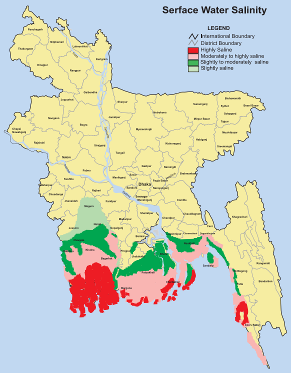

Local Level Hazard Maps for **FLOOD, STORM SURGE** & **SALINITY**

June 2013

STUDY REPORT

Comprehensive Disaster Management Programme (CDMP II)

Ministry of Disaster Management and Relief

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Conducted By

INSTITUTE OF WATER MODELLING
IWM

Institute of Water Modelling
Bangladesh Centre for Advanced Studies

Supported by

Comprehensive Disaster Management Programme (CDMP II)
Ministry of Disaster Management and Relief

Local Level Hazard Maps for FLOOD, STORM SURGE & SALINITY

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Local Level Hazard Maps for **FLOOD, STORM SURGE** & **SALINITY**

FOREWORD

Bangladesh is a hotspot for geophysical and climatic hazards. The country is relatively ranked very high in terms of vulnerability to natural calamities. Geographical location and geophysical configuration combined with its topography and dense population made the country prone to various disasters including climate change which often resulting in high loss of life and economic damage. The economic impact of disasters usually consists of direct damage e.g. infrastructure, crops, housing, loss of lives and livelihoods, and indirect damage e.g. loss of revenues, unemployment and enduring poverty. It is therefore increasingly becoming a major concern for the government, development partners, researchers and communities as well.

The country frequently experiences multiple natural hazards including floods, cyclones, droughts, salinity, water-logging, river and coastal erosion, hailstorms, tornados, tidal surge and landslides etc. Impact of climate change is increasing the threat of natural disaster and affecting the lives and livelihood of millions. In this scenario, the underpinning needs for detail technical research study in relations to disaster Hazard reduction and various options for climate change adaptation issues have been long due. I am very happy that the Comprehensive Disaster Management Programme (CDMP II), Ministry of Disaster Management and Relief has taken initiatives for conducting some technical research on various critically concerning areas of DRR and CCA from the country perspectives.

I hope the research study report on 'Local Level Hazard Maps for Flood, Storm Surge & Salinity' will serve as a resource for understanding, analyzing and addressing the Hazards and vulnerability associated with disaster and climate change for the relevant stakeholders.

I encourage not only relevant researchers or development professionals but all concerned citizens to make use of the study, utilize the recommendations part and take pro-active effort to pursue the research benefits to bring positive impacts in the life of the vulnerable communities. I congratulate and convey my sincere thanks to the study team and fellow colleagues who were involved in thorough editing and publishing of the document.

Mohammad Abdul Qayyum
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Comprehensive Disaster Management Programme (CDMP II)

ACKNOWLEDGEMENT

The study on 'Local Level Hazard Maps for Flood, Storm Surge & Salinity' has become possible due to the contribution made by a considerable number of people and organizations. CDMP expresses deepest indebtedness and profound gratitude to all of those who were involved in the whole study, from inception to the completion of the study and preparation of the report.

CDMP wishes to extend heartfelt thanks and acknowledges the hard work and sincere efforts of the study team of the Institute of Water Modelling (IWM).

Special thanks and gratitude are due to the team of reviewers especially Dr. Ainun Nishat, Vice Chancellor, BRAC University, Mr. Tarik-Ul-Islam, Assistant Country Director, UNDP, Md. Mahfuzur Rahman, Project Director, CDSP/BWDB, Dr. Md. Sabbir Mostafa Khan, Professor, BUET, and Mr. Saiful Alam, Principal Scientific Officer, WARPO for their review and valuable inputs for the improvement of the results, discussion and the final report.

The comments and suggestions received from the workshop participated by development professionals, research scientists, government officials and others have contributed a lot to improve the report.

Finally, the guidance from the Department of Disaster Management, Ministry of Disaster Management and Relief and financial contribution from the development partners, UNDP in particular, are gratefully acknowledged.

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ACRONYMS

AR4	IPCC 4th Assessment Report
BMD	Bangladesh Meteorological Department
BoBM	Bay of Bengal Model
BWDB	Bangladesh Water Development Board
CDMP	Comprehensive Disaster Management Programme
CRA	Community Risk Assessment
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute (now DHI Water & Environment)
EHRM	Eastern Hilly Regional Model
FFWC	Flood Forecasting and Warning Centre
FM	Flexible Mesh
GBM	Ganges-Brahmaputra-Meghna
GCM	Global Circulation Model
GIS	Geographical Information System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modelling (erstwhile SWMC)
MSL	Mean Sea Level
NCRM	North Central Regional Model
NERM	Northeast Regional Model
NWMP	National Water Management Plan
NWRM	Northwest Regional Model
PWD	Public Works Department
SERM	Southeast Regional Model
SWMC	Surface Water Modelling Centre (now renamed as IWM)
SWRM	Southwest Regional Model
SWSMP II	Surface Water Simulation Modelling Programme Phase-II

EXECUTIVE SUMMARY

INTRODUCTION

Bangladesh comprises unique geographical, physiographic and climatic settings with dynamic hydrological, morphological landscape and ecological characteristics governed by the world's three great river systems - the Ganges, the Brahmaputra and the Meghna. Due to its location in the low-lying deltaic floodplains at the convergence of three Himalayan Rivers, heavy monsoon rainfall concomitant with poor drainage often results in annual flooding. About 21 percent of the country is subjected to annual flooding and additional 42 percent areas are at Hazard of floods with varied intensity. The coastal zone of Bangladesh is vulnerable to cyclonic storm surges and salinity intrusion to landward and thus eventual damages of infrastructures, agriculture and aquaculture. The frequency and intensity of cyclone induced storm surges and mean sea level are likely to increase in the changing climate, consequently the associated Hazards are quite high. In this scenario the local community always remains on the frontline of any impact of disasters and changing climate. To address the vulnerability context of local community the Comprehensive Disaster Management Programme (CDMP II) of the Ministry of Disaster Management and Relief has developed and introduced a simplistic and uniform Community Hazard Assessment (CRA) methodology. Community Hazard Assessment (CRA) is the basic building block of CDMP where community is to assess their own Hazard at present and in the changing climate. In order to assess community Hazard preparation of inundation Hazard map of flood and storm surge and salinity maps are of immense importance. In this context, the study aims to develop flood, storm surge and salinity information to be available at union level to support and sustain disaster management activities particularly the Community Hazard Assessment. Comprehensive Disaster Management Programme (CDMP II) assigned Institute of Water Modelling (IWM) to carry out the study.

Storm Surge Inundation

Cyclonic storms affecting the coastal region of Bangladesh cause heavy loss to life and property. The coastal region bordering the Bay of Bengal suffers the worst because most of the tropical cyclones have genesis over the Bay of Bengal and strike the coast of Bangladesh. The vulnerability of coastal area to storm surge flooding are considerably high, since it is predominantly low-lying and characterized by numerous tidal rivers and polders. Usually cyclones hit the country's coastal regions in the early summer (April–May) or late rainy season (October–November). Most of the cyclones hit the coasts of Bangladesh with north-eastward approaching angle. Over the last 52 years (1960-2012) about 19 severe cyclones hit the coast of Bangladesh. A cyclone can hit at any tidal phase during a tidal cycle and 19 severe cyclones hit the coastal area either during low or high tides. Total 38 cyclone tracks were derived from 19 cyclones considering landfall at the opposite tidal cycles compared to the actual one. In addition to these 38 cyclone tracks, three synthetic tracks were also simulated to find the inundation Hazard of the whole coastal area and those were also simulated for high tide and low tide. The present inundation Hazard has been assessed applying the storm surge levels of 44 simulations. The high Hazard area is defined as the area that experiences 1m or more inundation depth since such depth can cause human casualties and damage of crops and infrastructure. Table E1 presents the high Hazard area at present and in the changing climate.

Scenarios	Regions		
	South West (area in Km^2)	South East (area in Km^2)	Eastern Hill (area in Km^2)
Base Condition	14038.24	2916.92	2191.72
Climate Change Condition	15055.32	3299.76	2390.88
Additional Risk Area due to Climate Change	1017.08	382.84	199.16

Table E1: High risk area inundated by surge height ≥ 1 m

Flood Inundation

Bangladesh has been incurring significant damages in terms of crop losses, destruction of roads and other infrastructure, disruption to industry and commerce, and injuries and losses in human lives from severe inland monsoon floods once every three to five years. The 1998 flood inundated over two-thirds of Bangladesh and resulted in damages and losses of over $2 billion or 4.8 percent of GDP (WB, 2010). Increased monsoon precipitation, higher trans-boundary water flows, and rising sea levels resulting from climate change are estimated to increase the depth and extent of flood inundation and rural communities will be exposed to higher Hazard. The present study made a detailed investigation with available flood models, digital elevation model, maps and data to assess the flood inundation Hazard for characteristic floods of 1988, 1998, 2004 and 2007 as well as 10 year and 20 year flood events and the added Hazard of these flood in the changing climate. Considerable flood maps have been prepared under different flood events and for 3-hr duration. A number of flood maps under different flood events are illustrated in the Table E2.

Flood Event	Characteristic Flood				Return Period		Climate Change		Total
	1988	1998	2004	2007	10 yr	20 yr	2050	2080	
Number of Maps	106	160	138	106	124	124	139	139	1036

Table E2: List of flood inundation maps

The flood maps show a considerable area of different Upazilas of 40 flood-prone districts remain submerged during characteristic floods and additional area likely to be submerged under climate change condition that may cause deterioration of the well beings of the local community. In order to assess the severity of flood, area under different land types were calculated for specific upazila of a district for four characteristic flood events and under climate change conditions for 2050 and 2080. It is evident from the Table E3 that most of the area of the Ullahpara Upazila were submerged with higher inundation depth during the past characteristic flood events and more area are likely to be exposed for higher inundation depth in the changing climate with increased precipitation and sea level rise.

Land Type	Class Interval (m)	Area (km^2)					
		1988	1998	2004	2007	2050 (Climate Change)	2080 (Climate Change)
F0	0-0.3	1.26	0.54	0.63	15.21	0.45	0
F1	0.31-0.9	14.94	4.23	5.85	73.8	3.78	2.25
F2	0.91-1.8	141.93	90.18	123.84	171.63	76.86	50.31
F3	1.81-3.6	238.86	282.42	273.15	148.86	287.55	298.98
F4	>3.6	18.54	38.16	12.06	6.03	46.89	63.99

Table E3: Inundated area under different flood events of Ullahpara Upazila

Simulation results of 1998 flood event under climate change conditions for year 2050 and 2080 show that more area of Rajshahi, Natore, Rangpur, Bogra, Netrokona and Sylhet districts are likely to be submerged with higher flood depth decreasing the F0 and F1 land.

Salinity Maps of the Coastal Area

Saline water intrusion is highly seasonal in Bangladesh and during dry season deep landwards intrusion occurs through the various tidal rivers in the western part of the delta, and through the Lower Meghna estuary. Salinity starts to form during the month of November and reach to the peak level at the end of April or middle of May. Salinity decreases with the onset of monsoon during late June. Salinity intrusion in the western part (Malancha, Pussure and Sibsa river system) is higher than the eastern part (Baleswar, Biskhali, Buriswar and Tetulia river system) because available fresh water flow is higher in the eastern part. Salinity increases with the decrease of fresh water flow from the upstream during dry season.

The study shows that more saline water intrusion is likely to occur during dry season with the increased sea level rise of 50cm in the year 2050. It is seen that 632 km^2 new areas are likely to be affected by higher salinity. It is also evident from the model results that more saline water intrusion through Baleswar-Bishkhali river system under climate change and eventually freshwater zone becomes saline. At present, salinity level remains from 0 to 2ppt in Nazirpur and Nesarabad upzilla of Pirojpur districts during dry period and river water is used for agriculture and aquaculture and other domestic and industrial uses. However, in the same area salinity level is likely to increase up to 5ppt in the changing climate with the sea level rise of 50cm in the year 2050 causing scarcity of freshwater for agriculture and other domestic uses during dry season.

Benefit of Inundation Hazard Maps

Storm Surge Inundation maps

Due to the increase in the developmental activities in the densely populated coastal region, the vulnerability of this region to storm surges and the need for quantitative estimates have increased in recent years. Large damages and losses, reduced economic growth and slowed progress in reducing poverty following recent climate-related disasters like AILA and SIDR, however, indicate that present measures are inadequate to protect the exposed population and assets against existing Hazards and added Hazard. Storm surge induced inundations by the past cyclones provide essential data on the coastal plains for developing zoning map of different Hazard area. This zoning map can be useful for planning of adequate number and proper location of cyclone shelters, re-engineering of existing coastal infrastructure, planning and design of future infrastructure in the coastal area as well as planning of mangrove afforestation for reduction of surge height and damage of embankment. The study builds upon and strengthens the analytical models and quantitative assessment tools already in use in Bangladesh in support of the research and knowledge management themes. The storm surge inundation maps are useful for (a) assessing community Hazard, (b) examine the potential physical impacts of climate change; (c) assess the associated damages and losses in key economic sectors, on vulnerable populations, and in the overall economy; and (d) estimate spatially disaggregated costs of adaptation options that can reduce these impacts.

Flood Inundation

Most people living in inundated areas, however, are likely to be exposed to higher inundation depths under the climate change scenario. The estimated population exposed to different inundation depths can be estimated using the flood depth maps. These maps are expected to enable the planner to find different elements at Hazard like road, homestead and crop fields. Rural communities can find adaptation measures for their homesteads based on these flood maps. Cost of potential damages of road infrastructure can be assessed and adaptation measures can be devised. Flood inundation depth maps can be instrumental for awareness building of local communities and assessment of associated Hazards.

Salinity Intrusion

Salinity maps are useful to find the water availability in different months for agriculture, drinking, industrial and other household requirements. Adaptation in fisheries sector and crop planning can also be benefitted from salinity zoning maps. Salinity is an important parameter for characterizing the eco-systems and its sustainability in the changing climate. Salinity zoning maps can be used to find the effect of climate change on the coastal ecosystem as well as on biodiversity.

CHAPTER 1

Introduction

1.1 Background

Bangladesh is one of the most vulnerable countries to natural disasters due to its geographic location and geo-physical condition. Bangladesh experiences frequent floods as the country is located at the downstream of the GBM basins. The coastal region experiences frequent cyclones and storm surges including salinity intrusion to landward. It is predicted that climate change will exacerbate these natural calamities. Due to its location in the low-lying deltaic floodplains at the convergence of three Himalayan rivers, heavy monsoon rainfall concomitant with poor drainage often results in annual flooding. These river systems drain a catchment area of about 1.7 million km^2. The intensity of the floods depends on the magnitude and pattern of precipitation in the three river sub-basins. Among the peak discharge of the three rivers, the Brahmaputra contributes the greatest volume 58%, while the Ganges and the Meghna contribute about 32% and 10% respectively. The floodplains are home to a large population, most of which is rural and poor, whose life is intricately linked to the flooding regime.

The Bangladesh Water Development Board (BWDB) has labeled different areas of Bangladesh those are vulnerable to various categories of floods. About 21 percent of the country is subjected to annual flooding and an additional 42 percent is at Hazard of floods with varied intensity (Ahmed and Mirza, 1999). Annual regular flooding has traditionally been beneficial, providing nutrient laden sediments and recharging groundwater aquifers; while low frequency but high magnitude floods have adverse impacts on infrastructure, rural livelihoods and crop yield. Saline water intrusion is highly seasonal in the coastal zone of Bangladesh. Salinity and its seasonal variation are dominant factor for sustained coastal eco-system, fisheries and agriculture. Therefore, any changes on present spatial and temporal variation of salinity will affect the whole coastal eco-system and livelihood of the coastal community. The coastal zone is vulnerable to cyclonic storm surges and eventual damages of infrastructures. The frequency and intensity of cyclone induced storm surges are likely to increase in the changing climate, consequently the associated Hazard is quite high. In this scenario the local community always remains on the frontline of any impact of disasters and changing climate. To address the vulnerability context of local community the Comprehensive Disaster Management Programme (CDMP II) of the Ministry of Disaster Management and Relief has developed and introduced a simplistic and uniform Community Risk Assessment (CRA) methodology. Community Risk Assessment (CRA) is the basic building block of CDMP where community is to assess their own Hazard. In order to assess community Hazard preparation of inundation Hazard map of flood and storm surge and salinity maps are of immense importance. Following the Hazard assessment by the community at the union level the union level RRAPs are prepared. Presently, Flood Forecasting and Warning Centre (FFWC) of BWDB is responsible for providing flood information up to the district level. However, in practice, FFWC provides flood warnings to the district administration only when water level reaches near and crosses the danger levels at BWDB stations within a district. The present study aims to develop flood information at union level to support disaster management activities and also location specific impacts of climate change scenarios. The data, simulation results, salinity maps and inundation Hazard maps are instrumental for community Hazard assessment, flood zoning and to find elements at Hazard at present and in the changing climate.

