Balochistan. It consists of such physical regions as:

a) the western offshoots of Himalayas which cover its northern and north western parts of which the highest peak K-2 rises to 8611 meters above sea level;

b) the Balochistan plateau

c) The Potohar Plateau and salt range and d) The Indus plain, the most fertile and densely populated area of the country. It gets its sustenance from the Indus river and its tributaries.

Climatically, Pakistan enjoys a considerable measure of variety. North and north western high mountainous ranges are extremely cold in winter while the summer months of April to September are very pleasant. The plains of the Indus valley are extremely hot in summer with a cold and dry weather in winter. The coastal strip in the South has a moderate climate. There is a general deficiency of rainfall. In the plains annual average ranges from 16 cm in the northern parts of lower Indus plain to 120cm in the Himalayan region. Rains are monsoonal in origin and fall late in summers. Due to the rainfall and high diurnal range of temperature, humidity is comparatively low. Only the coastal strip has high humidity. The country has an agricultural economy with a network of canals irrigating a major part of its cultivated land. Wheat, cotton, rice, millet and sugar cane are the major crops.

D.1 Coastal zones and floods in Pakistan

The coastal zone of Pakistan is extended over a length of 1,046 km in between 62 ^{o}E to 68 ^{o}E longitudes. The coast line of Balochistan province is situated on 25.5 ^{o}N Latitude, whereas for Sind Province it is at about 24 ^{o}N. As for as the geology of the coast line area is concerned, it mainly consists of the quaternary sedimentary rocks and tertiary sedimentary rocks. The average January temperature is 18 ^{o}C, whereas it is about 27-32 ^{o}C in June, which is hottest month for the coastal area. The January air pressure on the coast line is about 10,000 N/m^2, whereas, it is about 9,000 N/m^2 in July. The climate of the area can be classified as arid with warm summer and mild winter. The average annual rainfall over the coast line varies from 125-250mm. The monsoon rainfall varies 25-250mm, whereas the winter rainfall varies 25-125mm. The monsoon rainfall increases with the increase in longitude along the coast line, whereas, winter rainfall decreases with the increase in longitude. As for as vegetation and soils are concerned, it is mainly tropical thorn and mangroves, whereas the soils along the coast lines are shallow loamy gravely soils and rock outcrops of plateaux and loamy sandy and gravely soils of river valleys and alluvial cones. The urban population along the coast line varies from 10 to more than 400 persons per Km^2. The coastal line region does not produce any crop and fruits etc. As for as natural hazards are concerned, the entire length of the coast line is subjected to tropical cyclones. As for as environmental aspects are concerned, for a long portion of the coast line it contains the unsafe drinking water and near Karachi area there is marine pollution.

Localized and widespread floods are common in Pakistan, especially in the Indus Basin Plains. Monsoon currents originating in the Bay of Bengal and resultant depressions often cause heavy downpour in the Himalayan foothills.

These are additionally affected by weather systems from the Arabian Sea (by seasonal lows) and from the Mediterranean Sea (through westerly waves), which occasionally produce destructive floods in one or more of the main rivers of the Indus system. Furthermore, exceptionally high floods have also been experienced due to the overtopping/breaching of some of the small dams, both man made (e.g. Shadi Kor dam in Pasni breached on 11.2.2005 washing away 80 people) and those resulted by the landslides and avalanches.

D.2 Study area

For the present study the coastal city selected from Pakistan is Karachi based on various factors as have been discussed earlier in the report. Karachi is the most populous as well as a city of highest population density in Pakistan (average population density of 6666 persons/ km^2). The total population of Karachi in 1998 was reported as 9.856 million with 9.33 million urban population and 0.517 million as rural population [Population Census, 2002]. The present (2005) estimated population of Karachi is 12 million with a population growth rate of about 4 %. Karachi is the largest city of Pakistan and the capital of the province of Sindh. It is the financial and commercial hub of Pakistan. The city is located on the Arabian Sea north west of the mouths of the Indus River. The geology of Karachi consists mainly of sedimentary rocks having two ranges namely Kirthar range and Pab range. The soils of Karachi City are classified into two types; the loamy sandy and gravilly soils of river valleys and alluvial cones near the coast line and shallow loamy gravelly soils and rock outcrops of plateaux. The southern part of the Karachi district has the swamps.

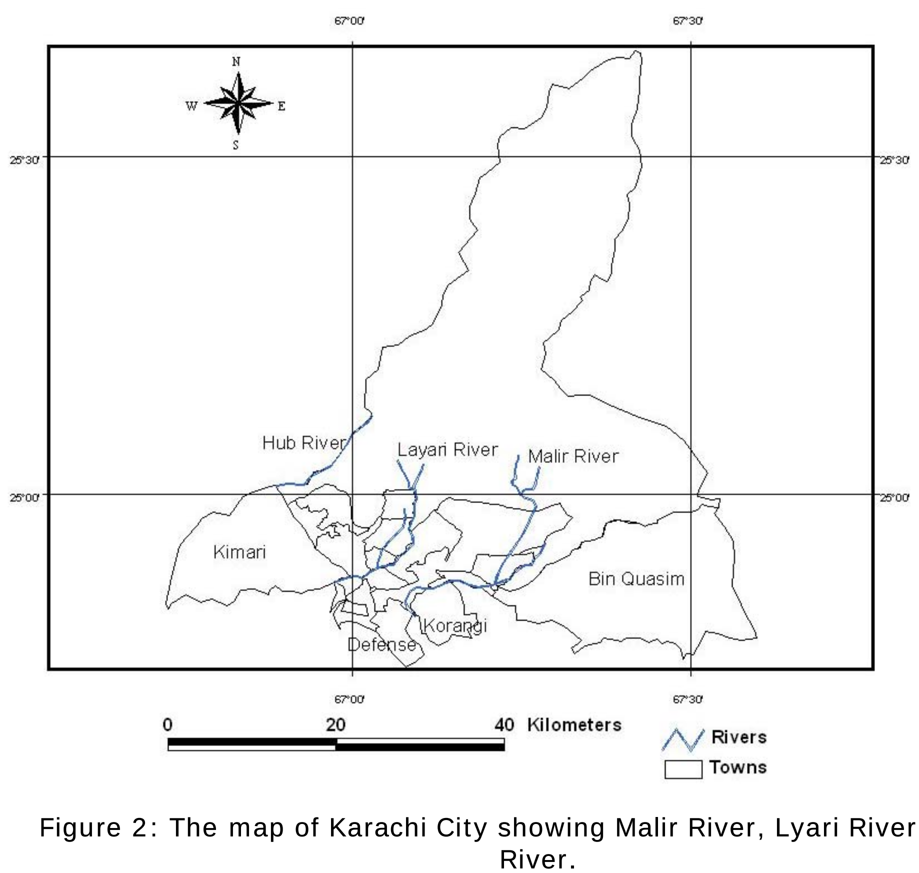

Figure 2: The map of Karachi City showing Malir River, Lyari River and Hub River.

Karachi lies in the semi arid zone and its rainfall is highly variable both in intensity and duration. In some years it has been as high as 750mm while in others it was a few centimeters. However because of its location in the coastal belt, rainfall of high intensity is experienced on occasions. There is no fixed cycle for the occurrence of these occasional heavy downpours. They are dependent upon the local atmospheric disturbances in the sea which occur from time to time.

Though floods are common in various parts of the Pakistan particularly along the river Indus and its tributaries, most of the flood events appear in Monsoon season due to the snow melting and monsoon rainfalls. The River Indus flows much away from the Karachi City, so no impacts of flooding appear on the study area due to flooding in River Indus.

Floods in Karachi City are rare, and are only result of heavy rainfall over the city area. There are two main non perennial rivers crossing the thickly populated city areas before outfalling into Arabian Sea, the Malir River and Lyari River. The map of the city, depicting the layout of these two (Malir and Liyari) along with another the Hub river, is shown in Figure 6.2. Hub River lies on western boundary of Karachi and new settlements are now reaching this boundary due to shortage of land in the inner city. In monsoon season, Malir and Lyari River are seen flooded and there are katchi abadies settled along the banks of the rivers and some industrial units. Also due to insufficient drainage capacity of the storm sewer network water stays over the roads for few days after severe rainfalls and slightly disturbs the daily life routines and slight damages to the road network. The catchment of Malir river is comparatively larger and extends up to 112 km towards north of Karachi, whereas catchment area of Lyari river is very small and flood water reaches the city soon after the rain, with little warning time.

D.2.1 Hydrometeorological characteristics

The weather of Karachi City is tropical, with average January temperature of 18 ^{o}C, whereas it is 32 ^{o}C in June. The January air pressure on the Karachi area is about 1000 millibars, whereas, it is about 900 millibars in July. The climatology of the city may be classified as arid with warm summer and mild winter. Average annual rainfall over the city varies from 25-250 mm. The monsoon rainfall varies 125-250 mm, whereas winter rainfall is about 25 mm. on the city area.

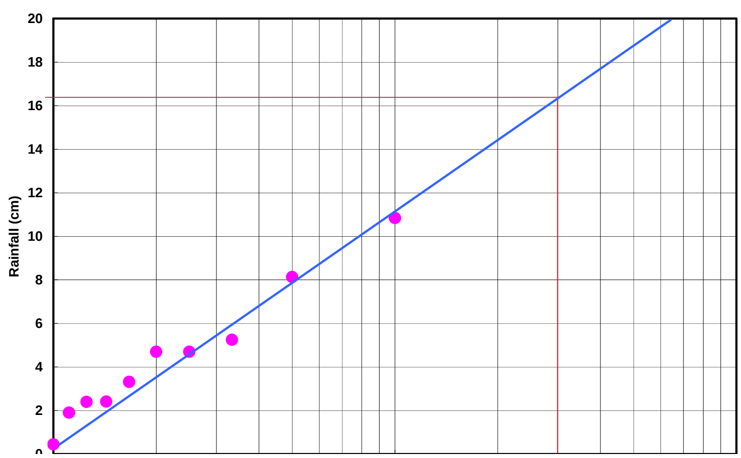

Figure 3: Rainfall frequency analysis for the Karachi City

Department, Karachi for the Karachi air port for ten years (1994-2003). Based on this ten year data record, the maximum observed daily precipitation is 108 mm some time in July, 2003, whereas the average daily precipitation for the Karachi City is computed as 0.4 mm. Based on ten years data record, the annual precipitation for the Karachi City comes equal to 161 mm. The frequency analysis was also carried out for the Karachi City and it was found that the precipitation over this area is 163 mm for a return period of 30 years as shown in Figure 3. Based on 10 years data record, the Probable Maximum Precipitation (PMP) is computed as 511 mm.

D.2.2 Socio-economic characteristics

Karachi is the financial capital of Pakistan. It is also home to the largest stock exchange of Pakistan: the Karachi Stock Exchange. Most Pakistani banks have their headquarters in Karachi. The headquarters of nearly all the MNCs (multi-national companies) based in Pakistan are located in Karachi, along with the headquarters of most of the Pakistani corporations.

Karachi also has a huge industrial base. There are large industrial estates on most of the fringes of the main city. The main industries are textiles, pharmaceuticals, steel, and automobiles. Apart from this there are many cottage industries in the city as well. Karachi is also known as software outsourcing hub of Pakistan.

Currently, the Karachi Port is the only deep port in Pakistan, and is central to all shipping in Pakistan. Plans are underway to build a motorway linking Karachi to the rest of the nation but it will be some times before it gets to Karachi. The port is not used for passneger traffic as a regular service. The airport of Karachi, Quaid-e-Azam International Airport is also the largest airport in Pakistan and the hub of most local airlines. For years it served as the gateway to Asia with all major airlines operating from the Airport. The airport has potential to act as the major logistic hub for the region but bureaucracy and internal and geo-political compulsions undermine the efforts. Apart from the Quid-e-Azam international Airport, Karachi also have two more airstrips, but not used for commercial flights.

Karachi is linked via railway to the rest of the country. Karachi City and Karachi Cantt are the two major junctions / railway stations of the city. Karachi also has a circular railway system that is going to be extended and made functional shortly. This will form the backbone of the city's mass transit system.

Karachi is the nerve centre of Pakistan's economy and is pinnacle to any economic activity. The economic stagnation due to ethnic strife in the 1980s and 1990s led to mass efflux of industry from Karachi and resulted into economic stagnation of the country despite some revival and economic boom in the up country. Karachi has a well developed Free Zone with growth rate of nearly 15% year on year. Karachi accounts for the lion's share of Pakistan's GDP. The city is said to contribute about 48 percent of the national revenues.

Karachi has the highest literacy rate, the highest number of universities and colleges than any of Pakistan's other districts. The city is well-known for its young student population who flock from all parts of Pakistan and different parts of the world.

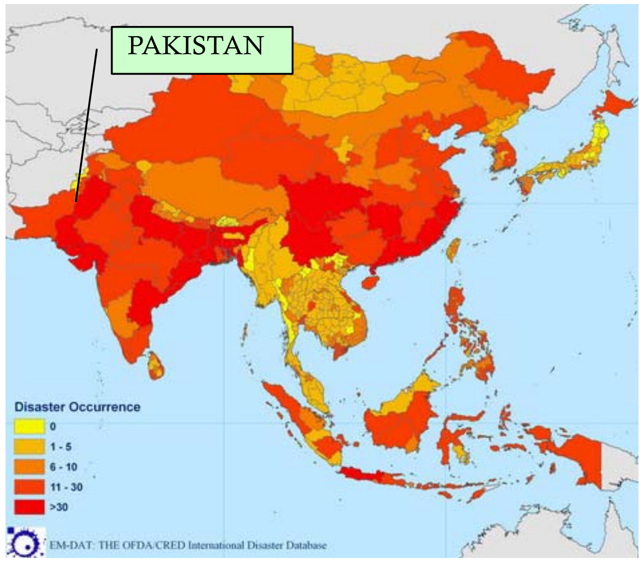

Figure 4: Natural disasters occurrence 1975-2004 [EMDAT 2005(b)].

D.2.3 Flood history and vulnerability

Pakistan has long history of flooding, both in pre-independence era (prior to 1947) and in post independence period. It is one of the five South Asian countries with the highest annual average number of people physically exposed to floods, which occur normally due to storm systems that originate from Bay of Bengal during the monsoon from July to September [WCDR, 2005]. Flood events of 1950, 1992 and 1998 caused thousands of deaths and billion of dollars of losses to the national exchequers in addition to uncountable human sufferings.

Data regarding disasters and flooding from various sources [EM-Dat, Dartmouth, The DAWN, Flood] clearly mark Pakistan as a country highly vulnerable to floods and other kinds of disasters (Figure 4). A number of national and international sources have reported the financial losses, since 1947, due to floods of the range of US$ 2-10 Billion.

Table 2: Top ten disasters of Pakistan by causalities and by # of people affected

(Source:"EM-DAT: The OFDA/CRED International Disaster Database, www.em-dat.net - Université catholique de Louvain - Brussels - Belgium")

Disaster	Date	Killed	Disaster	Date	Affected
Earthquake	31-May-1935	60,000	Flood	Sep-1992	12,324,024
Wind Storm	15-Dec-1965	10,000	Flood	9-Feb-2005	7,000,450
Earthquake	28-Dec-1974	4,700	Flood	9-Aug-1992	6,184,418
Earthquake	27-Nov-1945	4,000	Flood	2-Aug-1976	5,566,000
Flood	1950	2,900	Flood	Aug-1973	4,800,000

Disaster	Date	Killed	Disaster	Date	Affected
Flood	Sep-1992	1,334	Flood	Jul-1978	2,246,000
Flood	3-Mar-1998	1,000	Drought	Mar-2000	2,200,000
Flood	Jun-1977	848	Flood	19-Aug-1996	1,300,000
Wind Storm	14-Nov-1993	609	Flood	22-Jul-2003	1,266,223
Flood	Jul-1995	600	Flood	22-Jul-1995	1,255,000

Natural calamities like floods, earthquakes, windstorm and droughts are the main reason of colossal losses in Pakistan (Table 2), hampering the Government's struggle to improve socio-economic condition of the population. Floods are by far the major sources of human sufferings (more than 41.9 millions are affected by floods only) in Pakistan, although not the major source of causalities [EM-DAT (a)].

As per data collected by Pakistan Water Gateway, the agency responsible for making database regarding water sector of Pakistan, the damages due to floods since independence are of the orders of Pak Rs. 225 Billion (US$1 approx equal to Pak Rs. 60) (1955 price level) and lives lost are 7,706 [Floods, 2005]. A summary of the major floods experienced in Pakistan is provided in Table 3.

Table 3: Major floods and damages in Pakistan.

Year	Monetary Losses (Billion Rs. at 1955 price level)	Lives Lost (No.)	Villages Affected (No.)	Area Flooded (miles^2)
1950	9.08	2,910	10,000	7,000
1955	7.04	679	6,945	8,000
1956	5.92	160	11,609	29,065
1973	5.52	474	9,719	16,200
1975	12.72	126	8,628	13,645
1976	64.84	425	18,390	32,000
1978	41.44	393	9,199	11,952
1981	N/A	82	2,071	N/A
1982	N/A	350	7,545	N/A
1988	15.96	508	100	4,400
1992	56.00	1,008	13,208	15,140
1995	7.00	591	6,852	6,518
1998	N/A	47	161	N/A
2001	N/A	201	0.4 million. *	N/A
2003	N/A	230	1.266 million *	N/A
2005	N/A	350 +	60,000 * +	N/A

* no of people affected.

+ from newspapers clippings [The Dawn (a), (b), (c), The Pakistan Times].

╕ (US$1 approx equal to Pak Rs. 60)

A similar figure is quoted by a latest policy document of Pakistan 'The Water Sector Strategy, 2002' [Min of WandP, 2002]. It has reported that the economic losses due to flooding since independence (1947) are around US$ 10 Billion. A

WHO funded comprehensive database of disasters in Pakistan [EMDAT, 2005(a)] reports the financial losses of US$ 2.7 Billion and human losses of over 11,600 (due to floods only). Details of other losses due to 46 reported flooding events are shown in table 4.

Table 4: Various kinds of losses due to flood event in Pakistan [EMDAT, 2005(a)]

	No of event	Killed	Injured	Homeless	Affected	Total Affected	Damage US$ (000's)
Flood	46	11,661	1,242	8,923,985	38,148,374	47,073,601	2,746,030
Average per event		254	27	194,000	829,313	1,023,339	59,696

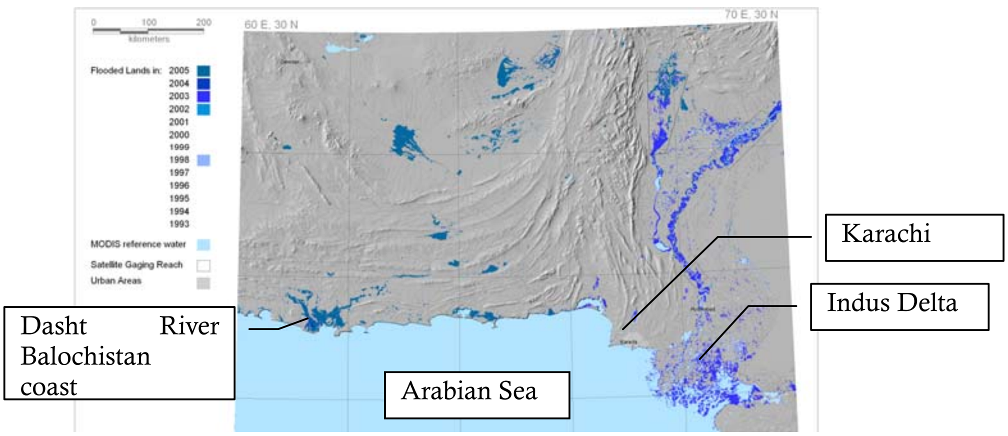

Figure 5: History of flooding in Pakistan (inland and coast) through satellite images [Dartmouth, 2005]

In previous couple of years (2001-2005), Pakistan has experienced some of the major floods, both localized and widespread. A composite of satellite images of flooding in various years (2001-2005) is shown in Figure 5, to underscore the vulnerability of the country to the natural as well as man made flooding.

Karachi:

The flood susceptibility of the Karachi City is the least among all other coastal cities selected for this study due to having relatively small annual rainfall and because Karachi is located outside of the Indus Basin, the major source of flooding in Pakistan. Having said that, the concentrated spell of rain in the catchment of Malir river and Liyari rivers, occasionally cause flash floods affecting the thickly populated areas on both sides of these rivers. Such flooding have been experienced in 1967, 1973, 1977, 1978, 1984 1989 and in 2003. The flashy nature of the streams of Karachi is shown in Figure 6.6 depicting the rainfall in the catchment of Malir river and the resulting discharges at one of the river gauging station namely Super Highway Bridge with contributing catchment area of 2,240 km^2. Although rainfall in Karachi is comparatively lower than other Asian cities in this study, yet due to major economic hub, being home to nearly 10% of population of Pakistan and due to proximity to Arabian Sea, Karachi is more vulnerable to flood damages than any other city of Pakistan.

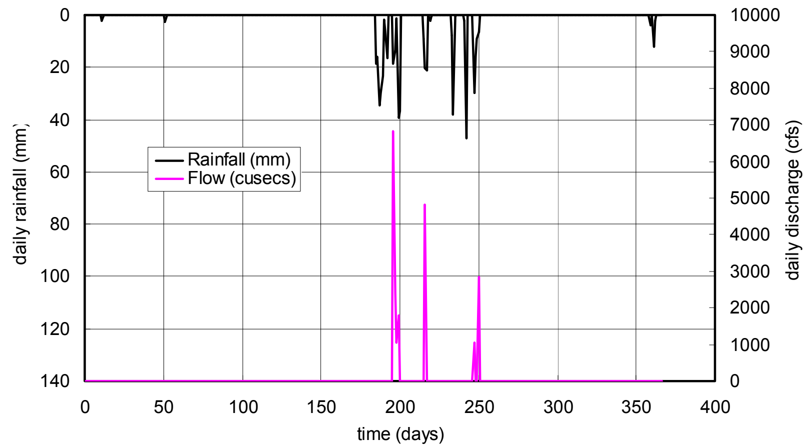

Figure 6: Flash floods in Malir river at Super Highway Bridge gauging station

The largest damages due to floods in Karachi are caused in 1977 due to the abnormal rainfall of 30th June, 1977 (254 mm in one day). The discharges of flood waters on that day for Malir river and Lyari rivers were estimated as 6,380 and 1,420 m^3/s, respectively. The flooding of the Karachi City results in huge losses due to synergetic effects of; absence of flood warning system, encroachment in flood plains, concentrated rain and the flashy nature of the rivers (high slopes of upper catchment). Rainfall in the upper catchment only and no rain in lower catchment (like what happened in 1977) results in a surprise flood for the inhabitants of the city in absence of proper warning system. Due to these reasons the losses of life and property due to 1977 flood were quite high. Only in Karachi, about 300 persons were washed away [Iqtidar, 2005], while it claimed 848 lives in Pakistan(Table 2) and about 350 industrial units in Korangi including National Oil Refinery sustained damages to the extent of US$ 16.7 Million.

Another kind of disaster is flooding due to Cyclones in Arabian Sea having potential to cause large-scale damage to the coastal areas of Sindh and Balochistan. The World Conference for Reduction of Disaster [WCDR, 2005] reports that the cyclone of 1999 in Thatta and Badin districts wiped out 73 settlements, and resulted in 168 lives lost, nearly 0.6 million people affected and killing of 11,000 cattle. It destroyed 1,800 small and big boats and partially damaged 642 boats, causing a loss of Rs 380 million (US$1 approx equal to Pak Rs. 60). The losses to infrastructure were estimated at Rs. 750 million . The period 1971-2001 records 14 cyclones.

The concept of ‘vulnerability’ is very important in understanding the effects of floods and to design the means to reduce these effects. Different researchers have defined vulnerability in their own context. The concept of vulnerability is, however, the subject of much debate [Green, 2000] and there are a variety of definitions, three of them are:

Blaikie et. al. (1994) defines vulnerability as: ‘the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard’. Thus high vulnerability means high losses, without any concern with quantum and nature of flood, which is a drawback of this definition.

Vulnerability can also be defined as a characteristic of the flood to which that population is exposed (e.g. the floods magnitude, speed of onset etc.). Thus a flood of certain characteristics will make population of all kinds (e.g. rich and poor) at same level of vulnerability, which a serious drawback of this definition.

Vulnerability is also defined as a function of both flood characteristics and the capacity of the people to cope with it. This definition is more comprehensive and comprehends both the nature of the flood and the characteristics of the population at risk.

In case of Pakistan, although maps are available which present the extent of historically flooding at country level, no large scale systematic study has been done to show the extent of flooding of various return periods at country level especially in urban areas. As such no flood risk zoning maps are available at country level. Similarly the resilience (opposite of vulnerability) is also not studied at country level. Thus only a general view of the vulnerability can be presented in this report.

In Pakistan, as in other countries the group of people who are at low income level and who live in or around the flood plains and coastal areas are more vulnerable to flooding. As Pakistan's 30% population is below poverty level [World Bank, 2005] and more are at border line of poverty, these are the group of people which need immediate attention of planner. Also areas susceptible to more economic losses (like urban centres) are also highly vulnerable and special measures are required to protect them.

D.2.4 Existing flood disaster mitigation measures

Institutions:

Up to the end of 1976, the provincial governments were responsible for the planning and execution of flood protection works. The disastrous floods of 1973 and 1976 causing heavy losses (claiming above four hundred lives each) indicated that the protection facilities and planning at that time were inadequate[WCDR, 2005]. It resulted the creation of the Federal Flood Commission (FFC) in January 1977. It is the principal institution for flood protection planning and control in Pakistan. Its mandate includes the preparation of the national flood protection plan, approval of flood control schemes, review of flood damages, plans for reconstruction works, improvements in flood forecasting and warning system, monitoring and evaluation, etc.

Other institutions that play a major role in flood management are Provincial Irrigation and Drainage Authorities (PIDAs) / Provincial irrigation Departments (PIDs), Water and Power Development Authority (WAPDA), Provincial Relief Organizations, Pakistan Army, Pakistan Commissioner for Indus Waters, Emergency Relief Cell and National Flood Forecasting Division (Figure 6.7). A brief description of responsibilities of the major organizations (as for as flood mitigation is concerned) is given below:

Federal Flood Commission (FFC): The Federal Flood Commission (FFC) was created in 1977 in the Ministry of Water and Power. It is the only department who is fully dedicated to planning the flood control, mitigation and monitoring functions. Its major responsibilities are:

- Preparation of flood protection plans for the country
- Approval of flood control / protection schemes prepared by provincial governments and concerned federal agencies
- Recommendation regarding principles of regulation of reservoirs for flood control
- Review of damage to flood protection works and review of plans for restoration and
- reconstruction works
- Measures for improvement of flood forecasting and warning system
- Preparation of a research program for flood control and protection
- Standardization of designs and specifications for flood protection works
- Evaluation and monitoring of progress of implementation of the National Flood Protection Plan

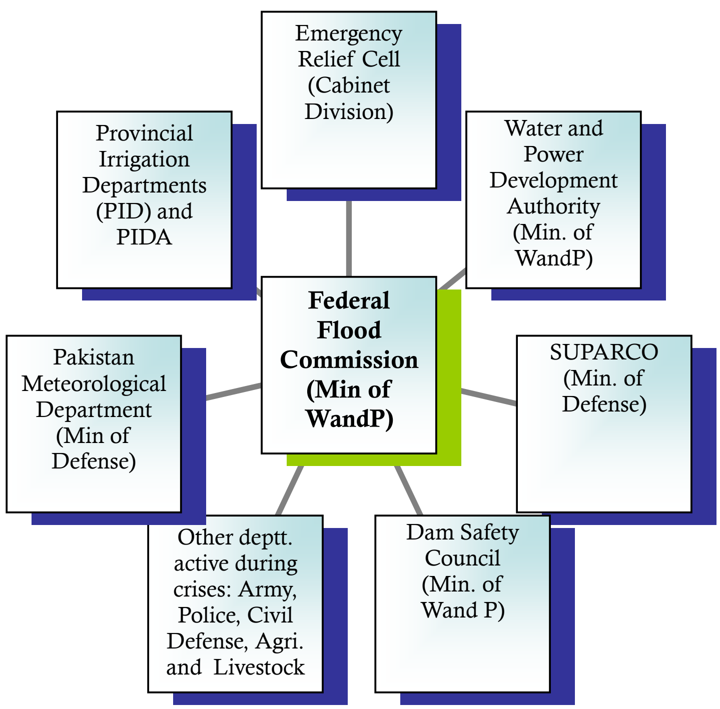

Figure 7: Organizations responsible for flood mitigation in Pakistan

- Monitor the provincial government's implementation of the national Flood Protection Plan.
- The federal government provides the resources for meeting the capital cost of the project(s)

Emergency Relief Cell (ERC): ERC is a cell in cabinet secretariat (the Prime Minister Secretariat) Islamabad under the supervision of cabinet secretary, in order to carry out coordination during the emergency situation of any kind, including flooding. Responsibilities of the ERC in connection with Flood relief are:

- To provide in cash as well as in kind to supplement the resources of the provincial governments in the event of major disasters
- To coordinate the activities of the Federal Division, Provincial Governments, as well as governmental, semi governmental, international and national aid-giving agencies, in the conduct of operations for relief of disasters
- To maintain contact with international aid-giving agencies/ voluntary organizations and donor countries for disaster relief measures
- To administer Relief Funds, being maintained at the Federal Level
- To stockpile certain items of basic necessity and establish central inventory of resources
- To provide assistance to the calamity stricken friendly countries

Pakistan Meteorological Department: The Meteorological Department is a scientific as well as a service department, and functions under the Ministry of Defense. It is responsible for providing meteorological service throughout Pakistan. The major functions of the Meteorological Department are to provide information on meteorological and geophysical matters with the objective of disaster mitigation due to weather and geophysical phenomena, agriculture development based on climatic potential of the country, prediction and modification of weather forecast. The department has established:

- A network of observing stations to generate meteorological, geophysical and phonological data.
- A telecommunication system for speedy dissemination of data
- Meteorological offices to analyze data for issuing forecasts and warnings for aviation, agriculture, shipping, sports, irrigation etc.
- Climatologic data processing units for scrutinizing, comparing and publishing data for appraisal of long term weather trends and earthquakes.
- The department has introduced a modern flood forecasting system using dynamic hydrological models and telemetric data acquisition system.

Civil Defense Department: The Civil Defense Department was established through an ordinance in 1951. It is now governed through 1952 Civil Defense Act. Since 1993 it is assigned with an additional task during peace times to take remedial measures against natural or man-made disasters. Specifically, the Civil Defense is to:

- assist local administration / Army in rescue, evacuation and relief measures
- supplement anti-flood equipment of Army
- Provide personnel for anti flood training in rescue and relief work

Provincial Relief Departments: Provincial relief departments have similar functions as ERC in the center, i.e. to coordinate the relief efforts during crises. Its major duties are:

- Provide adequate resource support to area Administration through co-ordination with Provincial Government Departments / Agencies
- Provision of necessary funds to the area administration for relief work
- Oversee the working of area administration for relief work
- Obtain field reports of losses and apprise the Provincial Government / Federal Government
- Assess and evaluate losses and suggest to the Federal / Provincial Governments for providing relief to the affected persons

Provincial Irrigation Departments: Although their major duty is to irrigation and drainage but at the same time Provincial Irrigation Departments (PID's) are responsible for construction and maintenance of batteries of flood protection embankment and spurs in the respective provinces. As such their duties with respect to flood mitigation and relief are:

- Complete repairs of the flood protection works in the pre-flood season
- Provide funds to the Army for replenishment of stores
- Review the plan for regulation of water supply
- Position requisite machinery and material at safe localities near vulnerable points for emergency repairs
- Inspection of breaching sections and carrying out final survey

Army: Pakistan Army help the civilian Government in all times of natural crises including flooding. Their functions regarding flood mitigation are:

- Survey and inspect flood protection works
- Assess resources for relief, rescue and evacuation work
- Position personnel, material and equipment at planned pre-determined location
- Review and revise flood protection and relief operation plans
- Train civil / military power boats operators
- Review the logistics of ration, POL, arms and ammunition, medical cover, tentage, communications and allied measures for movement of troops in aid of civil powers
- Set-up flood emergency cells at each corps headquarters
- Carry out rescue and evacuation operations during emergencies

Police Department

Operate through Police Telecommunication the wireless and tele-printer network for flood information and messages to all concerned departments and agencies

Ensure law and order during flood emergency

Provide assistance in flood warning, rescue, relief and evacuation operations

Space and Upper Atmosphere Research Commission (SUPARCO): SUPARCO undertakes studies / surveys on environment and has developed natural hazard monitoring system that deals with thunderstorms, floods, drought and desertification. It also keeps tracks of the movements of tropical cyclones in the Arabian Sea. By using satellite images, cloud cover and rainfall data, SUPARCO monitors drought conditions in Pakistan. Satellite Remote Sensing has been used to monitor and map flood risk zones in order to enable the flood risk zones management agencies to take remedial measures to minimize damages to population and property.

In addition to the above mentioned departments, other Government functionaries, which play their role in flood disaster mitigation are;

Provincial Health Departments: to avoid the spread of epidemics and to provide the necessary health services.

Provincial Agriculture and Livestock Departments: to assist in saving crops, agriculture land and livestock in disaster situation

Provincial Food Departments: to ensure adequate availability of food stocks in disaster situation

Communication and Works: to organize emergency repairs for restoration of public transport routes

Dams Safety Council: to carry out periodic inspections of dams and advise WAPDA and provincial governments regarding repairs and maintenance of dams and reservoirs

Emergency Relief Cell has distributed a total amount of about Pak Rs. 1.2 Billion (about US$ 19.6 Million at exchange rate 1US$ = 60 Pak Rs.) to flood and rain affected population from 1996 till 2003. Area wise detail of this distribution is shown in table 5. Similarly to help the flood affected population, the items necessary for livelihood (blankets, tents, beds etc) were distributed in bulk quantity during each flood event. The statistics of a typical flood event of 1996 shows (Table 6) that about six thousands blanket and more than 2300 tents were distributed to flood affected people in various parts of Pakistan.

Table 5: Relief assistance (in cash) through Emergency Relief Cell since 1996 (Rs. in millions) (Ref: WCDR, 2005)

Year	Disaster	Punjab	Sindh	NWFP	Balochistan	AJK	NAs	FATA
1996	Flood	66.211	-	1.709	11.05	-	-	1.098
1997	Flood and Earthquake	237.476	0.541	7.913	15.142	0.810	11.787	-
1998	Flood	-	-	-	21	100	-	-
1999	Cyclone	-	500	-	-	-	-	-
2001	Rain/Flood	20	-	20	-	-	-	-
2003	Rain/Flood	-	110	-	50	-	-	-
Total		323.687	610.541	29.622	97.192	100.81	11.787	1.098

Table 6: Items distributed as flood relief measures during 1996 Floods (Ref: WCDR, 2005)

Sr. No.	Item	Punjab	Balochistan	Northern Areas	Azad Jammu Kashmir
1.	Tents (No)	1000	700	500	150
2.	Blankets (No)	2000	2000	2000	-
3.	Bed Camp (No)	300	-	-	-
4.	Ground Sheet (No)	241	-	-	-
5.	Utensil Sets (No)	92	-	-	-
6.	Musaffa (Water disinfectant) (Bags)	525	-	-	-

Structural measures:

Since the creation of FFC, the majority structural interventions in flood protection schemes are covered under National Flood Protection Plans as under;

- National Flood Protection Plan I (1977-87) worth Pak Rs. 1.767 billion
- National Flood Protection Plan II (1988-98) worth Pak Rs. 7.576 billion
- Presently country is running the medium term development plan know as
- Ten-Year Perspective Development Plan (2001-2011)

*(1US$ = 60 Pak Rs.)