The Comprehensive Disaster Management Programme (CDMP II) engaged the consortium, the Institute of Water Modelling (IWM) through a formal contract agreement signed on 14th October, 2010 to carry out this study.

1.2 Study Area

The study area (Figure 1.1) includes all coastal districts (19 districts) and selected flood-prone districts from rest of the country. The present study focused 40 districts in assessing the flood inundation Hazard and in preparing union-wise flood maps and coastal districts for storm surge inundation and salinity maps. Flood-prone districts have been selected in consultation with the officials of CDMP.

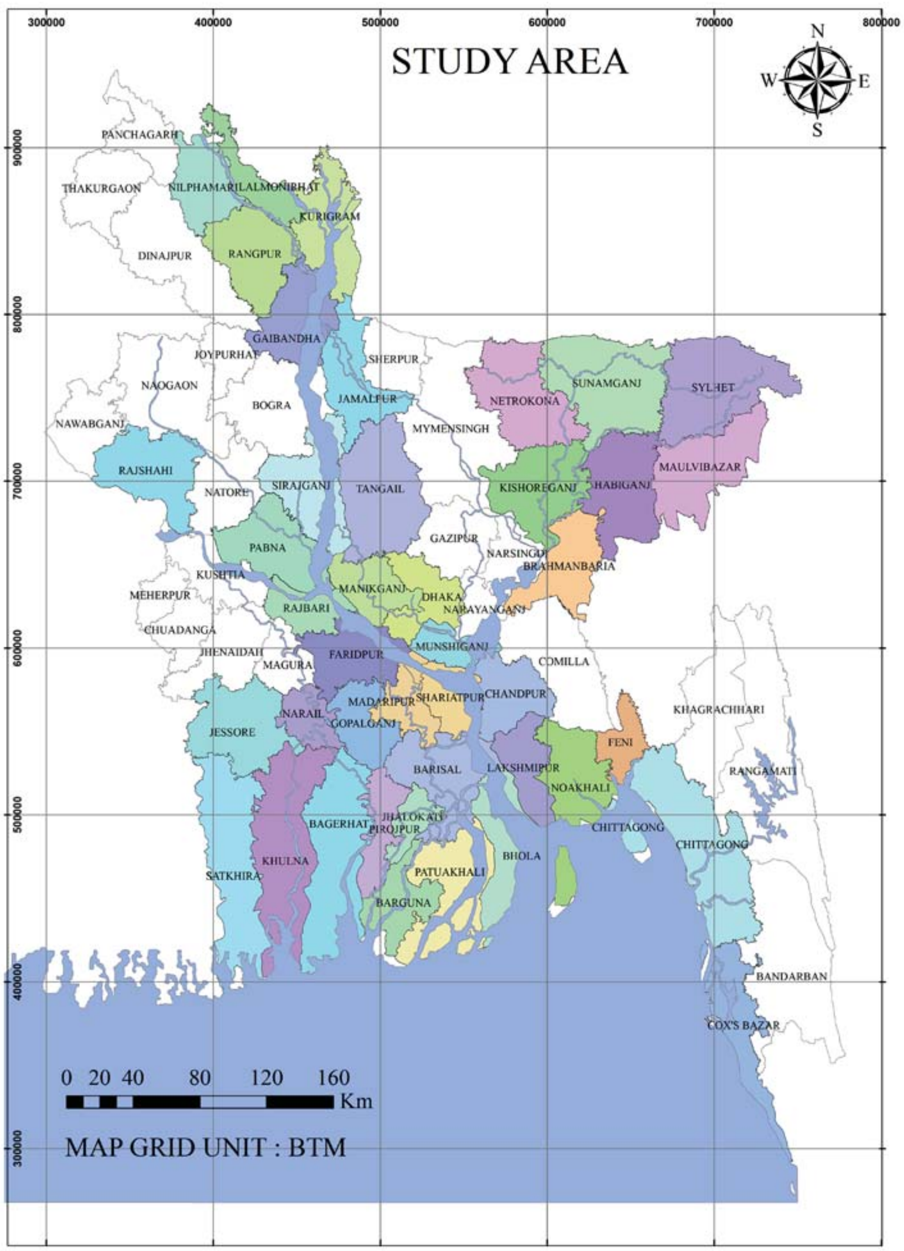


Figure 1.1: Study area (colored shows the selected districts)

1.3 Objectives, Outcomes and Scope of Works

Objectives

The overall objectives of the study are:

- To develop union level flood inundation, storm surge inundation and salinity level data set based on historical flood and cyclone events and salinity data utilizing the existing regional models; and
- To identify probable impacts due to climate change for the flood-prone unions of Bangladesh.

Outputs

- Data set on inundation pattern of unions for historical major floods;
- Union-wise flood maps for historical flood events, 1988, 1998, 2004 and 2007 and for 50 year and 100 year return periods;
- Assessment of impact of climate change on flooding, cyclone induced storm inundation and salinity and consequences on land use pattern;
- Flood zoning maps and updated base map for cluster of unions incorporating all available information;
- Salinity zoning maps, storm inundation maps and updated base map for cluster of unions incorporating all available information;
- Flood, cyclone induced storm inundation and salinity vulnerability and Hazard maps including Hazard elements to consider for an impact assessment following the findings of this study;
- Spatial distribution of maximum and minimum salinity in the coastal area of Bangladesh in a monthly basis for current condition;
- Spatial distribution of maximum and minimum salinity in the coastal area of Bangladesh in a monthly basis due to climate change and sea level rise;
- Zoning map of isohaline of 1ppt, 2ppt, 3ppt and 5ppt for current condition and under different sea level rise scenarios;
- Assessment of impact of climate change on drinking water, irrigation sources and fisheries;
- Identification of Hazard elements following the changed situation to have an impact assessment;
- Inundation Hazard maps at upazila level for cyclone-induced storm surge.

Scope of the Study

The following are the scope of work for fulfilling the objective of the proposed local level hazard study:

- **Collection of study reports, maps, data and available satellite images, review and analysis of these, identification of flood-prone areas of Bangladesh;**

- Review the level of information available in the existing regional models for each flood-prone unions of the selected districts of Bangladesh;
- Updating of regional models with detailing in each flood-prone, salinity-prone and storm-prone unions as much as possible utilizing available secondary data;
- Collection of field information on past flooding, salinity and storm surge and their respective devastation, change of land use patterns over the years and present Hazards through interview survey in some of the selected unions to verify the model output;
- Carry out spot level survey in selected flood-prone, salinity-prone and storm surge-prone unions where it seems important for updating the flooding condition, development of existing DEM incorporating spot level survey data;
- Carry out frequency analysis on river flow and water level at selected key locations, from regional point of view, and

determine extreme flood events, i.e. 10 yrs, 25 yrs and 50 yrs return periods and base year;

- Development of potential options for climate change in consultation with the CDMP officials;
- Simulation of regional models for extreme flood events including various climate change scenarios for future projection of 2050 & 2100 and analysis of results;
- Generation of union-wise inundation maps historical major flood years (1988, 1998, 2004 and 2007), generation of union-wise storm surge (2007, 2009) and climate change scenarios utilizing updated regional models and compare with available satellite images;
- Generation of union-wise inundation data for base year, extreme storm surge inundation (2007, 2009, etc) events and salinity intrusion and climate change scenarios based the model simulation results and identify impacts on flooding conditions;
- Development of union-wise flood inundation mapping based on the model results for various flood events including climate change scenarios;
- Based on the evaluation of model simulation results prepare flood, salinity, storm surge Hazard zoning map and outline possible adoptive measures;
- Organize workshop for dissimilating and sharing of study findings with the stakeholders;
- Reporting that includes inception, annual, draft final and final.

1.4 Approach and Methodology

Data Collection

Available data on water level, water flow, rainfall, evaporation, river bathymetry, salinity level, cyclone track and satellite imageries are essential for analyzing the flooding, salinity distribution and storm surge height in the recent and past years to develop baseline condition. All available data in different organizations have been collected and analyzed for establishment of baseline condition, up gradation of model, historical trend of rainfall and frequency analysis of flood and cyclone.

Selection of Climate Change Scenarios

Climate change and sea level rise have large impact on natural resources of Bangladesh. The main threats of climate change in Bangladesh are increased flooding, drainage congestion, decrease of flow in winter, salinity intrusion, frequent cyclone and storm surge flooding. Climate change will intensify the rainfall resulting more flood during monsoon. Increase in temperature and less rainfall during dry season will cause severe draught. Salinity will intrude more towards land due to sea level rise. Again intensity and frequency of cyclonic storm surge will increase due to climate change. However, the extent, intensity and magnitude of impacts are not known exactly. The present study has focused on the change in flood depth, salinity distribution and cyclonic surge height due to climate change and sea level rise.

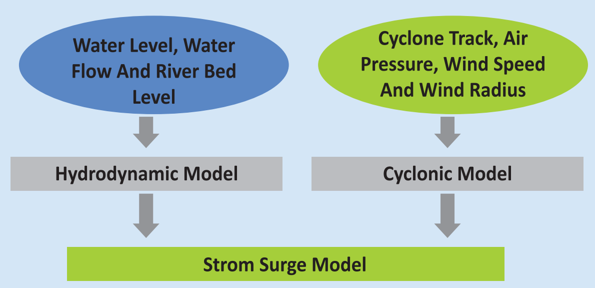


Figure 1.2: Flow Diagram of Storm Surge Model

The main aim of this component is to devise climate change scenarios for flood, salinity intrusion and cyclonic storm surge separately to assess impact of climate change in the year 2050.

Storm Surge Hazard Maps for Cluster of Unions

Storm surge Hazard maps were produced based on the results from Bay of Bengal Storm Surge Model. Flow Diagram of

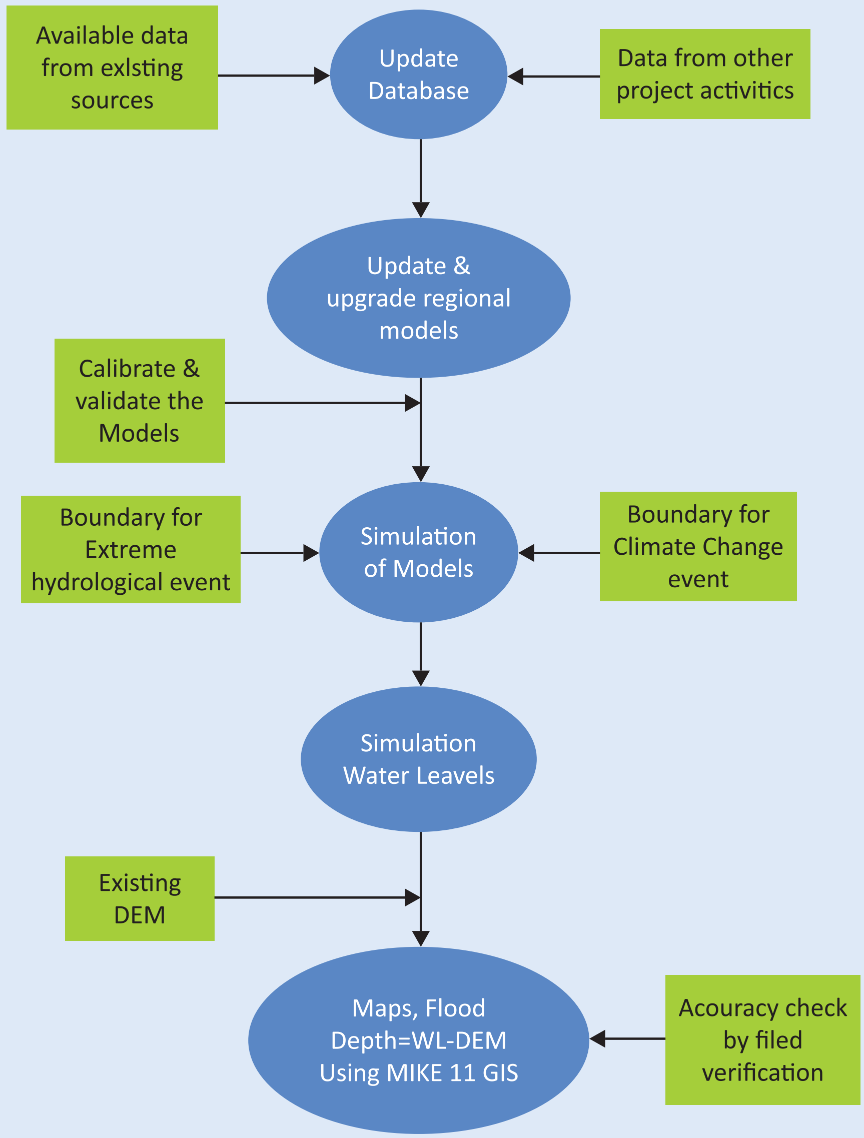


Figure 1.3: Flow Diagram for Flood Mapping

Storm Surge Model is shown in the Figure 1.2. The model were simulated both for past severe cyclones and will be verified with field data. The model was also simulated for climate change condition especially for sea level rise and increased wind speed. Maximum inundation depth maps for all the cyclone-induced storm surges and climate change conditions were generated based on the model results. Finally inundation maps were generated at union level using GIS tool.

Flood Hazard Maps for Cluster of Unions

Flood inundation maps were produced based on the model results from six regional models namely Norwest Regional Model, Northeast Regional Model, North Central Regional Model, Southwest Regional Model, Southeast Regional Model and Eastern Hilly Regional Model. All those models were updated and verified with field data under this project. The calibrated models were simulated for four different characteristics flood such as 1988, 1998, 2004 and 2007. Besides, all the models were also simulated for climate change condition and different return periods. Depth-duration flood maps were produced from all of those model results using GIS tool. A flow diagram for flood mapping is shown in the Figure 1.3.

Salinity Hazard Maps for Cluster of Unions

Salinity Hazard maps were produced based on the three coastal river regional models namely southeast regional salinity model and eastern hilly regional salinity model. All the models were calibrated and validated against secondary flow and salinity data. The calibrated models were then simulated both for base and climate change condition. GIS tools were used to produce the maximum salinity maps for different months from February to May and zoning maps for different salinity levels.

1.5 Limitation of the Study

Topography is a crucial dataset for determining the impacts of sea level change because the shape of the physical landscape influences the direction that water flows over it, where it accumulates, and how and where it drains. The accuracy with which coastal topography has been mapped directly affects the reliability and usefulness of climate change impact assessment and is the most important factor in determining accuracy of inundation maps. The coastal area is characterized by flat topography, small changes in sea level cause greater changes in the extent of areas inundated by sea level rise. The reliability of the inundation maps largely depends on the quality of the model results. Simulation results provide water level at different locations of the river and drainage channels at different flood events that are the main data used along with land level or digital elevation data in producing maps. There are inherent uncertainties in the observed/measured data of water level and land level because of human and instrumental errors. Model results also have different degree of uncertainty depending on data used, calibration and validation of model.

Another source of uncertainty is the projection on sea level rise and change of precipitation in the changing climate. Mainly IPCC projections presented in the AR4 are used in this study.

In the present study best available data on land level/digital elevation model is used. Models are also well calibrated and validated. However, local drainage channels are not included in the model, where community consultations were carried out for validation of model results. Lidar survey data on land level can enable to enhance the quality of digital elevation model, which would be instrumental for generating quality inundation maps. River and flood plain integration using river and flood plain model can provide more accurate results on inundation depth. However, it is expensive and time consuming.