Extensive efforts have been made under above mentioned plans and schemes to train the rivers and protect the adjoining areas from river erosion and flood damages. Physically this has been done with the help of a network of embankments/levees reinforced by various types of spurs. To safeguard the areas from inundation, about 5,600 km of embankments have been constructed along major rivers and their tributaries in Pakistan. In addition, more than 600 spurs have been constructed to protect these embankments. Province wise detail of these structures is given in table 7.

Table 7: Embankments and spurs constructed in Pakistan

Province	**Embankments (km)**	**Spurs (Nos.)**
Punjab	2,690	408
Sindh	2,378	35
NWFP	250	171
Balochistan	277	-
Total in Pakistan	**5,595**	**614**

(Ref: http://www.waterinfo.net.pk/)

The current Ten Year Perspective Development Plan (2001-2011) envisaged to construct 303 spurs and 1101 km of flood embankments. In addition improvement of flood warning systems will be carried out. During the current three-year program (2002-05), 240 and 68 km of flood embankments were planned to be constructed to safeguard the life and property.

Karachi:

After the occurrence of 1977 flood in Karachi, consequently the Government appointed a Technical committee to examine the problems of Rainstorm Flood flows and to determine the suitable flood control measures for Karachi. On the recommendations of this committee, the "Karachi Flood Control and Drainage Commission" was constituted in November, 1977 and preparation of "Karachi Flood Control Plan" was entrusted to WAPDA. The WAPDA after conducting Hydraulic model studies and finalizing the feasibility studies provided complete plan called "Karachi Flood Control".

In the light of feasibility report and design prepared by the WAPDA, the Government of Sind, Pakistan decided to construct embankments on both sides of Malir river. It was taken up by the Karachi Development Authority and was completed successfully in five different phases. The flood protection embankment on the left side of the Malir river is shown in Figure 8.

In addition to this, the river training works were also executed on the Malir river between the portions from National Highway Bridge up to seashore thereby saving the thickly populated adjoining areas from flood hazards. The two other recommendations of the Plan vis-à-vis construction of a by pass channel and construction of delay action dams upstream have yet to be materialized.

Secondly, the construction of Express road has been taken up by the government on both banks of Lyari river which is in under progress. By virtue of this express road both banks of Lyari river would be strengthened and would provide protection against floods if occurred in Lyari river.

The present City Government is planning to convert the dry river-bed (presently) of the Malir river into a man-made forest [Iqtidar, 2005]. The Karachi Nazim (Mayor) had indicated once to convert the dry river-bed of the Malir river into a lively park. Any such action which will be encroaching the river width will be a disaster if proper hydrological studies are not carried out.

Figure 8: Flood protection embankment on the left side of the Malir river

D.2.5 Existing flood risk management policies

Pakistan:

Since floods are almost a routine annual feature in the monsoon season in the areas lying along the rivers and their basins, the government had a two-pronged flood management strategy, which is still being practiced. The flood management is carried out through Structural measures and Non-Structural measures. Structural measures include:

- Construction of embankments
- Construction of spurs / battery of spurs
- Construction of dikes / gabion walls / flood walls
- Construction of dispersion / diversion structures
- Channelization of flood waters
- Construction of delay action dams
- Construction of bypass structures
- Non-structural measures include:
- Improved flood forecasting system through:
- Effective data collection and dissemination system
- Real time rain fall and river flow data collection
- Weather radar prediction
- Modern system of transmission of flood forecasts and, Improved early flood warning system:
- Based on effective flood forecasts, early flood warning is issued
- Reliable interaction between all related flood control and relief agencies
- Timely warning and evacuation arrangements by provincial relief departments and district administrations

Despite of this two-pronged policy adopted by the Government, the quantum of losses due to flooding does not seem to abate (Table 3). Recent flood of 2005 (claiming more than 300 lives) in Balouchistan and Mega flood of 1992 (claiming above 1300 lives) in the country (Table 2) are clear examples of shortfalls in the policies and management.

While formulating the first ever Water Policy of the country in 2002, the Ministry of Water and Power realized the importance of flood protection measures too. Although the Draft Water Policy is still awaiting the cabinet approval (Khaleeq, 2005), the policy clauses regarding the flood protection are worth to be mentioned to have an insight into the planners view about flood protection. The Draft Water Policy's clauses are reproduced as under (National, 2005);

15.1.1 Flood zoning shall be established and appropriate land use enforced by avoiding growth of vulnerable developments in flood-hazard areas. Where feasible, land use shall be adjusted to ensure compatibility with the frequency and duration of flooding.

15.1.2 The Flood Manual shall be updated on a periodic basis making use of experience of successes and failures so that the Flood Management Plan is continuously improved.

15.1.3 Reservoir operational rules shall be reviewed and optimized to ensure efficient and prudent decisions to control floods provided, however, that the safety of the dam, embankments, spillways, dam abutments, foundations and all other hydraulic structures is under no condition placed at risk.

15.1.4 Effective use shall be made of non-structural measures like flood forecasting and early warning systems to minimize flood losses through better forecasts and warning.

15.1.5 The construction of additional flood protection facilities, shall continue where needed, concurrently with development of other measures specified here. Greater emphasis shall be laid on proper maintenance of the existing infrastructure.

15.1.6 The design and maintenance standards of existing flood protection structures, shall be reviewed and changes made where necessary to bring them to the level of functional capability and reliability.

'The Pakistan Water Sector Strategy' [Min of WandP, 2002], while making medium term plan for water sector development has put forward following objectives for flood protection schemes to be initiated in future;

- to place priority of flood protection in areas of major human inhabitation and economic importance
- prepare flood and drought management strategies especially for major cities
- promote the delineation of flood risk planning zones to be adopted by all agencies as part of planning process.

Flood risk zoning, better forecasting and warning methods, improved reservoir operation policies and more structural measures are main points of these policy documents. Still the emphasize of the policy makers is to avoid the floods rather than learn to live with the floods and harness the waters of the floods for the reduction of water shortage.

Karachi:

The Sindh Katchi Abadis (unauthorized dwelling) Act (1992) pertains to zoning and construction of building type can be further strengthened in the context of Flood Risk Management by developing Thematic Flood Hazard Maps based on spatial proximity analysis technique using a high resolution grid of 0.5 to 1 m contour interval. The scope and services of Indus River System Authority (IRSA) and Federal and Provincial Flood Programs funded by Asian Development Bank are also important for considering the flood risk management policies.

D.3 Development of GIS database

Although entire Karachi Metropolitan covers an area of about 1800 km^2, this study is focused on the city having area of about 1000 km^2 on the basis of Karachi development Plan for the year 2000.

The information on spatial variation of elevation in the study area was obtained from HYDRO1K DEM (http://lpdaac.usgs.gov/gtopo30/hydro/index.asp) having 1 Km resolutions. The landuse map used in the study is taken from USGS (http://lpdaac.usgs.gov/glcc/glcc.asp) global data set of 1 Km resolution. A local Landuse map developed by the Karachi Development Authority (KDA) was scanned and then digitized and used for verification purpose.

To generate spatial distribution of the rainfall, the daily rainfall data was collected for a station in Karachi from Pakistan Meteorology Department, Karachi. Similarly, daily evaporation data for one station in Karachi was obtained from the Sind Irrigation Department. The water level of Malir river at Superhighway Bridge was also obtained from Sind Irrigation Department.

The population distribution information for the study was obtained from Grided Population of the world (GPW) website (http://sedac.ciesin.columbia.edu/plue/gpw) for 1990 and 1995. Population information for year 2000 was obtained from Karachi development Plan, 2000. On the basis of the available population information, future projections were made for years 2025, 2050, 2075 and 2100 using Gibb's method. Similarly, building distribution was computed on the basis of population distribution. The DEM and landuse map of the Karachi City is shown in Figure 6.9. Similarly, rail and road network in the city is shown in Figure 10.

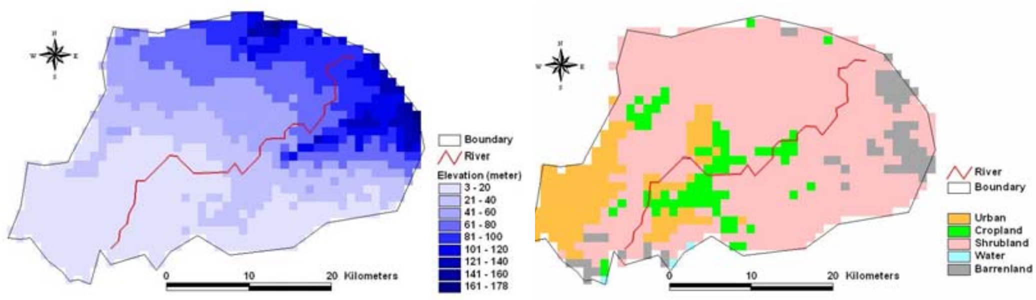

Figure 6.9: DEM and Land-use map

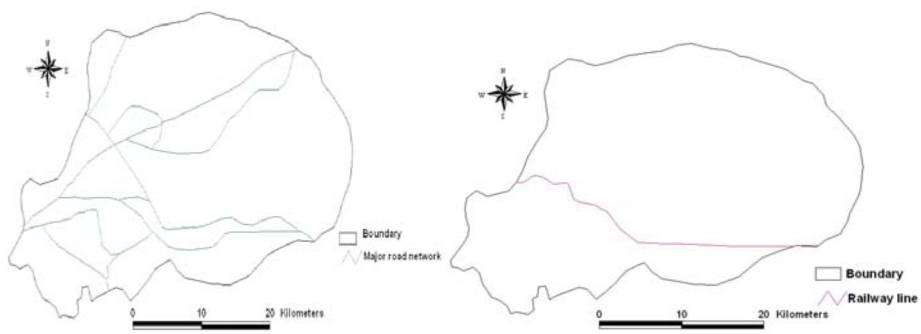

Figure 10: Road and rail network

Based on input GIS data base, i.e. the Landuse, topography and rainfall pattern over the city, the flood modelling is carried out. The flood inundation maps are generated for the years 2025, 2050, 2075 and 2100 to simulate the climate change scenario for the Karachi City.

D.4 Modeling flood characteristics under climatic change condition

Under climatic change conditions the flows over the watershed plains and in the rivers is simulated based on the rise in MSL due to global warming after each quarter century. According to IPCC, the A1 scenario indicated an increase in MSL of 14, 32, 57 and 88 cm for the future years of 2025, 2050, 2075 and 2100 respectively. For the simulation, the observed MSL for the year 2003 was considered as present condition, and the sea level was increased by 14, 32, 57 and 88 cm from the present level to obtain future flood inundation condition in Karachi. Moreover flows are generated considering the increase in population and effluent discharges from the domestic, and industrial sewages.

Institute of Industrial Sciences Distributed Hydrological Model (IISDHM, Dutta et. al.) is used for flood modelling. Different spatial inputs (DEM, landuse) for the model were prepared with the collected GIS data base. The water level of Malir river at Superhighway Bridge is taken as upstream boundary condition for the simulation while tide level at the mouth of Malir river is taken as downstream boundary condition. On the basis of the collected data, the highest flow was observed in the last week of July in Malir River. So, the simulation was carried out from July 27 to 29. The rainfall and upstream boundary condition used for the flood simulation is shown in figure 11.

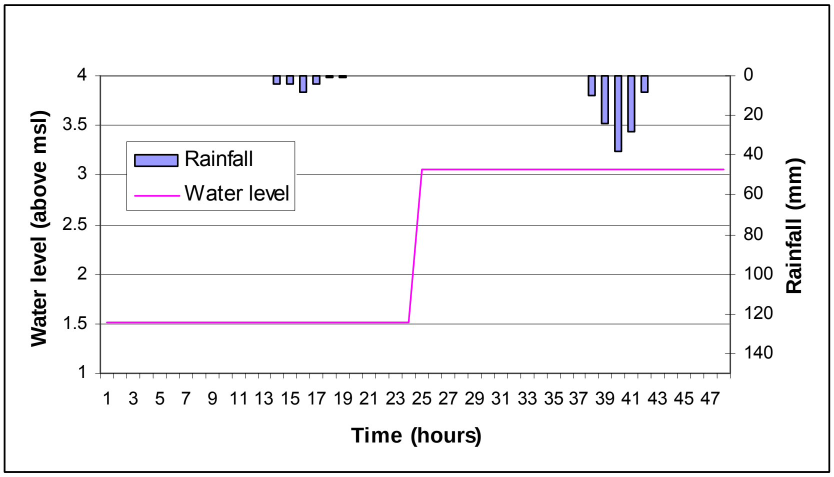

Figure 11: Upstream boundary condition and rainfall input for the model

For future scenario, the change in downstream boundary condition (sea-level

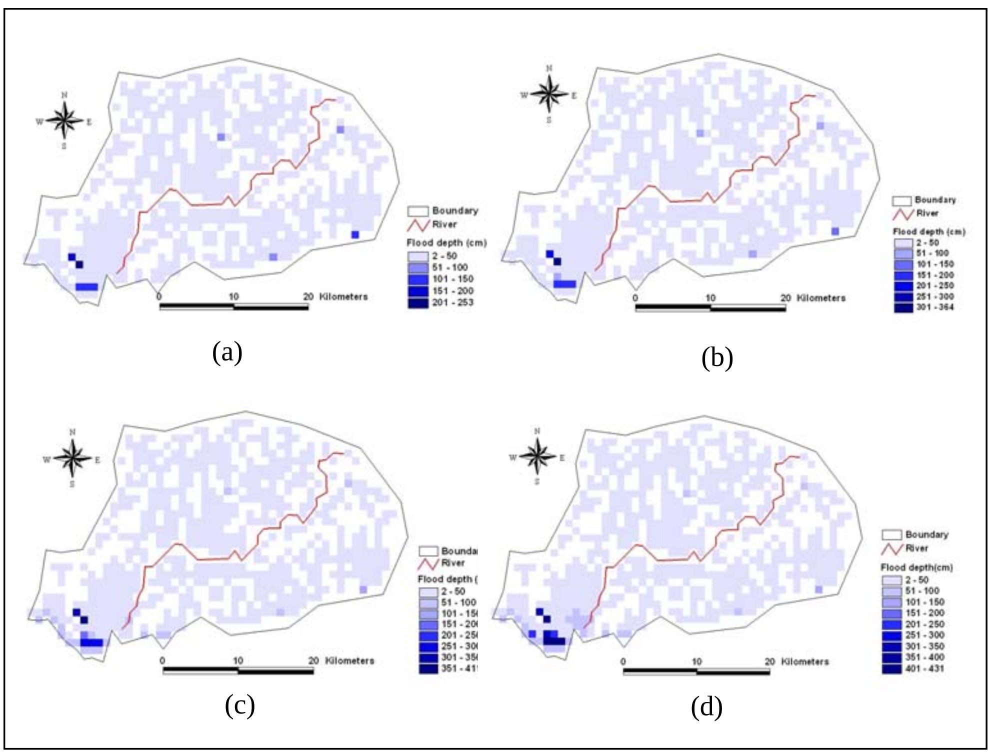

Figure 12: Flood simulation results for scenarios of (a) 2003, (b) 2025, (c) 2050, (d) 2075

rise) is considered according to IPCC report and simulation was carried out. Finally, the flood inundation maps for the study area have been developed for the years 2025, 2050, 2075 and 2100. The flood simulation result for the present scenario (year 2003) is shown in Figure 12(a). The results for the year 2025, 2050 and 2075 are shown in Figures 12 (b), (c) and (d), whereas, simulation result for the year 2100 is shown in Figure 13.

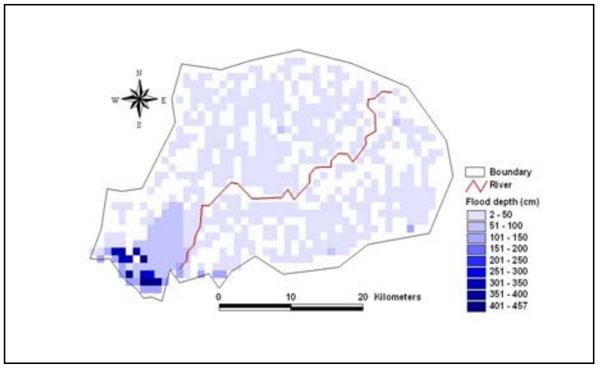

Figure 13: Flood simulation result for scenarios of 2100

The simulated results reveal that impact of flooding due to climate change is significant only on the limited lower area of the city. This is mainly due to the topography of the area. Elevations are higher on northern side and it protects the intrusion of ocean flood waves to the on-shore areas.

D.5 Assessment of socio-economic impacts and vulnerability

Questionnaire survey was carried out for the impact assessment of flooding on different parameters (population, building, transportation network) for Karachi City. On the basis of questionnaire survey, flood risk indices were prepared for different flooding scenarios. For the assessment of socio economic impacts and vulnerability, grid based approach is used. The grid resolution used in the study is of 1 km by 1 km. The impact of flood depth on population is presented in Tables 8 and 9.

Table 8: Flood impact on population

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Moderate	Moderate
0.60-1.00	Moderate	Moderate	High	High	High
1.00-3.50	High	Highest	Highest	Highest	Highest
> 3.50	Highest	Highest	Highest	Highest	Highest

Table 9: Flood impact on population in present and future scenarios

Population affected					
Impact index	*2003*	*2025*	*2050*	*2075*	*2100*
Less impact	240,137	253,908	251,286	261,138	226,384
Moderate impact	3,127	3,479	17,380	19,213	42,558
High Impact	6,229	3,945	4,356	4,401	28,727
Highest Impact	-	2,449	2,532	3,291	6,405

Detailed building inventory in the city was not available. So, building analysis was carried out on the basis of population. Average family size is taken to be 5. The impacts of flood on buildings are presented in Tables 10 and 11.

Table 10: Flood impact on buildings

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Moderate	Moderate	High
0.60-1.00	Less	Less	High	High	Highest
1.00-3.50	Moderate	High	High	Highest	Highest
> 3.50	High	Highest	Highest	Highest	Highest

Table 11: Flood impact on buildings in present and future scenarios

Buildings affected					
Impact index	*2003*	*2025*	*2050*	*2075*	*2100*
Less impact	32,370	33,412	34,636	37,253	35,804
Moderate impact	828	1,231	2,096	1,585	3,815
High Impact	-	134	326	437	850
Highest Impact	-				

The impacts of flood on road and railway network are presented in Tables 12, 13 and 14.

Table 12: Flood impact on road

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	No Impact	Less	Less	Less	Less
0.60-1.00	Less	Moderate	Moderate	High	High
1.00-3.50	Moderate	High	High	Highest	Highest
> 3.50	High	Highest	Highest	Highest	Highest

Table 13: Flood impact on railway

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
0.00-0.10	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	No Impact	No Impact	No Impact	No Impact	No Impact
0.60-1.00	Less	Moderate	Moderate	High	High
1.00-3.50	Moderate	Highest	Highest	Highest	Highest
> 3.50	High	Highest	Highest	Highest	Highest

Table 14: Flood impact on road and railway in present and future scenarios

Year	**2003**	**2025**	**2050**	**2075**	**2100**
Impact Index	*Road length (Km)*	*Road length (Km)*	*Road length (Km)*	*Road length (Km)*	*Road length (Km)*
Less	-	3	12	18	43
Moderate	-	5	4	5	23
High	-	1	1	4	5
Highest	-	-	-	-	6
Year	**2003**	**2025**	**2050**	**2075**	**2100**
Impact Index	*Rail way length (Km)*	*Railway length (Km)*	*Rail way length (Km)*	*Railway length (Km)*	*Railway length (Km)*
No Impact	134	134	134	134	134
Less	-	-	-	-	-
Moderate	-	-	-	-	-
High	-	-	-	-	-
Highest	-	-	-	-	-

It is observed from the analysis climate change scenarios affects population and road network in some extent while rail network will remain unaffected.

D.6 Links among policy, socio-economic factors, floods and impacts

Impact of floods on socio-economic factors of the urban population is very much dependent on the policy to manage the floods. At country level, it appears that the government's response was mainly for crises management. The Emergency Relief Cell, National Crises Management Center and Provincial Relief Agencies are all adopting reactive approach of crises management. Their importance is valid, but the second phase of disaster management, commonly known as Risk Management is not well defined in the context of Pakistan. The Risk Management helps in living with the risk rather than trying to remove the risk altogether (which is not a feasible solution both technically and economically). Risk Management techniques like risk and vulnerability analysis, awareness raising, risk spreading and transfer (insurance) better prediction and warning should be implanted in the flood management policies. It will result in better aware population, more prepared public and institutions and reduced socio-economic sufferings.

For Karachi, there is a strong requirement to develop an integrated pro-active policy approach keeping in view the multi-dimensional and multidisciplinary environment in the context of socio-economics, floods and impact analysis. The Government of Pakistan (GOP) under its Federal Policy Program has created a Coastal Development Authority, a regulating agency, for the management/planning and maintenance of coastal areas with a legislative framework to regulate fisheries, live stock, horticulture and agriculture of coastal areas.

Whereas, it is important to register that Karachi District City Government (CDGK) under its Terms and References is responsible for the development of infrastructure programs has no direct coordination with federally regulated agencies such as Coastal Development Authority, Karachi Port Trust (KPT) and Maritime Security Agency (MSA) and Sindh Irrigation and Power Department (IandP). Each organization is independent and very much work in their exclusive domains. Under such nonconformity situation, it is highly recommended to develop an integrated approach on a scientific integrated platform and to identify the various interrelated activities to achieve a fast and expeditious system of flood data analysis and its impact on general socio-economic features datasets.

D.7 Issues, challenges and recommendations

From the review of the flood disaster mitigation situation in Pakistan, following issues and the challenges are identified, which need the immediate attention of policy makers;

Issues [**WCDR, 2005**]	Challenges	Recommendations
Flood disasters management primary focus is on rescue, relief and rehabilitate (basically only crises management)	Change in policy is required	Flood Management should be done using Risk Management as well as Crises management techniques of disaster management.
Applied disaster management policy sometimes carries strategic biases that are aimed at protecting locations and infrastructure of greater economic, political and strategic significance at the cost of areas and communities with lesser influence and importance.	Involve the stake holders and enhance the public participation in risk management.	Through active participation and prior trainings of the stakeholders, the decisions to protect the important infrastructure and economic centers should be done by the stakeholders and the risks should be taken by the fully informed affected people. The principles of community based disaster risk management (CBDRM) should be adopted.
Within disaster management bodies in Pakistan, there is a dearth of knowledge and information about hazard identification, risk assessment and management, and linkages between livelihoods and disaster preparedness.	Enhanced knowledge of disaster management is required, which requires funds and political will.	Better tools and decision support system along with training for these tools is required for managing the disasters in a more scientific way and more professionally.

Issues [**WCDR, 2005**]	Challenges	Recommendations
Absence of a central authority for integrated disaster management and lack of coordination within and between disaster related organizations is responsible for effective and efficient disaster management in the country.	Integrated Disaster Management	Need better coordination, disaster policy formulation and implementation.
State-level disaster preparedness and mitigation measures are heavily tilted towards structural aspects and undermine non-structural elements such as the knowledge and capacities of local people, and the related livelihood protection issues.	Need a policy shift	Both structural and non-structural measures should be adopted. For Non structural measure, the early warning system, better forecasting and public training to reduce their vulnerability are recommended.
Disaster and relief departments and organizations largely remain under-resourced, untrained, and not given required importance within administrative hierarchy.	Secure financial position of the disaster mitigation agencies is a must for better disaster management.	Some progress in this regard is already made through he PM Disaster Relief Fund, established in 2000, a risk mitigation fund of US $ 5 million established to assist the poor in case of loss of income generating assets due to unforeseen circumstances beyond their control.

Karachi: Being one of the most rapidly growing cities in the world, Karachi faces problems that are central to many developing metropolises including overpopulation, overcrowding, traffic, terrorism and crime. Karachi faces a very severe problem of excessive traffic. The number of cars far outstrips the roads that they need to ply on. This makes driving considerably dangerous and causes loss of time due to traffic congestion.

Considering the present scenario, flooding of the Karachi is causing impacts on "katchi abadies", slight impact on transportation and infrastructure of the city and impact on income of low income groups. However, keeping in mind the future climate change scenario flooding of the city would cause a serious problem for the city which should be addressed right now.

The Sindh Katchi Abadis Act (1992) pertains to zoning and construction of Building type can be further strengthened in the context of Flood Risk Management by developing Thematic Flood Hazard Maps based on spatial proximity analysis technique using a high resolution grid of 0.5 to 1 m contour interval.

Sindh Katchi Abadi Act seems to be only dealing with the flooding in Katchi abadies which are settled along the Malir and Lyari rivers needs to be revised for entire city considering the future climate change scenario.

Provisions should be incorporated to address the flooding of the costal zone in the "Coastal development authority" which is a federal government organization.

It is true that more than 50% discharges in the river Indus are due to snow melting, but luckily Karachi is much away from the course of river Indus. The streams of Karachi are more or less local and this aspect may be neglected for predicting the increase in flows due to global warming.

D.8 Conclusions and recommendations

Following general recommendations are made for better disaster management at country level;

- An integrated approach of crises management (disaster mitigation) and risk management (disaster preparedness) should be adopted for better management of the disasters.
- Better coordination between the agencies related with flood disaster management.
- Enhancing the Capabilities of the public and institutions to cope with the calamities
- Developing useful tools for better warning and forecasting.
- Promoting and sharing knowledge among states and countries
- Involving the communities in the disaster management.

As for as Karachi City is concerned following specific recommendations are offered;

Urban flooding has been a serious problem for Karachi coastal city especially along the back of Malir River. Although there exists a dike system for the flood protection, periodic maintenance and strengthening of dikes.

In the city, climate change and environmental issues are being dealt with by different organizations and there is no strong link among them. A strong link and interaction network should be established among them.

Kachi-Abadi Act (1992) deals with the zoning and construction of building types in flood plains, low-lying areas. Kachi-Abadi Act should be extended to other buildings also, not only to low lying areas

Climate change effects should be addressed properly.

Coastal Development Authority Act should incorporate climate change effects.

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Appendix E: Sri Lanka Case Study

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E.1 Coastal zones and floods in Sri Lanka

Sri Lanka is an island situated in the tropical zone (79º 39' and 81º 53' E and 5º 54' and 9º 52' N). The island has a land area of 65,600 km^2 and a coastal line of about 1585 km. The coastal zone of the country has varied ecosystems including mangroves, sea grass beds, marshland, lagoons and coral reefs. The coastal region currently supports about 34% of Sri Lanka's population and 24% of its land area. Significant erosion is already evident on many of Sri Lanka's beaches and it is likely to increase with accelerated sea level rise.

Sri Lanka is prone to natural disasters such as floods, cyclones, droughts and landslides. Floods being a quick on-setting type produce the highest damages, disruptions to livelihood and economic losses. Both inland and coastal plains are vulnerable to floods due to local discharges and river overflows. Floods and landslides are more localized while droughts are more widespread. In the past decade most of these disasters occurred in every year and also the occurrence is seen to be seasonal. The main causes of the frequent occurrence of floods are heavy seasonal rainfall, deforestation, lack of flood protection schemes and unplanned developments in the flood plains.

Wet-zone rivers such as Kelani, Kalu, Nilwala and Gin are most prone to flooding, affecting both urban centers and rural areas. While the wet zone suffers periodic river breaching the country's vast dry zone plains are not spared calamitous flooding. When the dry zone is subject to unusually wet weather during the inter-monsoons the floods often become greater than those in the wet zone (Ariyabandu and Hulangamuwa, 2000). The number of deaths, affected families and the expenditure for relief during most disastrous floods are summarized in Table 1 (Fernando 1999). Additional expenditure was incurred for rehabilitation and mitigatory measures.

Table 1: Damage due to major historical floods in Sri Lanka

Year	Type of Disaster	No. of Deaths	No. of Affected Families	Expenditure for Relief (LKR)
1981	Flood and Landslides	2	15,318	2,291,930
1982	Flood and Landslides	42	129,513	14,621,023
1984	Flood and Landslides	44	248,356	4,658,558
1985	Flood and Landslides	19	18,869	2,780,699
1986	Flood and Landslides	40	118,494	13,676,252
1988	Flood and Landslides	3	26,373	2,867,089
1989	Flood and Landslides	325	86,176	49,077,863
1990	Flood and Landslides	37	157,427	38,694,275
1991	Flood and Landslides	34	55,491	78,876,485
1992	Flood and Landslides	25	71,080	154,572,300
1993	Flood	6	210,874	30,001,904
1994	Flood	-	353,409	37,401,904
1995	Flood	-	353,409	37,401,904
1996	Flood	3	8,238	12,224,897
1997	Flood	4	29,948	16,746,908
1998	Flood	2	34,746	31,236,159
1999	Flood	6	94,352	43,862,752

(Exchange rate US$ 1 = LKR 100)

Prolonged torrential rains on 16th and 17th of May 2003 caused the worst flooding and landslides in southern Sri Lanka in more than 50 years. Flooding affected five districts in the south of Sri Lanka. The Ministry of Social Welfare estimates that around 150,000 families or 600,000 people were directly affected. About 235 deaths have been confirmed and 9,500 houses destroyed, with a further 30,700 damaged. The highest numbers of deaths were attributed to major landslips in Ratnapura (81) and Matara (63) Districts, with flooding accounting for lesser numbers. This study uses the data of this flood for calibration of the flood model and for scenario analysis.

Both direst and indirect impacts of the floods severely affect the economy of the country. Losses of lives, adverse effects on the livelihood of the affected people, damages to the infrastructures are some of the major direct impacts. The isolation of the affected cities, disruption to the links between other cities through disruption to traffic flows, post disaster epidemics are some of the main indirect effects.

E.2 Study area introduction

Matara is the main commercial city in the southern province of Sri Lanka and it is the capital city of the Matara district. The city and the surrounding agricultural area were subjected to frequent floods due to overflowing of the Nilwala River that flows through the city. The catchment of this river has an inverted pear shape which contributes towards origination of quick rising floods incurring high damages. In 1993 parallel dykes were built in the flood plain as a flood mitigation measure. However, the third phase of the project was not carried out and it causes flood problems in the city under severe weather conditions.

The Nilwala River originates at an elevation of about 1000 m and flows down to the sea after following a course of about 70 km length and draining an area around 971 km^2. The river traverses two different geo-morphological zones. The uppermost zone consists of steep slopes with hilly terrain and the elevations drops steeply. Lower zone consists of mainly the plains of very mild slope and few scattered hillocks. Around halfway of the river course the bed slope reduces to about 0.4 m per km while further down at a point about 18 km to sea the slope is further reduced to about 0.25 m per km. The average slope of the river bed is almost zero along the last 13 km of the river where flood plains are located. This variation of bed slope from steep slopes in central hills to mild slopes of the surrounding flat terrain also aggravated the flood conditions in the flood plains. This is mainly due to quick drainage in the hills followed by low flow velocities in the flat terrain resulting inundation of the flood plains.

In the upper part of the basin, floods do not cause any considerable inundation along its major course due to very narrow floodplains though flash floods are a recurrent feature in its tributaries. The lower basin extending inland up to about 12 km from the coastline is subject to severe flooding with southwest monsoonal rains experienced from May to June and with convectional and cyclonic activities from October to November. The intensity and duration of floods vary depending on the location.

E.2.1 Hydro-meteorological characteristics

Sri Lanka is divided mainly into three different climatic zones based on the amount and pattern of the rainfall received. The zones are named as wet zone, intermediate zone and dry zone. The Nilwala River catchment falls into both wet and intermediate zones. The catchment receives an annual average rainfall about 3000 mm. This generates about 35 mm of specific runoff.

Elkaduwa and Sakthivadivel (1999) analyzed in detail the rainfall runoff relationship and its correlation with the land use pattern changes of the upper Nilwala basin. Table 2 shows the results obtained by them in change analysis of high and low flows. It is interesting to note that the high flows in May have been significantly increased in all three different periods considered from 1948 to 1997. The increment is much higher than the other high flow period from October to November. This shows an increase in the discharges during the month which in turn will increase the probability of flood occurrence. The 2003 flood used for this case study is categorized as a fifty year flood and it too, occurred during the month of May.

Table 2: Variations in mean monthly flow

Period	Dec.-April *prominent low flow*	May *high flow*	July-Sept. *low flow*	Oct.-Nov. *high flow*	Annual
1948–1964	+ 7.75 %	+ 13.10 %	+ 29.51 %	+ 8.74 %	+10.82 %
1965–1997	- 17.87 %	+ 18.33 %	+ 11.54 %	+ 20.46 %	+ 00.11 %
1990–1997	- 34.04 %	+ 22.44 %	+ 16.09 %	- 9.42 %	- 15.53 %

E.2.2 Socio-economic characteristics

Elkaduwa and Sakthivadivel (1999) indicated the land use changes in the Nilwala catchment as given in Table 3. The dense natural forest area in the catchment went down by more than 50% by 1983. The agricultural and built up area increased to take up the place. By 1983 some barren or wasted land also emerged in the catchment. Change of population, their increased needs, development and better business opportunities were seen as the major reason for the land use change. In addition to the natural change of population the lifetime internal migration given in Table 4 and urbanization as shown in Table 5 contributed to changes of population and its distribution pattern in the Matara district. The respective changes in the adjoining districts are also shown in the same table to facilitate comparison.

Table 3: Area of the catchments under different land use categories in different years

Land use category	Percentage of the area under each category		
	1956	1972	1983
Dense natural forests	34.17	20.06	16.31
Degraded forests	2.38	3.13	1.85
Scrublands	0.50	11.79	8.21
Forest plantations	0.18	0.18	1.43
Large tea plantations	12.97	14.13	10.28
Tea smallholdings	1.37	15.71	16.00
Rubber plantations	7.86	5.30	3.16
Coconut plantations	0.06	0.09	0.12

Cinnamon plantations	0.04	–	0.07
Land cleared for cultivation	12.57	3.10	11.52
Rice fields	5.88	7.98	9.51
Grasslands	4.90	3.21	0.83
Barren lands	–	–	0.05
Home gardens	16.01	14.17	19.94
Towns, villages and other buildings	0.04	0.13	0.24
Water bodies	1.07	1.07	1.07
Total	100.00	100.00	100.00

Table 4 Lifetime internal migration, 1971 and 1981

	1971			1981		
District	Lifetime Out migration	Lifetime in migration	Net lifetime migration	Lifetime out migration	Lifetime in migration	Net lifetime migration
Galle	162601	67618	-94983	164879	45899	-118980
Matara	176242	56574	-119668	174318	40871	-133447
Hambantota	38872	52565	+13693	53986	53058	-928

Source: Department of Census and Statistics, Sri Lanka

Table 5 Change of Urban population in Matara, Galle and Hambantota Districts

District	1891	1901	1911	1921	1946	1953	1963	1971	1981	2001*
Sri Lanka	321.4	414.0	543.0	637.9	1023.1	1239.1	2016.3	2848.1	3192.7	
Galle	33.6	37.2	41.8	42.4	59.0	66.4	130.0	154.9	166.4	110.7
Matara	8.6	19.4	22.5	26.0	34.8	40.5	61.1	66.1	71.2	64.5
Hambantota	2.5	5.2	6.6	7.7	10.8	11.2	22.2	33.3	41.4	21.7

Source: Department of Census and Statistics, Sri Lanka

E.2.3 Flood vulnerability and history

The southwest monsoon in 2003 brought record-breaking rain and floods to the country. Sri Lanka experienced the worst flood in its history, spanning over 50 years. Floods and consequent landslides affecting many of the regions of south and southeastern Sri Lanka caused severe human suffering and death. The districts affected by the floods are shown in Figure 1. The floods were due to the rainfall occurred in 16th and 17th of May 2003 and the spatial distributions of rainfall for these two days are shown in Figure 2. The majority of the infrastructure in the affected areas was badly damaged and many roads in these areas were submerged by floodwaters or obstructed by landslides, making them impassable. Spatial extent of flood inundation estimated from the affected districts and villages are given in Table 6. The major damaged was to Matara district. Indika (2005) estimated that the total damage is about 4332.86 million rupees (Exchange rate US$ 1 = LKR 100). It is 58.5% of the total estimated damage and the breakdown of the damages according to affected districts are shown in Figure 3.