CHAPTER 2

Data Collection, Screening and Analysis

IWM has maintained different coastal and river models for the last several years but it is essential to update the models incorporating the recent bathymetry and hydrodynamic conditions and then validate all these models before applying in any study. That is why data on water level, water flow, rainfall, evaporation, river bathymetry, salinity level, salinity distribution and storm surge height in the recent and past years were collected to develop baseline condition and also to validate the existing models. All the relevant data were collected both from secondary sources and those were analyzed

Table 2.1: Inventory of salinity data

Sl. No.	Station Name	River Name	Period of Collection	Frequency
1	Hiron Point	Pussure	Dec 2010 – May 2011	Daily High and Low Water Slack, Alternate day measurement, 2 samples in a day
2	Mongla	Pussure	Do	Do
3	Nolianala	Sibsa	Do	Do
4	Kobadak	Kobadak	Do	Do
5	Koikhali	Madar Ganga	Do	Do
6	Basantapur	Isamoti	Do	Do
7	Khulna	Rupsa	Do	Do
8	Sharankhola	Baleswar	Do	Do
9	Pirojpur	Kacha	Do	Do
10	Amtoli	Buriswar	Do	Do
11	Chandpur	Meghna	Do	Do
12	Bamni	Bamni Khal	Do	Do
13	Borhanuddin	Tentulia	Do	Do
14	Daulatkhan	Meghna	Do	Do
15	Boradia	Nabaganga	Do	Do

Secondary data on water level, flow/discharge, rainfall, evaporation and salinity were collected from different sources to validate all the existing models. Details of secondary data have been furnished below:

for the establishment of baseline condition, updating of existing models, historical trend of rainfall and frequency analysis of flood and cyclone.

Salinity data collected under different on-going and completed projects of different agencies were used in this study. An inventory of the salinity data is furnished in the Table 2.1. These salinity data were used to validate the existing salinity model.

Water level data

Recent water level data also was collected for eleven different stations, which is furnished in the Table 2.2.

Table 2.2: Inventory of Water level data

Sl. No.	Station Name	River Name	Period		
			Dry 2011	Monsoon 2011	Dry 2012
1	Burhanuddin	Tentulia	29/01/2011-23/03/2011		01/01/2012-15/04/2012
2	Alipur	Mohipur Channel			
3	Amtali	Buriswar	23/01/2011-03/03/2011	01/08/2011-09/10/2011	01/01/2012-01/02/2012
4	Mollahat	Modhumati	07/02/2011-10/03/2011		
5	Kaliganga	Kaliganga	29/01/2011-30/03/2011	21/08/2011-15/09/2011	13/02/2012-30/03/2012
6	Pirozpur	Katcha	29/01/2011-01/04/2011	01/08/2011-14/09/2011	01/01/2012-25/04/2012
7	Char Doani	Baleswar	02/02/2011-03/04/2011	01/08/2011-10/09/2011	24/01/2012-30/04/2012
8	Bardia	Nabaganga	24/01/2011-10/03/2011		18/02/2012-26/04/2012
9	Khulna	Rupsha	01/02/2011-31/03/2011	18/08/2011-19/09/2011	01/01/2012-23/04/2012
10	Mongla	Pussur	11/03/2011-01/04/2011	16/08/2011-28/09/2011	14/02/2012-28/05/2012
11	Nalianala	Sibsa	05/02/2011 -17/02/2011	23/08/2011-30/09/2011	13/02/2012-09/04/2012

Discharge data

Flow in the coastal river was also collected from eleven different stations. The duration of all the discharge data with their location is presented in the Table 2.3.

Table 2.3: Inventory of Discharge data

Serial No	Station Name	River Name	Period		
			Dry 2011	Monsoon 2011	Dry 2012
1	Hilsha	Ilisha			22/02/2012
2	Amtali	Buriswar	23/01/2011	08/09/2011 14/09/2011	02/03/2012 09/03/2012
3	Modhumati	Modhumati	07/01/2011 15/01/2011 20/02/2011 26/02/2011	11/11/2011	22/03/2012 31/03/2012
4	Kaliganga	Kaliganga	06/01/2011 13/01/2011	22/08/2011 15/09/2011	25/03/2012 01/04/2012
5	Char Doani	Baleswar	09/01/2011 15/01/2011	07/09/2011 16/09/2011	05/03/2012 12/03/2012
6	Bardia	Nabaganga	09/01/2011 24/01/2011 21/02/2011 27/02/2011		21/03/2012 30/03/2012
7	Khulna	Rupsha	06/01/2011 16/01/2011 23/02/2011 01/03/2011	19/08/2011	17/02/2011 22/02/2012
8	Mongla Nala	Mongla Nala	14/02/2011 19/02/2011 06/03/2011 30/03/2011	08/10/2011 13/10/2011	23/03/2012 02/04/2012
9	Mongla	Pussur	09/02/2011 14/02/2011 30/03/2011	08/10/2011 13/10/2011	23/03/2012 02/04/2012
10	U/S of Akram Point	Pussur	06/02/2011 12/02/2011 13/03/2011 21/03/2011	07/10/201 11/10/2011	
11	U/S of Akram Point	Sibsa	07/02/2011 11/02/2011 14/03/2011 20/03/2011	06/10/2011 10/10/2011	

Salinity data

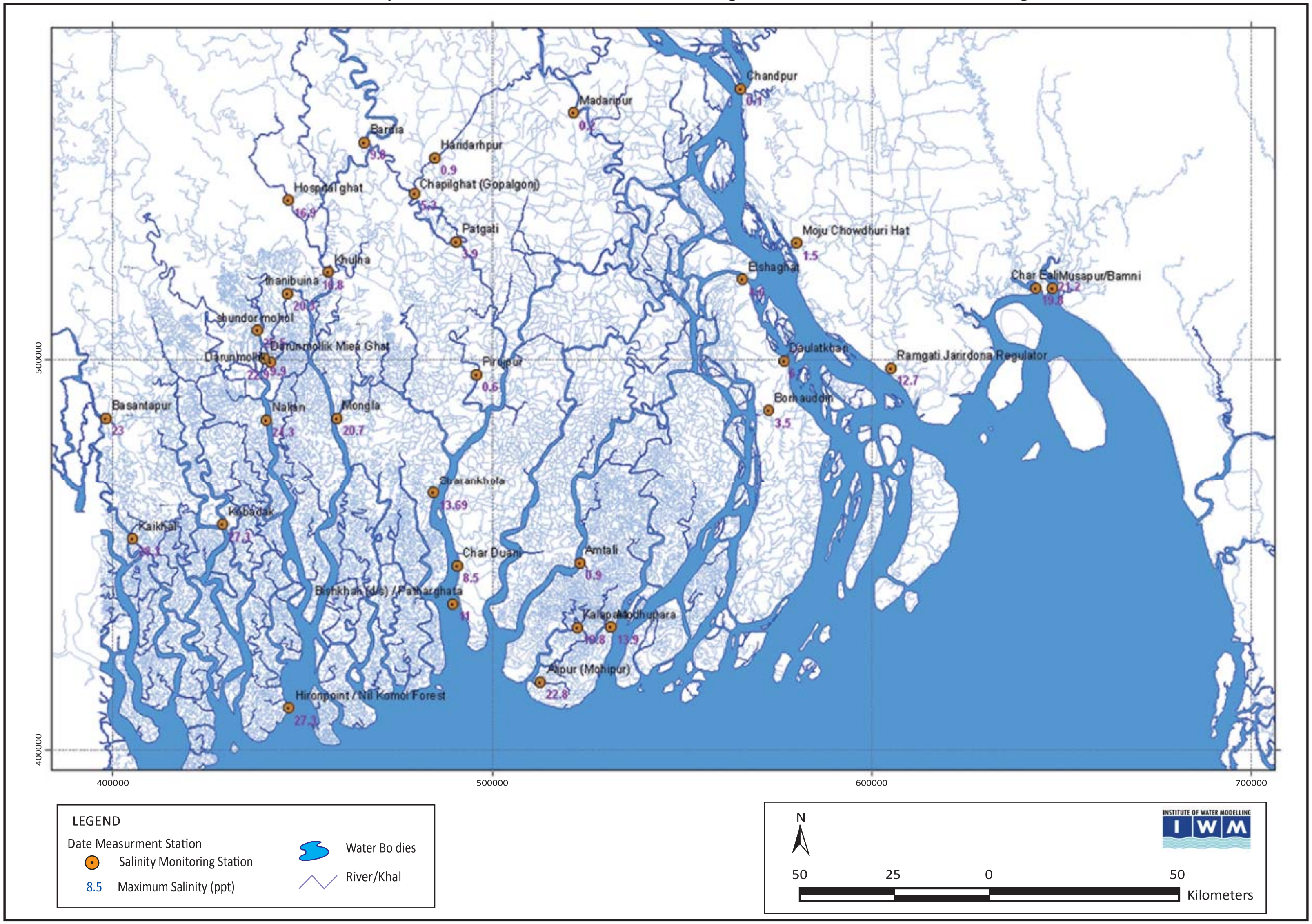
Salinity data was also collected from secondary sources. Salinity data was collected from 27 different stations. Period and frequency of all the data are presented in the Table 2.4.

Table 2.4: Inventory of secondary salinity data

Sl. No.	Station Name	River Name	Period of Collection	Frequency
1	Nalian	Sibsa	Dec 2010 – May 2011	Daily High and Low Water Slack, Alternate day measurement, 2 samples in a day
2	Madhupara	Andharmanik	Do	Do
3	Mohipur	Shibbaria Khal	Do	Do
4	Moju Chowdhury Hat	Meghna	Do	Do
5	Ramgati Jarirdona Regulator	Meghna	Do	Do
6	Habour Khali	Darunmo llik Miea Ghat	Do	Do
7	Badurgasa	Darunmollik	Do	Do
8	Gangrail	Shundor mohol	Do	Do
9	Shalta	Thanibuina	Do	Do
10	Bhairab	Hospital ghat/Fulbari ghat	Do	Do
11	Chapailghat	Modhumati	Do	Do
12	Patgati	Modhumati	Do	Do
13	Swarupkathi	Swarupkati	Do	Do
14	Bishkhali DS	Bishkhali River	Do	Do
15	Haridashpur	Madaripur Beel Route	Do	Do
16	Madaripur	Arialkha	Feb 2011– May 2011	Do
17	Hilsha	Ganeshpura	Feb 2011– May 2011	Do
18	Bishkhali	Bishkhali	Apl 2010 – July 2010	Do
19	Andar Manik	Modhupara	Apl 2010– June2010	Do

Based on salinity data, a map of maximum salinity was produced for the southwest region of the coastal area. The maximum salinity map is furnished in the Figure 2.1.

Map Showing Yearly Maximum Salinity (ppt) (2010-2011)
Salinity Intrusion in Coastal Zone of Bangladesh due to Climate Change



D:\POO25\C o astal Map\Salinity Stations_v2.mxd[mtn²070612]

Figure 2.1: Maximum salinity in the coastal region based on measured data of 2011 (Data source: Gorai River Restoration Project)

CHAPTER 3

Selection of Climate Change Scenarios for Cyclone, Flood and Salinity

Three different climate change scenarios are devised for three different disasters based on the influencing parameter such as rainfall for flood, sea level rise for salinity intrusion and sea level rise and wind speed for cyclonic storm surge inundation. The selection of sea level rise, change in precipitation pattern and increase of wind speed for the year 2050 are described below.

Sea Level Rise:

In devising sea level rise scenarios for year 2050 two different reports namely 4th Assessment Report by IPCC (AR4) in 2007 and IPCC Synthesis Report 2009 have been consulted. Prediction on sea level rise from both the reports are superimposed which is shown in the Figure 3.1 to make it more convenient for the selection of sea level rise. The only difference between both the predictions is Greenland ice melting. The Synthesis Report considers the Greenland ice melting whereas the AR4 doesn't. Figure 3.2 shows the rate of change of Greenland ice melting.

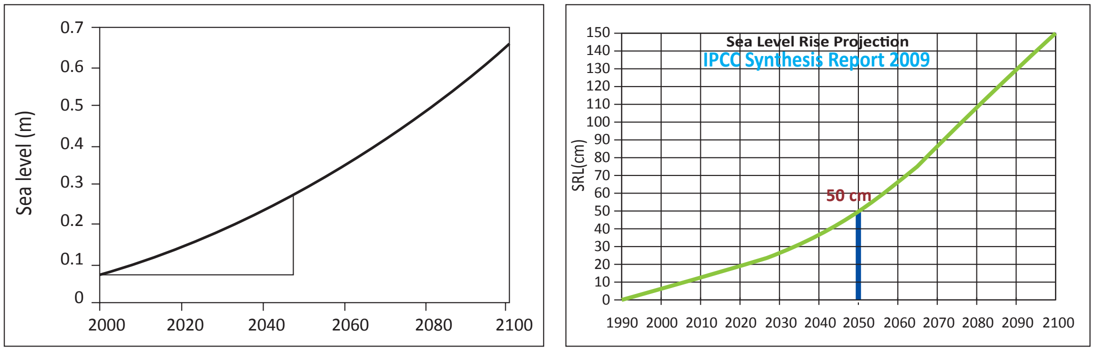


Figure 3.1: Projections of sea level rise both from AR4 and Synthesis Report.

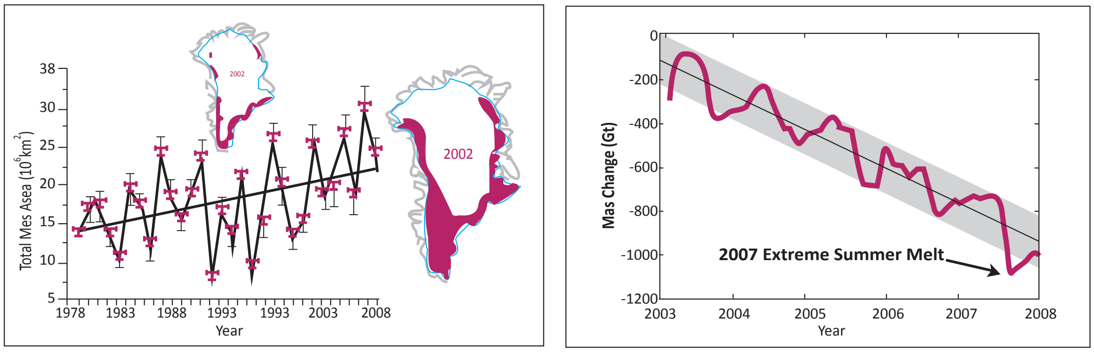


Figure 3.2: Area of surface melting across the Greenland ice sheet (left) and change of ice sheet from 2003 to 2008 (right)

It is clear from the Figure 3.1 that the sea level rise for the year of 2050 is 50 cm based on Synthesis Report whereas only 23 cm from AR4. Finally 50 cm is selected as AR4 does not include the Greenland ice melting.

Wind Speed

According to the study of Unnikrishnan et. al. 2006, both the frequency and intensity of tropical cyclones in the Bay of Bengal will be increased due to climate change. Whereas from the report of Knutsonand Tuleya, 2004 and IPCC, 2007, an increase of 10% to 20% in tropical cyclone intensities (wind speed) for a rise in sea-surface temperature of 2°C to 4°C relative to the current threshold temperature is likewise projected in East Asia, South-East Asia and South Asia. Amplification in storm-surge heights could result from the occurrence of stronger winds, with increase in sea-surface temperatures and low pressures associated with tropical storms resulting in an enhanced Hazard of coastal disasters along the coastal regions of East, South and South-East Asian countries. Considering the above analysis, 10% increase of wind speed is selected for the year 2050.

Precipitation

Projection of precipitation for Bangladesh cannot be obtained directly from the 4th IPCC report. However, projections of South Asia can be obtained from AR4, which is illustrated in Table 3.1.

Table 3.1: Projected changes in surface air temperature and precipitation for South Asia (5N-30N; 65E-100E) of Asia's sub-regions under SRES A1F1 (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices, namely 2020s, 2050s and 2080s.

Season	2010 to 2039 (2020s)				2040 to 2069 (2050s)				2070 to 2099 (2080s)			
	Temperature °C		Precipitation %		Temperature °C		Precipitation %		Temperature °C		Precipitation %	
	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1
DJF	1.17	1.11	-3	4	3.16	1.97	0	0	5.44	2.93	-16	-6
MAM	1.18	1.07	7	8	2.97	1.81	26	24	5.22	2.71	31	20
JJA	0.54	0.55	5	7	1.71	0.88	13	11	3.14	1.56	26	15
SON	0.78	0.83	1	3	2.41	1.49	8	6	4.19	2.17	26	10

Note: *DJF: December-January-February, MAM: March- April-May, JJA: June-July-August, SON: September-October-November*

Note[1]: DJF: December January February, MAM: March April May, JJA: June July August and SON: September October November

Note[2]: A1 Scenario – based on homogeneous world of very rapid economic growth, high global population that peaks in mid-century and the rapid introduction of new and more efficient technologies. It represents a convergent world with a substantial reduction in regional per capita income. Based on emission it is divided into three categories such as A1Fl, A1T and A1B.

A1Fl – Based on fossil fuel intensive – represent very high emission

B1 Scenario: based on convergent world with the same global populations as in A1 but with rapid change in economic structures and the introduction of clean and resource-efficient technologies. Special emphasis is given on global solution to economic, social and environmental sustainability including improved equity. It represents very low emission.

But it is difficult to get the actual value for the year 2050 from the Table 3.1 and it gives a similar rate of change for the whole South Asia which will not happen in reality. To solve the above problem, result of a GCM (Global Circulation Model) was used under this study to get the change in precipitation for the year 2050 for the whole GBM basin. A list of GCMs is presented in the Table 3.2.

Table 3.2: List of GCM models

Sl.	Model ID	Sponsor(s), Country
1	BCC-CM1, 2005	Beijing Climate Centre, China
2	BBCR-BCM2.0, 2005	Bjerknes Centre for Climate Research, Norway
3	CCSM3, 2005	National Centre for Astronomical Research, USA
4	CGCM3.1(T47), 2005	Canadian Centre for Climate Modelling and
5	CGCM3.1(T63), 2005	Analysis, Canada
6	CNRM-CM3, 2004	Centre National de Recherches Meterologiques, France
7	ECHAM5/MPI-Om. 2005	Max Planck Institute for Meteorology, Germany
8	ECHO-G. 1999	Meteorological Institute of the University of Bonn
9	FGOALS-gI.0, 2004	Institute of Atmospheric Physics, China
10	FGOALS-gI.0, 2004	Institute of Atmospheric Physics, China
11	GFDL-CM2.0, 2005	
12	GFDL-CM2.1, 2005	NOAA/GFDL, USA
13	GISS-AOM. 2004	
14	GISS-EH. 2004	NASA/GISS, USA
15	GISS-ER. 2004	
16	INM-CM3.0. 2004	Institute of Numerical Mathematics, Russia
17	IPSL-CM4. 2005	Institute Pierre Simon Laplace, France
18	MIROC3.2(hires). 2004	Centre for Climate System Research (University of
19	MIROC3.2(medres). 2004	Tokyo), JAMSTEC, Japan
20	MRI-CGCM2.3.2. 2003	Meteorological Research Institute, Japan
21	PCM. 1998	National Centre for Atmospheric Research, USA
22	UKMO-HadCM3, 1997	Hadley Centre for Climate Prediction and Research/
23	UKM-HadGEM1, 2004 O	Met Office, UK

Projections of five GCMs namely CCSM, ECHAM, GDFL, MIROC and UKMO are available in IWM. All these projections were used to produce the flooded area for whole Bangladesh considering 3-hr duration flood. Figure 3.3 shows the percentage change in extreme flooded area for the year 2050 under A2 emission scenario. It is evident from the figure that IPCC, MIROC and UKMO provide almost similar result which is between 6% to 8%. GDFL provides negative result for both A2 and B1 emission scenarios which are not consistent with that of IPCC. Again, B1 scenario of CCSM and ECHAM model provides less flooding than A2 scenario which is also not consistent with the definition of IPCC emission scenarios. According to the definition, A2 is more severe than B2. Only MIROC and UKMO provide the consistent result with that of IPCC. Since projections of MIROC provide consistent results on flooding with that of IPCC under A2 and B1 scenarios then MIROC has been selected for this study.

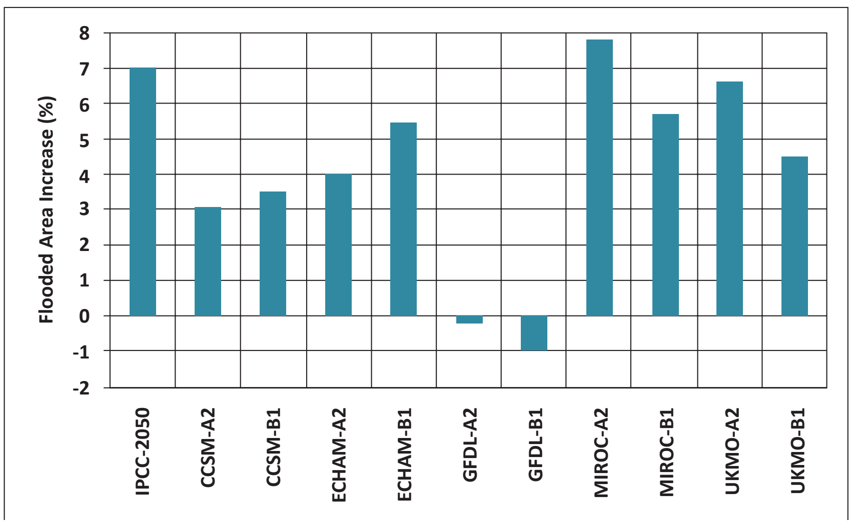


Figure 3.3: Changes in extreme year flooded area due to climate change in 2050

CHAPTER 4

Storm Surge Inundation Hazard Maps for Cluster of Unions

4.1 Selection of coastal districts for storm surge inundation Hazard map

There are 19 (nineteen) coastal districts in the coastal area and simulation results were analyzed for all these districts to assess the surge height due to cyclonic storms. Names of the coastal districts are presented in the Table 4.1 and Figure 4.1 shows map of coastal districts.

Table 4.1: List of coastal districts

Sl. No.	District	Sl. No.	District	Sl. No.	District	Sl. No.	District
1.	Jessore	6.	Gopalganj	11.	Barguna	16.	Noakhali
2.	Satkhira	7.	Pirozpur	12.	Patuakhali	17.	Feni
3.	Khulna	8.	Shariatpur	13.	Bhola	18.	Chittagong
4.	Bagerhat	9.	Barisal	14.	Chandpur	19.	Cox's Bazar
5.	Narail	10.	Jhalkathi	15.	Lakshmipur		

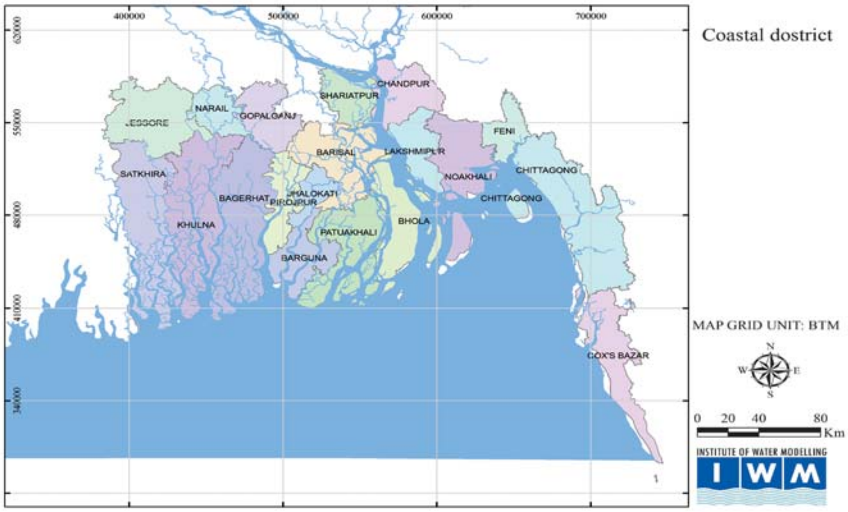


Figure 4.1: Coastal districts of Bangladesh

4.2 Simulations of historical storm surges

There are 19 (nineteen) severe cyclones that hit the coastal area from 1960 to 2009. This cyclone made landfall at different tidal phases i.e. either low tide or high tidal phase. All these 19 cyclones were simulated at original tidal phase and then opposite tidal condition i.e. if cyclone made landfall on low tide then both low tide and high tidal conditions of each cyclones were simulated. Total 38 cyclone tracks for the whole costal area have been considered based on 19 observed cyclones. In addition to these 38 tracks, three synthetic tracks were also simulated to cover the whole coastal area and those were also simulated for high tide and low tide. Altogether 44 simulations were carried out to define base condition. List of simulated cyclones are furnished in the Table 4.2 and are shown in the Figure 4.2.

Table 4.2: List of simulations

Sl. No.	Cyclone event	Occurred during HT/LT	Simulated for	
			HT	LT
1	1960	LT	√	√
2	1961	LT	√	√
3	1963	HT	√	√
4	1965-May	LT	√	√
5	1965-Dec	HT	√	√
6	1966	LT	√	√
7	1970	HT	√	√
8	1974	LT	√	√
9	1983	LT	√	√
10	1985	HT	√	√
11	1986	HT	√	√
12	1988	LT	√	√
13	1991	HT	√	√
14	1995	HT	√	√
15	1997-May	LT	√	√
16	1997-Sep	HT	√	√
17	1998	LT	√	√
18	2007	LT	√	√
19	2009	LT	√	√
20, 21 & 22	Synthetic track		√	√

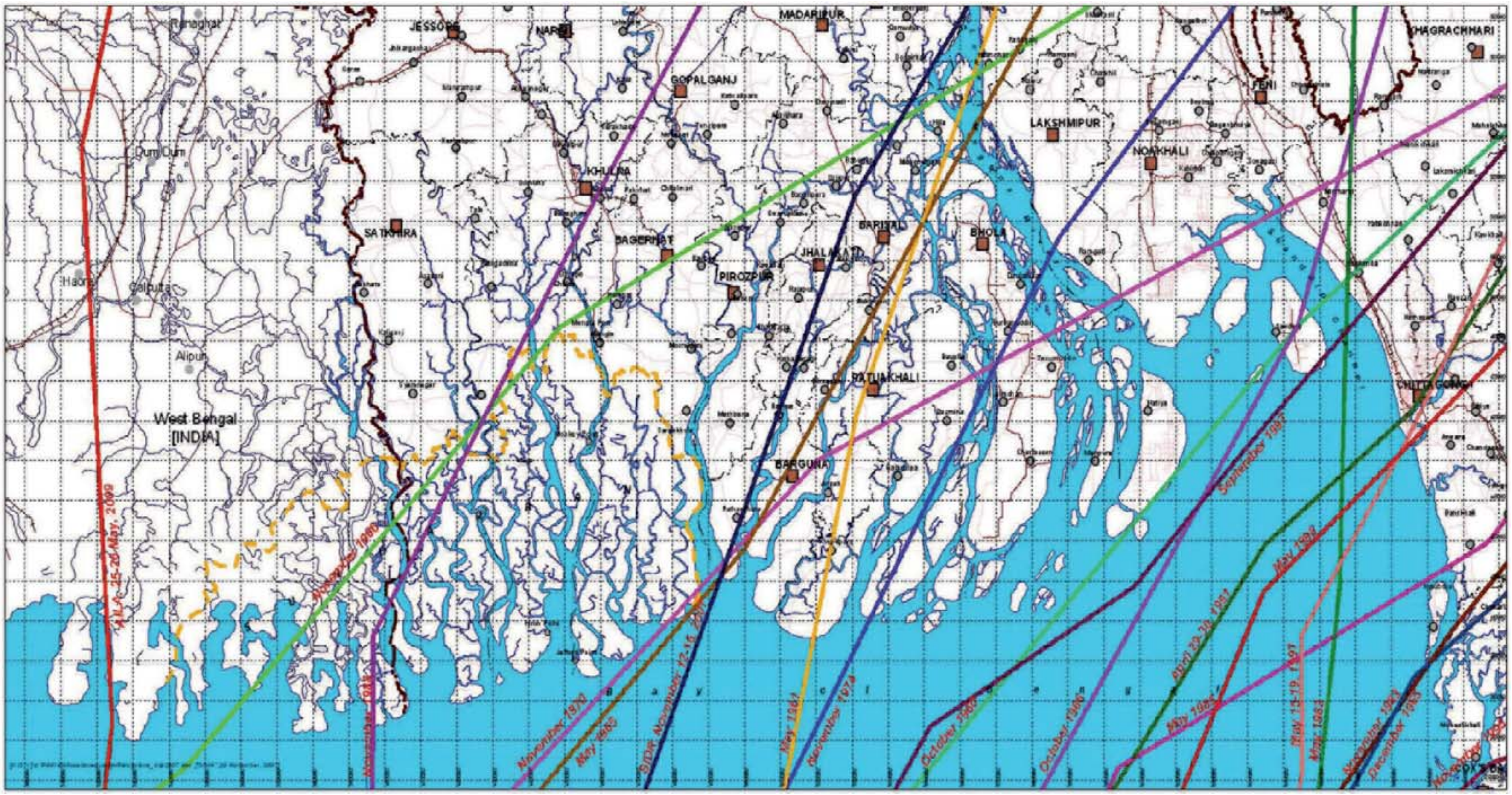


Figure 4.2: Simulated cyclone tracks

4.3 Updating and validation of Bay of Bengal Cyclone and Storm Surge Model

4.3.1 Hydrodynamic model

The existing two-dimensional Bay of Bengal model has been updated under this project with data from different secondary sources. The model is based on MIKE21 modeling system developed by DHI. The model domain covers the coastal region of Bangladesh up to Chandpur and the Bay of Bengal up to 16° latitude. The MIKE 21 modeling system includes dynamical simulation of flooding and drying processes, which is very important for a realistic simulation of flooding in the coastal area and inundation.

The hydrodynamic model is four way nested two-dimensional models and it includes four different resolution levels in different areas. The coastal region of Bangladesh and the Meghna estuary are resolved on a 200 m grid whereas the highest resolution is 5400 m. Figure 4.3 shows the four way nested bathymetry of the Bay of Bengal Model.

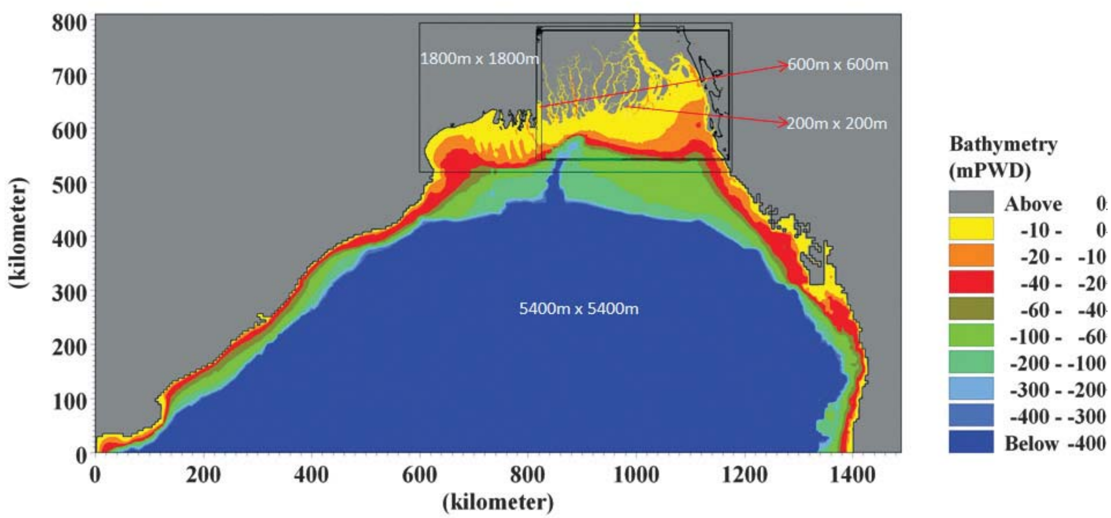


Figure 4.3: Nested bathymetry of Bay of Bengal Model

Following data were used to develop the Bay of Bengal Hydrodynamic Model:

Bathymetry Data

The Bay of Bengal model domain extends from Chandpur to 16° latitude in north-south direction. The main source of bathymetry of the model is the C-Map (an Electronic Chart System Database), Meghna Estuary Study, Phase II (MES II, 1998-99), Mongla Port Study (2004), IPSWAM (2008) and other projects of Bangladesh Water Development Board (BWDB).