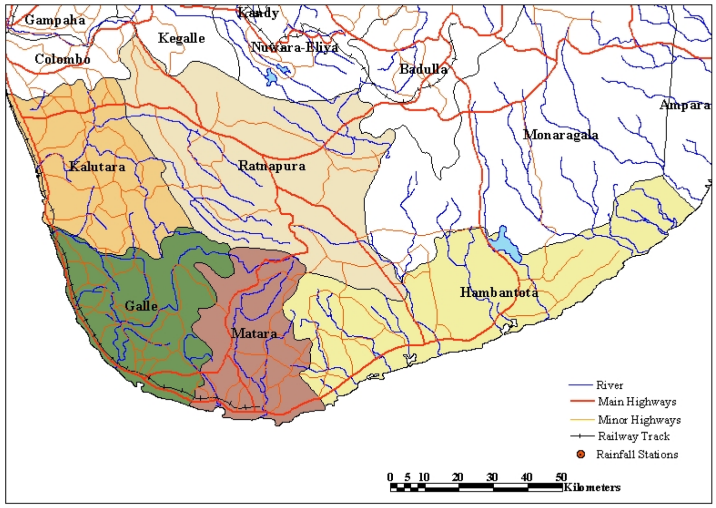


Figure 1: Affected districts from the flood in May 2003

Table 6: Affected area from the flood in May 2003

District	Total divisional secretariat divisions*	Affected divisional secretariat divisions*	Total village level divisions	Affected village level divisions	Percentage affected village level divisions
Ratnapura	17	10	575	220	38.3%
Galle	18	14	896	278	31.0%
Matara	**16**	**15**	**650**	**326**	**50.2%**
Hambantota	12	9	576	298	51.7%
Kalutara	14	9	762	225	29.5%
Total	77	57	3459	1347	38.9%

* the sub-district level managerial divisions

Distribution of affected number of families due to floods and landslides according to districts are shown in Figure 4. The highest number of affected families was in Matara district. It is 51,227 families or 37.1% of total affected families in above five districts which is 135,065 families. Figure 4 also shows the percentage of families affected, to total number of families in each district.

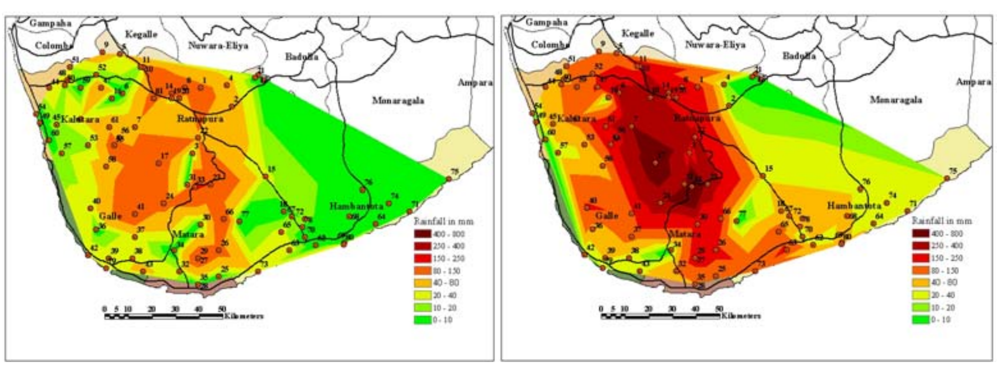


Figure 2: Spatial distribution of rainfall on 16th and 17th of May 2003

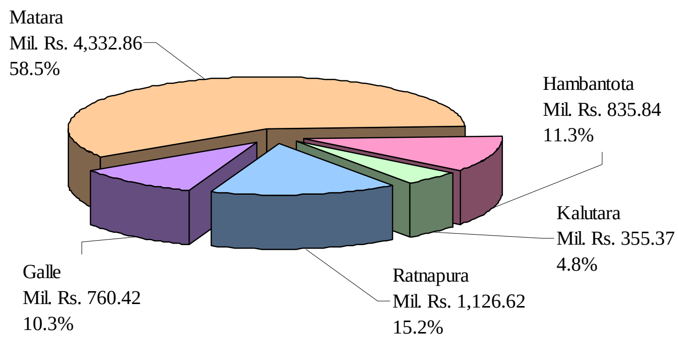


Figure 3: Extent of damages to affected districts due to flood in May 2003(1US$ = Rs. 95.00 in 2003)

The total number of deaths due to both floods and landslides were estimated as 234 and 65% of deaths were due to landslides and the other 35 % were due to floods. Eighty one persons died in Matara district and a greater number is due to landslides.

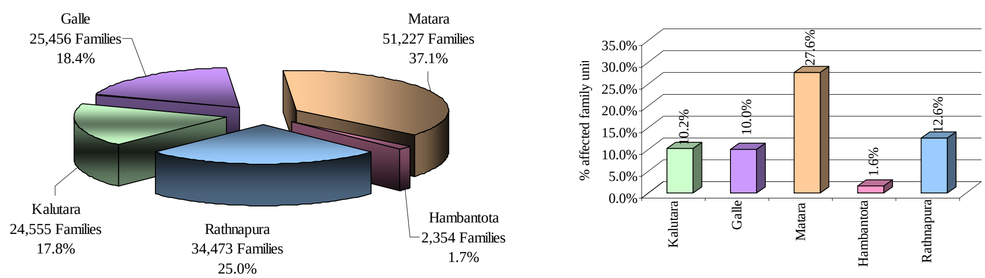


Figure 4: Distribution of number of affected families and their proportion to total population in each district

Damage to the infrastructure was a major burden on the economy of the country. In Matara district 2083 houses were completely damaged and 5173 were partially damaged. The number of fully damaged houses and partially damage houses in five districts are indicated in Figure 5. The estimated sectoral damage to infrastructure is shown in Figure 6. The proportions of the sectoral damage to total damage as well as the damage figures are given. Table 7 gives the damages in monetary terms to few major infrastructure sectors in the Matara district.

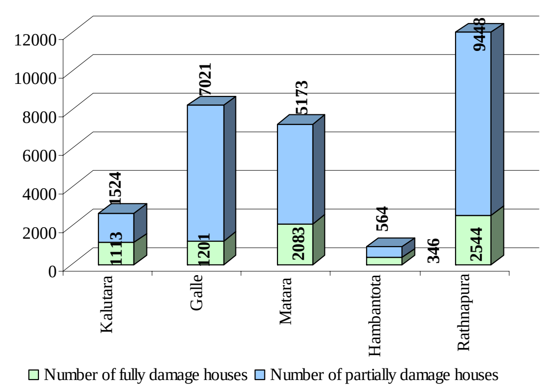


Figure 5: Number of houses damaged in each district

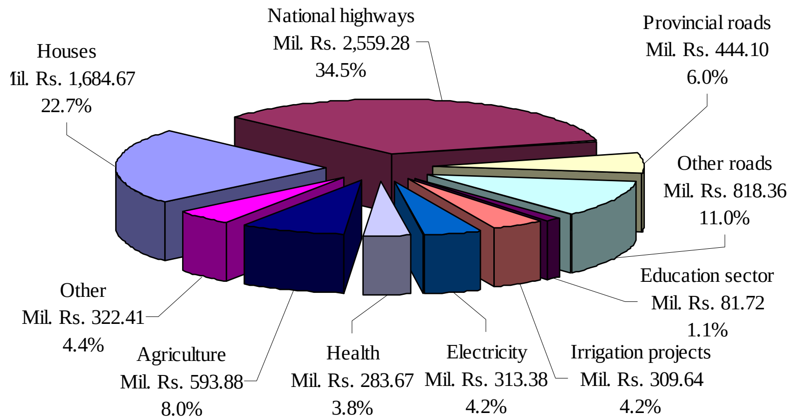


Figure 6: Sectoral distribution of the damage to infrastructure (1US$ = Rs. 95.00 in 2003)

Table 7: Estimated expenditure for reconstruction in major infrastructure sectors of Matara district (1US$ = LKRRs. 95.00 in 2003)

Sector	Required Expenditure (in million Rs.)	Percentage of total expenditure for the sector
Houses	583.48	34.8%
Highway	2729.25	71.4%
Electricity	103.63	33.1%
Irrigation systems	194.72	62.9%
Agriculture	354.55	59.7%

E.2.4 Existing flood disaster mitigation measures

Flood disaster mitigation in Sri Lanka, up to now takes two major forms. Flood control through reservoirs is the common method used where major reservoirs are available. However, the Nilwala Ganga river basin does not have any major reservoirs built across it. The other method is the dykes provided along the downstream reaches of the rivers. This type of flood protection schemes is available only for Gin Ganga and Nilwala Ganaga rivers in the southern province of the country.

The Nilwala Ganga flood protection scheme was completed in 1993 and it provides protection to 5600 ha of paddy lands. Drainage water outside the dykes is pumped in using three diesel driven pumping units. Of the three stages of project implementation, only two stages were completed leaving out the last stage unattended. Even though the scheme was originally designed for flood protection, the project was launched to provide drainage facilities for low lying lands and therefore the pumps have to be run everyday. Due to the non-completion of the third stage of the project and due to several other reasons, the scheme has not been very successful. The non-completion of the stage 3 of the project has also increased the flood threat to Matara City. In addition, about 2000 ha of developed lands are located in the unprotected area as the location of the newly constructed flood bunds are away from the river banks. (Fernando,1999)

Non-structural measures such as land use controls, land fill controls, mandatory environmental impact assessment for projects and emergency management and response plans are also adopted in addition to above mentioned structural measures.

E.2.5 Existing flood risk management policies

The National Disaster Management Plan (NDMP) of Sri Lanka is a cell functioning under the Ministry of Social Services and is mainly geared towards the post disaster social welfare. The major functions of NDMP are to cover the facility and management of major phases of Disaster Management identified as mitigation, preparedness, response and recovery. The vital areas covered in the NDMP include, preparedness, mitigation and preventive action; recovery, relief, rehabilitation and re-construction; control of floods, landslide hazards and cyclones; and improvement of meteorological observation, forecast and warning systems.

The Disaster Management in Sri Lanka took a new turn in 1993 when an Action Plan and the Disaster Counter Measures Bill were prepared. This bill was accepted by the parliament in 2005. The basic objectives of the Action Plan can be drawn from the Act itself (Fernando 1999). These are as follows:

- prevention and mitigation of disaster,
- protection of life and property from the effects of disaster,
- maintenance and restoration of order in areas effected by disasters,
- provision of facilities for emergency response, relief, rehabilitation and reconstruction in the event of a disaster,

The plan classified the activities under the following groups:

- preparedness action,
- relief operation,
- recovery, rehabilitation and reconstruction,
- awareness and public education,

The policy framework under which the plan would operate has been spelt out in the plan as follows:

- introduction of improved professional practices in the areas of agriculture, land use planning, construction and maintenance;
- encouragement of participation of non-governmental organization, private institutions and individuals, and soliciting and directing private donations to recipients in affected areas;
- fostering scientific and engineering studies (e.g. landslide hazard mapping) as tools for sustainable development;
- shifting of emphasis to pre-disaster planning and preparedness, while sustaining and further improving post - disaster relief, recovery and rehabilitation capabilities; and
- integration of disaster prevention and preparedness in the national as well as sub-national planning process

The government created a fully fledge disaster management center which will be under a Council of Ministers. This is to ensure that the center will get the full corporation from the other relevant organizations in providing the quick relief and continuing support in long term rehabilitation, reconstruction and mitigation works. First task of this disaster management center will be to prepare a workable policy considering all disasters pertaining to the country.

The current legislation named 'Flood Protection Ordinance' No 4 of 1924 (Ch 278 - 1980 Rev) is the Ordinance for the protection of areas subject to damage from floods. The major sections relevant to flood disaster mitigation are the Section 3: declaration of flood areas, Section 4: empowering Director of Irrigation to prepare scheme for flood protection, Section 7: empowering Government Agent or Municipal Council to be nominated a flood authority and Section 13 dealing with the Recovery term given for insurance.

In addition to these main policies on flood risk management the following policies also deals with the flood mitigation indirectly.

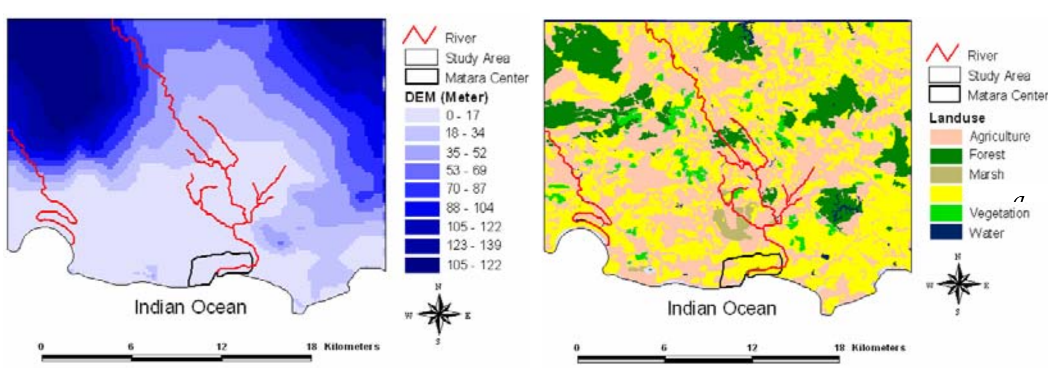
- Land use policy
- Land development policy
- Watershed management policy
- Environmental management policy
- Coastal management policy

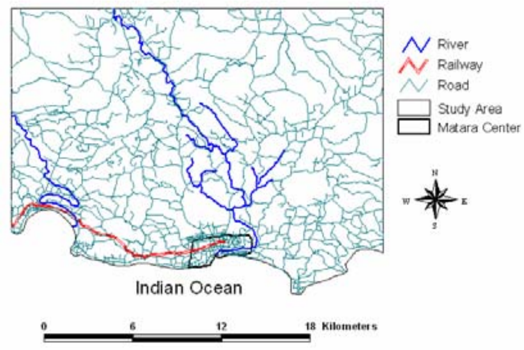
E.3 Development of GIS database

In this study, existing database of present hydrological characteristics and socio-economic conditions were collected and future characteristics were simulated. The detailed datasets are described as follows.

E.3.1 Spatial data

The land use map used in the study is taken from vector land use map in 1999 with scale of 1:50,000. The information on spatial variation of elevation in the study area was obtained from contour line with scale of 1:50,000 and HYDRO1K DEM with 1 Km resolutions shown in Figure 7. Also, River cross-section data with 1km resolution and transportation network in 1999 were collected shown in Figure 8. Soil dataset were derived from vector soil map in 1999 with scale of 1: 50,000. Administrative map and number of population and building at village level in 1998 and were collected and converted to grid format within 200m * 200m size shown in Figure 9.





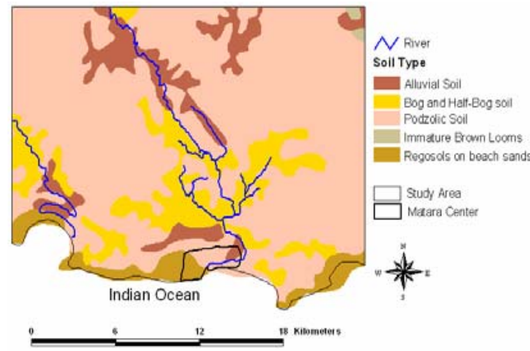


Figure 7: DEM and Landuse Map of study area; Figure 8: Transportation and Soil Map of study area

E.3.2 Temporal data

Daily rainfall for six rain-gauge stations, Goluwatta, Dediyawala, Mamadola, Panetiyana, Telijjawila and Kekanadura, on May, 2005 were collected. Pitabeddara station and Mirissa staion was identified as upstream boundary and downstream boundary respectively. Hourly water level of upstream boundary and downstream were collected shown in Figure 10.

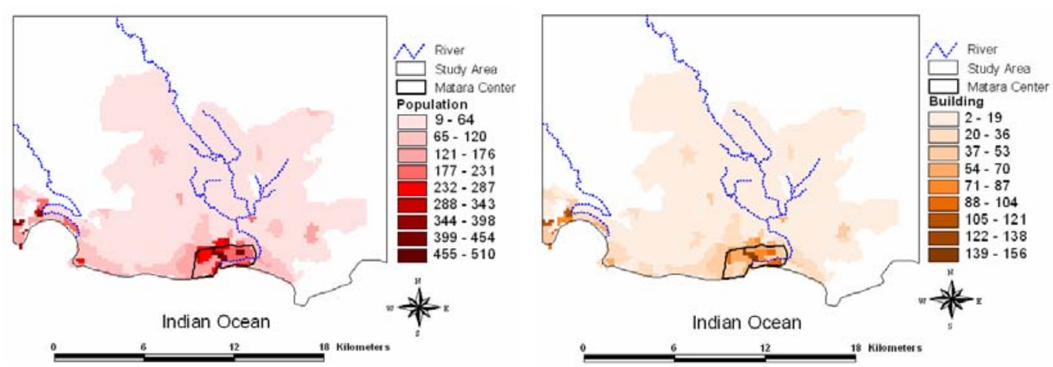


Figure 9: Transportation and Soil Map of study area

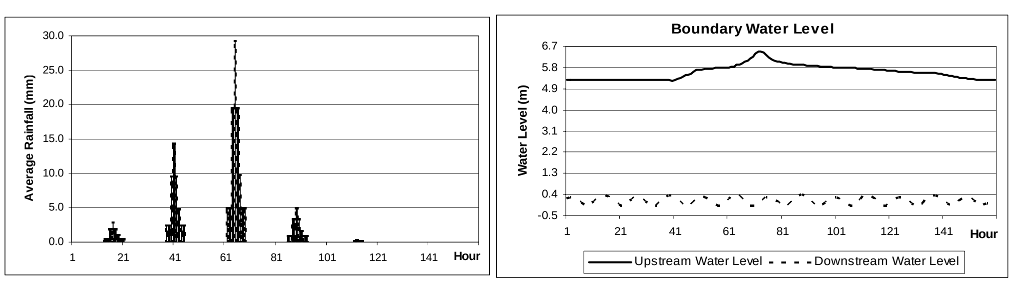


Figure 10: Hourly rainfall and boundary water level from 15 – 21 May, 2003.

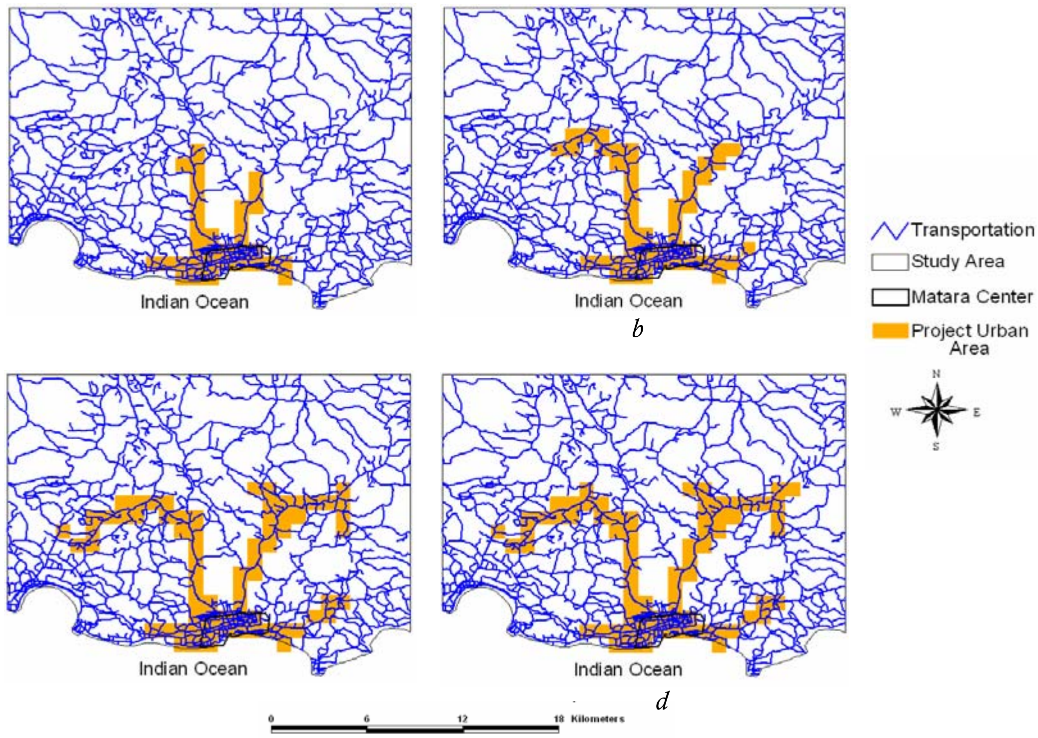


Figure 11: Projected Urbanization of study area in a) 2025, b) 2050, c) 2075, d) 2100

E.3.3 Project data

Projected population and land use change was carried out based on IPCC SRES B1 scenario. The population and urbanization of future scenarios are shown in Figure 11 and 12.

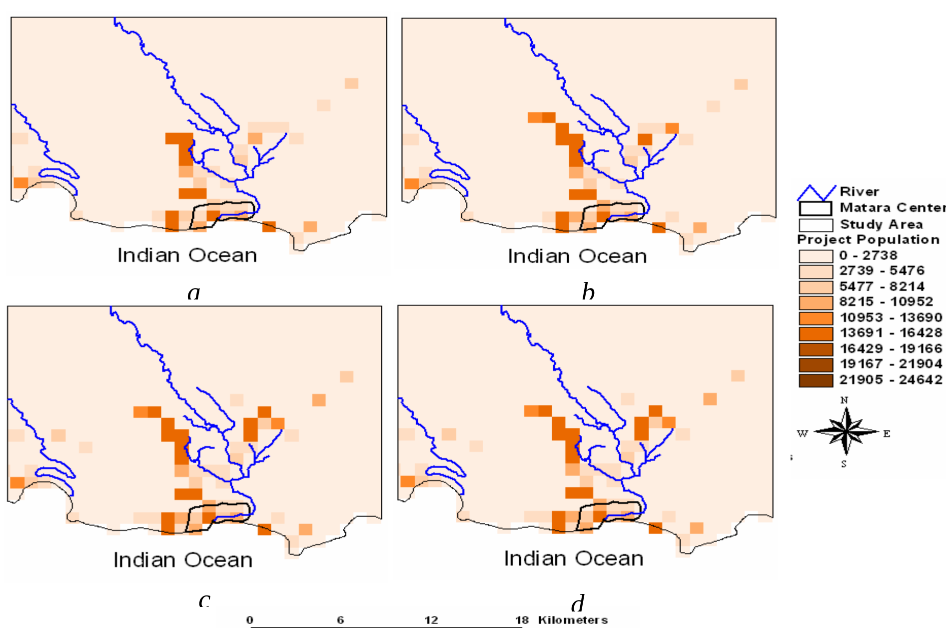


Figure 12: Projected Population of study area in a) 2025, b) 2050, c) 2075, d) 2100

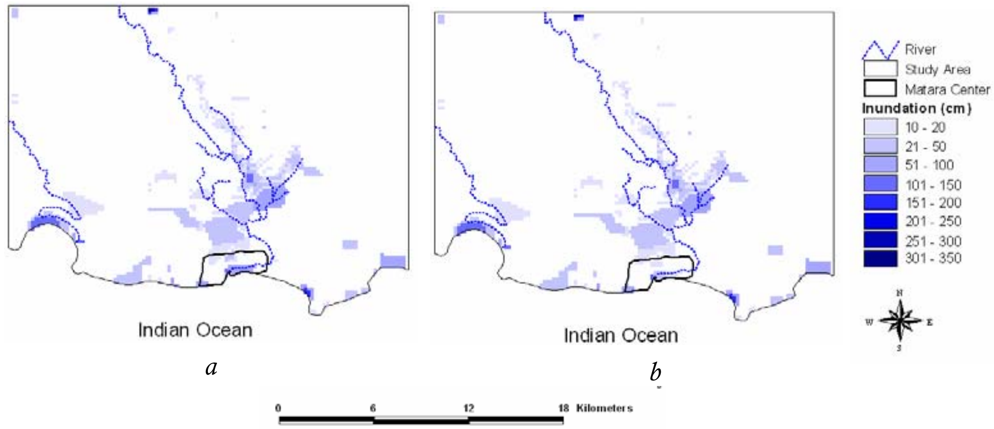


Figure 13: Simulated maximum flood inundation map in a) 2050, b) 2100

E.4 Modeling flood characteristics under climate change conditions

The model was simulated for present and future scenarios. Present scenario was generated for year 2003, and future scenarios in 2050 and 2100 were considered for sea level rising 50 cm and 100 cm. Institute of Industrial Sciences Distributed Hydrological Model (IISDHM, Dutta et. al.) is used for flood modeling. Figure 13 show the flood inundation of future scenarios.

Flood inundation area in different scenarios is shown in Table 8. The results reveal that impact of flooding area due to sea level rise is not significant, but the situation was aggravated. This is mainly due to the topography of the study area. Elevation nearby the coastal line increase very fast, which protects the intrusion of flood.

Table 8: Summary of flooded area in different year

Flood depth in cm	Simulated flood Area in km^2 (in %)		
	Flood in 2003	Flood in 2050	Flood in 2100
10-20	14.36 (3.35)	13.96 (3.26)	14.20 (3.31)
21-50	15.08 (3.52)	15.64 (3.65)	15.16 (3.56)
51-100	4.88 (1.14)	4.88 (1.14)	5.88 (1.37)
101-150	1.24 (0.29)	1.20 (0.28)	1.20 (0.28)
151-200	0.24 (0.06)	0.24 (0.06)	0.24 (0.06)
201-250	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
251-300	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
301-350	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
Total	36.12 (8.42)	36.24 (8.45)	37.12 (8.66)

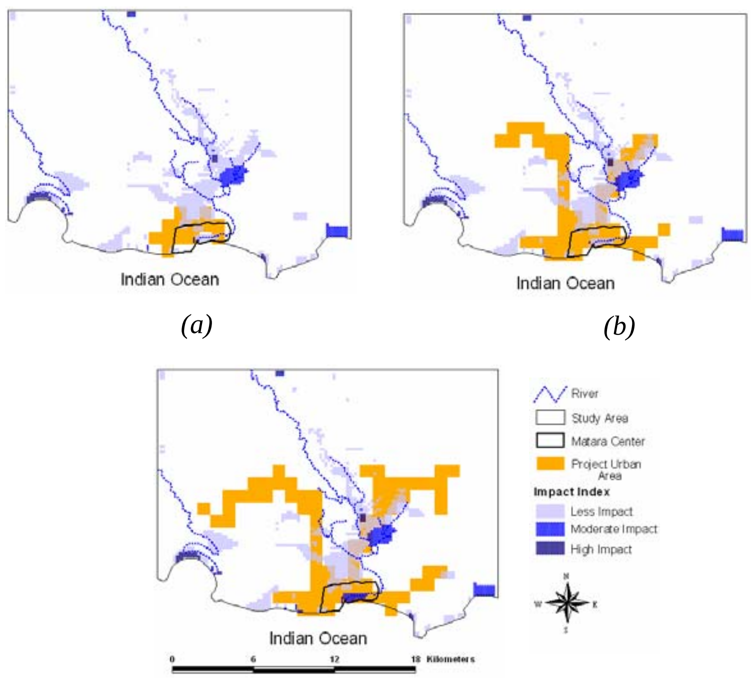
E.5 Assessment of socio-economic impacts and vulnerability

Questionnaire survey was carried out for the impact assessment of flooding on different parameters (population, building, transportation network) for Matara City. On the basis of questionnaire survey, flood risk indices were prepared for different flooding scenarios. For the assessment of socio economic impacts and vulnerability, grid based approach is used. The grid resolution used in the study is of 1 Km by 1 Km. The impact of flood depth on buildings is presented in

Table 9: Flood Risk Indices of buildings

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Less
0.60-1.00	Less	Moderate	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	Moderate	High	High
> 3.50	High	High	High	High	High

Tables 9 and 10. The hazard map generated for building category is shown in Figure 14.



(c)

Figure 14: Hazard map generated for Building category in a) 2003, b) 2050, c) 2100

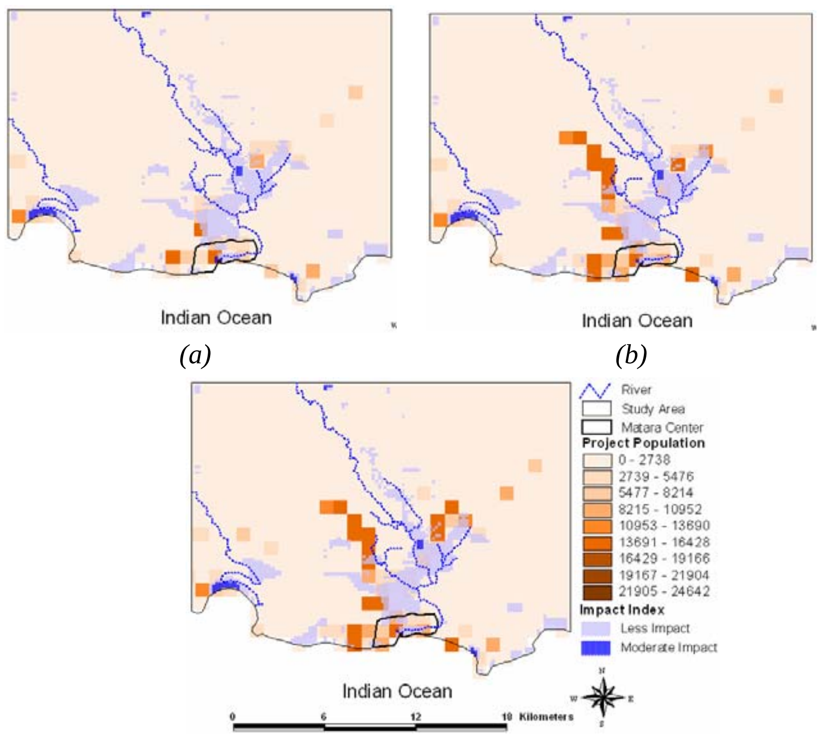
Table 10: Estimated numbers of affected buildings

Impact Index	No. of affected buildings in Study Area		
	Flood in 2003	Flood in 2050	Flood in 2100
Less Impact	9,810	12,354	13,079
Moderate Impact	320	403	426
High Impact	1,165	1,467	1,553

The impact of flood depth on Population is presented in Tables 11 and 12 The hazard map generated for population category is shown in Figure 15.

Table 11 Flood Risk Indices of population

Depth of flood (m)	Duration of flood				
	< 1 day	1-2 days	3-4 days	5-7 days	> 1 week
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Moderate	High
0.60-1.00	Less	Less	Moderate	High	High
1.00-3.50	Less	Moderate	Moderate	High	High
> 3.50	Less	Moderate	High	High	Highest



(c)

Figure 15: Hazard map generated for Population category in a) 2003, b) 2050, c) 2100

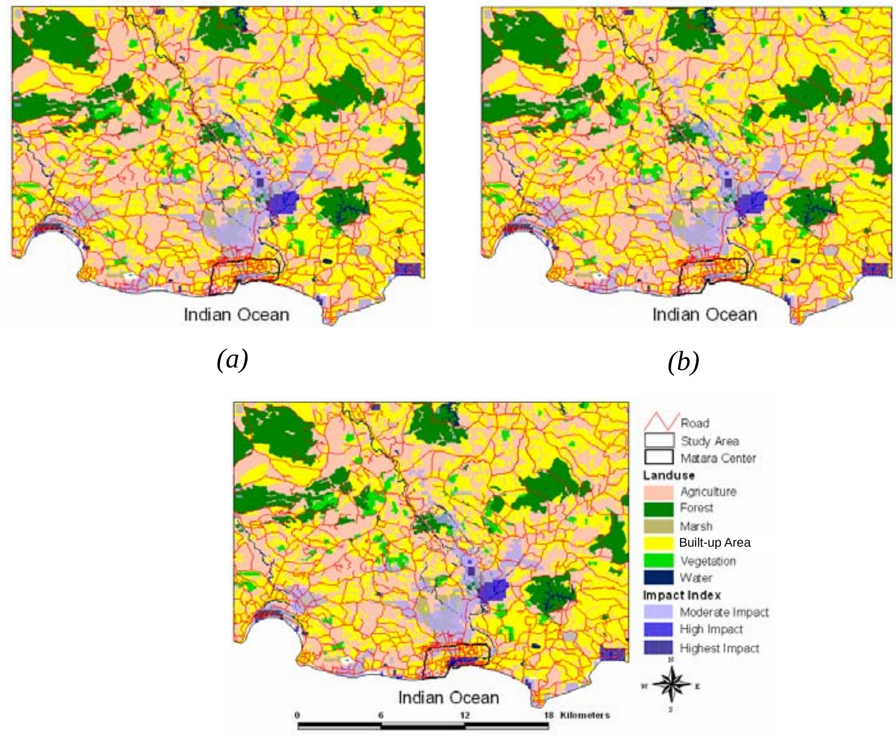
Table 12: Estimated numbers of affected people

Impact Index	No. of affected people in Study Area		
	Flood in 2003	Flood in 2050	Flood in 2100
Less Impact	50,081	81,728	86,731
Moderate Impact	6,044	6,049	6,092

The impact of flood depth on road is presented in Tables 13 and 14. The hazard map generated for road category is shown in Figure 16.

Table 13: Flood Risk Indices of road

Depth of flood (m)	Duration of flood				
	< 1 day	1-2 days	3-4 days	5-7 days	> 1 week
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Moderate	High	Highest	Highest
0.60-1.00	High	High	Highest	Highest	Highest
1.00-3.50	Highest	Highest	Highest	Highest	Highest
> 3.50	Highest	Highest	Highest	Highest	Highest



(a) *(b)*

(c)

Figure 16: Hazard map generated for Road category in a) 2003, b) 2050, b) 2100

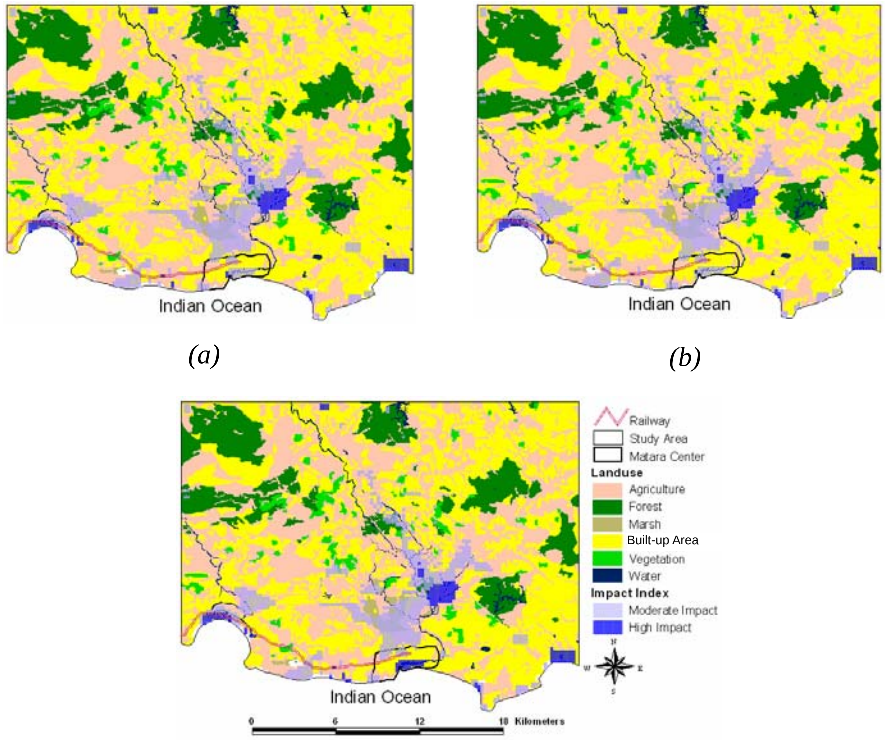
Table.14: Estimated length of affected roads

Impact Index	Length of affected Road in Study Area (m)		
	Flood in 2003	Flood in 2050	Flood in 2100
Moderate Impact	67,616	68,218	66,487
High Impact	6,022	6,022	10,678
Highest Impact	5,905	5,905	5,905

The impact of flood depth on railway is presented in Tables 15 and 16. The hazard map generated for railway category is shown in Figure 17.