Topographic Data (Digital Elevation Model)

The main source of land level data of the coastal region of Bangladesh is the FINNMAP land survey, FAP 19- National DEM (1952-64) and projects of Bangladesh Water Development Board (i.e. Khulna Jessore Drainage Rehabilitation Project, 1997; Beel Kapalia Project, 2008; and Beel Khuksia Project, 2004). The FINNMAP topographic maps and other data were digitized to develop Digital Elevation Model (DEM) of the coastal region of Bangladesh.
The DEM of the coastal region of Bangladesh is shown in Figure 4.4.

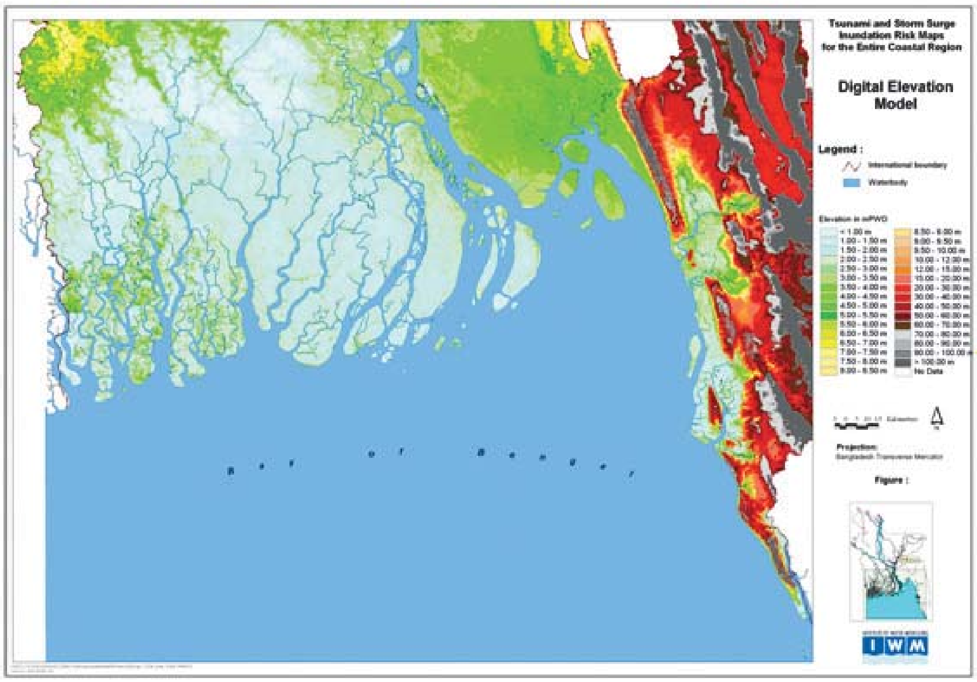


Figure 4.4: Digital Elevation Model of coastal region of Bangladesh

Boundary Data

The model has two open boundaries namely upstream and downstream boundary. The upstream boundary is defined by time series discharge at Chandpur in the Meghna river and the downstream boundary condition is given by predicted water level from Global Tide Model (Annexure – A) . There is no routine discharge gauging station at Chandpur and time series discharge is generated from calibrated southwest regional model. The details of Southwest model are described in the section 6.1.1.

Calibration and validation

The hydrodynamic Bay of Bengal model was calibrated and validated against water level and flow data from different stations in coastal river and in the sea. A sample plot of validation is shown in the Figure 4.5.

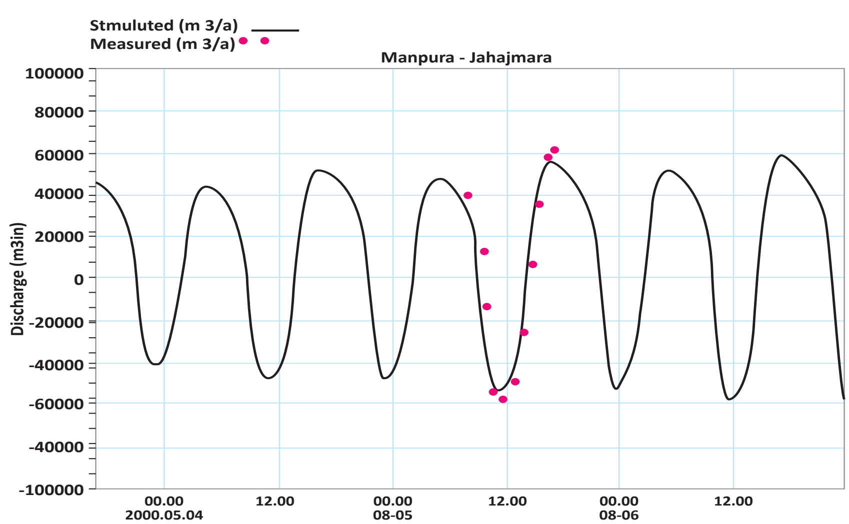


Figure 4.5: Validation Bay of Bengal Model against flow near Jahajmara ghat of Hatiya in the East Shahbazpur channel

4.3.2 Cyclone model

A proper cyclone model together with information of land levels is important and essential in order to calculate realistic inundation depths. Following information are used in the cyclone model:

- Radius of maximum winds;
- Maximum wind speed;
- Cyclone tracks, forward speed and direction;
- Central pressure; and
- Neutral pressure.

Cyclones Data

The source of cyclone data is the Bangladesh Meteorological Department (BMD). The cyclones' information includes cyclone period, position of cyclone, cyclone intensity, pressure drop (ΔP), maximum wind speed (Wm) and radius to maximum wind (Rm) for all the selected cyclones were collected from BMD.

4.3.3 Storm surge model

The storm surge model is the combination of Cyclone and Hydrodynamic models. Here, in the hydrodynamic model simulations of meteorological forcing like cyclone is given by wind and pressure field derived from the analytical cyclone model. Hydrodynamic model takes the water level, flow and river bed level as input and produce spatial and temporal variation of water level and current speed for the whole Bay of Bengal area. Whereas cyclone model takes cyclone track, air pressure, wind speed and wind radius as input and produce wind and pressure field for the Bay of Bengal area. A flow diagram of storm surge model is presented in the Figure 4.6

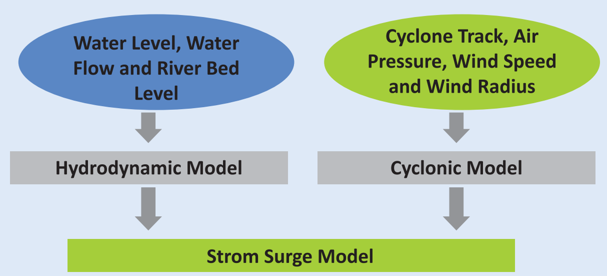


Figure 4.6: Flow diagram of storm surge model

The storm surge model was calibrated and validated with the storm surge level data for cyclone SIDR and cyclone AILA respectively.

Initial conditions

Initial conditions are essential part of the model and the so-called initialization shock must be absent in the models when different data are using in model as initial conditions. The initialization shock means sharp change of a solution of mathematical model at an initial time interval of its integration. The initialization shock is caused by inconsistence initial conditions. It is accompanied by large gradients of the solution with respect to time and space. That is why especial care was taken during the selection of initial conditions for storm surge model. In case of hydro dynamic model the initial conditions are water level, water flow and are provided based on available data and judgment based on experience. Historical data from secondary sources and prediction from harmonic constituents were used to settle the initial condition for water level whereas observed data from secondary sources are used for flow/discharge. For cyclone model, initial conditions are managed from the historical data from Bangladesh Meteorological Department (BMD). Details of initial conditions are furnished in Annexure B.

4.4 Preparation of Storm Surge Inundation Hazard Maps

4.4.1 Inundation Hazard maps for base condition

All the 44 simulations have been carried out to produce maximum storm surge levels in the whole coastal area especially for the influenced zone of cyclone. Unionwise inundation depth maps for the whole coastal area are prepared based on Digital Elevation Model (grided land level) and storm surge level using GIS technique. A new classification of surge height has been selected according to the suggestions from CDMP professionals and all the maps were reproduced according to that classification. Sample plots of 2 (two) upazila from two different districts are shown from the Figure 4.7 to Figure 4.8. Altogether 101 maps were produced to deliver under the base condition.

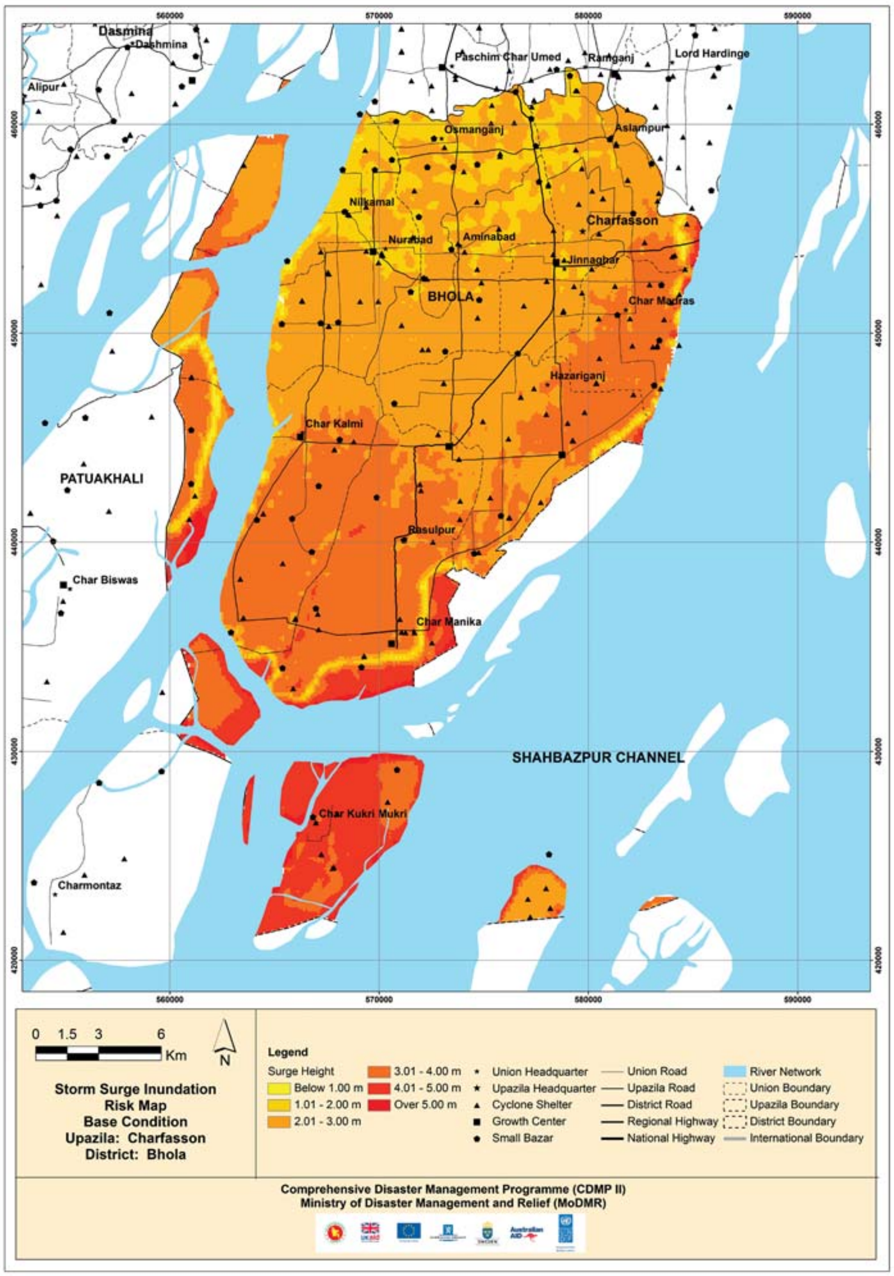


Figure 4.7: Inundation depth map for Charfassion upazilla of Bhola district

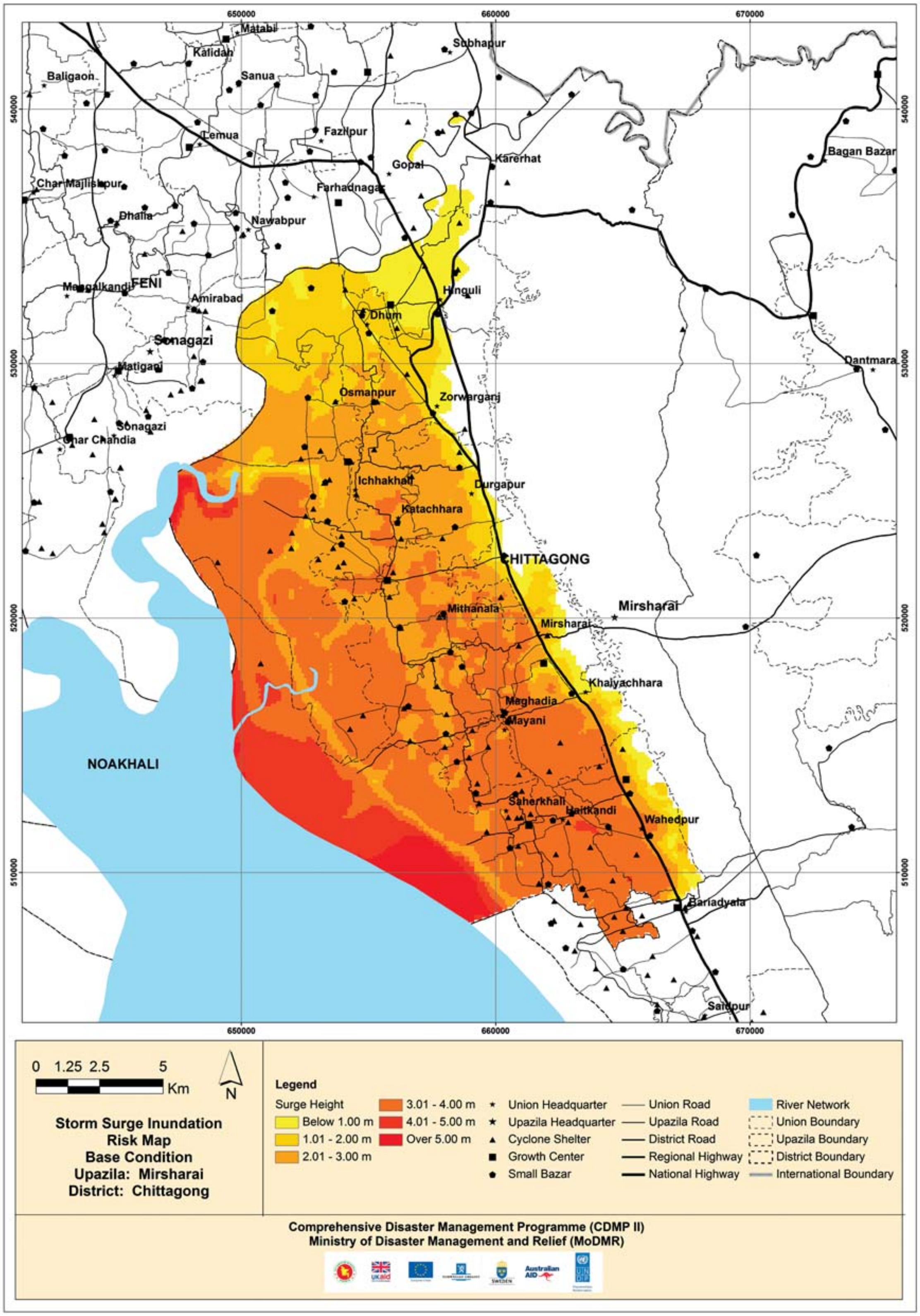


Figure 4.8: Inundation depth map for Mirsharai Upazila of Chittagong District

A map of the total coastal area was produced to represent the area of inundation greater than 1 m depth and it is shown the Figure 4.9. From the figure it is found that the area on the bank of the coastal river and open to the sea is the most vulnerable. Usually it is not possible for anyone to move within in a water depth of 1m, that is why the 1m water depth is selected for further analysis. It is evident from the analysis that an area of 19,146 km^2 is inundated by more than 1m water depth at base condition.