Table 15: Flood Risk Indices of railway

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Moderate	Moderate	Moderate	Highest
0.60-1.00	Less	High	High	High	Highest
1.00-3.50	Moderate	High	High	Highest	Highest
> 3.50	Moderate	High	Highest	Highest	Highest



(a) *(b)*

(c)

Figure.17: Hazard map generated for Railway category in a) 2003, b) 2050, b) 2100

Table 16: Estimated length of affected railway

Impact Index	Length of affected railway in Study Area		
	Flood in 2003	Flood in 2050	Flood in 2100
Moderate Impact	2,411	2,411	2,433
High Impact	1,637	1,637	1,637

E.6 Links among policy, socio-economic factors floods and impacts

Land use policy and land development policy ensures maintenance of sufficient vegetation cover that facilitates infiltration, detention areas and adequate drainage paths. Watershed management policy facilitates coordination among different administrative units and institutions responsible for flood mitigation. Environmental management policy requires environmental impact assessments done for all projects in which the project proponents have to evaluate the implications of the project on environment including the effects of floods. In every EIA the effect on natural drainage should be commented. If affected mitigatory measures, implementation and monitoring procedures are needed to be explicitly addressed. Incorporation of these in design, construction and at commissioning is monitored. If the demarcated river reservations are to be affected a flood modeling is required to be done to assess the effects on the upstream reaches and to evaluate any suggested mitigatory measures.

The costal management policy, deals with structural mitigation measures such as revetments, breakwaters, groynes and beach nourishment. It also deals with non-structural measures such as mandatory setbacks and limiting the nature of developments. There are several agencies responsible for the implementation action as indicated below for a selected policy option:

Watershed management policy – Mahaweli Authority, Department of Irrigation

Environmental management policy – Central Environmental Authority

Coastal management policy – Coast Conservation Department

However, flood risk management policies have to be implemented in parallel with development policies to provide alternatives to people who are restrained from various acts to ensure better flood control. For example, the people who are prevented from mining corals from the coral reefs or sand from rivers are not given adequate alternative lively hood options (by providing them with the necessary skills to go for an alternate employment). Worse is that cheaper alternatives to sand or lime are not given so that demand is reduced for such products. The necessity of flood mitigation to become a part of an overall plan for development is therefore has to be emphasized.

E.7 Issues, challenges and recommendations in implementing

Currently there is no strategy to counter the effects of climatic changes, especially the effect of sea level rise, though there is some mention about it in the Coast Conservation Act. This will be a major hindrance in implementing any counter actions proposed.

There is no single authority in Sri Lanka, which is responsible for coastal flooding. Hence implementing counter measures is an issue. It might require the assistance of more than one agency and an authoritative agency which could coordinate all the agencies to be involved.

It is recommended that the Council of Ministers and Centre for Disaster Management to be established under the Disaster Management Act. Centre for Disaster Management is needed to approach in resolving both the above issues.

Policy Issues

Flood is no body's core business

Various Acts mentioned earlier in the paper provides different agencies guideline and authorities for developing, regulating and controlling of land, infrastructure and amenities within their respective authority areas. Therefore these institutions are in a position to use those legal provisions to mitigate floods in various manners. However, as their core-business is not mitigating floods those institutions give a secondary consideration or no consideration at all at times.

Umbrella Organization for Disaster Mitigation and Response

Recently the Government brought legislation to safeguard people and property from natural disasters. This piece of legislation shelved for a long time and brought in by the Government after the Asian Tsunami, addresses the need to establish an umbrella organization responsible for disaster risk reduction. It is titled as Sri Lanka Disaster Management Act.

This Act suggests establishing a National Council for Disaster Management and Human and Natural Disaster Management Centre. The Centre is supposed to prepare a disaster management plan and a national emergency preparedness plan. Former would mitigate disaster impacts while latter is supposed to provide post disaster relief. It would be little premature to comment on whether it could address at least some of the unresolved issues in disaster risk management. It will finally depend on the ability of the Council and the Centre to deploy and coordinate multi-disciplinary expertise available in the agencies already operating and demarcating the responsibilities of each player clearly to make them responsible for specific tasks, while keeping the overall responsibility with the Council and the Centre. However one who reads the enactment gets the feeling that the emphasis is more on post disaster relief than pre-disaster mitigation. This is reflected in the fact that less deliberations being made on specific disasters in the Act that requires specific mitigation measures. The act does not mention about the legal authority the Centre would have on demarcating the responsibility of various agencies responsible for different disasters. As a result it can add to the already complex institutional mechanism rather than simplifying it.

<u>Water does not care Administrative Boundaries</u>

Problem with water is that it does not care any administrative boundaries. Hence the necessity of considering water shed as the area of jurisdiction is only rational. The Government therefore has brought in a National Watershed Management Policy. The policy recognizes the need to rationalize and remove policy gaps and minimize overlapping responsibilities among different institutions in watershed management. It recognizes the need to

1. Allocate an appropriate portion of the GDP through the national budget.
2. Cause mandatory allocation of a percentage of the income of all beneficiaries including directly involved statutory bodies.
3. Set aside a reasonable portion from the Provincial Council budgets and Local Authority budgets, for the sustenance and management of watersheds.
4. Give incentives to those who contribute a share of their income for the upkeep of the watersheds they are serviced by.
5. Make others to pay.
6. Prohibit releasing of all underdeveloped, steep and sensitive lands situated above 1500 m MSL, except for conservation purposes.

The policy document contains policy statements, strategies to implement policy and also indicators to determine the performance levels. However the Policy document is silent about the implementation mechanism, which is the most vital element.

<u>Implementation Issues</u>

Though not comprehensive there are sufficient policies and legislations to mitigate floods and assure safety of people and property but the implementation mechanisms are weak. Lack of interagency coordination, overlapping of responsibilities, compartmentalized work styles, etc., are some of the features that weaken the institutional set up responsible for implementing the policy.

No single agency is responsible for mitigating Coastal Floods. Irrigation Department maintains flood bunds and some pump houses in the North Colombo Area. Some drainage canals are maintained by the Reclamation and Development Corporation. Some canals are maintained by the Colombo Municipal Council and Some by the Local Authorities. The Urban Development Authority maintains certain canals and pump houses that affect their land.

Local Authorities refer the application for filling lands sometimes to the Irrigation Department and sometimes to the Reclamation and Development Corporation.

Confusion about the responsibility is not only among public and the institutions themselves are not sure their area of jurisdiction.

There are certain clauses in the enactments that give power to agencies which in turn will undermine the flood mitigation strategy. For example state land will be alienated to a person for a purpose that sometimes might undermine the flood mitigation strategy, which might not be the concern of the agency that alienate state land (District Administration along with the Ministry of Lands and Land Commissioner does the alienation). The agency, responsible for the particular flood mitigation strategy, can only intervene when the person concern start the development of the land.

Some time foreign funded projects take over the responsibility from line agencies and when the project is over there is no one to take the responsibility. This has happened with the soil conservation act. The Soil Conservation Division of the Department of Agriculture was responsible for implementing the act and it was very active till the 1960s, declined thereafter and ceased to exist in 1989. Coordination of soil conservation activities has lapsed since then, other than the fragmented efforts by Integrated Rural Development Projects and ad hoc initiatives of interested private sector organizations.

The lack of community participation in most of these endeavors is also seen as a major constraint. One reason could be that no alternatives are provided for people who are to restraint from various acts to ensure better flood control. For example, the people who are prevented from mining corals from the coral reefs or sand from rivers are not given adequate alternative lively hood options (by providing them with the necessary skills to go for an alternate employment). Worse is that cheaper alternatives to sand or lime are not given so that demand is reduced for such products. The necessity of flood mitigation to become a part of an overall plan for development is therefore has to be emphasized.

E.8 Conclusion and recommendation

Sri Lanka has some what adequate flood risk management policies, but in a fragmented form. The problem lies more with the institutional mechanism than the adequacy of the policy itself. Absence of a single authority which could coordinate the numerous agencies responsible for different aspect of flood management and flood risk management is probably the main issue. This gap is to be filled up by the proposed Human and Natural Disaster Management Centre proposed in the latest legislation on the subject, but whether the intended results would be achieved, is still a question.

Recommendations

- Single authority to coordinate other agencies needed because there are several organizations responsible right now for flood mitigation/control -- Disaster Management Center can be given authority to coordinate
- Clearly demarcate roles and responsibilities of different authorities with respect to flood mitigation
- Policies must consider alternative solutions (sand and coral mining) and livelihood options for disadvantaged groups

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Appendix F: Thailand Case Study

Appendix F: Thailand Case Study

F.1 Coastal zones and floods in Thailand

The total length of shorelines in Thailand is approximately 3,000km, which are located in 24 provinces in the central, eastern and southern regions. The shortest shoreline of 5 km is found in Bangkok while the longest of 240km is in Phang Nga province (OEPP, 1998). The four main types of coastal landuse were found i.e. agricultural land, forest and mangrove areas, residential area and abandoned land, and unclassified area, in which large mangrove areas have been converted to shrimp farms during the past 35 years.

Many promising coastal zones with white sandy beaches and colorful coral reefs and fish have been developed to be renowned tourist spots. Economic growth and spatial development then cause changes in landuse. The natural resource which is most affected by such changes is mangrove forest. Beach erosion occurs after the loss of mangrove. Flood and water pollution are commonly found in many coastal areas. Such disasters are followed by casualties and destructions in agriculture and economy in general.

A large proportion of the expansion of coastal cities is not caused by natural population growth, but rather rural to urban migration, with people leaving in the more rural inland to try their hand at some occupations in a coastal city. Moving to urban areas is especially popular in Thailand because of the opportunities that the coastlands provide for professions. The existing condition and future trend have shown that many adverse impacts are likely to occur on coastal population and environment. Urban expansion, land subsidence, higher flood discharge from upstream, inadequate safety level of structures are some of the factors that require to consider in the integrated flood management manner (Thanopanuwat, 2005). Strong support from the Government is needed to undertake researches in this area with systematic measurement and collection of data. Yumuang (2005) has summarized the coastal zone degradation problems causing by human activities in Thailand as shown in Table 1.

Table 1: Relationship between human activities and coastal zone problems (after Naish, M., and Warn, S., 2001).

Human activity	Consequences	Coastal zone degradation problems
Urbanisation and transport	- Land-use changes for ports - Congestion - Dredging and disposal of harbour sediments - Water abstraction - Waste water and waste disposal	- Disruption of coastal ecology and loss of species diversity and habitats - Visual impact - Lowering of groundwater table - Salt water intrusion of aquifers - Water pollution, including eutrophication
Agriculture, fishing and harvesting of Marine resources	- Land reclamation - Use of fertilizers and pesticides - Water abstraction - River channelisation - Over-fishing of vulnerable stocks	- Disturbance - Disruption to coastal sedimentation pathways through erosion and accelerated deposition - Increased flood risk - Encouragement of local subsidence
Tourism and recreation	- Land-use changes, e.g. golf courses, marinas	- Traffic pollution - Erosion
Industrial development	- Pollution - Land-use changes, e.g. building power stations - Extraction of natural resources - Effluent processing and cooling water - Tidal barrages, river impoundments	- Thermal pollution - Decreased input of sediment to the coastal zone - Oil spills
Fisheries and aquaculture	- Fish processing facilities - Fish farm effluents	- Over-fishing - Litter and oil pollution - Change in marine communities

Nowadays, flood problem in Thailand is perennial and produce tremendous losses to Thailand as shown in Figure 1. Urbanization causes the flood problem in urban areas to become more severe due to high density of people and property.

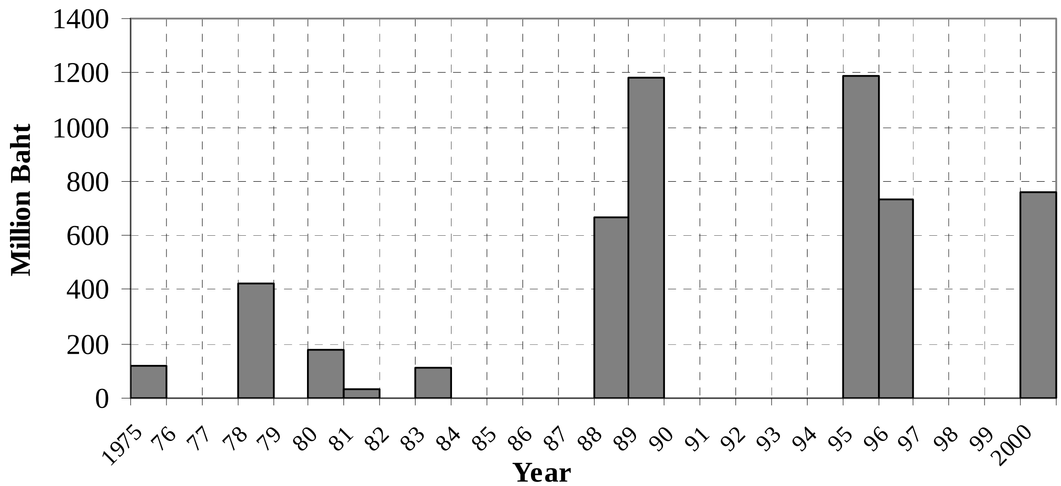


Figure 1: Total direct tangible flood damage in Thailand

(Source: Bureau of Disaster Prevention and Mitigation, 2001)

The Thailand Country Report on Hazards indicates that from 1975 to 1990, floods caused property damage of over US$ 1.22 billion (1.5% of GNP in 1990). In general the destructive impacts of floods generally include loss of life, exacerbating health problems, moral damage, damage to property and destruction of infrastructure important to the economic development of the country and livelihood of the people, especially the poor (Manuta, 2004).

From the study in 2001, Intergovernmental Panel on Climate Change predicted that global mean sea level may rise as high as 88 cm by the end of 21st century (Thanopanuwat, 2005). Climate change would affect to the standard design of flood protection works. The current flood study in Thailand has not yet put the climate change into consideration. In 1994, the inventory of greenhouse gas emission was estimated at 286 M tons of carbon dioxide equivalents and the major sources of emission were fuel combustion, followed by landuse changes and forestry, and industrial processes. As a Non-Annex I country, Thailand addresses the climate change problems by adopting the “No-Regrets” policy in reducing the greenhouse gases, collaborates with Japan in the Activity Implemented Jointly (AIJ) projects, and participates actively in research and development on climate change issues. In preparing for the Kyoto protocol implementation, a research project on “Clean Development Mechanism Strategy for Thailand” is being undertaken (ONEP, 2001).

Thailand has implemented some policies and measures regarding the climate change problems such as sustainable development policy, encourage research concerning the impact of the climate change including vulnerability and adaptation, provide the public with information on climate change, its impact, vulnerability and adaptation.

F.2 Study area introduction

Bangkok, the capital city of Thailand, is one of the major cities in Asia and a regional hub. It is located on the lower flat basin of the Chao Phraya River, which is originated in the northern most part of Thailand and discharged to the Gulf of Thailand after flowing approximate 900 km. The catchment area is 157,925km^2, which covers about 30% of Thailand's land area. The average annual discharge of Chao Phraya Basin is about 770 m^3/s with a peak of 4,560 m^3/s recorded in 1995 (Thammasittirong, 1999). Bangkok located at the 13^{0}45′ North latitude and 100^{0}28′ East longitude and its area is 1,568.7km^2. (Figure 2).

Floods, mainly caused by upstream inflow and high intensity rainfalls, are the most frequent natural disaster in Bangkok, which affect a large number of populations and causes huge economic damage every year. The ground-surface elevation of Bangkok is generally close to mean sea level (MSL). Due to its low elevations, ranging from 0m to 4m above msl, tidal effect is prominent in the Chao Phraya river upto several kilometers inside Bangkok and that attributes significantly to floods. There are usually two high tides and two low tides per day in Gulf of Thailand, but these are often asymmetrical with amplitude of 1-2m. The daily variation of tides is normally from -0.5m to 1.5m with a peak of 2.5m recorded in 1995.

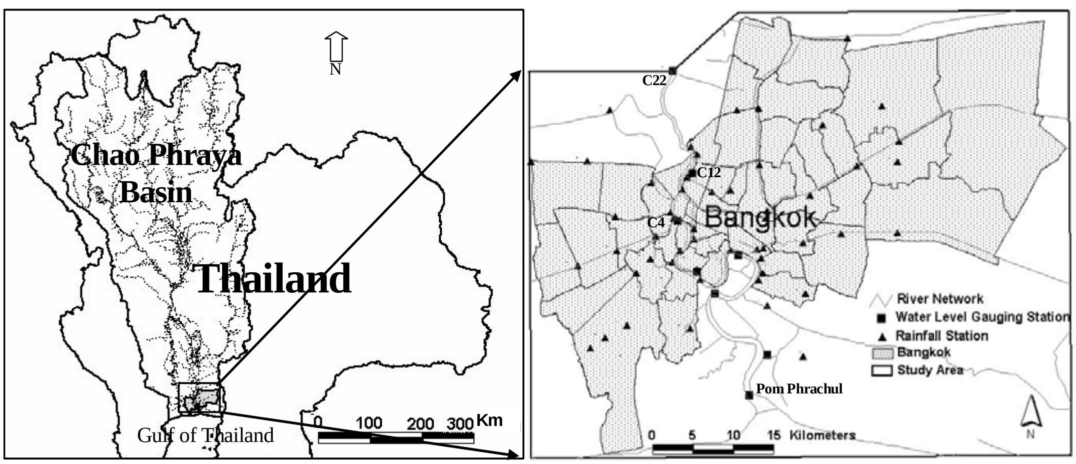


Figure 2: Location of study area

Flooding usually occurs in Bangkok at the end of the rainy season. Heavy rainfall is the primary cause of floods in Bangkok (BMA, 2005). Due to rapid urbanization of Bangkok, watercourse such as ponds, wells, canals, and ditches have been filled up and replaced by buildings and other structures. This often caused flooding and became a severe problem accordingly. In addition insufficient drainage capacity is also a factor for flood. Change in landuse conditions presently affects on flood condition drastically. Moreover, the runoff coefficient gradually increases resulting in more runoff and further loads on drainage system. Another critical factor for Bangkok flood problem is land subsidence due to groundwater abstraction.

F.2.1 Hydro-meteorological characteristics

Climatological condition in the study area, Bangkok, is tropical monsoon. Usually monsoon comes during the month of May to October. Average annual rainfall varies from 900mm to 2,000mm while the average annual rainfall is about 1,400mm. Average Temperature of Bangkok is about 28.2°C. The climate seasons are based on two major wind systems, the north-east and south-west monsoons, each with its own weather characteristics. The north-east monsoon, the dry and cool period, occur from mid-October to mid-February due to winds flowing from the north-east region. The south-west monsoon, the wet period, occurs from mid-May to October. Two transitional periods are in between the monsoons, from mid-February to mid-May due to the varying winds from the east and south-east, and during October, due to the replacing of the south-westerly wind by the north-easterly wind.

For the whole country, in addition to monsoons Thailand is also subjected to tropical storms. The major source is the South China Sea, while secondary sources are the Western Pacific, the Gulf of Thailand and the Andaman Sea. They are born as typhoons, tropical storms and tropical depressions. Obviously the higher the moisture supply while moving over the water surface, the higher the severity of the typhoon. After losing its moisture supply while moving over the land surface, it then weakens and is finally dissipated. Mean annual rainfall ranges from 1,000 mm near central North-eastern Thailand to 4,000 mm in the Truong Son mountain between the Lao PDR and Viet Nam. Some 80–90% of all rainfall occurs during the wet season.

Upper Thailand i.e. the Northern, Northeastern, Central and Eastern Parts usually experiences a long period of warm weather because of its inland nature and tropical latitude zone. March to May, the hottest period of the year, maximum temperatures usually reach near 40^{o}C or more except along coastal areas where sea breezes will moderate afternoon temperatures. The onset of rainy season also significantly reduces the temperatures from mid-May and they are usually lower than 40^{o}C. In winter the outbreaks of cold air from China occasionally reduce temperatures to fairly low values, especially in the Northern and Northeastern Parts where temperatures may decrease to near or below zero.

In the Southern Part temperatures are generally mild throughout the year because of the maritime characteristic of this region. The high temperatures common to upper Thailand are seldom occur. The diurnal and seasonal variations of temperatures are significantly less than those in upper Thailand.

F.2.2 Socio-economic characteristics

Thailand's longer-term record in poverty reduction until the end of the 1980s had been impressive. Poverty incidence had fallen from over 57% in the early-1960s to about 22% in 1988. And significant complementary gains had been made in most social indicators including infant mortality, primary school completion, and life expectancy. Despite this secular improvement, there were concerns because the reduction in poverty had slowed during the 1980s with the number of poor actually rising between 1981 and 1988. This slowing pace of poverty reduction, especially in the poorest regions, raised concerns that the link between poverty reduction and economic growth had weakened.

Recent analysis of data from the Socio-Economic Surveys (SES) shows that the slowdown in poverty reduction during the 1981-88 was a temporary lull in the longer-term decline of poverty in Thailand. Using official poverty lines, poverty incidence fell sharply during 1988-92 from over 22% to about 13%. The dramatic reduction in the *number* of poor was matched by declines also in the *depth* and *severity* of poverty. Public participation is helps in disaster management both in short term and long term basis.

From the National Statistical Office (NSO, 2005), Thailand population is 65,444,371 (growth rate: 0.9%). It has birth rate for 15.7/1000, infant mortality rate for 20.5/1000, life expectancy for 71.6 years old, and population density 855 per km^2 (2005 est.). The major religion is Buddhist for 95%, remaining Islam 3.8%, Christian 0.5%, Hindu 0.1%, other 0.6% (1991). Literacy rate in Thailand is 96% (2003 est.). Thailand GDP/PPP (2004 est.) is $524.8 billion; per capita $8,100. Growth rate is 6.1%, inflation 2.8%. Unemployment is about 1.5% (Nov. 2004 est.). Major agricultural products are rice, cassava (tapioca), rubber, corn, sugarcane, coconuts, and soybeans. Labor force is about 36.43 million people (Nov. 2004 est.), in which the major part goes for agriculture 54%, remaining for industry 15%, and services 31% (1996 est.). The main industrial sectors are such as tourism, textiles and garments, and agricultural processing.

For our study area, population of Bangkok is 8,838,500 (metro. area) and 6,610,800 (city proper). Population density of Bangkok is 4,603 people per km^2 and urban population is 32% of total population (ASEAN Statistical Yearbook, 2004). The city has 50 administrative districts. Bangkok is split into two sides by the Chao Phraya River. GDP of Bangkok is 7,010US$ per capita (2002).

F.2.3 Flood vulnerability and history

In order to understand the causes of flooding in the basin, three major historical flood events with different characteristics revealed in the Chao Phraya Flood Management Review (AIT, Danish Hydraulic Institute, Acres., 1996) are illustrated here. In 1942, the Chao Phraya Basin was in a comparatively undeveloped state in terms of water resources. In many respects, the basin was close to its natural condition. Throughout the monsoon in 1942, which is not expected to occur more than once in a hundred years or more, rainfall amount over Wang, Yom, Nan, and Pasak catchments was over 1,600mm from May to October compared with an average around 1,000mm. Downstream on the Chao Phraya at Ang Thong, the discharge shows a peak on 28th September of 1,500m^3/s, which however considerably less than the 2,700m^3/s recorded in 1995. Further downstream, at Ayutthaya and the Memorial Bridge in Bangkok, the peak water levels are identical to those in 1995. The huge excess volume of water at Nakhon Sawan in 1942, 33,000Mm^3 compared with 23,000Mm^3 in 1995, had been dissipated over the wide and unprotected flood plains. The high spring flood tide propagated upstream against the flood wave from upstream to give a peak water level of 2.27mMSL at Memorial Bridge on 12th October 1942.

By 1983, the Chao Phraya Basin as we know it today was taking shape. Deforestation in the upstream reduced the forest area to 70% of the area in 1942, while the Chao Phraya Dam, Bhumipol and Sirikit Reservoirs were constructed, and the agricultural land was protected against flooding at the basin below Chainat Province. Urban development, particularly in and around Bangkok, increased abstraction of groundwater resulted in land levels subsiding at rates of up to 15cm per year. This created additional problems in drainage. The heavy rainfall occurred in August. Bangkok experienced exceptionally heavy rainfall 434mm compared with an average of 170mm. As rainfall in the upstream was not severe, and the Chao Phraya river level was well below bank level, this rainfall caused only local flooding. In October and November, the lower basin suffered the same heavy rainfall with a total of 405mm compared to the mean of 215mm. On 9th and 26th November, coinciding with consecutive high spring tides, the Chao Phraya water level peaked with level of 2.13mMSL at Memorial Bridge in Bangkok. Large areas of Bangkok were unprotected and the flooding was extensive.

By 1995, twelve years on from 1983 further development in the Chao Phraya Basin has been in the urban areas, particularly in Bangkok. Restrictions on groundwater abstraction has reduced but not eliminated land subsidence. Dikes around Bangkok and along the Chao Phraya provide a level of protection to the city. The most significant flood protection work is the King's Dike protecting the low lying areas of east Bangkok from flooding from overland flow from the north and east. These constructions, while successful in protecting the city core, east Bangkok and parts of west Bangkok have left unprotected areas more vulnerable and exposed a limitation in the capacity of the canals to the east and west of Bangkok to drain the diverted flood water the Gulf of Thailand. Very heavy rainfall from a sequence of tropical storms occurred throughout the basin from the end of July to the beginning of September. The runoff from the heavy rainfall in Nan basin in August far exceeded the remaining storage capacity of Sirikit Reservoir; therefore 2,900Mm^3 was released downstream. At the end of October, the peak flow more or less coincided with the spring tides which followed the total solar eclipse on 24th October produced the highest recorded water leveling in the Chao Phraya since 1942. The excess spread across the unprotected areas causing extensive flooding to the north, west and east of Bangkok. The available drainage capacity was unable to cope, and many areas remained flooded into December, before the flood water was able to drain to the Gulf of Thailand. This resulted the highest economic lost from flood for 11,858MBaht which is close to lost occurred from flood in 1989 for 117,939MBaht (Department of Local Administration Records).

Causes of flooding

There are many causes of flooding in Bangkok, which Tangpraprutgul (2005) has generally classified into 2 categories i.e. natural and physical causes.

The natural causes are:

- Heavy intensity of rainfall results in limited capacity to drain water from the flooded area in a short time
- Run-off from both northern and eastern parts flows to Bangkok due to the topography. This mostly causes flooding problem in the eastern part of Bangkok.
- Excessive run-off from the North and the Chao Phraya River Basin flowing through Bangkok towards the sea causing overflow and flooding in the area
- The high tide from the sea increases water level in Chao Phraya River causing difficulty in drainage and sometime even spilling over the river bank.

The physical causes are:

- Land subsidence due to over pumping of underground water results in sinking of the ground surface to such a level that lower than mean sea level leading to more difficulty in draining of flood.
- Poor or insufficient of drainages inside Bangkok
- Uncontrolled landuses and unfixed city planning

Direct heavy rainfall in the city can create local flooding if the excess rain water cannot easily be removed because of inadequate drainage. In addition, heavy rainfall in surrounding areas can result in high runoff which will finally accumulate in the canals and flow to the city. High discharge is sometime due to the heavy rainfall at the upstream parts of the basin. The runoff from local rainfalls normally has less significant contribution to the high discharge in the downstream of the river. Large releases from the upstream reservoirs such as Bhumibol Dam, Sirikit Dam and Chao Phraya Dam, sometimes create high discharge in the downstream of the river. Therefore to find out appropriate measures for flood protection due to high discharges resulting in high water level in the river, a comprehensive study at a basin scale particularly for a large river basin is necessary (Tangpraprutgul, 2005).

Tangpraprutgul (2005) also depicted that flood water is normally drained to the drainage canals and then to the Chao Phraya River and finally discharged to the Gulf of Thailand. If the water level at the river mouth is rather high, the drainage will be more difficult in which the flood can be prolonged. The longer the flood period prolonged, the problem becoming more complicated due to the tidal effect. The method to estimate the amount of water which can be discharged to the sea for a certain period is not simple. The mathematical hydrodynamic model has to be used for this case. The model must be able to evaluate the effectiveness of the alternatives of flood protection.

In addition to the causes of flooding mentioned above, some other factors such as poor or insufficient internal drainage, uncontrolled landuse, unfixed city planning, urbanization, and land subsidence will make the flood problems more severe. A comprehensive study and detailed analysis to obtain sufficient knowledge of flooding causes for the basin are very important in order to find out the appropriate measures of flood protection for the area.

F.2.4 Existing Flood Disaster Mitigation Measures

Bangkok Metropolitan Administrative (BMA, 2005) has categorized Bangkok flood disaster mitigation into two major measures i.e. structural and non-structural measures. Structural measures contain both short and long term plans. Non-structural measures are such as warning systems and flood forecasts.

Structural measures

Short-term plans are such as sewer cleaning, canal cleaning, and pumping station maintenance. The following activities are carried out every year by Bangkok Metropolitan Administrative (BMA) to support these plans.

1) Cleaning and maintenance of sewers, improvement of draining efficiency, repairing of damaged/clogged sewers with total length of more than 1,000km to accelerate the discharging of water to canals and river by using BMA labors and manpower from the Penitentiary Department together with the use of vacuum sewer cleansing truck
2) Clearing waterways in canals, ditches and maintenance by removing garbage and hyacinth, dredging and improving draining efficiency and scenery of 250 canals with total length of more than 750km
3) Installation of about 800 units of pumps to accelerate the discharging of water from inundated areas and maintenance of pumps to be ready for use
4) Controlling the operation of more then 60 Pumping Stations and 90 Water

Gates in order to regulate the water level in the canals to accelerate the discharging of inundation from the area including the improvement of drainage control structures to have full draining efficiency at all times.

5) Construction of flood walls and temporary embankments to prevent overflow from the Chao Phraya River and canals during high run-off period

Long-term plans are such as construction of embankments, retention basins, pumping stations, improvement of drainage canals and tunnels, and provision of drainage pumps, dikes and zoning. Existing flood protection and drainage facilities consist of flood barriers or dikes, polders, regulators, and pump stations. Much of the Bangkok area also contains combined wastewater and stormwater drainage systems that discharge into local canals. However, these systems are typically not adequate to carry runoff from even moderate rainfall events.

Since Bangkok is a flat and low-land area, the Polder System is used as flood protection and drainage measure which help: 1) preventing inflow of water from outside of polder by construction of flood barriers such as dikes, earth embankments, road, railways and many forms of buildings, 2) discharging water out of the polder by construction of pumping stations, watergates, tunnels and sewers, improvement of drainage canals by constructing dikes and dredging of canals, and 3) retaining rain water temporarily by construction and improvement of ponds and wells to serve as temporary retention basin (Tangpraprutgul, 2005). Major facilities for flood protection are the polders. These polders are drained using pumps that discharge to the Chao Phraya River or local canals. Regulators or gates are located at the mouth of many of the canals to prevent water flowing into the canals during high river stage or high tide. Many of these regulators are equipped with pumps to discharge local runoff. The Department of Drainage and Sewerage (DDS) of BMA has constructed and improved the drainage system in order to accelerate the draining of inundation inside the polder by constructing pumping stations, water gates, tunnels and sewers, dikes, and dredging of canals. At present, the draining capacity is about $775 m^3/s$, with about $527 m^3/s$ for Bangkok area and about $248 m^3/s$ for Thonburi area (BMA, 2005).

Flood protection on the east bank of the Chao Phraya River consists primarily of two exterior dikes, interior polders, and regulators, gates and pumps on the canals and Chao Phraya River. Dikes have also been constructed along the banks of the Chao Phraya River. The dikes typically make use of existing or new roads and highways. Existing flood protection on the west bank of the Chao Phraya River consists of an external dike, interior polders, regulators, gates and pumping stations. Flood barriers along the Chao Phraya River with total length of about 88km are partly completed with height of barrier ranges from +2.50m to +3.00m MSL. The remaining will be constructed and completed accordingly (BMA, 2005). Due to the severe damage caused by flooding in Bangkok in 1983, a diversion canal was built to discharge excess flow directly to the sea, together with preventing tidal effects by building a sea barrier in order to protect the city core of Bangkok from major flooding in 1995.

The King's initiative project known as Monkey Cheeks Project is to acquire the areas as temporary retention basins to prevent flooding (Chaipattana Project, 2005). His Majesty the King observed that most monkeys, when they have obtained bananas, will store them in their mouths. They will do this for a whole bunch of bananas or until their cheeks are filled up. Only then they will start to chew and swallow the bananas. His Majesty has modeled the technique for water retention on the way monkeys eat. He has directed the Royal Irrigation

Department (RID) to construct large water retention reservoirs in a ten square kilometers area near the coast, in order to store water from natural water courses and newly-dug canals. New water gates are also to be constructed to release water into the sea during low-tides, with the gates to be closed during high-tides to prevent sea-water from flooding the reservoirs and the surrounding areas. The full implementation of the project needs careful study and planning which takes time, however in the preliminary stages, certain phases of the project can be carried out to alleviate flood problems in the interim.

Although the capacity of draining water from the area is up to about 775m^3/s. (67 mil.m^3/s /day), there is still about 13mil.m^3 of water inundated within the polder area (if rain falls continuously for 3 hours in one day). It is therefore necessary to allocate areas to be used as retention basins for detaining such amount of water to prevent flooding in low areas, road, and streets by acquiring two types of monkey cheeks: 1) Private Monkey Cheek is a small retention basin in private land to detain water from houses and housing villages by specifying in the BMA regulations and promoting cooperation from the private sector, and 2) Public Monkey Cheek is large area to detain large amount of water from canals. Presently, there are Monkey Cheeks available to detain water of about 7Mm^3. The remaining areas to further accommodate 6Mm^3 of water have to be acquired as soon as possible (BMA, 2005).

In addition, after the flooding in Bangkok in the year 1983, His Majesty King Bhumipol had advised the 5 methods in resolving the problem of flooding in Bangkok, these are: 1) accelerate the draining of water to the sea through the canals at the eastern part of Bangkok, 2) allocate green belt area to prevent the city's expansion and to convert it to be the drainage way during the high run-off period, 3) set up flood protection system in Bangkok area, 4) construct retention basins in various locations of Bangkok to support the Flood Protection Program, and 5) enlarge and /or clear the waterways where the highways and railways pass. The DDS had already carried out projects in accordance with the Royal advice as follows: 1) construction of eastern King's dike with total length of about 72 km. in association with the RID, Department of Highway, and State Railway of Thailand, 2) allocation of temporary retention basins (monkey cheeks) such as Nongbon Pond, Makasan pond, Rama IX pond, Kum pond, Kratiam pond, and Piboon-Wattana pond, with total retaining capacity of 7Mm^3, and 3) DDS in association with the RID had carried out the Monkey Cheeks projects at Canal Mahachai, Canal Sanamchai in the western side of the Chao Phraya River at Bangkhunthien District (BMA, 2005).