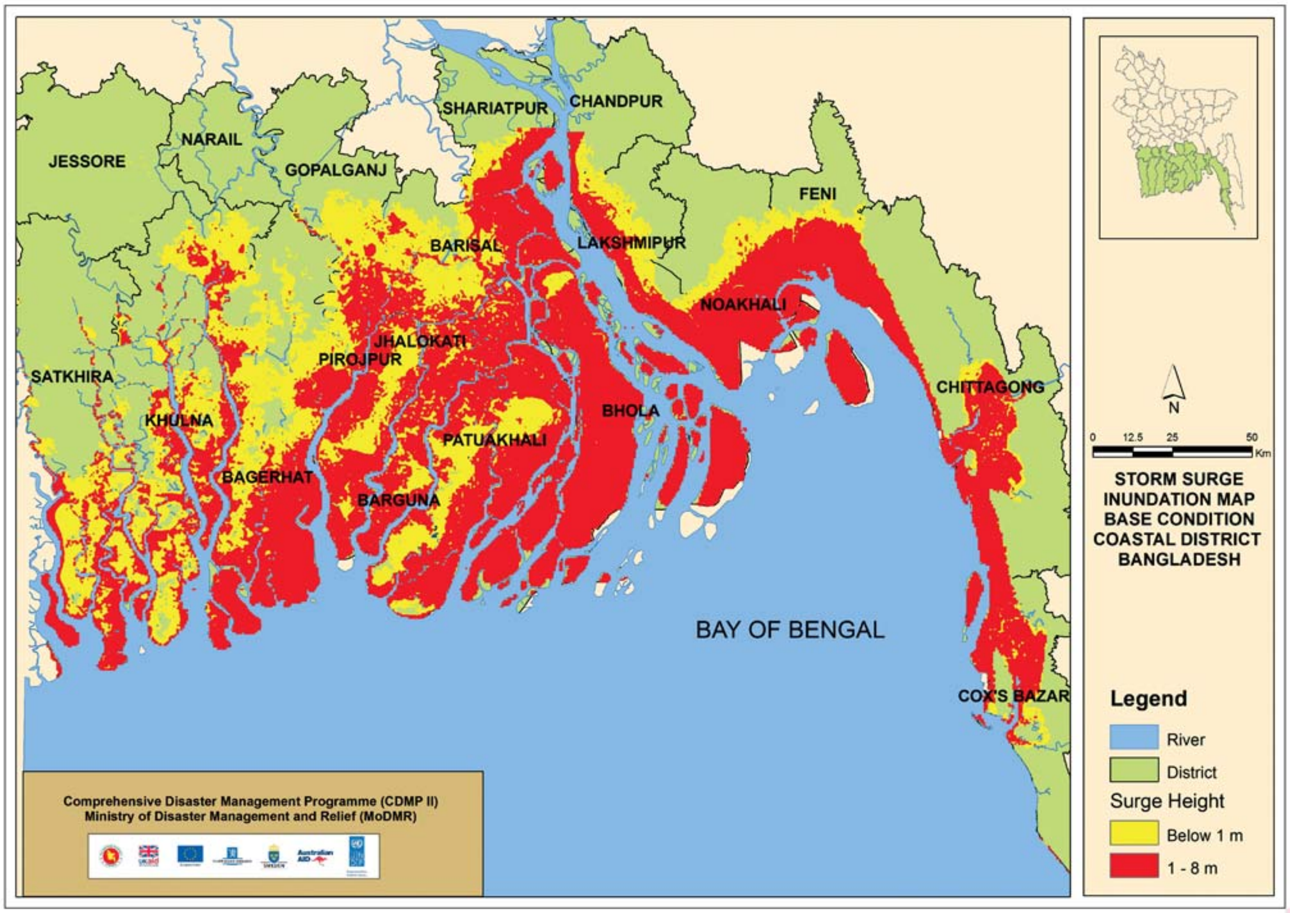


Figure 4.9: Cyclone induced inundation depth greater than 1m under base condition

4.4.2 Inundation Hazard Maps for Climate Change Condition

All the above mentioned 44 cyclones were simulated considering changing climate such as sea level rise and increase of wind speed. All the simulations were carried out for the year 2050 considering a sea level rise of 50 cm and 10% increase of wind speed. Inundation maps for all the upazila were produced for the changing climate. Sample plots of 3 (three) upazila from three different districts are shown from the Figure 4.10 to Figure 4.11.

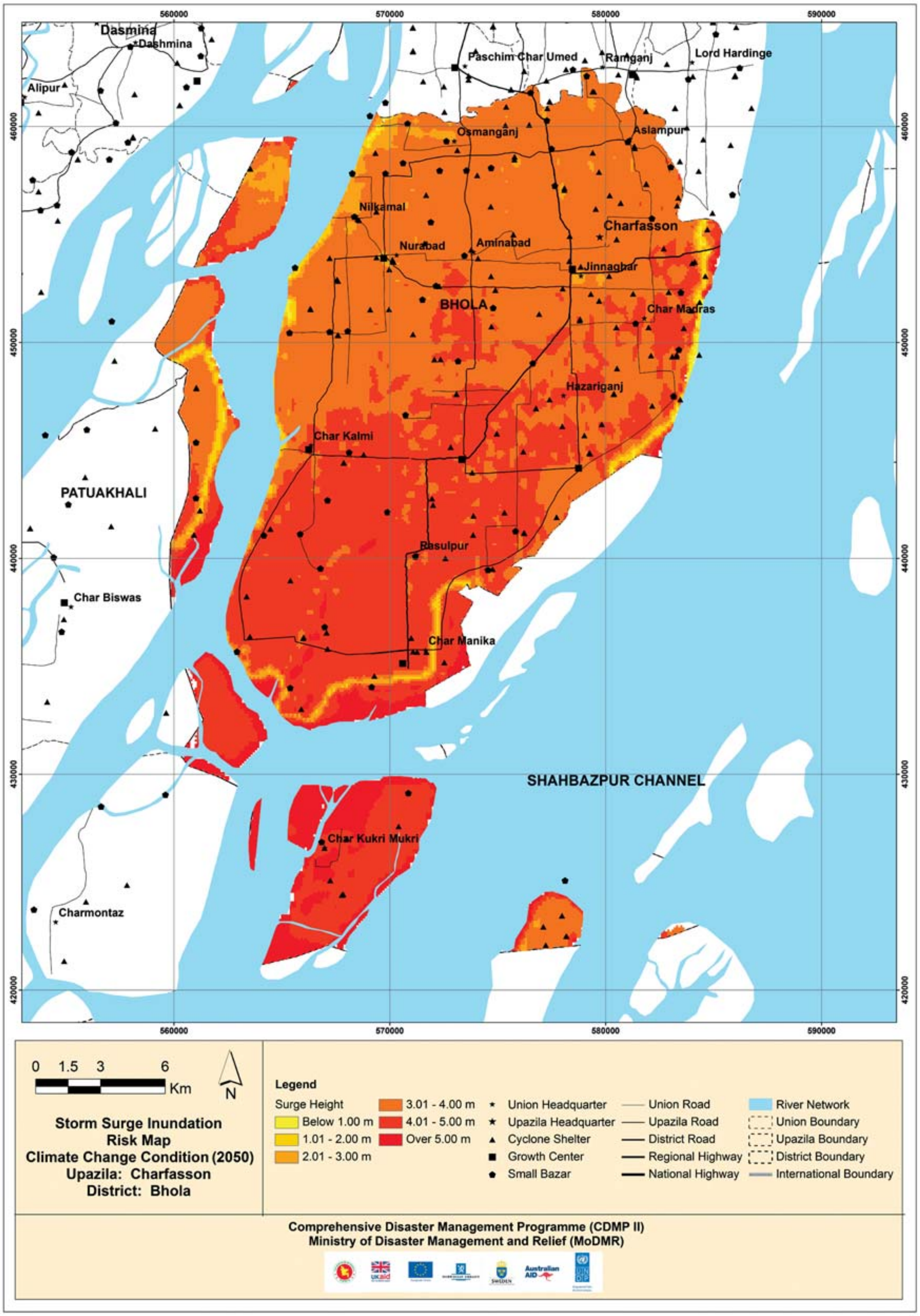


Figure 4.10: Inundation depth map for Charfassion Upazila of Bhola District due to climate change

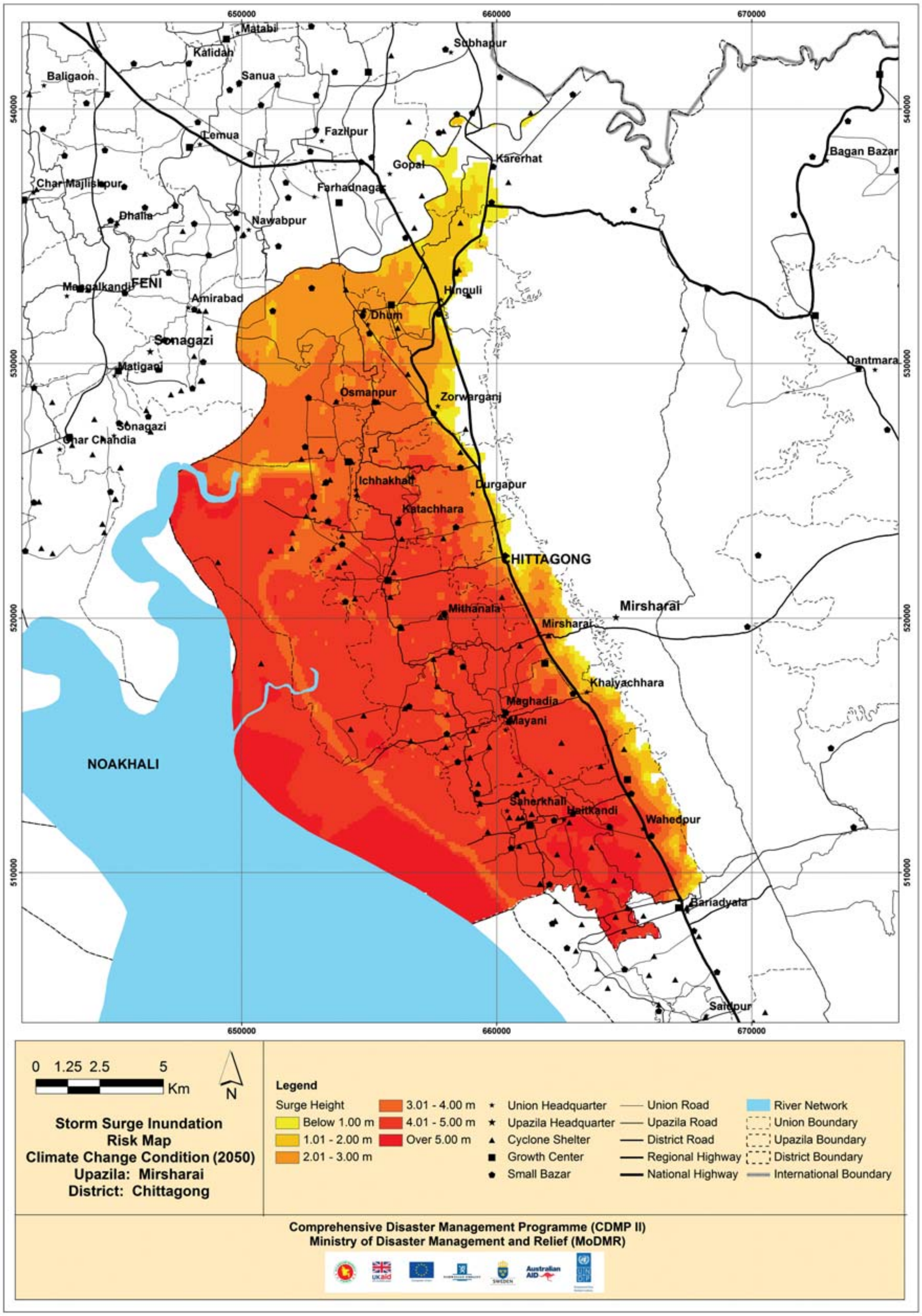


Figure 4.11: Inundation depth map for Mirsharai Upazila of Chittagong District due to climate change

A map of the total coastal area was also produced for the changing climate to represent the area of inundation greater than 1m depth and it is shown in the Figure 4.12. The analysis of the inundated area shows that an area of 20,745 km^2 is inundated by more than 1m water depth in the changing climate. The comparison of inundation Hazard maps with and without climate change shows the evidence of increase of inundation area and extent of inundation more than one meter depth in the climate change condition. Altogether 107 maps were produced to deliver under the climate change condition.

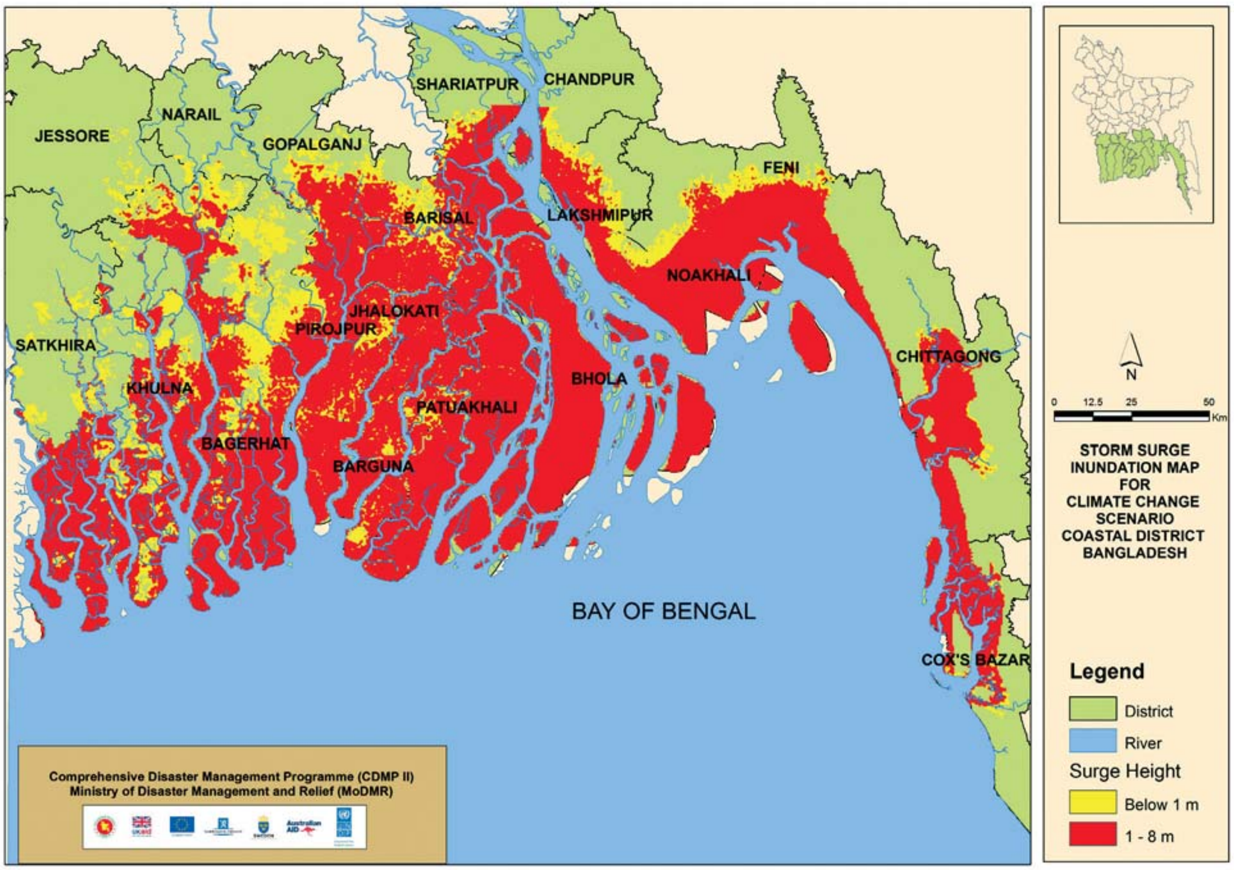


Figure 4.12: Cyclone induced inundation depth greater than 1m for changing climate

It is evident from the model results that Bhola, Laxmipur, Chittagong, Noakhali, Bagerhat, Barguna, Patuakhali, Pirojpur, Jhalkathi and Barisal are more vulnerable district for base condition whereas in the climate change condition Khulna, Sathkhira and the rest part of Pirojpur, Barisal, and Jhalkathi will be become vulnerable.

A comparison presentation between base and climate change condition for more than 1m inundation depth is shown in the Figure 4.13. It is evident from the Figure 4.13 that the southwest region is more vulnerable than that of other two regions.

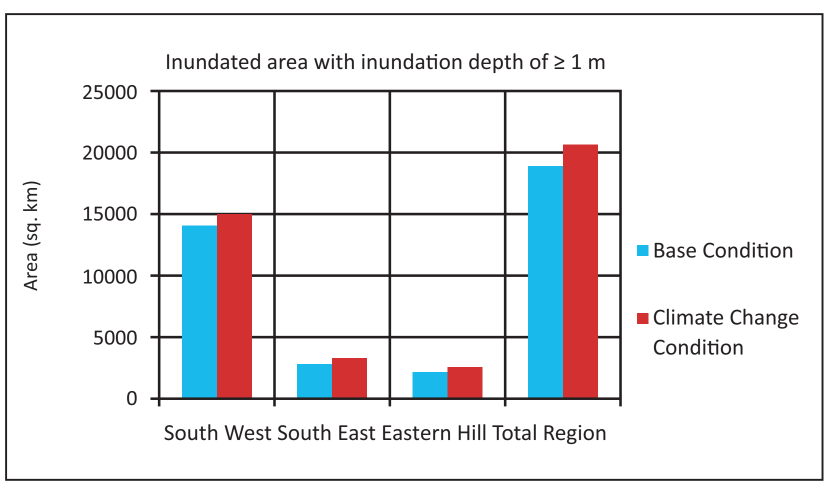


Figure 4.13: Regionwise inundated area for more than 1m depth

CHAPTER 5

Preparation of Flood Depth Map for Cluster of Unions

Updating and upgrading of regional models is the continual process which has been practiced by IWM through incorporating latest available hydrological, hydrometric and river cross-section data and maps. Simulated water (flood) levels and available digital elevation model are used to compute the depth of water in a certain location or grid using MIKE 11 GIS software. The flood depths are classified in accordance with the NWMP guidelines. Thus, the flood levels are the result of interpolation of monsoon water level of model grids surrounded with the rivers and channels in the locations of interest. A field verification survey of the flood maps of selected areas was also conducted to check the accuracy. The methodology adopted for generating flood maps is given in the flow diagram in Figure 5.1.

Flood inundation maps for various flood and climate change event have been prepared and all the maps were produced for 3 hour duration. Maps are produced for union level in A3 size showing Union Headquarter, Upazilla Headquarter, cyclone shelter, growth center, small bazar and all types of roads.

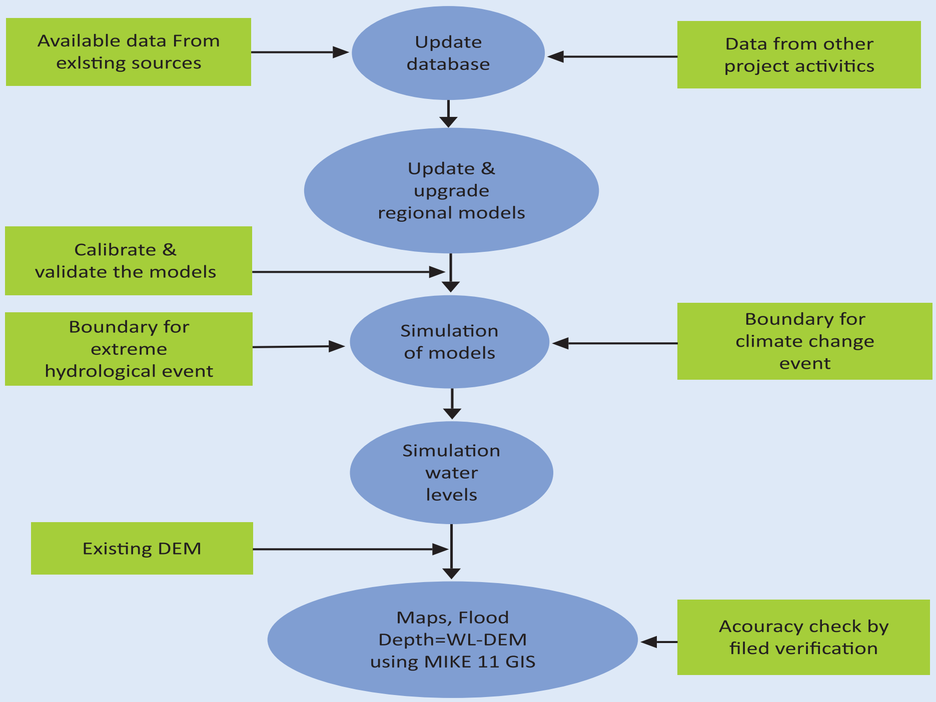


Figure 5.1: Flow Diagram for flood mapping

5.1 Updating and validation of existing flood models

5.1.1 Ganges-Brahmaputra-Meghna Basin Model

The Ganges-Brahmaputra-Meghna (GBM) basin model was originally developed at FFWC, BWDB in 2005. After development, the model has been tested at IWM using several rainfall data sets. The model has also been used in several studies in the last several years. The model is developed based on MIKE BASIN, the GISbased water resource modelling package developed by DHI Water & Environment. The model includes 133 sub-catchments out of which 79 in the Ganges river basin, 47 in the Brahmaputra river basin and the rest 7 in the Meghna river basin. Areas included in the Ganges, Brahmaputra and Meghna basins are 979503 sq. km, 520663 sq. km. and 26567 sq. km, respectively. The model includes snow melt feature in the snow fed catchments of Hindukush Himalaya region. However, inclusion of the glacier melt phenomenon is still under progress. Lumped features of the water retention and control structures (reservoirs and dams) within India are incorporated in the model. The model is calibrated at three outlet stations: Hardinge Bridge of the Ganges river, Bahadurabad of the Brahmaputra, and Amalshid of the Barak river. The performance of the model could not be tested within India due to non-availability of measured data. The model is updated and validated with recent data and information of intervention routinely. The extent, sub-catchments distribution and river system of GBM basin model is shown in Figure 5.2. The comparison plots of model results and observed discharges at Hardinge Bridge and Bahadurabad have been shown in Figure 5.3, 5.4 and 5.5.

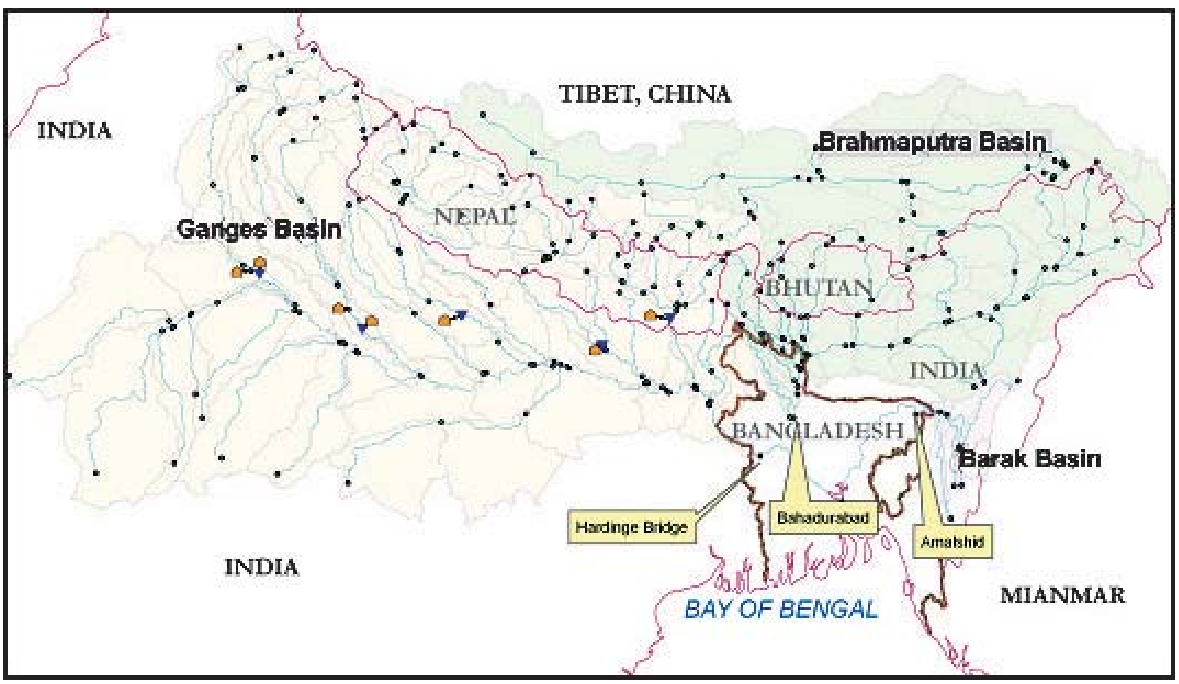
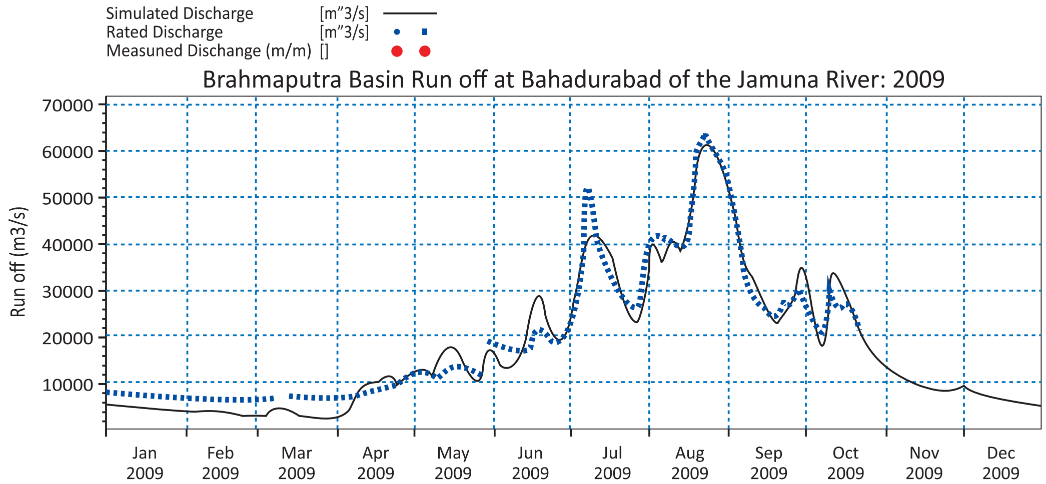
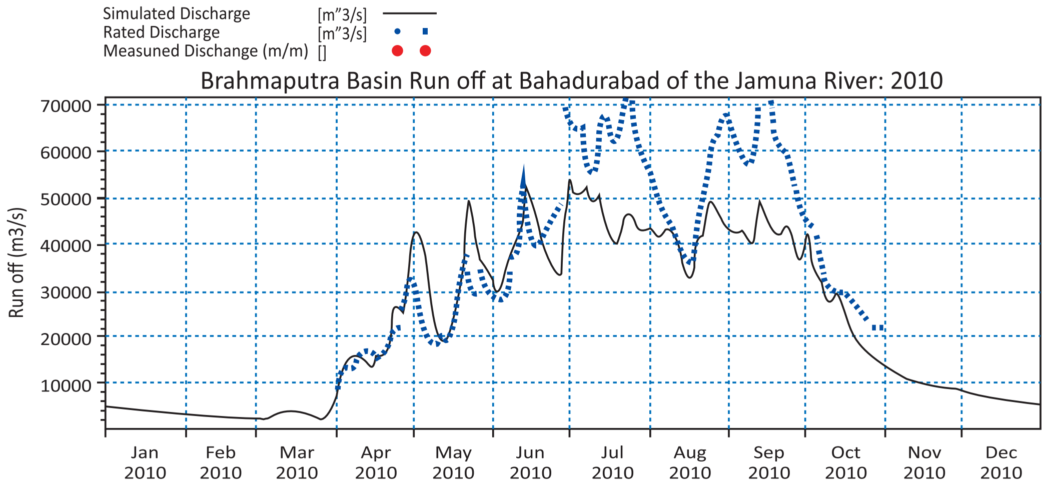


Figure 5.2: The GBM Basin Model





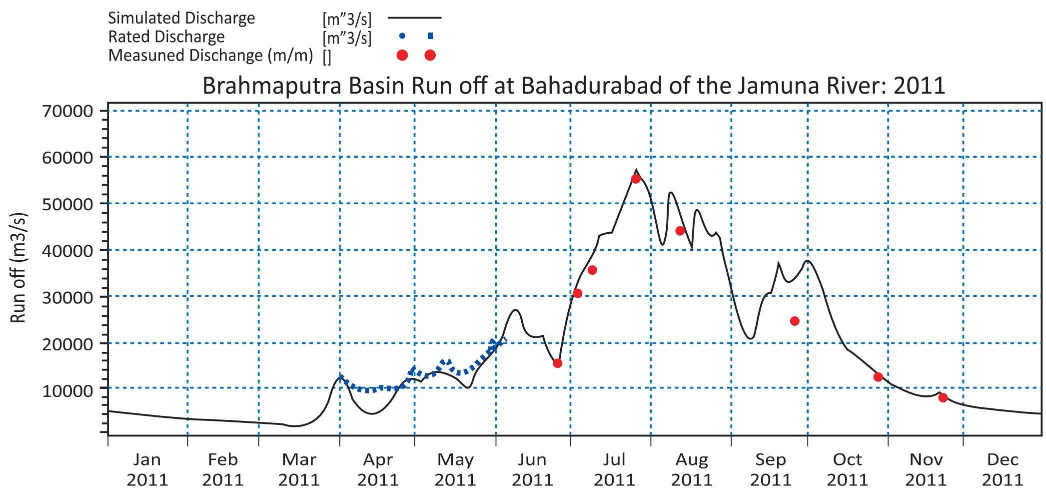


Figure 5.3: Comparison plot of model simulated and measured/rated discharge of the Brahmaputra Basin at Bahadurabad