Non-structural measures

Warning system composes of flood measurement and flood warning. The BMA has positively implemented many flood protection schemes to prevail the problem and Bangkok Metropolitan Flood Control Center is one of the tools that BMA try to utilize computer technology for systematic and efficient management of operation and administration of flood protection facilities. Bangkok Metropolitan Flood Control Center had been established in 1990 and was rehabilitated to a more efficient and more coverage area in 1997. The system comprises of a master control center located at the DDS and with fifty (52) remote sites scattered around Bangkok cover 1,000km^2. At these remote sites, all data required such as water level in the canal, water level in the Chao Phraya River, rainfall, pump status and water quality for flood protection will be collected automatically and transmitted in cyclic mode to the master control center via telemetering system over UHF radios. The Control system is based on SCADA (Supervisory Control and Data Acquisition) software which main functions are to calculate, database display, graphic display and interfaced with a gateway through TCP/IP on Ethernet Links for data exchange between the computer system and Remote sites. Real time data can be monitored through the computer screen, a video projector, or a Mimic board for instantaneous decision making. Alarm and event are displayed and printed. All history data are stored for later analysis (BMA, 2005).

Flood forecast – Flooding is a natural hazard which affects national economic growth. During the past decade, Thailand encountered serious flooding problems in both cultivated and urban areas. The National Economic and Social Development Board (NESDB) therefore has been seeking solutions to the problem. One such solution is seen in modern technology on flood forecasting. The first flood forecasting system was established in the Chao Phraya River Basin as it is the major river contributing benefits to the country.

Existing flood risk management policies

Flood management is not the primary responsibility of any one agency in Thailand. Many national agencies involved in irrigation (e.g. Royal Irrigation Department, RID), electricity supply (e.g. Electricity Generating Authority of Thailand, EGAT), navigation, science, technology and meteorology (e.g. Thai Meteorological Department, TMD), and metropolitan (e.g. BMA) and local administration (e.g. Tambon Administrative Organization, TAO) together with provincial and local governments all have responsibilities for some aspects of flood management (AIT, Danish Hydraulic Institute, Acres, 1996).

Flood related policies, endorsed by the National Water Resources Committee (NWRC) in its 20 July 2000 meeting, are included in the Thailand's nine - point National Water Policy and Vision as set forth by that the RID details how this will be implemented (Sethaputra, 2001). Some of the points are:

Accelerating preparation of plans for flood and drought protection, including early warnings, damage control and efficient and equitable rehabilitation with proper use of land and other natural resources.

Create water management organizations both at national and at river basin levels with supportive laws. The national organization is responsible for formulating national policies, monitoring and coordinating activities to carry out the set policies. The river basin organizations are responsible for preparing participatory water management plans.

Providing sufficient and sustainable financial support for action programmes in line with national policy, including water-related research, public relations, information collection and technology transfer to the public.

For flood protection and also sustainable irrigation, Thailand River Basin Management Policies are set up. Water resources development master plan for 25 basins together with the implementation plan of large and medium scale irrigation projects are prepared (Sethaputra, 2001). Direction of water management in the Ninth National Plan is supporting the establishment of river basin organizations, eventually to cover all 25 river basins, with the participation of all concerned parties. In 1997, a Chao Phraya Basin Water Management Strategy, which Bangkok is the part of this river basin, was prepared with technical assistance from the World Bank. NESDB supervised the work in collaboration with major water agencies. The recommendations of this strategy related to flood were establishing the Chao Phraya River Basin Organization and Flood Management.

The Chao Phraya Flood Management Review (AIT, Danish Hydraulic Institute, Acres, 1996) illustrated the basic principles of policy for the Chao Phraya Basin and Bangkok as follows.

1) Proposals for flood protection works must be analyzed for the impact on the pattern of flow and water levels in adjacent areas and downstream. Adverse impacts have to be taken into account in the economic and environmental analysis.

In particular, flood protection for agricultural land in the Chao Phraya Basin must be carefully considered as this increase the pressure on the more valuable urban flood defenses. Upgrading of the existing standard of protection should be subject to the same careful analysis as new works.

RID has constructed flood protection embankments for the extensive irrigated areas along the Chao Phraya from Chainat downstream. In many places these embankments leave settlements on the river side of the embankment, where embankments raising water levels in the river channel, e.g. Pamoke. These settlements should be brought within the flood protected area as a priority.

2) Urban land should be protected to a standard of around 1 in 100 years. The standard of protection for agricultural land should not exceed 1 in 10 years. Thus for any combination of circumstances giving ruse to flooding of protected urban area, agricultural land will be flooded before the more valuable and essential urban land, and the pressure on the urban flood defenses will be relieved.
3) Proposals for new building works, housing, offices, factories, roads, etc., must be subject to the approval of the relevant authority in respect of drainage requirements. Compensatory works may take the form of compensatory storage, improved local drainage, or a tax payable to the drainage authority who would use the funds to improve the general drainage for the area. Land raised above the flood level additionally requires an equivalent volume of compensatory storage at the same elevation.

There must be no exemptions for government, military or agricultural use.

4) Structural works must be designed for floods greater than the standard for the required level of protection and should *degrade gracefully*, i.e. failure of an embankment should not result in sudden and widespread inundation of the protected area. Embankments should be constructed with fuses, i.e. weak points which will fail before any other part collapses. The resulting inundation can be controlled to a degree which will ensure that essential access routes, communications and services remain functioning.
5) Land corridors designated as floodways to channel flood water across the flood plain should have no buildings or raised land which will act as a barrier and obstruct the passage of flood water. Suitable uses for the land are parks and open recreation areas. Vegetation should either be grasses or reeds, or trees whose lowest branches will be above the design water level.

Under BMA, Department of Drainage and Sewerage (DDS) policy for 2005-2008 relevant to flood controls contains two major strategies (Tungpraprutgul, 2005);

Strategy 1: Following Governor Policy i.e. active flood solving, and canal pathway improvement.

Strategy 2: Following DDS duties i.e. responsible for the sub-polder systems, drainage efficiency, information technology in organizing flood control center, SCADA network station, and observing movement of rainfall from BMA radar.

For the Future Plan for Flood Protection of BMA, the DDS will develop the flood protection system to prevent and resolve flooding problems with main goals i.e.

1) immediately improve and complete the construction of flood walls at both sides of Chao Phraya River and Canal Bangkok Noi within Bangkok area,
2) prevent run-off from the North and East flow into the area and accelerate the discharging of water from the eastern are down south to the sea,
3) improve the main drainage system to have better efficiency, these are: by constructing dikes and dredging of main canals, by constructing main drainage system and tunnels to accelerate the discharging of water from the inundated areas to the river and sea, by improving and constructing lateral sewer system in all areas to suit the main drainage system in order to resolve the problem of flooding in streets,
4) accelerate the allocation of retention basins (monkey cheeks) to be sufficient in detaining flood water,
5) accelerate the development and improvement of Flood Control Center to have better efficiency by being able to forecast rainfall within 3-6 hours in advance and to forecast the possible flooding area(s) within 3 hours in advance in order to warn the people; by implementation of water management system using mathematical simulation model to control water gates, pumping stations and the operation to achieve the maximum efficiency (BMA, 2005).

In addition, the Public Works Department, Ministry of Interior, Royal Thai Government has requested the Regional Environmental Management Center (REMC) to carry out a Study for Preparation of Flood Protection Master Plan for Thailand. This study covers 49 provinces affected by the flood of 1995. The main objective of this study was to plan for the national flood protection in a systematic way. REMC had signed a consultancy contract the World Bank to carry out Flood Management study of the Chao Phraya river basin. This project is a part of the Chao Phraya Water Resources Management Strategy (CPWRMS). The objective of this study was to assist the Royal Thai Government in identifying high priority flood management projects, as well as charting out a conceptual program for basin-wide flood management. The assignment covers the entire Chao Phraya Basin, with a focus on flood management in its lower part (south of Nakhon Sawan province). The scope of work covers macro-level flood study, identification of current and planned flood management initiatives, formulation of flood policy, evaluation of flood management options, and flood management program.

As proposed by Tawatchai (2005a), flood disaster management can be divided into three stages: before disaster, during disaster, and after disaster.

1) **Before disaster**: Proactive approach in flood disaster management is important to minimize the impact of the disaster. In this case, effective disaster preparedness is essential. There are several steps that can be

considered for creating an effective disaster preparedness program and government should involve seriously for ensuring its successfulness (McEntire and Myers, 2004):

- Establishing law: Law will give the program power and authority. It shows that the government has commitment in the preparedness program and shows the responsible personnel in the program.
- Assessing the flood hazard: Assessment can be done by recording prior disaster events and searching information for historical data on the disaster.
- Creating an emergency operation plan (EOP): An EOP indicates the general courses of action to be taken during the disaster, however it should be flexible enough to allow some improvement.
- Creating a warning system: Warning provides vital information for the community such as when the disaster will occur, how long the disaster will last, and what people can expect.
- Identifying and acquiring resources and grants: An emergency manager should be able to reach people who can authorize the use of personnel, equipment, and supplies for relief activities.
- Initiating mutual aid agreement: Mutual aid agreement is a contract between different local governments to assist each other during the disaster.
- Training and exercising: Both are important to ensure that the personnel understand their responsibility during the disaster and also to test the applicability of the EOP.
- Public education: Public education will provide information regarding the disaster to the community; therefore they will understand to take proactive action during the disaster impact.

2) **During disaster:** During the critical time of disaster, it is important that people are well informed regarding the disaster. People should remain calm and follow the emergency procedures and proactive actions that have been prepared in advance. This information can save many lives and preparing for the disaster.
3) **After disaster:** An effective relief program is essential to help people recover from the impact of the disaster. Some aspects that should be considered in relief program are as follow (McEntire, 1999):

- Declaration of the disaster: This shows that the disaster is recognized and that help is needed.
- Distribution of aid: It is necessary to understand the needs of the people who suffered.
- Coordination and collaboration: Relief operations need coordination and collaboration among various agencies and organizations. .
- Knowledgeable relief workers: Experience in relief work is essential to ensure appropriate caring.
- Integration of relief and development: Development should become a high priority in the relief program to people to rebuild their areas and bounce back from the effects of the disaster.

The cycle of disaster management and activities is presented in Figure 3.

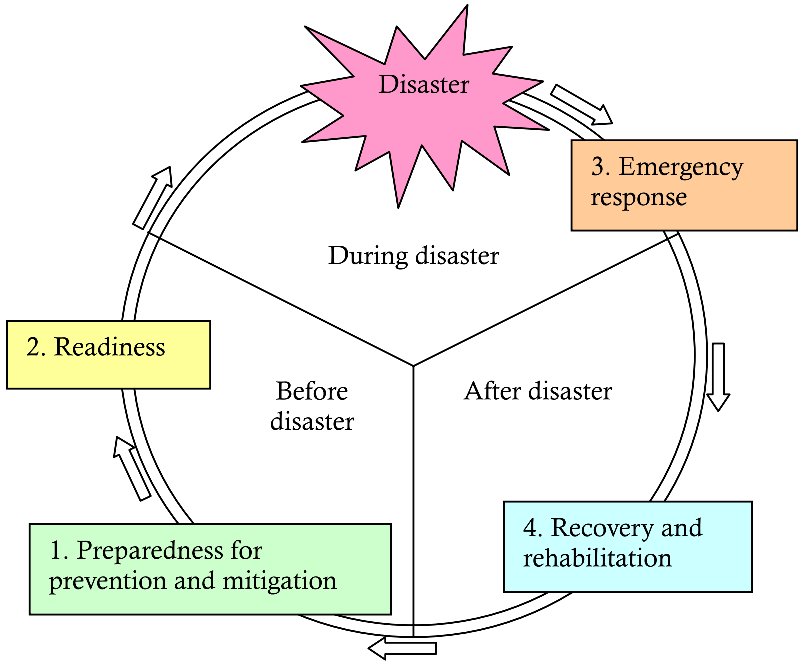


Figure 3: Flood and Natural Disaster Management Cycle (Tingsanchali, 2005)

In the past Thailand used reactive approach in disaster management and mainly the activities were rescue relief and recovery during and after disaster impact. At that time, Thailand used the concept of civil defence (2R): readiness and response in disaster management.

After reform of government system on 1 October 2002, Thailand started to change from reactive approach to proactive approach. The goal of this proactive approach is to reduce severity and effect of disaster by using prevention and preparedness. Thailand changed the concept of disaster management to the combination of 3E (engineering, education, and enforcement) and 4R (reduction, readiness, response, and recovery) (Teeraoranit, 2003; Tingsanchali, 2005b). The comparison of disaster management between before and after government reform is presented in Table 2.

Table 2: Comparison of Disaster Management between Before and After Government Reform

Factor	**Before Government Reform**	**After Government Reform**
Laws	34 laws related to disaster management and they had lack of enforcement. Confusing roles for organizations which participate in the disaster management.	Many laws were established to improve the disaster management. The purpose is to clearly set the roles of different organizations in disaster management.

Organization Structure	• Ministries, departments, central and local government and organizations had overlap responsibilities. • There are many levels of command. • No emphasize on NGOs and public sectors. • Use 2R concept.	• Department of Public Disaster Prevention and Relief lead the disaster management under Civil Defence Act B.E. 2522 and National Civil Defence Plan B.E. 2545. • Use combination of 3E and 4R concept.
Operations	• Use reactive approach. • No specific organization in disaster management. • Operation involved many organizations under the direction of Office of Civil Defense Secretary.	• Use proactive approach. • Operation is under management of Department of Public Disaster Prevention and Relief.

Source: Teeraoranit (2003)

F.3 Development of GIS database

In this study, existing database of present hydrological characteristics and socio-economic conditions and future predictions were collected. The detailed datasets are described as follows.

F.3.1 Spatial Data

The source of DEM data is Hydro1k with 1km resolution. The landuse data used for the study are collected from BMA. Soil data source utilized in this study was collected from Food and Agriculture Organization (FAO) with grid size of about 10 km. Number of population and building at district level in 2000 were collected. Also, River cross-section data with 1km resolution and transportation network in 2000 were collected. The DEM and landuse map of study area is shown in Figure 4. Transportation and soil map of study area is shown in Figure 5.

F.3.2 Temporal Data

Hourly rainfall data for 5 rain-gauge stations, E08, E17, E20, E25, E33, from August to October 1995 were collected (Figure 6). C22 station and Pom Phrachul Station were identified as upstream and downstream boundary respectively. Hourly water level of upstream and downstream boundary was collected. Daily evaporation for flood event in 1995 was collected as well. All temporal dataset obtained from Royal Irrigation Department (RID), Bangkok Metropolitan Administration (BMA) and Thai Meteorological Department (TMD).

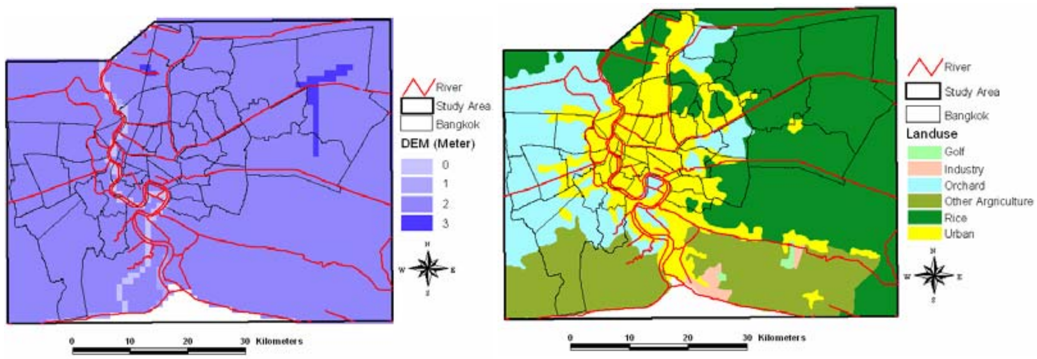


Figure 4: DEM and Land-use map of study area

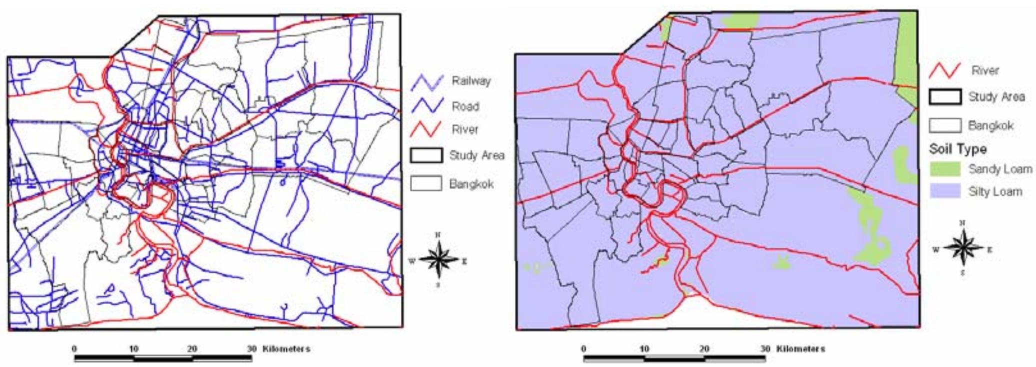


Figure 5: Transportation and Soil map of study area

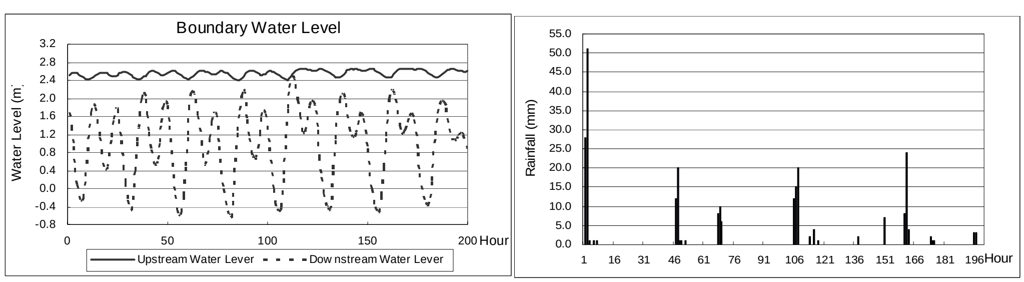


Figure 6: Hourly boundary water level (Oct 23rd to 31st , 1995)

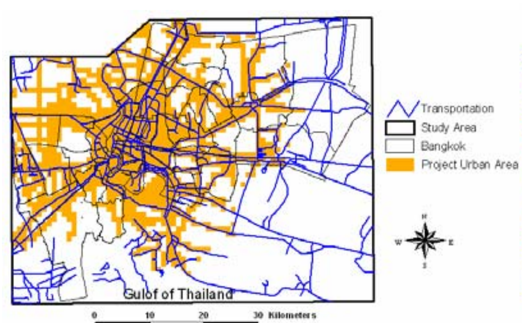
and average ranifall (Aug 4th to 13th, 1995)

F.3.3 Project Data

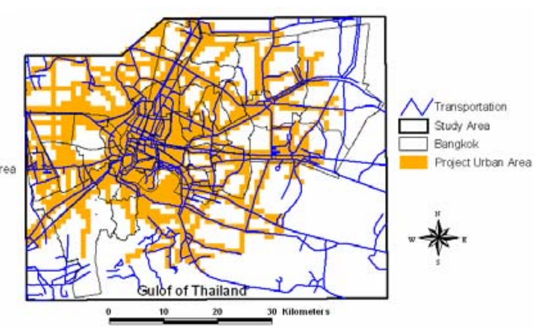
Projected population and landuse change was conducted by using LUCC model based on scenario of SRES B1. Maximum population density was designed as 20,000 persons / Km^2. The population and urbanization of future scenarios are shown in Figure 8.7 and Figure 8.

F.4 Modeling flood characteristics under climate change conditions

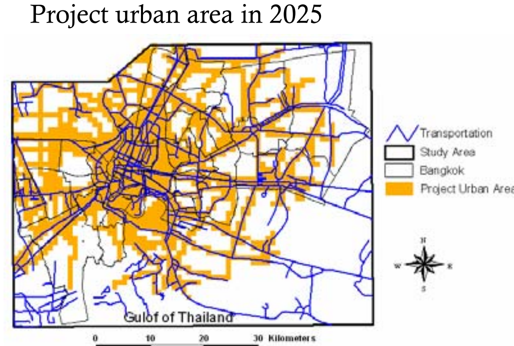
The model was calibrated and verified two selected flood events of 1995. The calibrated parameters were Manning's roughness in the river and runoff coefficient. Calibration and verification was performed using the observed water level data for the C12 and C4 water level gauging stations in the Chao Phraya River. The calibrated value of runoff coefficient was 0.4 and Manning's roughness for river was 0.04. Figure 8.9 shows the comparison of simulated and observed water levels at C12 and C4 stations during the period of verification. As can be seen from Figure 8.9, the simulated water level agrees well with the observed water levels at C12 for the peak and pattern of flow. However there are some overestimations of simulated water level at C4. The simulated maximum surface inundation during the period of verification for the flood event of 1995 is shown Figure 8.10. It shows that surface inundation was highest at the lowest part of the study area. Inundation height in most of the areas was within 1m, as mentioned in several reports on the 1995 floods. However, in absence of any ground actual flood inundation map, simulated results could not be verified.



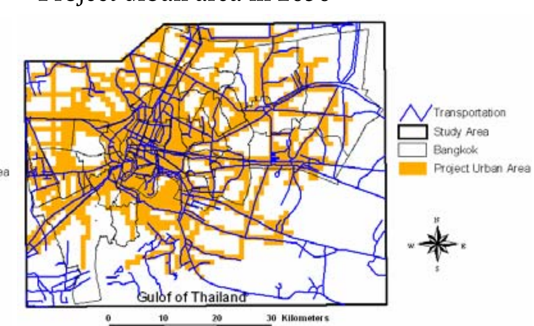
Project urban area in 2025



Project urban area in 2050



Project urban area in 2075



Project urban area in 2100

Figure 7 Projected Urbanization of study area in 2025, 2050, 2075 and 2100

For analyzing the impact of climate change, four scenarios are considered. According to sea level rise prediction made by IPCC in 2001, 14cm in 2025, 32cm in 2050, 57cm in 2075 and 88 cm in 2100 of downstream boundary was increased respectively based on sea level of flood event in 1995. To simulate extreme flood event, the boundary condition data was selected from 23-31 October 1995, the highest water level duration recorded in 1995. Hourly rainfall data was taken for the higher rainfall duration of 1995 floods that is from 4-13 August. Figure 11 shows the flood inundation maps for the years 2025, 2050, 2075 and 2100. The result was summarized in Table 3.

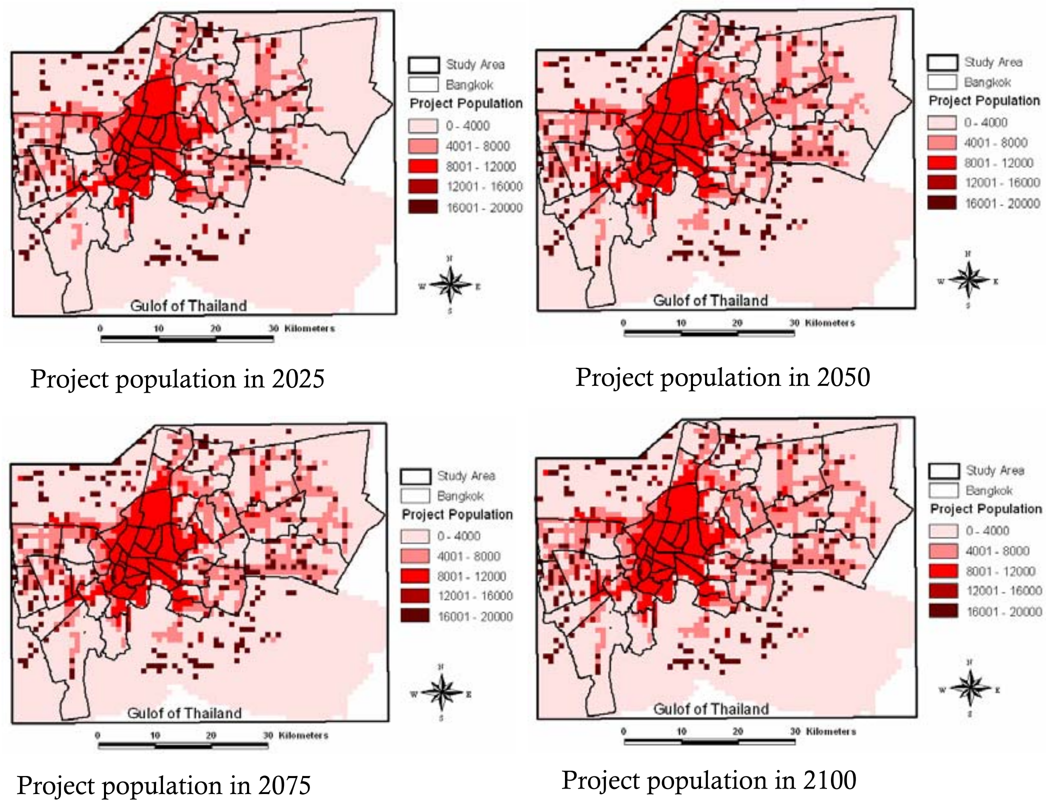


Figure 8: Projected population of study area in 2025, 2050, 2075 and 2100

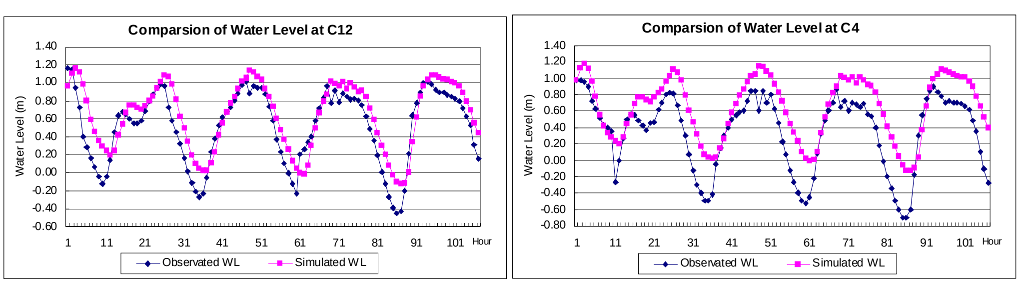


Figure 9: Comparison of simulated and observed water level at station C4

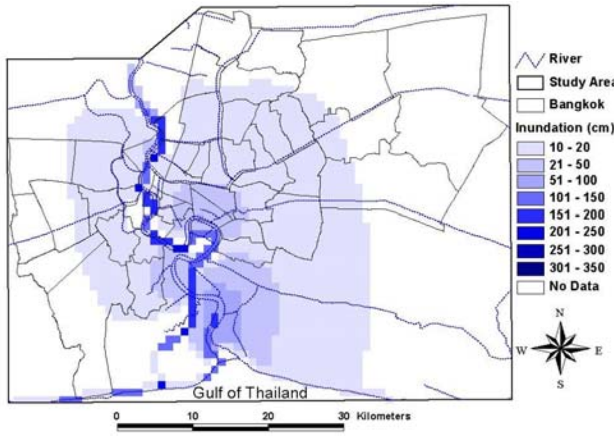
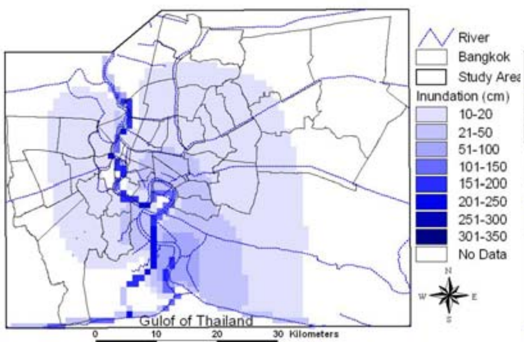
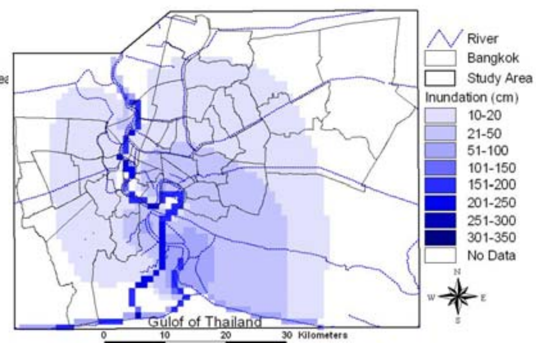


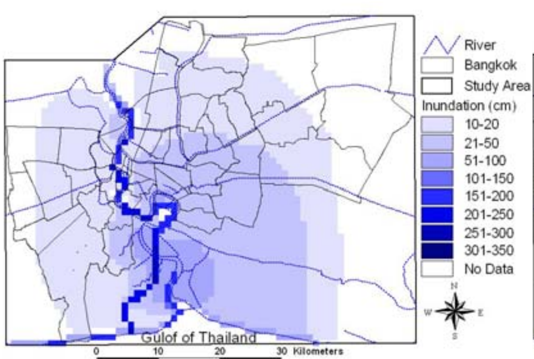
Figure 10: Simulated maximum flood inundation in 1995



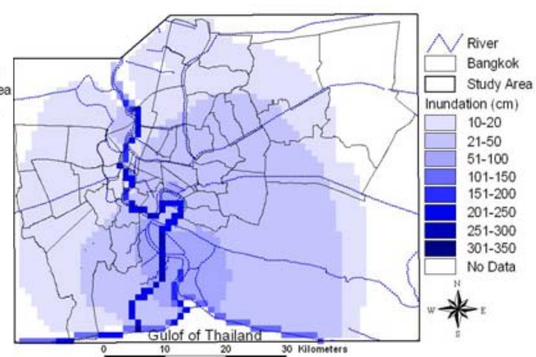
Simulated flood inundation map in 2025



Simulated flood inundation map in 2050



Simulated flood inundation map in 2075



Simulated flood inundation map in 2100

Figure 11: Simulated maximum flood inundation map in different scenarios in 2025, 2050, 2075 and 2100

Table 3: Summary of flooded area in different year

Flood depth in cm	Simulated flood Area in km^2 (in %)			
	2025	2050	2075	2100
10-20	1002(30.1)	970(29.1)	1031(31.0)	1003(30.1)
21-50	304(9.1)	457(13.7)	663(19.9)	1034(31.1)
51-100	56(1.7)	113(3.4)	152(4.5)	163(5.0)
101-150	30(0.9)	5(0.15)	1(0.03)	41(1.2)
151-200	24(0.7)	44(1.3)	39(1.2)	12(0.36)
201-250	13(0.4)	21(0.63)	24(0.7)	48(1.4)
251-300	0 (0.0)	1(0.03)	7(0.2)	9(0.3)
301-350	0 (0.0)	0 (0.0)	0 (0.0)	1(0.03)
Total	1,429(43)	1,611(48)	1,917(57)	2,311(69)

F.5 Assessment of socio economic impacts and vulnerability

Questionnaire survey was carried out for the impact assessment of flooding on different parameters (population, building, transportation network) for Bangkok. On the basis of questionnaire survey, flood risk indices were prepared for different flooding scenarios.

The flood risk index for buildings, population, road, and railway are presented in Tables 8.4, 8.6, 8.8 and 8.10, respectively. Their hazard maps of flood for different future scenarios (i.e. in 2025, 2050, 2075 and 2100) are shown in Figures 8.12, 8.13, 8.14, and 8.15, respectively. The summary of their effects in future scenarios are presented in Tables 8.5, 8.7, 8.9 and 8.11, respectively.

F.6 Links among policy, socio-economic factors floods and impacts

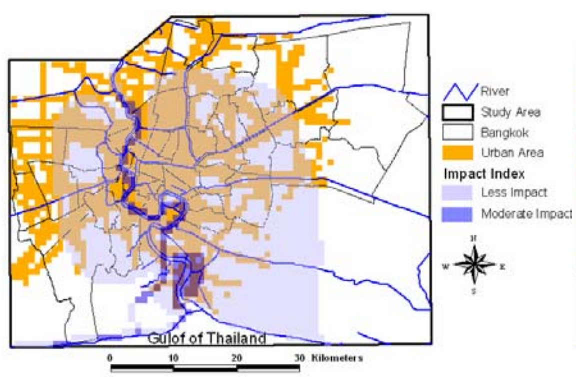
For flood protection and also sustainable irrigation, Thailand River Basin Management Policies which link socio-economic with physical factors are set up. Water resources development master plan for 25 basins together with the implementation plan of large and medium scale irrigation projects is prepared. Direction of water management in the present Ninth National Plan is supporting the establishment of river basin organizations, eventually to cover all 25 river basins, with the participation of all concerned parties. The Chao Phraya Flood Management Review (AIT, Danish Hydraulic Institute, Acres, 1996). constitutes an integral component of the overall basin management strategy to be formulated under the Chao Phraya Water Resources Management Study Project.

In Bangkok, the trend to higher flood damage values reflects a number of factors including price inflation and land subsidence in Bangkok. However, by a large margin the most important factor is the ongoing development of property vulnerable to flood damage in the flood plain of the river. The severity of floods has also increased due to changes in landuse.

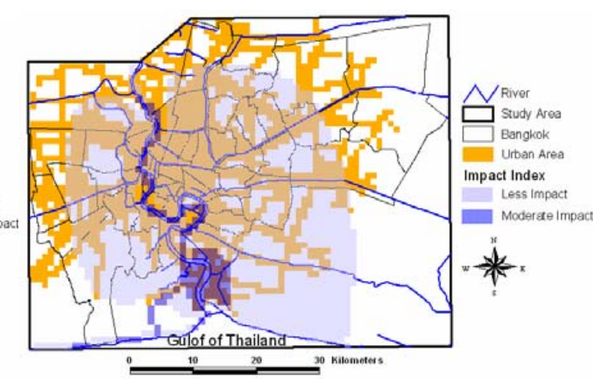
Tingsanchali (2005) suggested, for the disaster including flood management, that a master plan should be developed at national level first. At this level, the master plan covers all components of water-related natural disasters in Thailand. The plan also includes river basin or coastal zone planning that gives further detail to the master plan. The planning for this management should consist of four main steps: 1) Preparedness for disaster prevention and mitigation; 2) Readiness; 3) Emergency response; and 4) Disaster recovery and rehabilitation.

Table 4: Flood Risk Indices of buildings

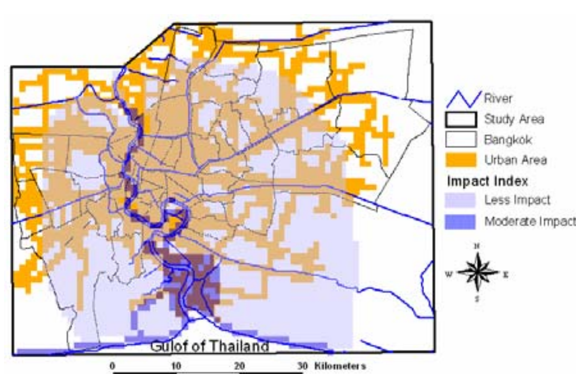
Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Less
0.60-1.00	Less	Moderate	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	Moderate	High	High
> 3.50	High	High	High	High	High



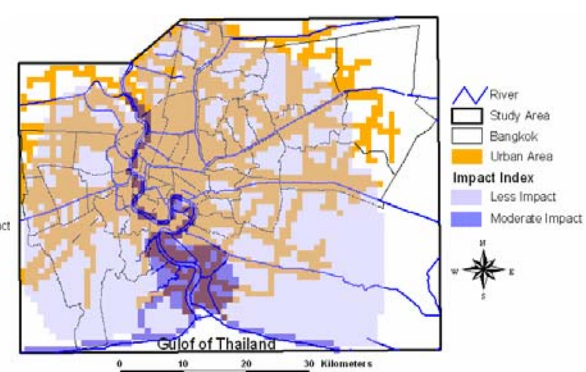
Impact on buildings in 2025



Impact on buildings in 2050



Impact on buildings in 2050



Impact on buildings in 2100

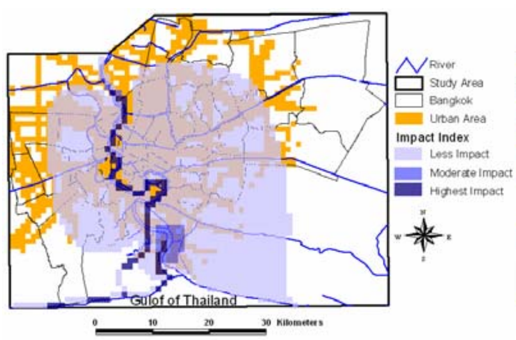
Figure 12: Flood impact on buildings in different scenarios in 2025, 2050, 2075 and 2100

Table 5: Summary of the affected buildings

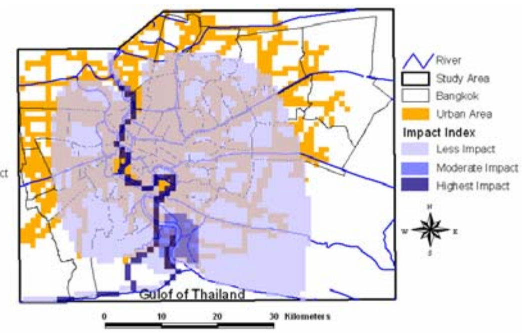
Impact Index	**No. of affected buildings in Bangkok**			
	2025	2050	2075	2100
Less Impact	1,145,980	1,451,322	1,629,826	1,791,502
Moderate Impact	82,008	97,071	105,328	110,577

Table6: Flood Risk Indices of population

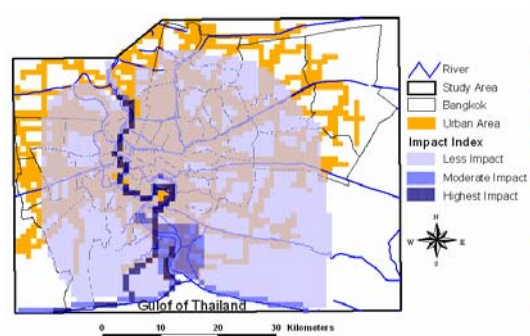
Depth of flood (m)	Duration of flood				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Moderate	Moderate	Moderate
0.60-1.00	Moderate	Moderate	Moderate	Moderate	High
1.00-3.50	Highest	Highest	Highest	Highest	Highest
> 3.50	Highest	Highest	Highest	Highest	Highest



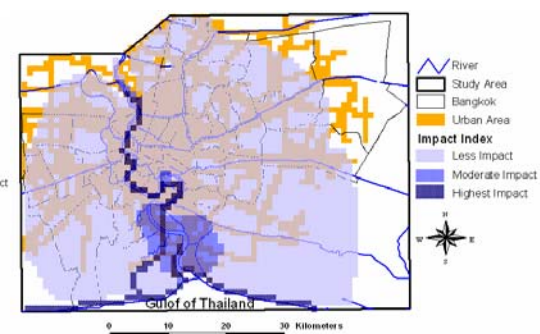
Impact on population in 2025



Impact on population in 2050



Impact on population in 2075



Impact on population in 2100

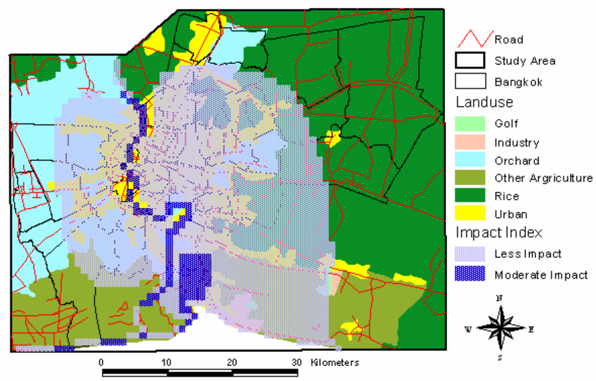
Figure 13: Flood impact on population in different scenarios in 2025, 2050, 2075 and 2100

Table 7: Summary of the affected population

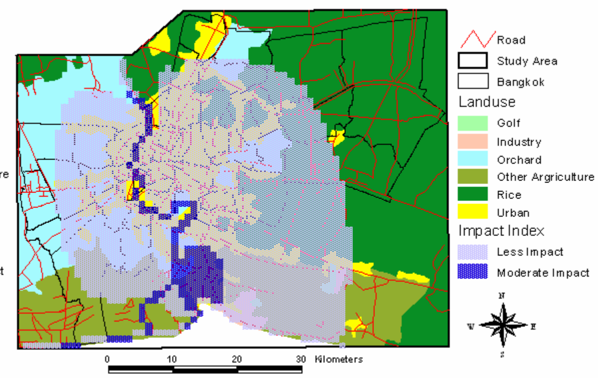
Impact Index	**No. of affected population in Bangkok**			
	2025	2050	2075	2100
Less Impact	5,720,020	6,804,316	7,632,711	8,969,668
Moderate Impact	134,045	227,777	340,657	446,810
Highest Impact	293,047	311,898	312,903	329,816

Table 8: Flood Risk Indices of road

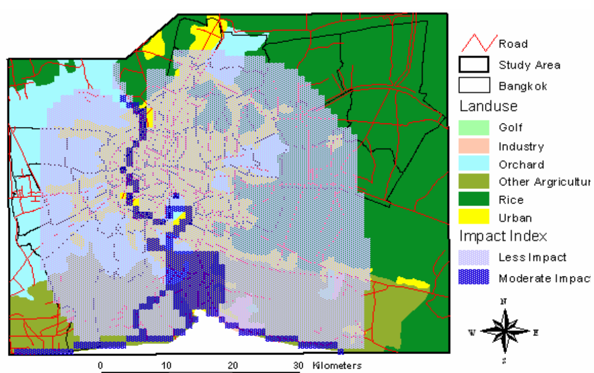
Depth of flood (m)	Duration of flood				
	< 1 day	1-2 days	3-4 days	5-7 days	> 1 week
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Less
0.60-1.00	Moderate	Moderate	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	Moderate	High	High
> 3.50	Moderate	Moderate	High	High	High



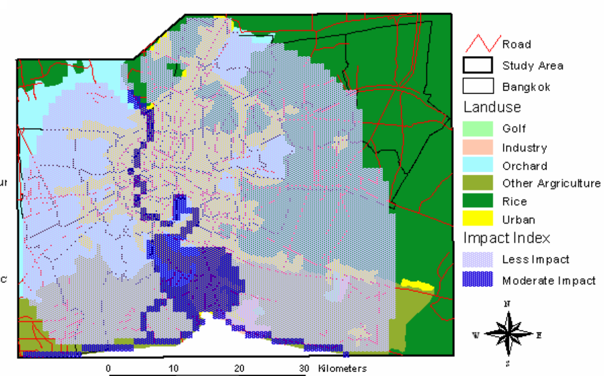
Impact on road in 2025



Impact on road in 2050



Impact on road in 2075



Impact on road in 2100

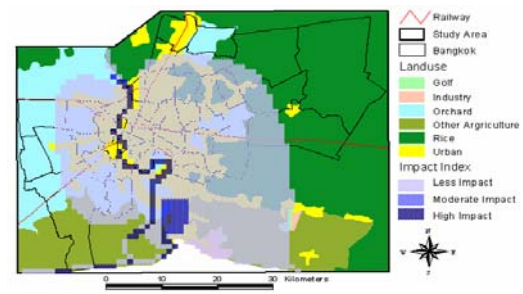
Figure 14: Flood impact on road in different scenarios in 2025, 2050, 2075 and 2100

Table 9: Summary of the affected road

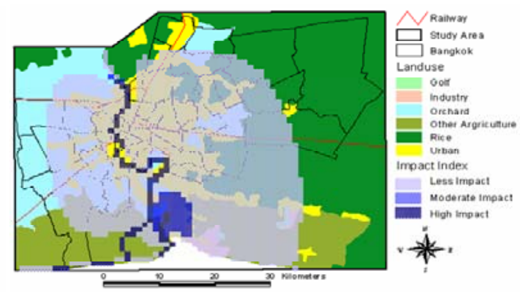
Impact Index	Length of affected road in Study Area (m)			
	2025	2050	2075	2100
Less Impact	569,742	624,118	695,961	837,332
Moderate Impact	65,522	80,041	110,741	133,836

Table 10: Flood Risk Indices of railway

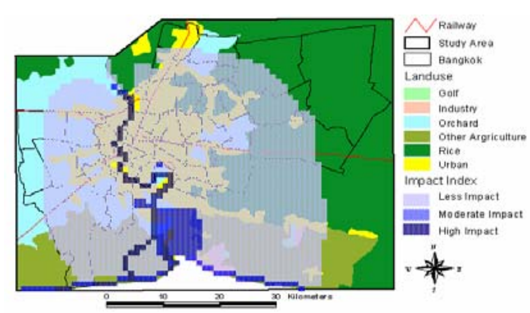
Depth of flood (m)	Duration of flood				
	< 1 day	1-2 days	3-4 days	5-7 days	> 1 week
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Moderate	Moderate
0.60-1.00	Moderate	Moderate	Moderate	High	High
1.00-3.50	High	High	High	High	High
> 3.50	High	High	High	High	High



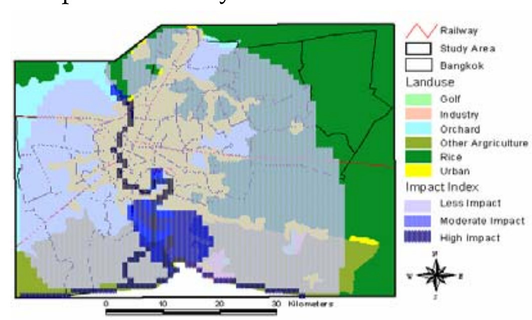
Impact on railway in 2025



Impact on railway in 2050



Impact on railway in 2075



Impact on railway in 2100

Figure 15: Flood impact on railway in different scenarios in 2025, 2050, 2075 and 2100

Table 11: Summary of the affected railway

Impact Index	Length of affected road in Study Area (m)			
	2025	2050	2075	2100
Less Impact	89,050	95,627	105,913	122,016
Moderate Impact	-	-	-	966
High Impact	1,430	1,430	1,430	1,430

Tingsanchali (2005a) has proposed the management strategies for floods and other disasters with links to policies and socio-economic factors, floods disaster and impacts as follows.

Key factors in flood disaster management

1. Policy: Government must have clear and continue policy in flood disaster management. It is necessary to integrate disaster management program into sustainable development of the country.
2. Laws and enactment: Government must have laws and regulations which are clear and updated to follow the present situation. Successful disaster management must be supported by the laws.
3. Incident commander: Incident commander must be unique and firm. Responsible organizations should provide necessary knowledge in disaster management to incident commander.
4. Participation of people and public sectors: Participation should exist in all stages of disaster management program.
5. Organization management: Good organization can utilize existing and allocated resources. It is necessary to increase the effectiveness of the organization.
6. Technology: Database is an important factor in disaster management. Computer technology, hardware, and software in information and communication system must be developed with human resources.
7. Study, research, and development: These are required for engineering, social, economic, art, cultural, and environment. Results of the study should be included in the integrated plan.
8. Domestic political support: Political system must realize the importance of disaster management. The main target is to provide the safety of life and properties of the people.

Public participation

- Public participation is viewed as a significant aspect in developing master plan for disaster management. It is a process of activities comprising of people involvement in contributing to developmental efforts, equitable sharing of benefits derived therein and decision-making with respect to setting goals, formulating policies and planning, and implementing economic and social development programs.

The seven basic steps for effective public involvement in any decision or activity as identified by USEPA (2004) are as follows:

1. Plan and budget for public involvement activities.
2. Identify the interested and affected public.
3. Consider providing technical or financial assistance to the public to facilitate involvement.
4. Provide information and outreach to the public.
5. Conduct public consultation and involvement activities.
6. Review and use input and provide feedback to the public.
7. Evaluate public involvement activities.

Proposed institutional arrangements

- In the past, activities in disaster management have faced problems in coordination and collaboration between involved parties and there has been a lack of responsible organizations. These problems have created ineffectiveness in disaster management program. It is recommended that disaster management should be done first by authorized lead agency, which has direct responsibility and legislation support. The Office of Public Disaster Prevention and Relief Committee should be established as well as 12 public disaster prevention and relief centres for unity of command. The proposed institutional arrangements are given in Figure 16. Another role is to support 75 public disaster prevention and relief offices in every province except Bangkok Metropolitan.

The advantages of this institutional arrangement are:

- Command directly from Prime Minister and other ministries will follow the Prime Minister.
- Level of command is direct to provincial authorities.
- Other organizations can bring the policy to implementation.
- Overview disaster management can be done for policy making, planning, and implementation.
- Better systematic coordination in disaster management.

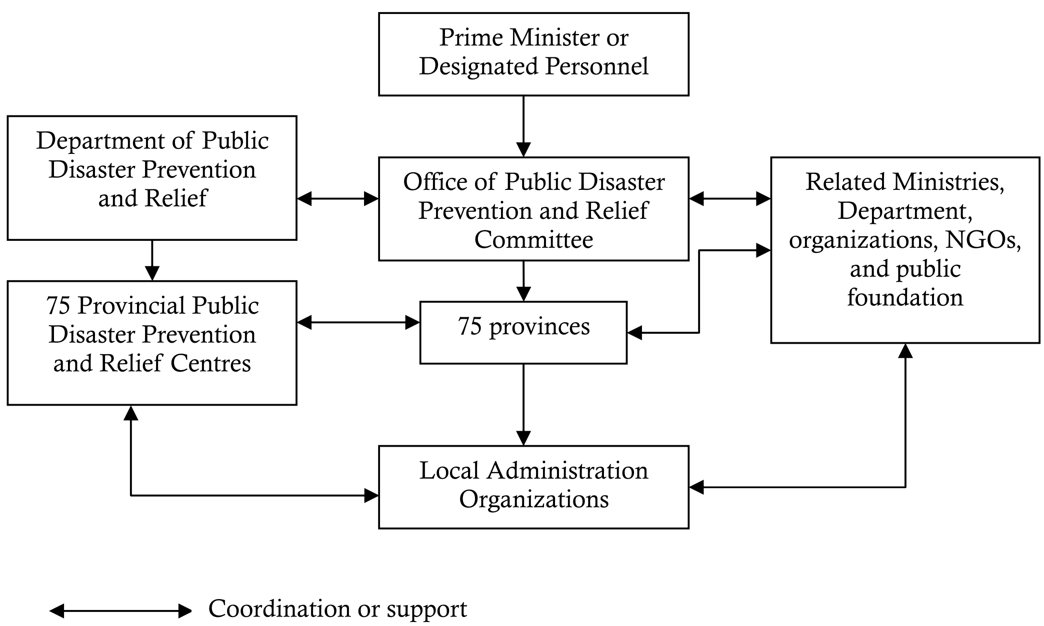


Figure 16: Proposed institutional arrangements for flood and natural disaster management

Reconstruction after disasters in Thailand

- 2004 Asian tsunami disaster forced Thailand government to carry out reconstruction to its impacted areas. Thailand government effort by constructing temporary shelter or housing for the tsunami victims. It was found that problems of unclear information still exist in the reconstruction project. To improve the existing condition, this study suggests these following success factors that need to be considered in the project level (Charoenngam, 2004):

- Clear defined goals (national policy, organizational goals, and project objectives).
- Top management support (executive commitment, on time decision, and acceptable cost overrun).

- Competent project manager (management and technical competency, law and contract competency).
- Competent project members (project owner, consultant, contractor, sub-contractor, and supplier).
- Sufficient resources (labours, material, tools and equipment, and clear shop drawings).
- Client consultation (marketing or user, cost adjustment, timeliness, and appropriateness of quality).
- Adequate communication (to reduce problems of cross culture, functional and conflict of interest).

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- Client consultation (marketing or user, cost adjustment, timeliness, and appropriateness of quality).
- Adequate communication (to reduce problems of cross culture, functional and conflict of interest).

Proposed coordination and collaboration in flood and natural disaster management

- Coordination and collaboration of disaster management in national level is essential to show the commitment of the country in this matter. In Thailand, there is a Department of Disaster Prevention and Mitigation to manage this issue which duties and responsibilities are as follow (Department of Disaster Prevention and Mitigation, 2005):

1. Formulate policy, guidelines and set up criteria for disaster management.
2. Study, analyze, research and develop the prevention, warning and disaster mitigation systems.
3. Develop information technology system for disaster prevention, warning and mitigation.
4. Mobilize people's participation in establishing disaster prevention and mitigation.
5. Create people's awareness and preparedness in disaster prevention and mitigation.
6. Arranging the training and exercise in disaster prevention and mitigation,

rehabilitation devastated area and in assisting the victims as stated by law.

7. Promote, support and carry out disaster prevention and mitigation activities, provide assistance to the victims and rehabilitate devastated areas.
8. Direct and coordinate the operation of assisting the victims and rehabilitate the devastated areas.
9. Coordinate the assistance with the organizations both internal and international in disaster prevention mitigation and rehabilitation.
10. Perform any other functions stated in by the laws as the Department's tasks or as assigned by Ministry of Interior or the Cabinet.

This department should manage and lead other parties in the country to ensure an effective disaster management plan. An example of disaster management coordination and collaboration among parties in a country is shown in Figure 17. Regional and international coordination and collaboration

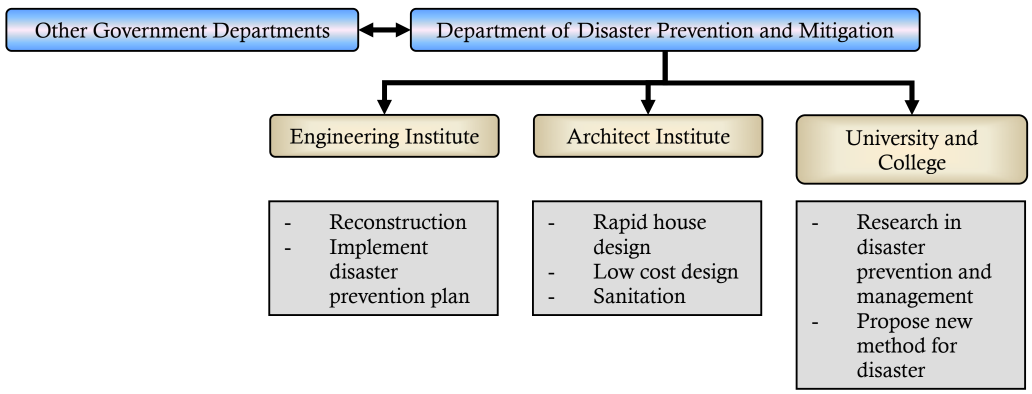

Figure 17: Flood and national disaster management in Thailand

should be established.

Thailand has shown improvement in its disaster management program. However, some problems still exist, especially coordination and collaboration problems among involved parties in the disaster management. This study suggests that Thailand should build a master plan for disaster management at national level first. After the plan can be implemented effectively in this level, the higher level planning, such as regional and international level, can be considered. This study proposes institutional arrangements that would be useful to reduce the impact of these problems. The study found that reconstruction projects after disasters in Thailand have lack of necessary information in each development stage. Therefore, critical success factors to improve this current situation are suggested.

F.7 Issues, challenges and recommendations

Issues:

- There should build a master plan for disaster management at national level.
- After implementation of the plan the higher level planning, such as regional and international level, can be considered.

Challenges:

- Coordination and collaboration problems among involved parties in the disaster management.

- Reconstruction projects after disasters in Thailand have lack of necessary information in each development stage.
- For the Chao Phraya river basin, most of the afore-mentioned methods of flood protection / prevention have been applied and they have brought about significant improvements in alleviation the floods in this basin. However, the recent sever flooding (in 1955) shows that a complete solution remains to be implemented.

Recommendations:

Existing policies should be revised and updated; and obsolete policies need to be revised.

Disaster management program have to be integrated into sustainable development of the country.

Government must have laws and regulations and successful disaster management must be supported by the laws.

There must have to be regional cooperation. Responsible organizations should provide necessary knowledge in disaster management to incident commander.

Technology transfer should consider and participation should exist in all stages of disaster management program.

Good organization can utilize existing and allocated resources. It is necessary to increase the effectiveness of the organization. Therefore capacity-building; Involvement of non-governmental organization should be increased.

Database is an important factor in disaster management. Computer technology, hardware, and software in information and communication system must be developed with human resources.

As the main target is to provide the safety of life and properties of the people so, political system must realize the importance of disaster management.

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Appendix G: Vietnam Case Study

Appendix G: Vietnam Case Study

G.1 Coastal zones and floods in Vietnam

Vietnam, Located in eastern Indochina, is bounded on the east by the South China Sea and by the Truong Son Mountain Range in the west. Its elongated shape, which faces the open sea, stretches over 1600 km between latitude 8° N to latitude 24°N. The country consists of three distinct topographical regions: the north, the central, and the south regions. The country consists of three distinct topographical regions: the north , the central and the south regions. (Shown in Figure 1).

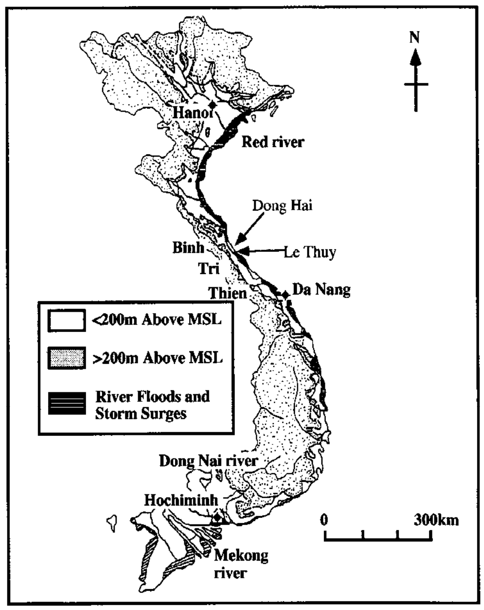


Figure 1: Topography of Vietnam with elevations above sea level and area damaged by river floods and storm surges shown by the horizontal shades.

The northern region is characterized by mountainous or hilly terrain. The major rivers, rising in the mountains to the west flow through hilly terrain into narrow flood plains and coastal plains. The Red river is the principal stream of this region. The river system in the central region is characterized by short streams with steep slopes. The average distance from the coast to the mountain range in only 70km. The southern region comprises the Mekong River delta where a low fat topography and numerous divergent flood channel are found.

Vietnam is affected by numerous types of natural disasters such as flood, storm, drought, forest fire, landslide, and earthquake. The impacts of each disaster are compared in terms of events, casualties, and the value of losses during the 1953 – 1991 period based upon the report by VNCINDNR (1994) in Figure 9.2. It's easily to see that the country is most heavily and frequently affected by floods. Water-related disasters are the most serious disasters among all the natural disasters in Vietnam. In 2003, damage from floods and storms cost at least VND 1.6 trillions ($101 million) claimed 180 lives and caused 191 injuries around the country (DMU, UNDP Project, 2004).

Prominent characteristics of major river systems in Vietnam:

The Red River System: This river system has a large basin area. Its greatest and smallest ever recorded flood discharges were 38,700 m^3/s and 3,500 m^3/s, respectively. Flood water level was once 10 meters higher than normal water level in the dry season. The biggest flood water elevation was 4-5 m higher than the average ground elevation.

The Central River System: Rivers in this region are short, steep therefore flood magnitude usually is high. Rainfall in the basin area can reach up to 1000 mm per day occasionally, causing 2m per hour flood magnitude.

The Mekong River System: the part of the system which runs through the Vietnamese territory is the system's downstream area and river mouths. Flood water discharge is high, flood duration is long, prolonging 2 to 3 months yearly.

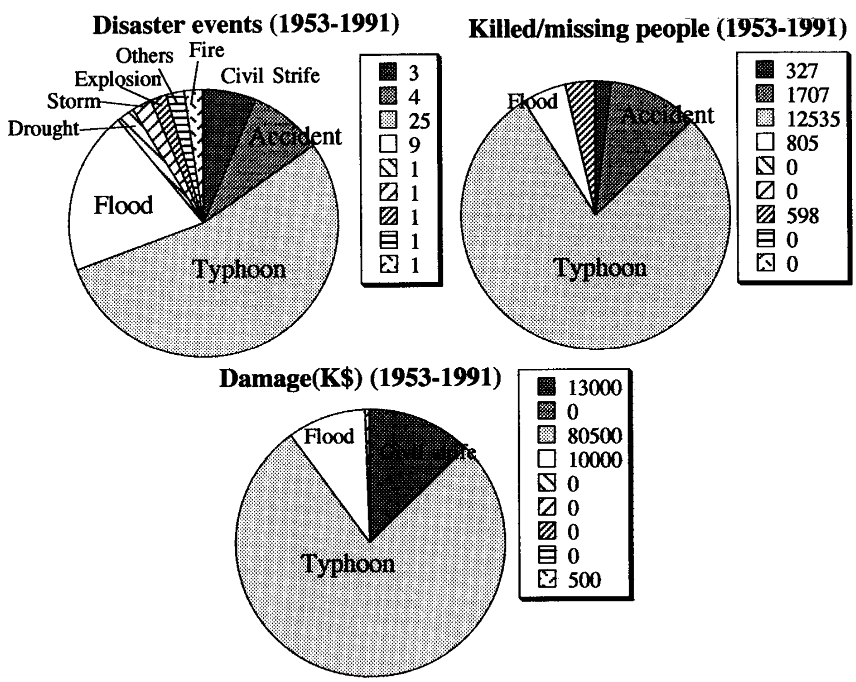


Figure 2: Estimated damage caused by man-induced and natural disasters in Vietnam (1953-1991)

The length of coastal line in Vietnam is 3260 km. A large system of river and coastal dikes has been constructed, However, Vietnam still continues to experience significant damage from floods and typhoons. Failures of sea dikes along the coast of Vietnam have occurred frequently. These failures have devastated villages and crops and caused loss of life and considerable damage to industry, commerce and the infrastructure. In addition, fresh water aquifers near the coast are being contaminated by seawater, partly through overpumping of ground water and partly because of reduced dry-season flow. This is severely disrupting agricultural enterprises and households that rely on ground water during the dry season. Moreover, the recent growth of the population has increased the number of popople living in the low land and coastal flood-prone areas.

G.2 Study area introduction

The study area is the Hue City of Thua Thien Hue Province in Vietnam. The location map is shown in Figure 3. Thua Thien Hue province is located in the central part of Vietnam, at the latitudes 16°14' - 16°15' North, longitudes 107°02' - 108°11' East, is 127 km long and 60 km wide on average, with mountains accounting for up to 70% of the natural land. Geographically, Thua Thien Hue borders Quang Tri Province to the North, Da Nang City to the South, with Laos P.D.R., separated by the Truong Son range, to the West, and over 120 km of seacoast to the East. The total area of the province is 5,009 sq-km and has a population of 1,050,000 in 1999 (Hoang Thanh Tung, 2003). The area lies in the tropical monsoon zone influenced by the convergent climate of the subtropical North and the tropical South. There are two distinct seasons: The rainy season, with storms and hurricanes, lasts from September to December; and the dry season, with little rain, last from January to August. Flood and storms are the main disasters in Thua Thien Hue Province (Hoang Thanh Tung, 2003).

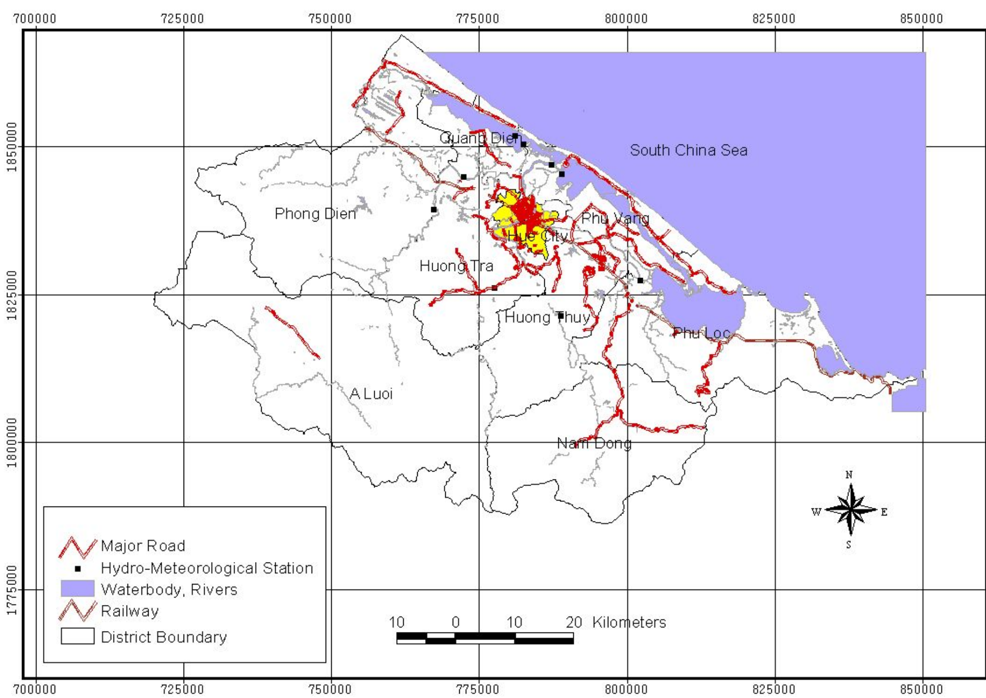


Figure 3: The location map of study area

G.2.1 Hydro-meteorological characteristics

Climatically, Vietnam is characterized by tropical monsoons with frequent typhoons in the northern and central regions but rarely across the southern region. The season distribution of rainfall is related to movement of the monsoons. The intensity of rainfall is extremely high and produces a rapid rate of runoff and serious flooding. Annual rainfall between 1800 and 2500mm, however, is unevenly distributed throughout the year. From 70% to 80% of the rainfall occurs in the rainy seasons, July, August and September. In the Mekong river area, for example, the discharge in the rainy season is bout 20 times greater than that in the dry season. The uneven distribution of rainfall is one of the main causes of river flooding (VNCIDNDR, 1994).

The Huong River is the greatest river of the Thua Thien Hue Province and located from 16°00' to 16°45' of the north latitude and from 107°00' to 108°15' of the east longitude, its west is the Truong Son mountains, its north is Bach Ma mountains, its south is contiguous to the Da Nang city and its east is Eastern sea.

The Huong River has a basin area of 2,830 km^2 that representing 56% of total area of Thua Thien Hue province and playing an important role on water resource as well as the inundation status of the province. Over than 80% of this basin area is hills and mountains with their heights from 200 to 1,708 m. A 5% of the basin area is the coastal dune with altitude from 4 – 5 m to 20 – 30 m; the remainder area is 3,700 ha which can be cultivatable.

Main flow of the Huong River originates from a high mountain area of the Bach Ma range where is from 900 to 1,200 m of altitude. From its origin to the Tuan cross river, the main flow is called as the Ta Trach and from the Tuan cross river, it is called as the Huong River (or the Perfume River), the river that expresses many bold romantic feature on life, culture and natural landscape of the Hue ancient capital. The form characteristic of the Huong River system and its great branches is shown in the table 1 below:

Table 1: The form characteristic of the Huong River basin

Name of river or branches	River class	Length (km)	Basin area (km^2)	Ave. height of basin (m)	River bed incline (%)	Ave. width of basin (km)	River network density (km/km^2)	Curve coefficient
Huong	Main	104	2830	330	4.8	44.6	0.6	1.65
Hai Nhut ravine	I	15	75.3		10.6			11.3
CaRum BaRan	I	29	219.3	458	62.3		0.58	1.45
Co Moc ravine	I	18	88.3					1.30
Huu Trach	I	51	729	326	3.7	14.6	0.64	1.51
Bo	I	94	938	384	9.5	12.7	0.64	1.85
Dai Giang	Tributary	27						

The Huong River water converges in the Tam Giang - Cau Hai lagoon that its length is of 67 km, average width is of 2.2km and its depth changes from 1. 5m, and then goes to the sea through mainly the Thuan An and Tu Hien estuaries.

G.2.2 Socio-economic characteristics

The population of Vietnam is about 65 million and the density of the rural population is among the highest in the world. Since Vietnam has developed as a nation by exploiting the low-lying river deltas and coastal lands for wet-rice agriculture, flood disasters are serious because most of the population lives in areas susceptible to flooding.

Thua Thien Hue Province has a area of 5053 km^2 and is divided into nine administrative districts. The population is over one million; 300,000 people reside in or around the capital city Hue. Much of the province's infrastructure and industry lies in the coastal plain. The North-South highway and the railway

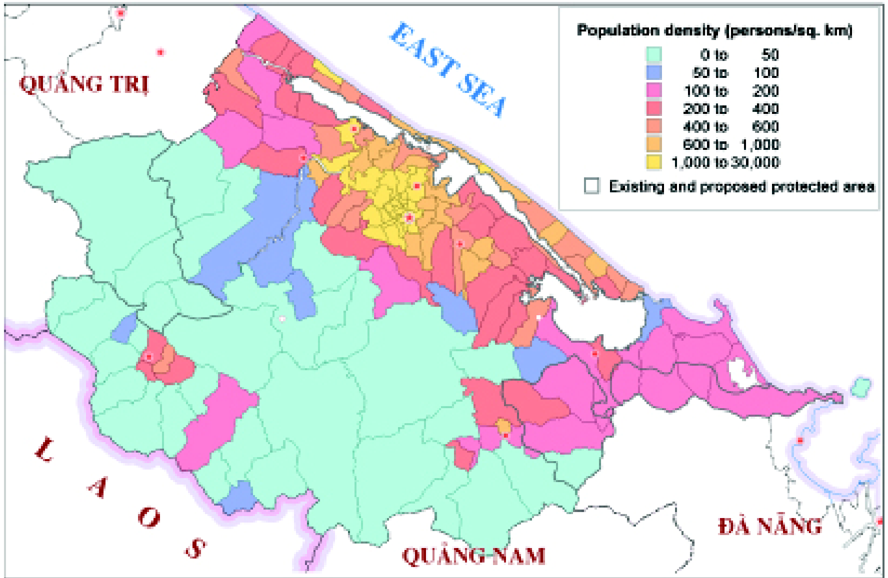
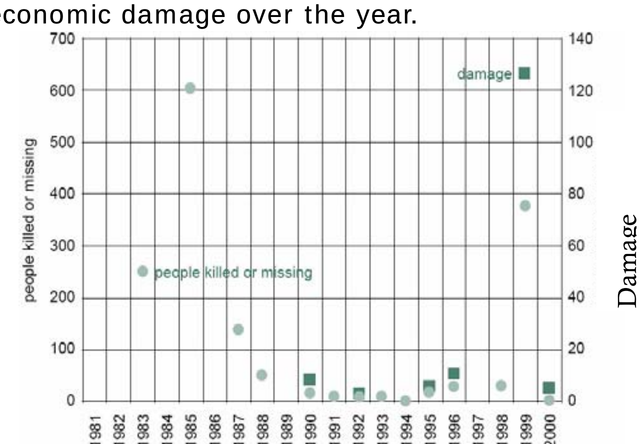


Figure 4: Population density, Thua Thien Hue Province

linking Hanoi to Ho Chi Minh City pass through Hue and effectively bisect the province. Most of the population lives on the coastal plain, within 25 km of the coast (Figure 4). Much of the interior of the province has a population density of less than 50 people km^2. The province's gross domestic product (GDP) was approximately US$240 million (at current prices in 2000), a per capital GDP of approximately US$230 at market prices (IMF2002; TTHSO 2001)

G.2.3 Flood vulnerability and history

Thua Thien Hue Province is an extreme case in terms of the potential effect of forest clearance. With the short, steep nature of the upland areas, deforestation and subsequent use of the land for different purposes – even for plantation forestry – are likely to increase flood severity. Figure 5 shows the loss of life and economic damage over the year.



G.2.4 Existing flood disaster mitigation measures

The major existing flood disaster mitigation measures are described as follows:

The Government of Vietnam has paid due attention to the construction and maintenance of dykes, regular enhancement of dyke protection capacity, and exertion of all-out efforts to protect dykes during disasters.

After the historical flood in 1971, Vietnam has upgraded flood diversion works in the Red River Delta and issued appropriate policies for managing flood diversion areas to ensure social equity and to create favorable conditions for rehabilitation and reconstruction.

The Government invested in building the Son La Reservoir, which is capable to retain up to 7 billion m^3 of water during flood events.

After successive years of serious disasters in the Mekong Delta, the Government decided to invest in establishing more than 800 residential clusters to accommodate over 1 million people previously residing in deeply inundated areas.

The National Committee for Search and Rescue was established to perform quick and effective search and rescue activities.

The Government advocated a program for planting 5 million hectares of forest in bare land areas.

Legal instruments relative to flood and storm control are continuously updated.

The mitigation measures are various in different part of Vietnam.

For mountain urban areas: These urban areas need to be re-planned, taking into account of preparation for and avoidance of flash flood and landslide.

For Hanoi Capital: It is the economic and cultural center of the country that being protected by 2 measures:

Structural measure:

- Closely and frequently managing the dyke system
- Constructing reservoirs in the upstream area.
- Diverging flood water
- Draining flood water: dredging and extending river flood plains
- Non-construction measure:
- Promoting flood and storm forecast and warning activities
- Afforesting in the upstream area
- Increasing the community awareness of the integrated management
- Planning residential areas
- Pruning off tree branches before annual storm season.

For the Central coastal cities:

- Planning of urban development based on flood extent maps
- Strengthening the storm and flood forecasting and warning capacity

- Promoting community awareness
- Constructing reservoirs
- Planting forests
- Promulgating regulations on construction for resisting flood and storm
- For urban areas in the Mekong River Delta:
- Strengthening houses, infrastructure constructions
- Organizing childcare centers
- Promoting flood forecast and warning
- Increasing community awareness of flood and storm preparation and avoidance.

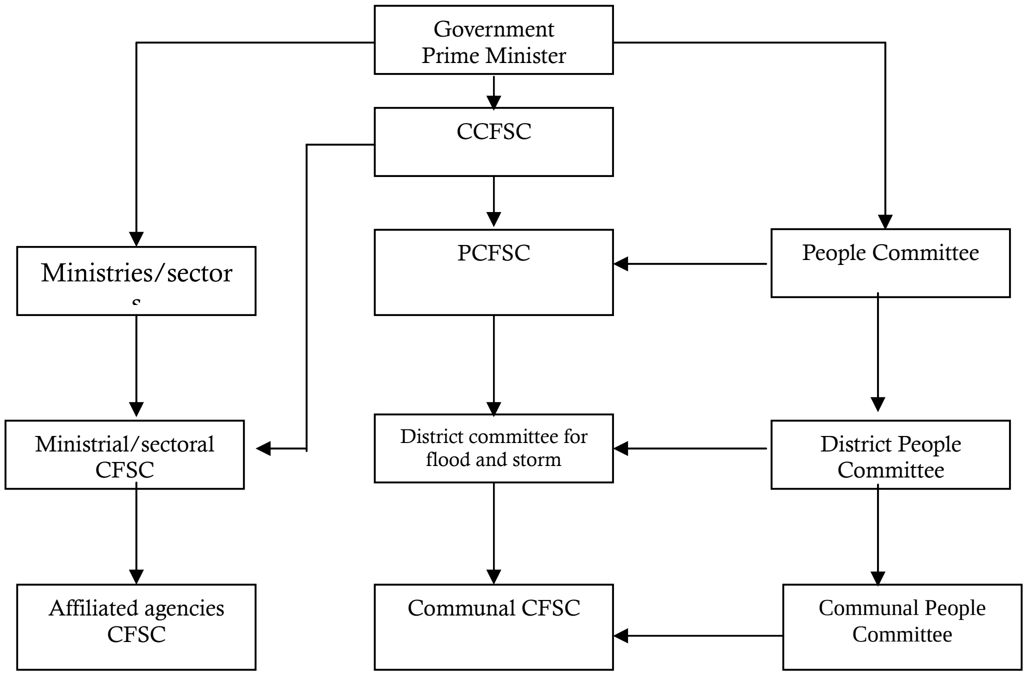
G.2.5 Existing flood risk management policies

The organization system for flood and storm control of Vietnam spreads from central level to local level. Having to undergo many changes, the current system is basically comprehensive, enabling disaster management practitioners to effectively perform flood and storm control. The system is elaborated bellow:

Participation of different organizations in flood and storm control

The Central Committee for Flood and Storm Control (CCFSC) is multi-sector agency. Members of the CCFSC are:

1. Ministry of Agriculture and Rural Development
2. Government Office
3. Ministry of National Defend
4. Ministry of Public Security
5. Ministry of Fisheries
6. Ministry of Transportation
7. Ministry of Natural Resources and Environment
8. Ministry of Planning and Investment
9. Ministry of Finance
10. Ministry of Science and Technology
11. Ministry of Industry
12. Ministry of Civil Engineering
13. Ministry of Telecommunication
14. Ministry of Commerce
15. Ministry of Labor, Invalids and Social Affair
16. Ministry of Foreign Affairs
17. Ministry of Health
18. Ministry of Education and Training
19. Vietnam Television
20. Radio Station Voice of Vietnam
21. Vietnam Red Cross



Long tradition of flood control has given Vietnam sound experience in flood risk reduction. However, traditional measures such as maintaining dyke systems have grown less effective as the following hindrances emerge:

- High speed urbanization and population expansion, resulting in serious problems with land use
- Degradation of dyke systems as primary structural measures for preventing inundation in the Red River Delta
- Serious destruction of upstream protection forests
- Reduction of flood water discharge capacity
- Rapid climate change causing natural disasters to develop more intensively extensively.

Vietnam has embarked on a new approach for flood risk management, which is composed of three components:

Before disaster: Active prevention and preparedness.

During disaster: Active protection of human life and property.

After disaster: Active rehabilitation of people's life and overcoming of disaster consequences.

Basically, flood management has been integrated into national and local plans and programs for socio-economic development.

Main features of flood control approaches, policies and strategies:

- There has been a remarkable shift in disaster management approach long adopted by Vietnamese disaster management practitioners. Accordingly, an important component of resources for disaster response is being used for disaster prevention and preparedness.
- Institutional capacity building for flood risk management is both an immediate and a long-term effort.
- Living with floods has the advantages of taking benefit from flood water and of reducing flood induced adverse impacts.
- Flood response measures are enforced with careful consideration of cost benefit.
- Due investment in disaster preparedness and mitigation bears sustainable development outcomes.

The related legal provisions were made for flood risk management.

Forestry related legal provisions:

- Forest Protection and Development Law, including provisions that prohibit upstream forest destruction
- Government Decree stipulating sanctions for violations of forest protection and management laws
- National Assembly Resolution on five million hectare reforestation
- Government policies on allocation of agriculture and forestry land to individual households.

Agriculture related legal provisions:

- The Ordinance on Dyke and Dyke Maintenance stipulates that the plantation of perennial trees in the proximity of river flood discharge routes is strictly prohibited.
- Ministry of Agriculture and Rural Development issues instructions for crop shifting measures, according to which crop structures are rescheduled to avoid flood season.

Construction related legal provisions:

- Ordinance on Flood and Storm Control provides for prohibition of any construction activity in floodwater discharge corridors; relocation of historical relics which are located in flood water discharge corridors, etc.
- To ensure safety of Hanoi Capital, decree on Flood Water Diversion stipulates that elevation of summer dykes-small and low dykes built by local residents outside of the main dyke system to protect small riverside stretches of land-must not exceed flood Alarm Level II of the Red River system.

G.3 Development of GIS database

In this study, existing database of present hydrological characteristics and socio-economic conditions were collected and the future scenario were projected. The detailed datasets are described as follows.

G.3.1 Spatial dataset

The data used in the study has been gathered from various sources. The preparation of spatial dataset engages extensive GIS use. The Digital Elevation Model (DEM) is used to prepare the 2-D model grids, which represent the surface elevation. All the grids are numbered and an index map is prepared for identification with other features. The land use map is used to assume roughness value for the surface. The river network is also delineated on the GIS map to identify the locations of the cross section with the surface grids.

Surface grids have been prepared from the digital elevation model of the Lower Mekong River Basin with 1 km resolution. The total number of model grids is 2939 for the study area as shown in Figure 6.

For the model input the raster grid of GIS file is converted into ASCII file. The ASCII file was processed for model input. Each grid is numbered and assigned with its neighboring grids i.e. the grids in north, east, south, and west direction and in the input file each grid contains the information of land elevation, manning roughness value, house occupation ratio, grid type (boundary or internal) for the model.

The land use map has been used for assuming roughness values for surface

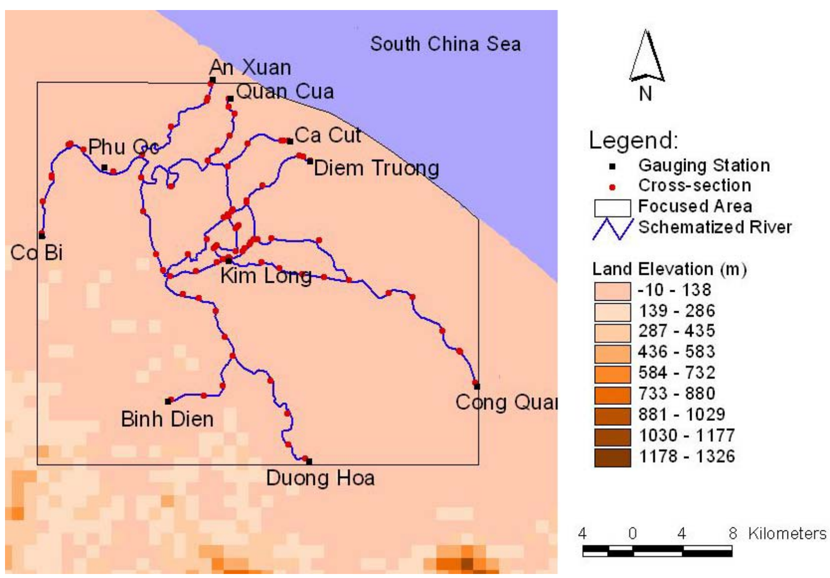


Figure 6: Digital Elevation Model of study area

grids. This map has been obtained from Global Map'97 dataset. The land use type is shown in Figure 7.

The river network and cross section data has been obtained from previous study (Hoang Thanh Tung, 2003), The river system comprises 11 channels as shown. The rivers are assigned with cross sections. The total number of cross section is 94. The raw cross section data has been processed to establish a relation of width, area and hydraulic radius with respect to level of the each cross section and assigned with river chain age. The cross section node of the river system is shown in Figure 8.

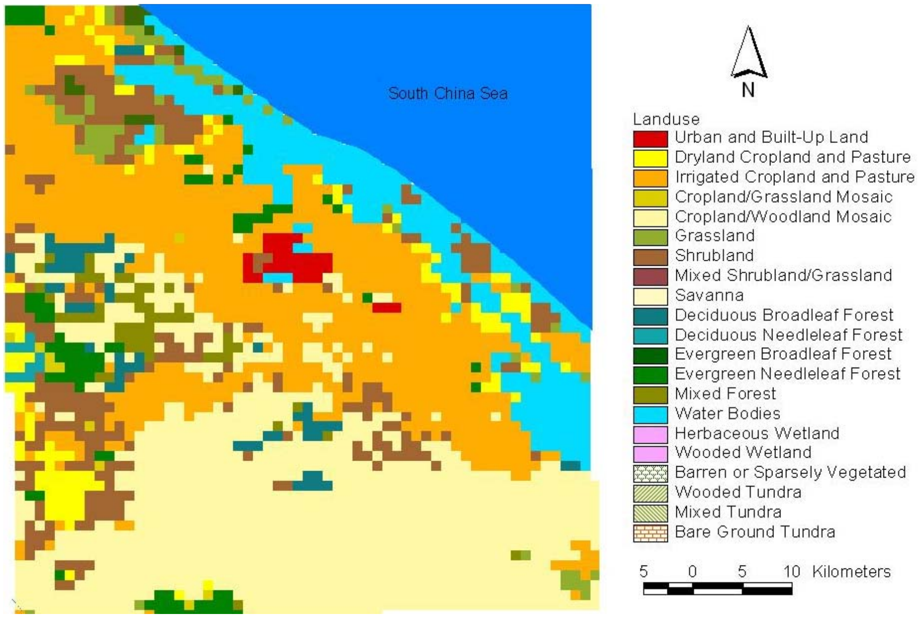


Figure 7: Land use map of the study area

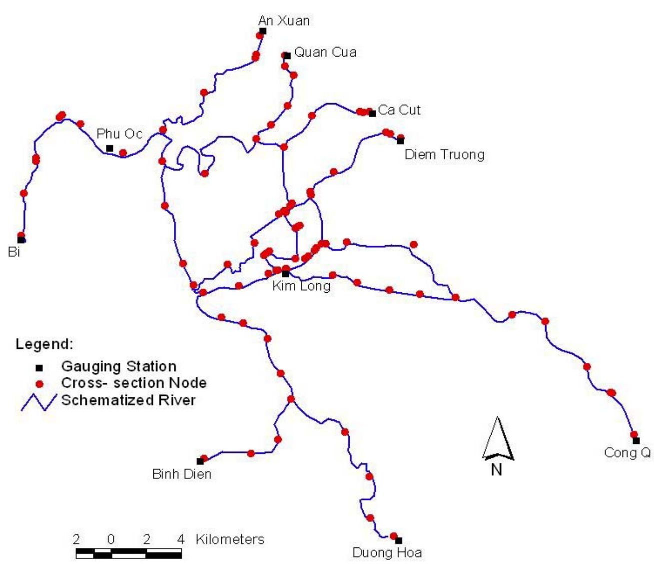


Figure 8 Schematized River Network

G.3.2 Temporal Dataset

The temporal water level, discharge and other hydro-meteorological data are those used in previous studies (Hoang Thanh Tung, 2003). Model needs good resolution of temporal dataset for proper simulation. Time series of hydro-meteorological data has been collected from the MRCS for the year 2000 and 2002. However, the discharge data is only available for 2002 from July to December. Water level data is daily. The list of the hydro-meteorological stations is given below (Table 2). The data is available for 1983 and 1999 flood simulation.

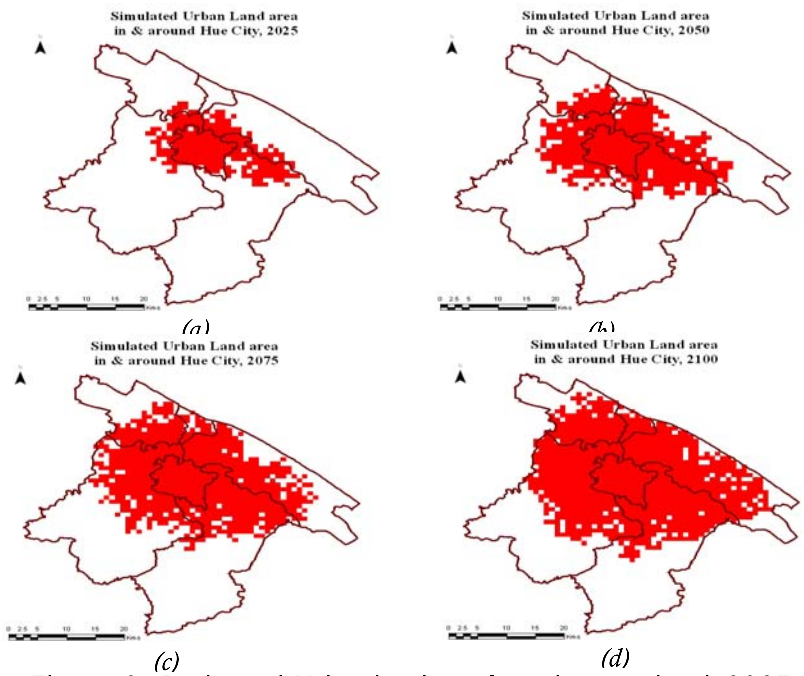


Figure 9: Projected Urbanization of study area in a) 2025, b) 2050, c) 2075, d) 2100

The rainfall data is available at 4 stations for 1983 which is daily value. In model application these 4 station data is averaged for surface input with one hour interval. However, in 1999 the data at hue is available with one hour interval. Only this station data has been used for this year simulation. The rainfall has been assigned on the focused area only since the runoff resulted from rainfall from the outside of the focused area has been considered as upstream boundary discharge at two locations Bienh Dien and Doung Hoa.

G.3.3 Project Dataset

Spatial Simulation is carried out based on IPCC SRES B1 Scenario of Economic growth and Population changes. The result is shown below:

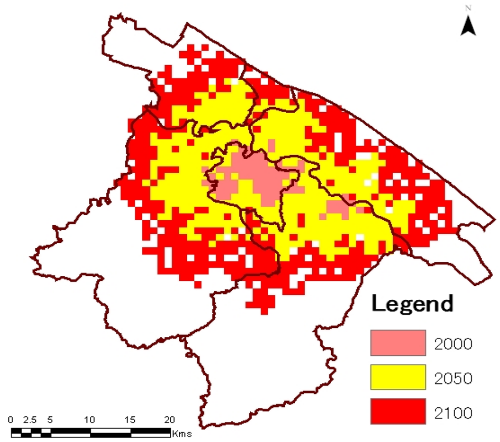


Figure 10: Urban area sprawl from 2000 to 2100

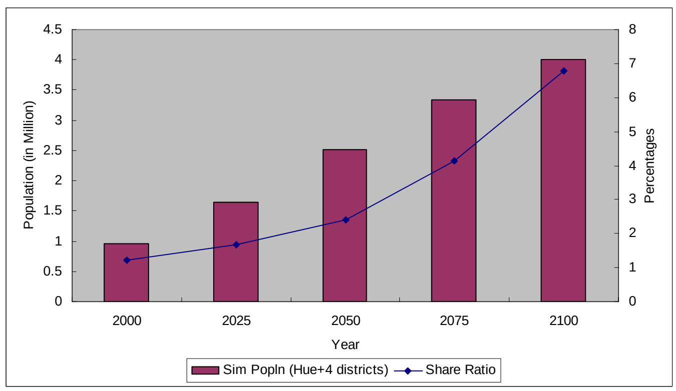


Figure 11: Population in Hue and Neighboring Districts

G.4 MODELING FLOOD CHARCTERISTICS UNDER CLIMATE CHANGE CONDTION

Calibration and Verification

The model has been applied for calibration and verification. The year 1999 has been considered for model calibration and 1983 for verification. Only 7days period simulation has been possible to carry out due to data limitation.

The initial water level in the river is assigned based on observed data. The initial surface water depth was considered based on the average water level on the downstream (Figure 12).

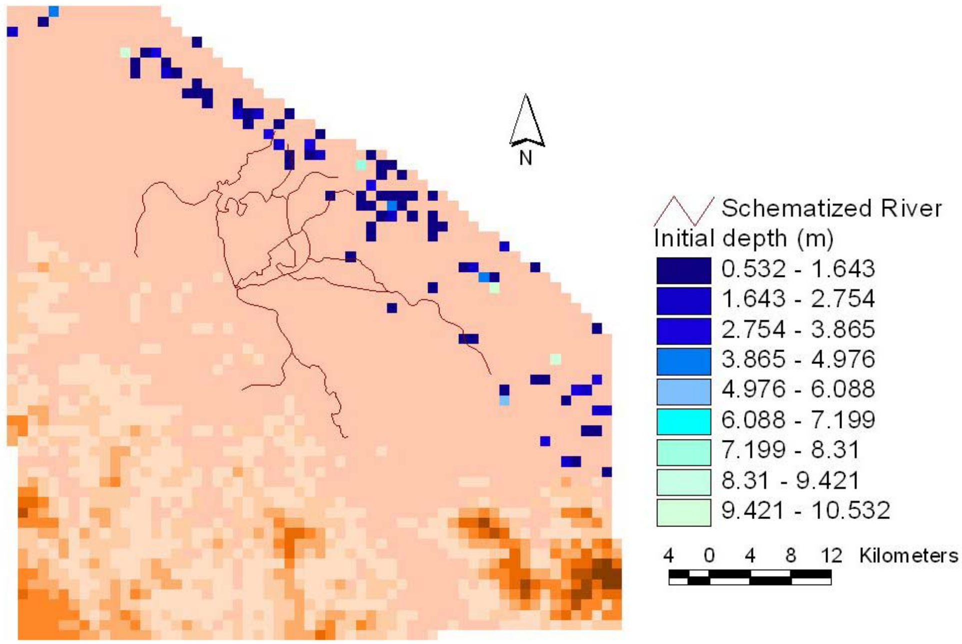


Figure 12 Initial Water Depth on the Surface

The upstream boundary locations are Bienh Dien, Doung Hoa and Co-Bi where discharge time series have been used as boundary condition. The discharge at Co Bi is observed data with one hour interval. The discharge at two others locations (Binh Dien and Doung Hoa) have been obtained from HEC-HMS model developed for this basin (Hoang Thanh Tung, 2003). The discharge hydrographs in 1999 and 1983 are shown in Figure 12.

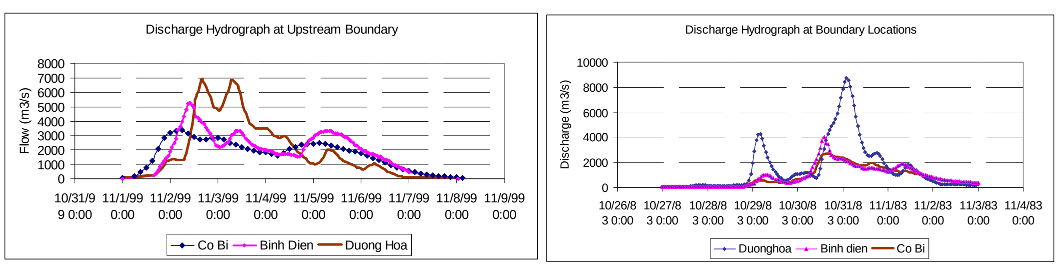


Figure 12 Boundary Discharge in 1999 and 1983

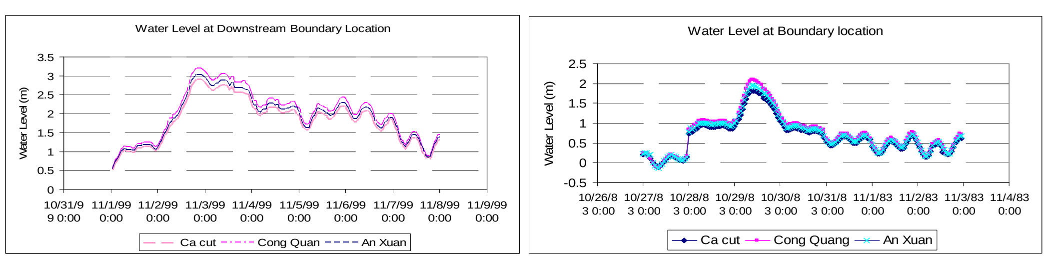
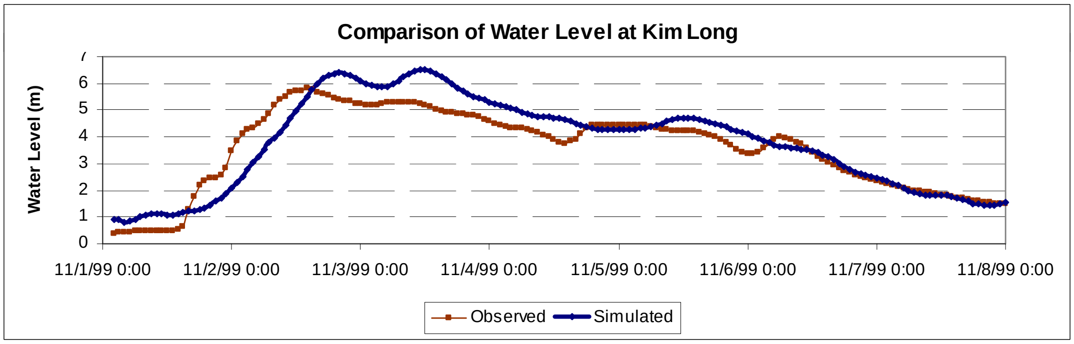


Figure 13 Water level at downstream boundary locations in 1999 and 1983

The hourly observed water level has been assigned as downstream boundary condition. The hydrograph is shown below Figure 13. The water level at Ca Cut and Diem Troung is same. Similarly An Xuan and Cuan Cua are also same.

The manning roughness was adjusted to obtain the good matching of simulated results with observed data for river flow. The roughness values for the surface of different land use have been obtained from standard text book [1]. The building influence on roughness is not considered since house occupation ratio for each grid is not known.

The model results have been compared with the observed water level at two locations. The model shows good agreement with the observed data. The simulation results are presented in Figure 14



Simulated and observed water level at Kim Long in 1999

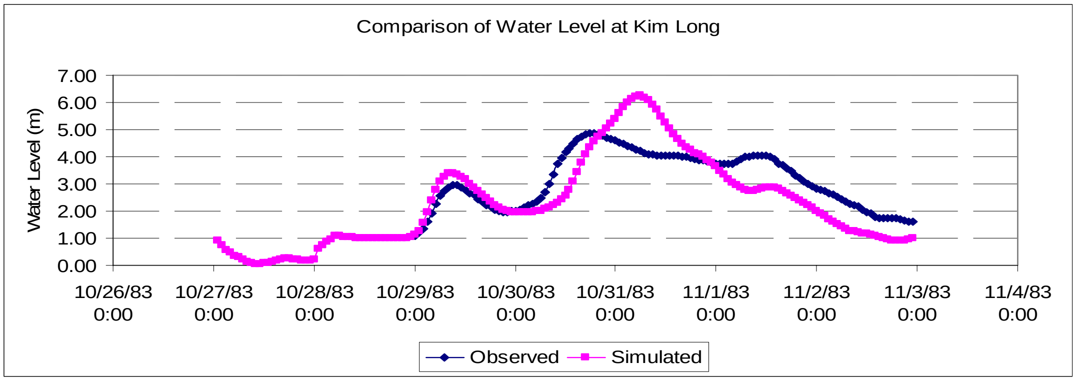
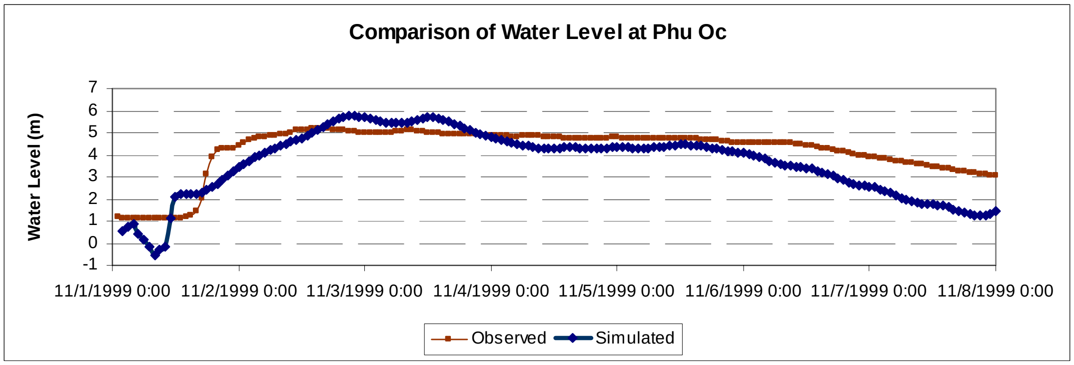


Figure 14: Comparison of water level at different stations



Simulated and observed water level at Phu Oc in 1999

Impact scenario for climate change

The model has been simulated for 30cm (2050), 50cm (2075), 88cm (2100) and 100cm sea level rise. The comparison of water level with base condition is shown in Figure 15 for Kim Long station. The extents of the flooding are shown in flood maps at peak discharge on 3rd November for different scenarios.

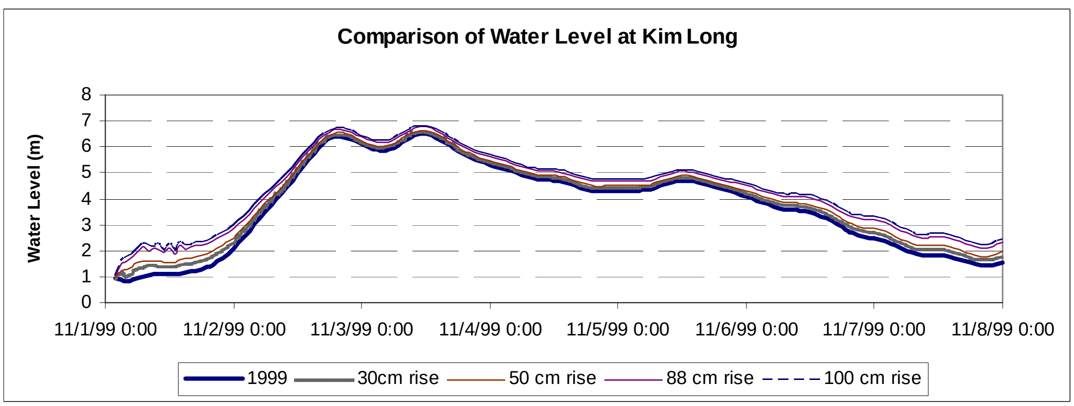


Figure 15: Water levels in different climate change scenarios at station Kim Long

Table 3: Summary of flooded area in different year

Flood depth in cm	Simulated flood Area in km^2			
	1999	2050	2075	2100
10-20	47	47	48	48
21-50	77	77	78	78
51-100	63	63	61	61
101-150	79	81	78	83
151-200	59	57	60	54
201-250	59	55	59	60
251-300	32	35	31	31
> 300	114	115	115	115
Total	530	530	530	530

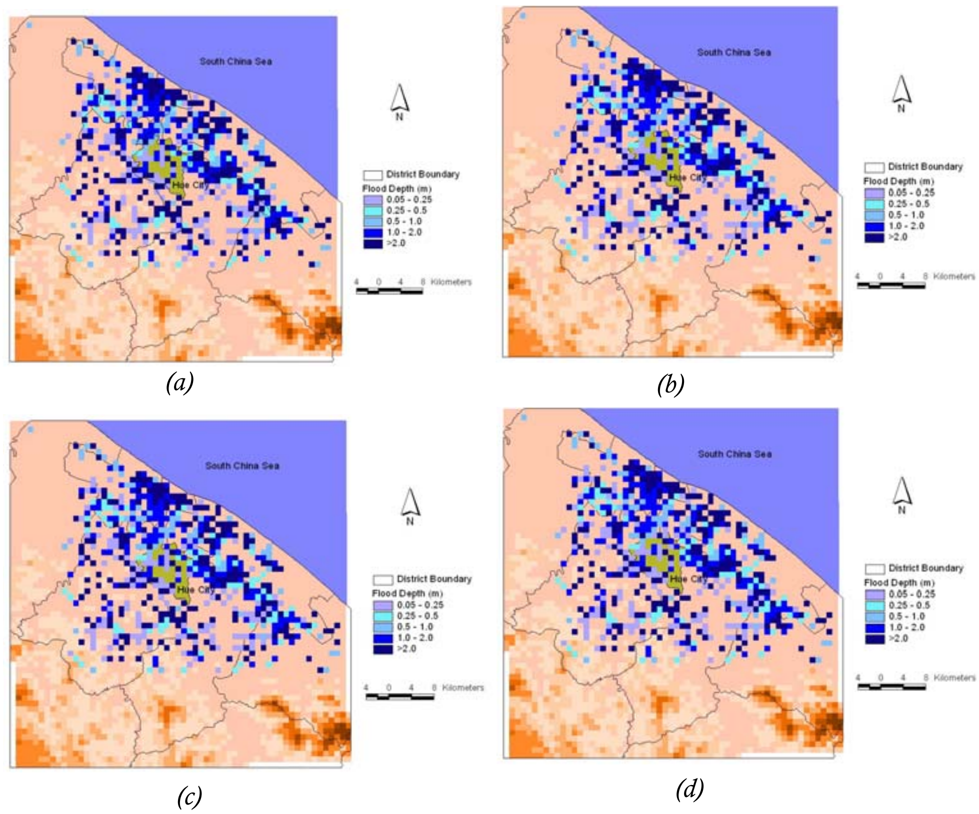


Figure 16: Simulated maximum flood inundation map in a) 1999, b) 2050, c) 2075, d) 2100

G.5 Assessment of socio-economic impacts and vulnerability

Questionnaire survey was carried out for the impact assessment of flooding on different parameters (population, building, transportation network) for Hue City. On the basis of questionnaire survey, flood risk indices were prepared for different flooding scenarios. For the assessment of socio economic impacts and vulnerability, grid based approach is used. The grid resolution used in the study is of 1 Km by 1 Km.

The impact of flood depth on population is presented in Tables 4 and 5. The hazard map generated for population category is shown in Figure 17.

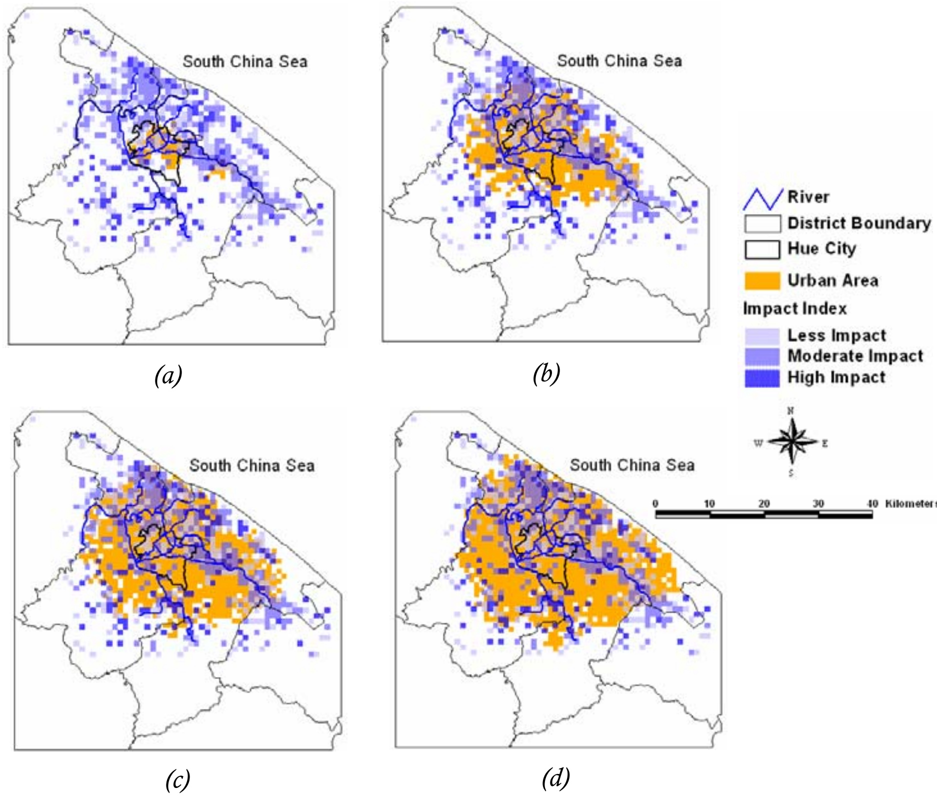


Figure 17: Hazard map generated for Population category in
a) 1999, b) 2050, c) 2075,

Table 4: Flood Risk Indices of Population

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Less
0.60-1.00	Less	Less	Less	Moderate	Moderate
1.00-3.50	Moderate	Moderate	Moderate	Moderate	High
> 3.50	High	High	High	High	High

Table 5: Summary of the affected population

Impact Index	**No. of affected population in Study Area**			
	1999	2050	2075	2100
Less Impact	148,441	368,165	465,019	495,633
Moderate Impact	247,867	690,545	871,645	961,705
High Impact	18,718	125,563	206,865	331,406

The impact of flood depth on buildings is presented in Tables 6 and 7 The hazard map generated for building category is shown in Figure 18.

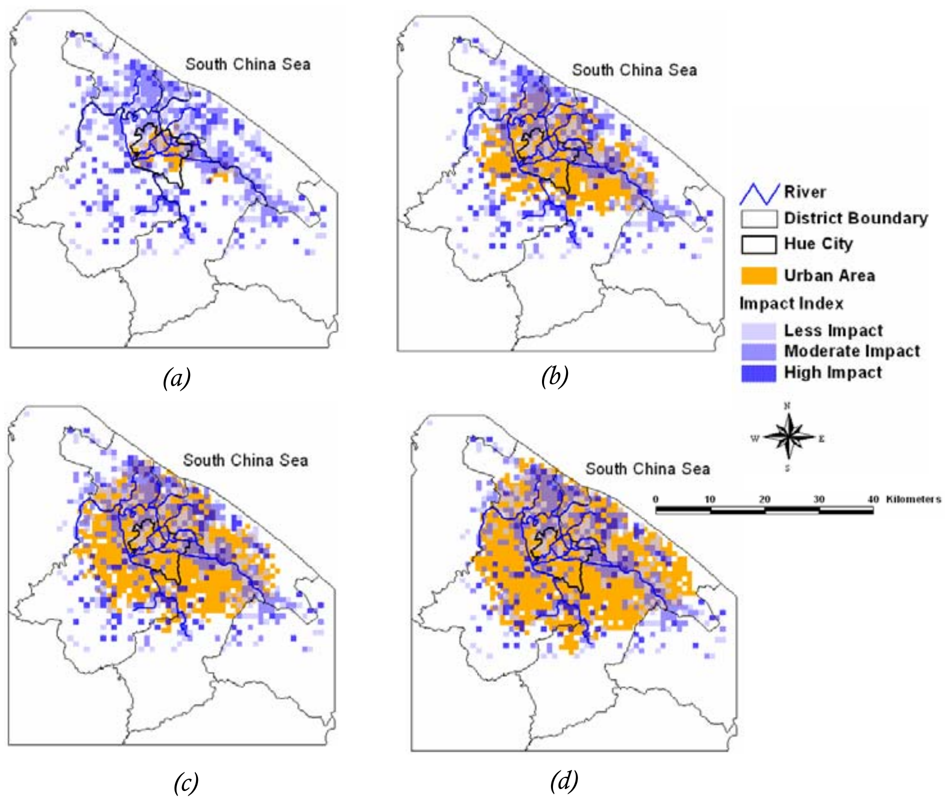


Figure 18: Hazard map generated for Building category in a) 1999, b) 2050, c) 2075, d) 2100

Table.6: Flood Risk Indices on building

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Moderate
0.60-1.00	Less	Less	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	High	High	High
> 3.50	High	High	High	High	High

Table 7: Summary of the affected building

Impact Index	**No. of affected buildings in Study Area**			
	1999	2050	2075	2100
Less Impact	37,043	91,976	116,189	123,841
Moderate Impact	61,879	172,566	217,843	240,358
High Impact	4,650	31,363	51,690	82,825

The impact of flood depth on road is presented in Tables 9.8 and 9.9. The hazard map generated for road category is shown in Figure 19.

Table 8: Flood Risk Indices on Road

Depth of flood (m)	**Duration of flood**				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Less	Moderate
0.60-1.00	Less	Moderate	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	High	High	High
> 3.50	High	High	High	High	Highest

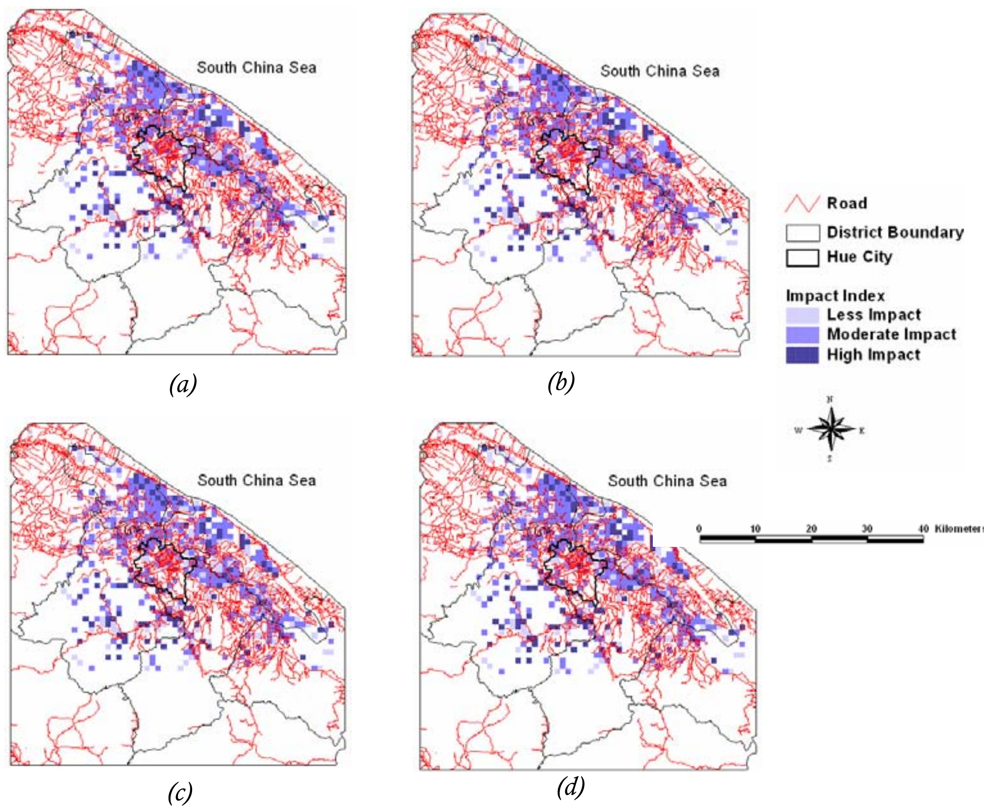


Figure 19: Hazard map generated for Road category in a) 1999, b) 2050, c) 2075, d) 2100

Table 9: Summary of the affected road

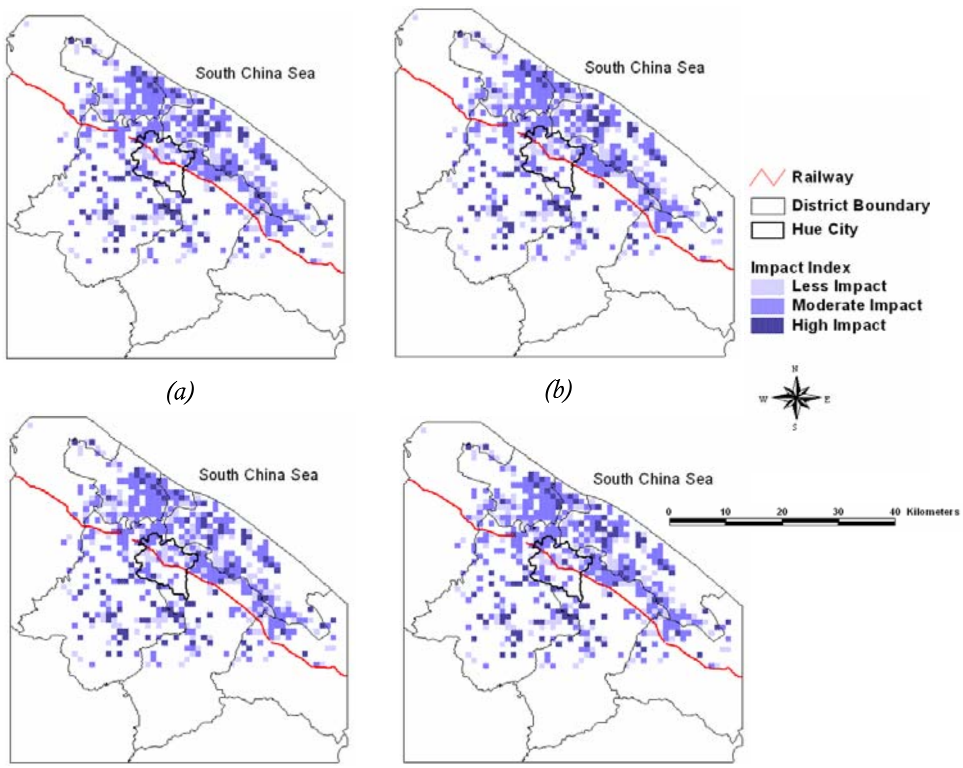
Impact Index	**Length of affected road in Study Area (m)**			
	1999	2050	2075	2100
Less Impact	239,667	239,667	235,871	225,978
Moderate Impact	413,096	413.,607	417,459	412,368
High Impact	85,369	84,856	84,815	93,473

The impact of flood depth on railway is presented in Tables 10 and 11. The

Table 10: Flood Risk Indices on Railway

Depth of flood (m)	Duration of flood				
	< 1 day	**1-2 days**	**3-4 days**	**5-7 days**	**> 1 week**
< 0.1 m	No Impact	No Impact	No Impact	No Impact	No Impact
0.10-0.60	Less	Less	Less	Moderate	Moderate
0.60-1.00	Moderate	Moderate	Moderate	Moderate	Moderate
1.00-3.50	Moderate	Moderate	High	High	High
> 3.50	High	High	High	High	High

hazard map generated for railway category is shown in Figure 20.



(c) *(d)*

Figure 19: Hazard map generated for Railway category in a) 1999, b) 2050, c) 2075, d) 2100

Table 11: Summary of the affected railway

Impact Index	Length of affected railway in Study Area (m)			
	1999	2050	2075	2100
Less Impact	7747	7,747	7,747	7,747
Moderate Impact	9,658	9,658	10,141	10,141
Highest Impact	-	-	-	-

G.6 Links among policy, socio-economic factors, floods and impacts

The Govt. of Vietnam has policies to take care and mitigation of disasters. Also Govt. has an intension on mitigation on human lives, socio-economic damage.

The main damages in Vietnam are caused by water related disasters and tropical storm. So, Vietnam pays attention mainly to this kind of disaster and tropical storm.

Vietnam has different policies and approaches for dealing with flood in different areas of Vietnam (Northern, Middle and Southern Vietnam.)

Estimation of damage causing by natural disaster is not so good. So, it's very difficult for Vietnam Govt. to make proper investment for disasters including flood. Cost benefit analysis is needed.

Vietnam has to consider more on climate change and increasing tendency of flood disasters.

G.7 Issues, challenges and recommendations in implementing

Issues:

- Infrastructure of urban areas doesn't meet the sustainable flood and storm resistant requirements, being vulnerable to disasters.
- In many localities, community awareness and experience in preparing and mitigating flood and storm is still low.
- Financial capacity needed for annual flood and storm control activities is limited.

Challenges:

Challenges for the management and mitigation of disasters in Vietnam are

- Natural disasters have the tendency to increase in number and in severity.
- High speed urbanization and industrialization has been contributing to the increase in number of natural disasters.
- Combination of different types of disasters in a particular locality hinders the preparation of disaster preparedness and mitigation strategies and action plans for that locality.

Recommendations:

- Improved/better forecasts for hydrologic parameter
- Closer cooperation among different agencies involved
- Database and knowledge management needed
- Community participation
- Operation and maintenance of existing infrastructure and urban areas
- People should know that there are capacities built; 6 Partners to arrange

Open Forum, invite stakeholders

- Continue in a broader scale
- Current links are highly inadequate as most of the simulations of impacts are based on flood statistics, there is a need to move towards process-based models
- Information gap leading to system understanding gaps especially about socio-economic aspects.

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VNCIDNDR, (1994). National report of the socialist Republic of Vietname, The national committee for IDNDR of Vietname. The IDNDR mid-term review and the 1994 world conference on Natural disaster reduction, 28 pp.

International Monetary Fund (IMF) (2002). Vietnam: Selected Issues and Statistical Appendix. IMF Country Report No. 02/5. Washington, D.C: International Monetary Fund.

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Appendix H: Symposium

Appendix H: Symposium

An International Symposium on "Floods in Coastal Cities under Climate Change Conditions" was conducted at the Conference Centre of the Asian Institute of Technology (AIT), Pathumthani, Thailand during 23-25 June 2005, which was organized by AIT and sponsored by the Asia Pacific Network for Global Change Research (APN).The main objectives of the symposium was to bring together researchers, academicians, practitioners and decision makers to discuss about impact of floods in coastal cities under climate change scenarios, to identify gaps in existing disaster mitigation policies and establish guidelines and strategies for improved policies for flood risk management in coastal cities under climate change, and to increase public awareness about risk of sea level rising and coastal flooding.

Agenda:

Day 0, 22 June 2005 (Wednesday)			
Time	**Activity**		
17:00-18:00	Pre-registration		
Day 1, 23 June 2005 (Thursday)			
Time	**Activity**	**Speaker**	**Affiliation**
08:00-08:30	Registration		
08:30-08:50	Opening Session		
08:50-09:30	Keynote speech	Teeradej Tangpraprutgul,	Director General, Department of Drainage and Sewerage, Bangkok Metropolitan Administration, 524/12 Soi 19, PRARAM 9 RD., Huaykwang, Bangkok, Thailand
09:30-10:00	*Group Photo and Coffee break*		
SESSION 1	**COASTAL FLOODS UNDER CLIMATE CHANGE SCENARIOS: CASE STUDIES and POLICY ISSUES**		
10:00-10:50	Bangladesh		*Representatives from Bangladesh* Dr. Mehedi Ahmed Ansary, Associate Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, E-mail: ansary@ce.buet.edu, ansaryma@yahoo.com Md. Liakath Ali, Senior National Expert, Program Development Office - Integrated Coastal Zone Management Plan (PDO-ICZMP), Saimon Centre (5th and 6th Floor), House 4A, Road 22 Gulshan-1, Dhaka-1212, Bangladesh, liakath@iczmpbd.org Md. Rafiqul Islam, Team Leader, Program Development Office - Integrated Coastal Zone Management Plan (PDO-ICZMP), Saimon Centre (5th and 6th Floor) House 4A, Road 22 Gulshan-1, Dhaka-1212, Bangladesh rafiq@iczmpbd.org
10:50-11:40	India		*Representatives from India* Prof. A. Narayana Swamy, Professor of Hydrology/ Remote Sensing, Dept. of Geophysics, Andhra University, Vishakhapatnam 530003, India, E-mail: answamy@hotmail.com
10:40-12:30	Pakistan		*Representatives from Pakistan* Dr. Habib-ur-Rehman, Associate Professor, Civil Engineering Department, University of Engineering and Technology, Lahore, Pakistan, E-mail: mughalhabib@uet.edu.pk Mr. Abdul Fattah Babar Sani, General Manager, Geospatial Technologies Engineering Consultant, 29, Block 7/8, Darul Aman Housing Society, Shahrae Faisal Karachi 75350, Pakistan
12:30-13:30	*Lunch*		
SESSION 2	**COASTAL FLOODS UNDER CLIMATE CHANGE SCENARIOS: CASE STUDIES and POLICY ISSUES**		

13:30-14:20	Sri Lanka	*Representatives from Sri Lanka* Dr. Uditha Rohana Ratnayake, Senior Lecturer, Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya 20400, Sri Lanka, E-mail: udithar@pdn.ac.lk P. P. G. Dias, Deputy Director of Irrigation (Hydrology), Irrigation Department, E-mail: dd_hyg@irrigation.slt.lk Nishantha Kamaladasa, Director, Center for Housing, Planning and Building, 33, Sunil Mawatha, Pelawatta, Battaramulla Sri Lanka. E-mail: nishanthakamaladasa@yahoo.com	
14:20-15:10	Thailand	*Representatives from Thailand* Dr. Mukand Singh Babel, Associate Professor, Water Engineering and Mangement, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120 Thailand msbabel@ait.ac.th Prof. Ashim Das Gupta, WEM FoS, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120 Thailand adg@ait.ac.th Dr. Dushmanta Dutta, Visiting Associate Professor, Water Engineering and Management, Program Coordinator – Regional Network Office for Urban Safety (RNUS), School of Civil Engineering, Asian Institute of Technology, P.O.Box 4, Klong Luang, Pathumthani 12120, Thailand. E-mail: Dushmanta.Dutta@sci.monash.edu.au Prof. Tawatchai Tingsanchali, WEM FoS, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani, 12120, Thailand tawatch@ait.ac.th	
15:10-16:00	Vietnam	*Representatives from Vietnam* Dr. Hoang Minh Hien, Expert in Disaster Management, Disaster Management Centre, Department for Dyke Management, Flood and Storm Control, Ministry of Agriculture and Rural Development, 2 Ngoc Ha, Ba Dinh, Ha Noi, Vietnam, E-mail: hmh@netnam.vn Mr. Nguyen Viet, Director, Hydro-Meteorological Forecasting of Thua Thien Hue province, Hue City, Thua Thien Hue province kttv_tth@dng.vnn.vn	
16:00-16:30	*Coffee break*		
SESSION 3	**BRAINSTORMING ON POLICY ISSUES** *(Facilitator: Ashim Das Gupta)*		
16:30-18:00	Round Table Discussions on Policy Issues	Representatives from South and South-east Asian countries	
18:30~	*Dinner*		
Day 2, 24 June 2005 (Friday)			
SESSION 4	**BRAINSTORMING ON POLICY ISSUES (CONTD.)**		
08:00-10:00	Round Table Discussions on Policy Issues		
10:00-10:20	*Coffee break*		
SESSION 5	**CLIMATE CHANGE IMPACTS**		
Time	**Title of Presentation**	**Speaker**	**Affiliation**
10:20-10:40	Study of 2001 Floods using Numerical Model in the Mekong River Delta, Vietnam	Le Thi Viet Hoa	Graduate Student , Institute of Natural Environmental studies, Graduate school of Frontier Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan hoa@nenv.k.u-tokyo.ac.jp
10:40-11:00	Risk Analysis of Hanoi City under Extreme Flood Scenario due to Hoa Binh Riservoir Failure	Fahmida Khatun	Research Associate, RNUS, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120 Thailand. E-mail: MstFahmida.Khatun@ait.ac.th
11:00-11:20	Fflood Simulations for SG Pinang: Assessing the Potential Impacts of Climate Change	Hock Lye Koh	Professor , School of Mathematical Sciences Universiti Sains Malaysia, 11800 Penang, Malaysia 2Technip GeoProduction Malaysia. E-mail: hlkoh@cs.usm.my

11:20-11:40	Long term impacts in river flows in the Mahanadi River Basin under Climate Change Scenarios	Shilpa Asokan	Research Associate, RNUS, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120 Thailand. E-mail: shilpam@ait.ac.th
11:40-12:00		Uruya Weesakul	Associate Professor, Faculty of Civil Engineering, Thammasat University, Klong Luang, Pathumthani 12120, Thammasat wuruya@engr.tu.ac.th
12:00-13:00	*Lunch*		
TECHNICAL TOUR			
13:00-14:00	To BMA for Technical Tour		
14:00-15:30	Presentation on Dept. of Drainage and Sewerage, BMA		
15:30-17:30	Visits to Krung Kasem Pumping Station and Si Praya Treatment Plant		
17:30-19:30	Dinner Cruise		
20:30	Arrive to AIT		
Day 3, 25 June 2005 (Saturday)			
SESSION 6	**TSUNAMI AND COASTAL FLOODING**		
Time	**Activity**	**Speaker**	**Affiliation**
08:30-09:20	Invited Talk	Kimiro Meguro	Professor, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan. E-mail: meguro@iis.u-tokyo.ac.jp
09:20-10:10	Invited Talk	Pennung Warnitchai	Associate Professor, STE, SCE, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120 Thailand pennung@ait.ac.th
10:10-10:30	*Coffee break*		
10:30-11:20	Multihazard Perspective for Coastal Zone Disaster Mitigation	Srikantha Herath	Senior Academic Programme Officer, United Nations University, 53-70 Jingumae 5-chome Shibuya-ku, Tokyo 150-0001 Japan. E-mail: herath@hq.unu.edu
11:20-12:10	Invited Talk	David Hastings	GIS Officer, Information, Communication and Space Technology Applications, UNESCAP, UN Building Rajademnern Nok Avenue Bangkok 10200, THAILAND hastingsd@un.org
12:10-13:00	*Lunch*		
SESSION 7	**BRAINSTORMING ON DEVELOPMENTS OF GUIDELINES FOR POLICY ISSUES** *(Facilitator: Mukand S. Babel)*		
13:00-15:00	Brainstorming for development of guidelines for policy related issues for coastal flood risk management under climate change		

Appendix I: Development of guidelines for policy issues

Appendix I: Development of guidelines for policy issues

The International Symposium on “Floods in Coastal Cities under Climate Change Conditions” was held on 23-25 June 2005 at the Asian Institute of Technology, Bangkok, Thailand.

During the symposium, brainstorming and round table discussions on policies and policy guidelines were conducted, wherein Project Partners presented the status of case studies in their respective countries as well as put forward their ideas regarding the gaps in existing policies, policy and capacity-building needs, and recommendations for the incorporation of external factors in policies and strategies. The project partners were asked to provide information and put forward their ideas on the following items for their respective case studies:

- Flood vulnerability and history;
- Socio-economic characteristics;
- Existing flood disaster mitigation measures;
- Flood risk management policies;
- Links among policy, socio-economic factors, floods, and impacts; and
- Issues, challenges, and recommendations.

Following is the summary of the outcomes of the brainstorming and discussion sessions for the participating countries:

Project Partners from Pakistan discussed about the vulnerability of the coastal city of Karachi to floods, especially in areas along the Mali River. Existing flood mitigation measures include the strengthening of embankments, the conduct of rainfall-runoff calculations, and depth-damage assessments. Models are, however, not employed in these analyses, and the necessity for such tools was recognized. The Sindh Katchi Abadis Act of 1992 is one of the existing flood risk management policies in the country. It pertains to zoning and construction of building types in flood plains especially in low-lying areas. It was noted that the development of thematic flood hazard maps could improve flood risk management efforts. Established institutions in the country include the Coastal Development Authority. But organizations reportedly do not interlink with each other, and the necessity for addressing this link issue was highlighted. It was reported that climatic change and environmental issues are being dealt with by different organizations in the country, and it was recognized that there is a need for interaction between these organizations. It was pointed out that the Meteorological Department of Pakistan is not looking into climate change, but only to forecasts and data collection and addressing only short-term and not long-term issues and needs.

For Bangladesh, the widely known vulnerability of the study area to floods was discussed, and it was pointed out that other vulnerabilities also exist. The existing mitigation measures in the country include polders, green belt, warning system, and preparedness. Risk management measures were reported to have been adopted recently. Policies and socio-economic conditions are, however, not linked in specific cities/localities. The identified gaps for the area are: unsuccessful translation of policies into action; disregard about the specifics of coastal cities; limited regional understanding; exclusion of climate change in city design and planning; and the failure to describe events (climate change) in popular terms.

The Project Partner from India discussed about the very long history of flooding and the very high vulnerability of the coasts in the study area to cyclones and floods. It was noted that storms in the region have been reducing in number but increasing in intensity. India was reported to have a very good flood disaster management program. Existing flood management measures mentioned include: a Disaster Management Policy, a Calamity Relief Fund, a Calamity Contingency Fund, Training of specialist teams, watershed management, soil conservation, and a Disaster Resource Network being established. Existing institutional systems include the Meteorological Department, which forecasts disasters, and the Central Water Commission.

For Sri Lanka, the existing measures discussed include: a dike system (first 2 phases in place; 3rd phase not yet implemented); land use control, especially in flood plain areas; and mandatory EIA for every project. The Project Partners discussed about the various policies in place in the region, which are the: Flood Risk Management Policy; Bill on Disaster Risk Management; and the establishment of the Council of Ministers under which is the Disaster Management Center for mitigation of disasters, protection of properties, maintenance of order, etc. There is also the Flood Protection Ordinance effective since 1924 and revised in 1980, which demarcates flood areas and implements flood mitigation and emergency measures, but have some clashes with the Disaster Management Act of 2005. The Coastal Management Policy in Sri Lanka was reported to not specifically say anything about floods in coastal areas but only about coastal erosion, although it mentions that climate change should be looked into. Other established policies apparently do not mention climate change. The identified gaps for policies in the case study area include: conflict between Acts of 1924 and of 2005; the fact that no single organization deals with floods; lack of integration between organizations in terms of responsibilities and mandates; and that alternatives (livelihood) are not given to people when implementing measures.

The great susceptibility of Vietnam to flooding was discussed by the Project Partners from the said country. Vietnam is reported to be very flood-prone, with a very long coastline and subject to many serious floods. It was pointed out that no single policy is adopted in all parts of the country, and that each part has its own set of policies. The three parts of Vietnam were reported to have different policies, approaches, and strategies. Examples of mitigating measures given were reservoirs; embankments; floodwater diversion; the implementation of basic guidelines; improvement of flood communication systems, warning systems, and emergency preparedness; capacity-building, education, and awareness; flood-hazard mapping; forecasting information; and the quick provision of information to people. Enumerated existing policies relate to: the active prevention and adaptation to floods; Integrated Coastal Zone Management; land use management that considers human settlement planning; financial support for poor people in building houses; strategy and master plan for flood mitigation, and ordinances for flood control. Flood risk management policies in the region were said to be linked with poverty reduction and hunger eradication. The identified gaps include the inadequate investment in flood mitigation, which is not enough for implementation, and the fact that policies are not adopted in all parts of the country because of geography, natural conditions, landscape, etc.

Keeping in mind institutional capacities, recommendations to address gaps in relation to the project were identified in the next part of the discussion. According to the Project Partners from Bangladesh, there is a need for more understanding of social and policy processes such that the study should be continued with emphasis on this issue. It was also recommended that the results of the case studies should be disseminated to the concerned individuals and agencies in the study areas, although it was pointed out that this is already in the project agenda. The need for the incorporation of coastal city issues in the broader ICZM approach was highlighted, and it was put forward that external factors (climate change) and their impacts should be the responsibility of one organization/agency. The presented recommendations for India include the extension of the case study. It was also pointed out that flood mitigation and management policies must be different from disaster management policy, such that it has its own identity, and hence, its own resources.

For Pakistan, it was recommended that the Katchi Abadis Act be extended to other building types. Furthermore, climate change effects should be addressed, and the Coastal Development Authority Act should incorporate climate change effects. For Sri Lanka, it was suggested that there should be a single authority to coordinate other agencies because there are currently several organizations responsible for flood mitigation/control. It was further suggested that the Disaster Management Center be given this authority to coordinate. Clear demarcation of the roles and responsibilities of different authorities with respect to flood mitigation was also suggested, and it was also put forward that policies must consider alternative solutions (sand and coral mining) and livelihood options for disadvantaged groups.

Recommendations from Thailand were: revisiting and update of existing policies, and revision of obsolete policies; promotion of regional cooperation; enhancement of technology transfer; and involvement of non-governmental organizations in capacity building. Project Partners from Vietnam presented the need for improved/better forecasts for hydrologic parameters, closer cooperation among different agencies involved, database and knowledge management, community participation, and operation and maintenance of existing infrastructure and urban areas. As a general recommendation, it was put forward that people should know that there are capacities built, such that the six Partners are to arrange Open Forums and invite stakeholders. It was also suggested that the study be continued in a broader scale.

Appendix J: Open forum

Appendix J: Open forum

Open forum was organized in the participating countries to disseminate the research findings. Posters were distributed during the forum to the policy makers and participants to further distribute them for raising awareness among the public. Details on the open forum conducted at Bangkok are elaborated here.

The open forum was organized in Bangkok on 7th September 2005 by the Water Engineering and Management (WEM) Field of Study and the Regional Network Office for Urban Safety (RNUS) of the Asian Institute of Technology to disseminate the findings of the research project on "Assessment of Socio-Economic Impacts due to Coastal Floods in South and Southeast Asia under Climate Change Scenarios". The project is an attempt to assess socio-economic impacts of flooding under climate change conditions in low-lying large coastal cities in South and South-east Asia. The main motivation for the open forum was to raise awareness among policy makers of Thailand on the socio-economic vulnerability of Bangkok city under climate change, and assist them in developing and implementing policies towards betterment of future flood management measures. The forum focused in disseminating the outcomes of the study carried out for Bangkok city (Bangkok Case Study).

About 30 participants from eight relevant public and private organizations of Thailand viz; Royal Irrigation Department (RID), Department of Public Works and Town and Country Planning (DPT), Thailand Meteorology Department (TMD), Hydrographic Department, Department of Disaster Prevention and Mitigation, Department of City Planning (BMA), TEAM Consulting Co., Ltd. and PANYA consultance Co., Ltd registered and participated in the forum.

An introductory speech was delivered by Prof. Suphat Vongvisessomjai, a former AIT faculty and now the Water and Environment Expert of TEAM Consulting Co., Ltd. The significance of conducting research on issues arising due to the changing climate was substantiated by the speaker. A brief description on Project Background was presented by Dr. Mukand Singh Babel, Associate Professor, WEM. Information on the objective and scope of the project, selection criteria of highly vulnerable coastal cities and the conceptual framework of the methodology followed in deriving the outcomes were presented and discussed. This was followed by a general presentation on the Potential Impact of Climate Change, where Dr. Babel delivered an eloquent talk on climate change impacts on different sectors of society. The idea was to raise awareness among the policy makers on the historical, contemporary and future trend of climate change, emphasizing on the vulnerability of low lying coastal cities under sea level rise scenario. Before the Bangkok Case Study presentation was announced, a short coffee break was arranged, during which two posters prepared by the research team were exhibited. One of the posters focused on the general issues arising due to climate change and, the other poster highlighted the results of Bangkok Case Study. The meeting resumed with a talk by Ms. Shilpa M. Asokan, Research associate, WEM on the core findings of the Bangkok Case Study. The results on socio-economic impacts under rising sea level scenarios for the future years were discussed. The major recommendations of the case study were (a) the need for a single organization or agency in dealing with flood mitigation and which can simultaneously address climate change issues and (b) the significance of incorporating climate change issues in the Coastal Development Authority Act. At the end of the talk, the venue was opened for discussion.

The major concern that evolved from the discussion was the extent of damage caused by the flooding scenario because of the assumption of extreme condition of sea level rise predicted by Intergovernmental Panel on Climate Change. According to the policy makers, a high degree of damage, as predicted by the study, is probably not imminent in Bangkok, owing to its existing flood mitigation measures such as dykes, polders etc. An Economist from RID, Ms. Wimolpat Bumbudsanpharoke expressed interest in the methodology followed for analyzing the socio-economic vulnerability indices. Mr. Sanguanpran Amornpatananat, a representative from Meteorology Department expressed interest and discussed the possibilities of use of the Distributed Hydrological Model for the Meteorological Department. The team from the Department of Disaster Prevention and Mitigation were highly motivated by the research outcomes, and were interested in future collaboration with AIT. Prof. Suphat Vongvisessomjai concluded the session by stating the existing flood situation in Bangkok, and the possible degree of vulnerability under climate change conditions. The concluding remarks were followed by poster distribution. A set of forty posters was distributed to individual organizations as a key step towards disseminating research outcomes to public. Photo session followed by a lunch marked the official conclusion of the forum.

Appendix K: Funding sources outside the APN

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Description	Amount (US$)	Source
In-kind: Support service for conducting training and workshop ▪ Administrative support ▪ Software for GIS database and Central Web server development ▪ Salary of researchers and staff ▪ Facilities for young professional and two-week intensive workshop	10,000	**RNUS, AIT**
▪ Improvement of the existing flood simulation and risk analysis model to make an adaptive model for selected areas of the participant countries ▪ Technical support for test run of the model	15,000	Grant for urban flood modeling: **NEWJEC Consultant, Osaka, Japan**
▪ Support for computational resources for scenario analysis ▪ Support for user interface	10,000	Grant for operational flood forecasting: **NECTEC, Bangkok, Thailand**
Total	**35,000**	

Appendix L: Abbreviations

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ADPC	Asian Disaster Preparedness Center
APN	Asia Pacific Network for Climate Change
Aus Aid	Australian Agency for International Development
ASEAN	Association of South East Asian Nation
BMA	Bangkok Metropolitan Administration
CBDRM	Community Based Disaster Risk Management
CCFSC	Central Committee for Flood and Storm Control
CDGK	Karachi District City Government
CDMP	Comprehensive Disaster Management Plan
CDS	Coastal Zone Strategy
CPWRMS	Chao Phraya Water Resources Management Strategy
CRZ	Coastal Regulation Zone
CZP	Coastal Zone Policy
CZPo	Coastal Zone Policy of Bangladesh
CSMMC	Management and Maintenance Committees
DCPs	Data Collecting Platforms
DDS	Department of Drainage and Sewerage
DEM	Digital Elevation Model
DHM	Distributed Hydrologic Model
DMU	Disaster Management Unit
DRM	Disaster Risk Management
EEZ	Extended Economic Zone
EIA	Environment Impact Assessment
ERC	Emergency Relief Cell
EOP	Emergency Operation Plan
FAO	Food and Agriculture Organization
FFC	Federal Flood Commission
GoB	Government of Bangladesh
GDP	Gross domestic product
GIS	Geographic Information System
GOP	Government of Pakistan
GPW	Grided Population of the World
HPC	High Powered Committee
ICZM	Integrated Coastal Zone Management
IDRN	India Disaster Resource Network
IISDHM	Institute of Industrial Science Distributed Hydrologic Model
IMD	India Meteorological Department
IMF	International Monetary Fund
IPCC	Inter Governmental Panel on Climate Change
IRSA	Indus River System Authority
KDA	Karachi Development Authority
KPT	Karachi Port Trust
MW	Mega Watt
MNCs	Multi-National Companies
MSA	Maritime Security Agency
MoWR	Ministry of Water resources
MSL	Mean Sea Level
NAPA	National Adaptation Plan of Action
NDMP	National Disaster Management Plan
NEP	National Environment Policy
NEPo	National Environment Policy of Bangladesh
NESDB	National Economic and Social Development Board
NFP	National Forestry Policy

NFoPo	National Forestry Policy of Bangladesh
NLUP	National Land Use Policy
NE	North East
NEMAP	National Environmental Management Action Plan
NLUP	National Land Use Policy
NSO	National Statistical Office
NWMP	National Water Management Plan
NWP	National Water Policy
NWPo	National Water Policy of Bangladesh
NWRC	National Water Resources Committee
ODRAF	Orissa Disaster Rapid Action Force
OSDMA	Orissa State Disaster Mitigation Authority
PIDA	Provincial Irrigation and Drainage Authorities
PID	Provincial Irrigation Department
PMP	Probable Maximum Precipitation
PRSP	Poverty Reduction Strategy Paper
REMC	Regional Environmental Management Center
RID	Royal Irrigation Department
Rs	Rupees
SE	South East
SELMAM	Sea Level Monitoring And Modeling
SES	Socio-Economic Survey
SRFM	Surface River Flow Model
SRES	Special Report on Emmissions Scenarios
SUPARCO	Space and Upper Atmosphere Research Commission
TERI	Tata Energy Research Institute
THB	Thailand Baht
Tk	Taka
TMD	Thai Meteorological Department
TTHSO	Thua Thien Hue Statistical Office
UNDP	United Nations Development Program
USGS	United States Geological Survey
VHF	Very High Frequency
VND	Vietnamese Dong
VSAT	Very Small Aperture Terminals
WAPDA	Water and Power Development Authority
WARPO	Water Resources Planning Organisation
WB	World Bank
WCRD	World Conference for Reduction of Disaster

- 1 US$ = 43.51 Rs (Indian Rupees)
- 1 US$ = 59.57 Rs (Pakistani Rupees)
- 1 US$ = 100 Rs (Sri Lankan Rupes)
- 1 US$ = 15,860.02 VND
- 1 US$ = 63.78 Tk
- 1 US$ = 41.75 THB

source: http://www.xe.com/ucc/ (July, 2005)