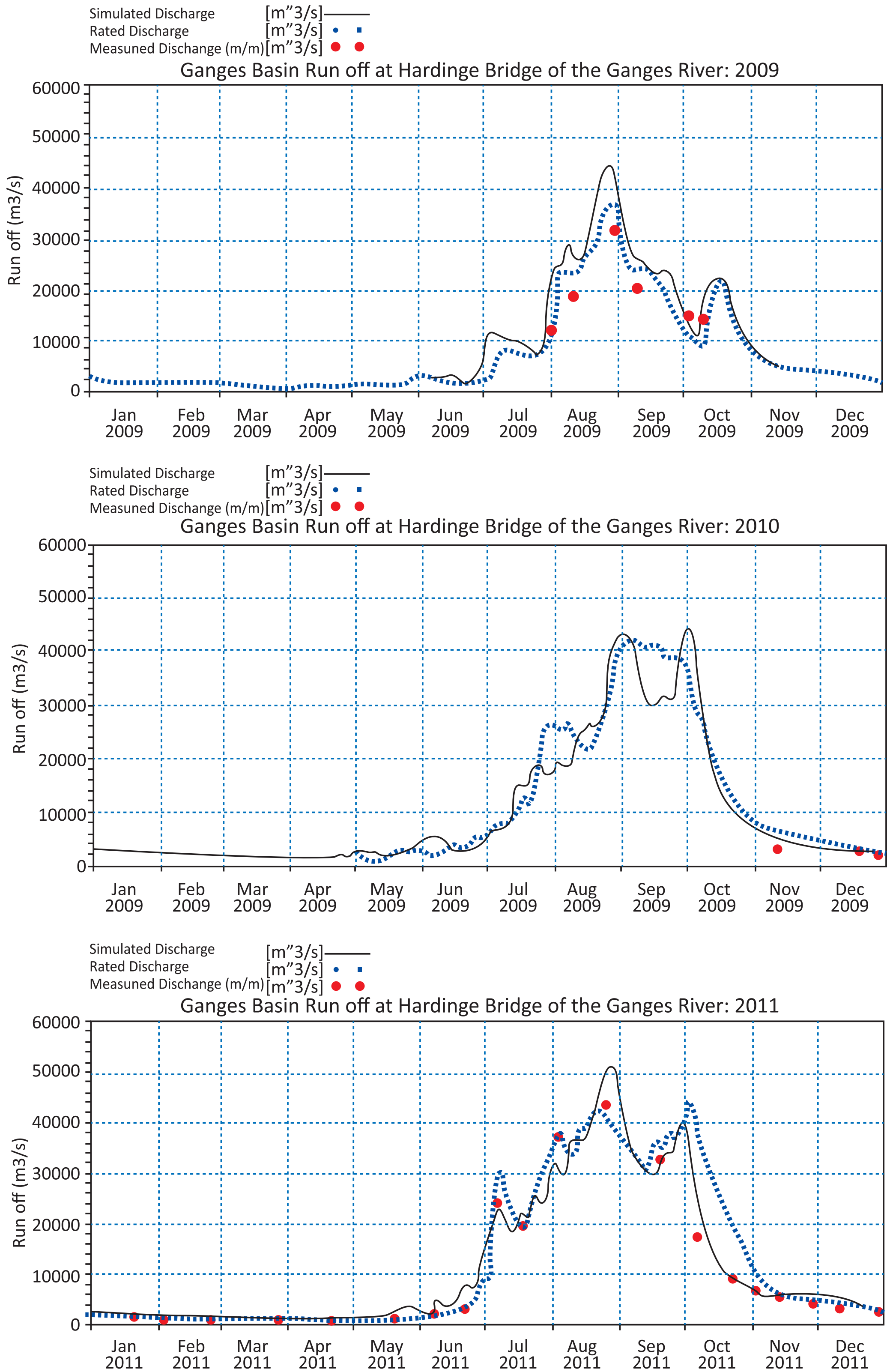


Figure 5.4: Comparison plot of model simulated and measured/rated discharge of the Ganges Basin at Hardinge Bridge

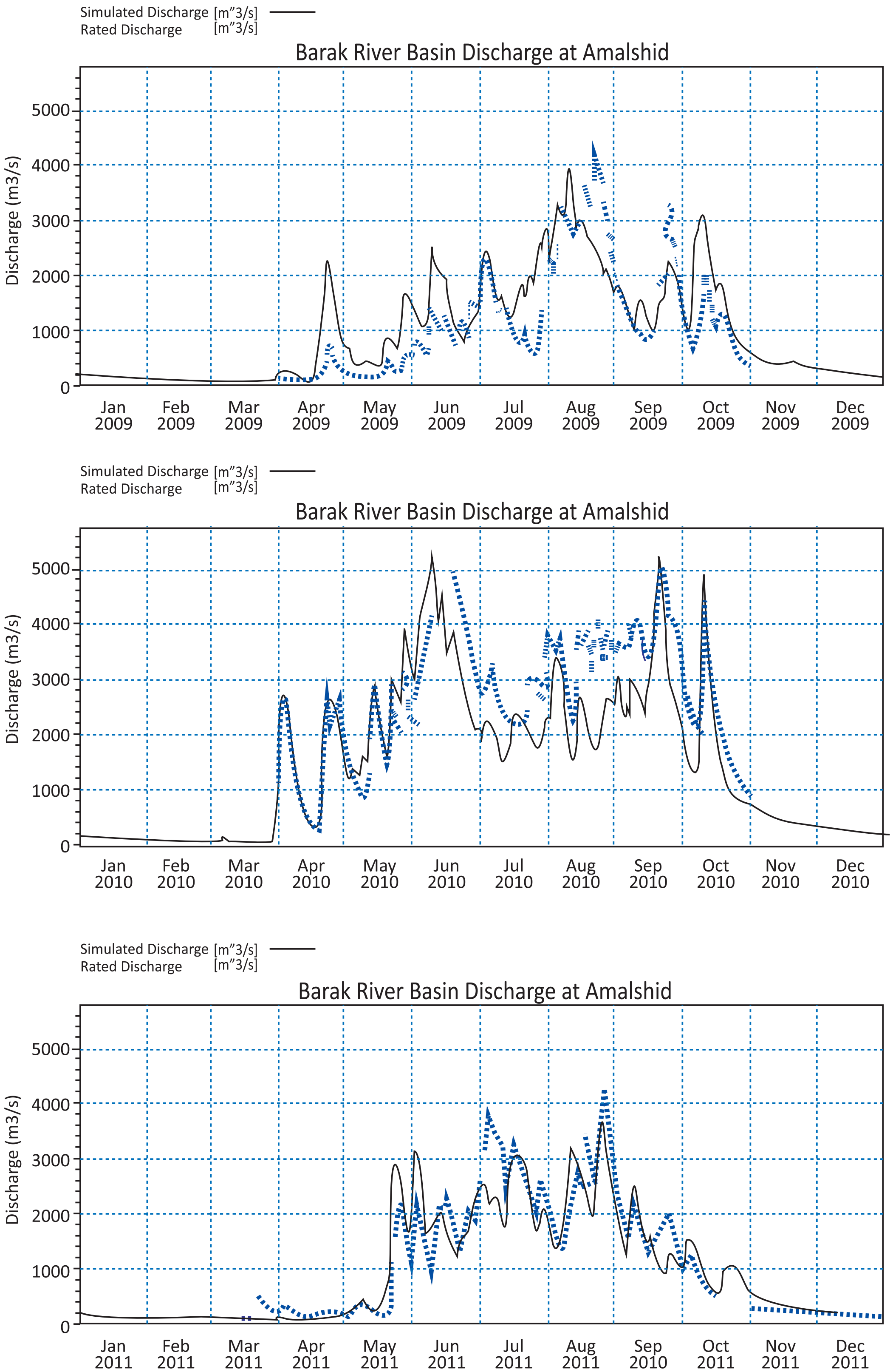


Figure 5.5: Comparison plot of model simulated and measured/rated discharge of the Barak Basin at Amalshid

5.1.2 Regional River Models

The regional models namely Northwest Regional Model (NWRM), North Central Regional Model (NCRM), Northeast Regional Model (NERM), Southeast Regional Model (SERM), Southwest Regional Model (SWRM) and Eastern Hilly Regional Model (EHRM) were developed during 1986-91 under the Surface Water Simulation Modeling Programme Phase-II (SWSMP II), and since then it has been updated and validated almost in every year. An overview of each model setup is given in Table 5.1 and hydrological boundary of each model area is shown in Figure 5.6. These models cover major river systems with hydrological conditions in a separate setup namely rainfall-runoff modules. A river having rapidly changed dynamics and topography needs to be updated and duly incorporated in a model. The regional models have been updated up to 2008-09 monsoon condition. The updating has been done under the various projects utilizing available data collected under those projects and secondary data of BWDB. Local topographic information collected under various projects has also been incorporated into the models. Hydro-meteorological data like rainfall, evaporation, water level, discharges and river sections have been collected from BWDB Hydrology. All the regional models, except EHRM, have been utilized in the study for generating flood related data. The regional models updated so far have been combined to develop a unique model. Simulations of the model for the selected hydrological scenarios have been carried out to get the flood levels. Flood in 1998 was the most severe in the recent history of Bangladesh. The flood maps for 1998 are being used for field investigation survey.

Table 5.1: Overview of all six regional models

Region Model	Area (sq. km)	No of Catchment		Rivers and Branches		No of Cross sections used	No of Hydrometric and Hydro-meteorological Stations					No of Boundary	
		Bangladesh	India	Nos	Length (km); Major River		WL	Q	RF	GWL	EVP	U/S	D/S
NWRM	32600	37	3	65	2800; Ganges, Teesta, Dharla, Dudhkumar, Mohananda	1258	78	44	80	31	11	32	4
NCRM	14700	19	1	40	2050; Buriganga, Dhaleswari, Old Brahmaputra, Lakhya	486	56	28	34	18	6	10	6
NERM	24265	38	20	110	3500; Kushiyara, Kalni, Surma, Baulai, Khowai, Manu	1200	55	38	45	21	4	23	1
SWRM	37330	44		90	5600; Lower Meghna, Arialkhan, Kobadak, Passur	2500	74	3	63	38	9	29	11
SERM	8500	35	8	135	1750; Gumti, Muhuri, Feni, Dakatia	2982	34	8	29	24	3	15	25
EHRM	8307	14		5	303; Sangu, Karnafuli, Matamuhuri	182	21	6	24		3	5	4

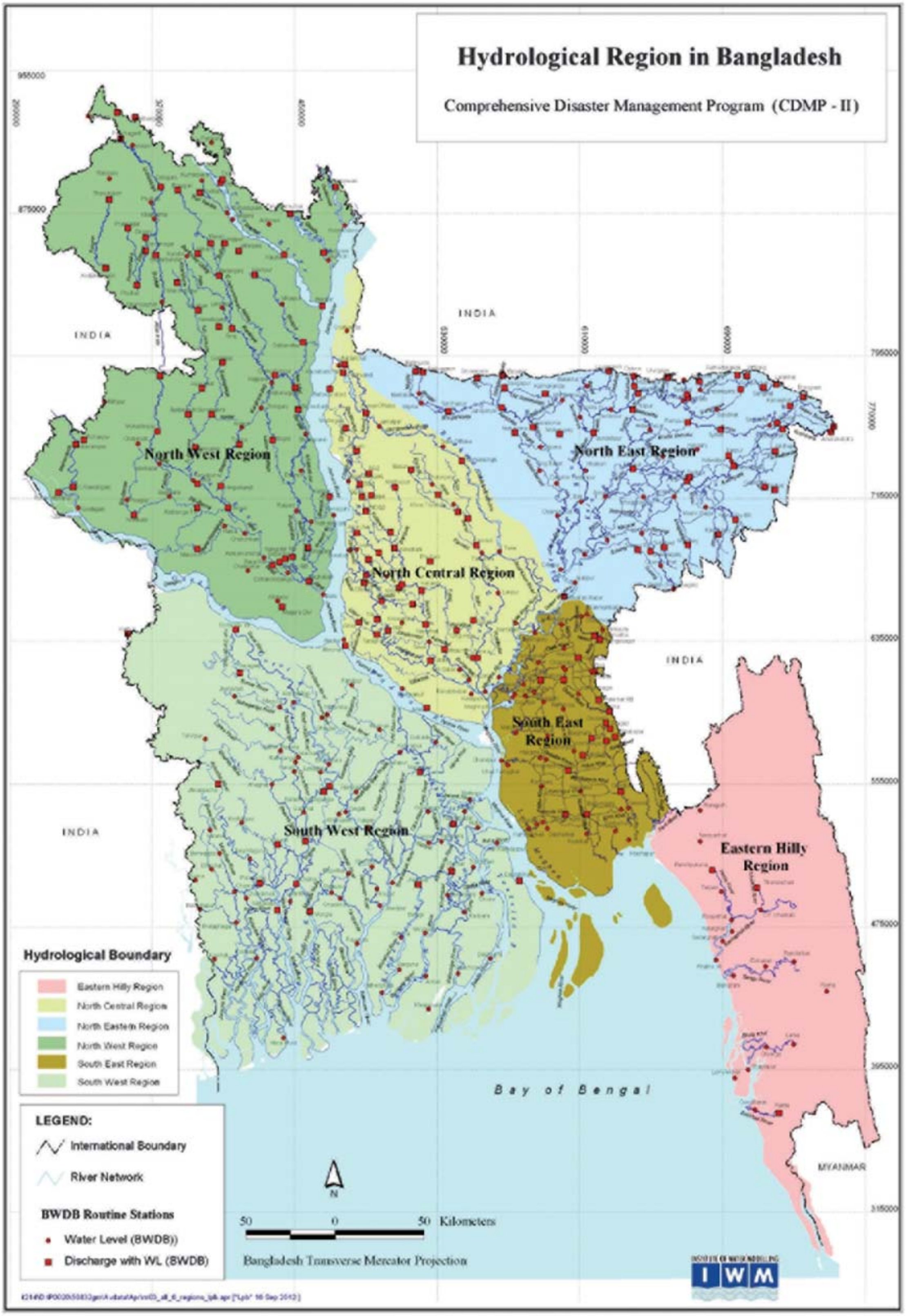


Figure 5.6: Boundary of six regional models

5.1.3 Bay of Bengal Model

The Bay of Bengal model was also validated under this study using the secondary water level and flow data. The model used to produce the boundary condition for three coastal river model namely southwest regional model, southeast regional model and eastern hilly regional model. The details of Bay of Bengal Model are described in the section 6.1.2.

Initial conditions for flood model

Initial conditions are essential part of the model and the so-called initialization shock must be absent in the models when different data are using in model as initial conditions. The initialization shock means sharp change of a solution of mathematical model at an initial time interval of its integration. The initialization shock is caused by inconsistency in initial conditions. It is accompanied by large gradients of the solution with respect to time and space. That is why especial care was taken during the selection of initial conditions for flood model/hydrodynamic model. In case of hydrodynamic model the initial conditions are water level, water flow and are provided based on available data and judgment based on experience. Historical data from secondary sources and prediction from harmonic constituents were used to settle the initial condition for water level whereas observed data from secondary sources are used for flow/discharge. Details of initial conditions are furnished in Annexure B.

5.2 Frequency analysis on river flow and water level at key locations

Bangladesh is located at the confluence of three large rivers - Ganges, Brahmaputra and Meghna. About 92.5 per cent of the combined basin area of these three rivers lies outside the country. Ganges and Brhamaputra basins are much bigger than Meghna basin. Flooding in Bangladesh highly depends on the magnitude of flow that comes from these three rivers. As the characteristics of these three basins are different, flooding pattern is also different in each basin and peak flood does not match with each other except the year 1998 and 2004. In the year 1998 and 2004 both the peak flow from Ganges and Brahmaputra coincided with each other and created huge flood all over the country. Frequency analysis of historical water level was carried out to select the representative year for the return period of 10 year and 20 year for three different basins. Three different stations from three different basins namely Bahadurabad for Brahmaputra basin, Hardings Bridge for Ganges basin and Bhairab Bazar for Meghna basin were selected for the analysis. The analysis of historical water level data was performed using the HYMOS software. HYMOS is an information system for storage, processing and presentation of hydrological and environmental data developed by WL | DELFT HYDRAULICS. The HYMOS data base is time series oriented with common facilities for spatial analysis. HYMOS makes use of an open data structure ensuring convenient interaction and data transfer with other existing databases and modeling systems. Historical maximum water level was used for the analysis and the Table 5.2 shows the available data for the three stations.

The results from the frequency analysis were furnished in the Table 5.3. It is clear from the Table 5.3 that the year 1995 represents Brahmaputra basin, the year 1998 represents Meghna basin and the year 1987 represents Ganges basin for 10 year return period flood whereas the year 2007 represents Brahmaputra basin, the year 1988 represents Meghna basin and 1988 represents Ganges basin. Based on the above mentioned analysis regional models were simulated for

Table 5.2: Available water data for selected three stations

Name of the stations	Duration of available data
Bahadurabad	1970– 2010
Hardings Bridge	1983– 2010
Bhairab Bazar	1983- 2010

respective year. Northwest regional model was simulated for 1987, 1995, 1998 and 2007, North central regional model was simulated for the year 1988, 1995, 1998 and 2007 and Northeast regional model was simulated for 1998. A sample plot of Log Normal Distribution for Hardings Bridge is shown in the Figure 5.7.

Table 5.3: Coincided water level for 10 and 20 year return period

	Bahadurabad	Hardings Bridge	Bhairab Bazar
Water level for 10 year return period	20.34	14.75	7.24
Coincide year	1995	1987	1998
Water level in the coincide year	20.36	14.80	7.33
Water level for 20 year return period	20.5	15	7.5
Coincide year	2007	1998	1988
Water level in the coincide year	20.40	15.19	7.66

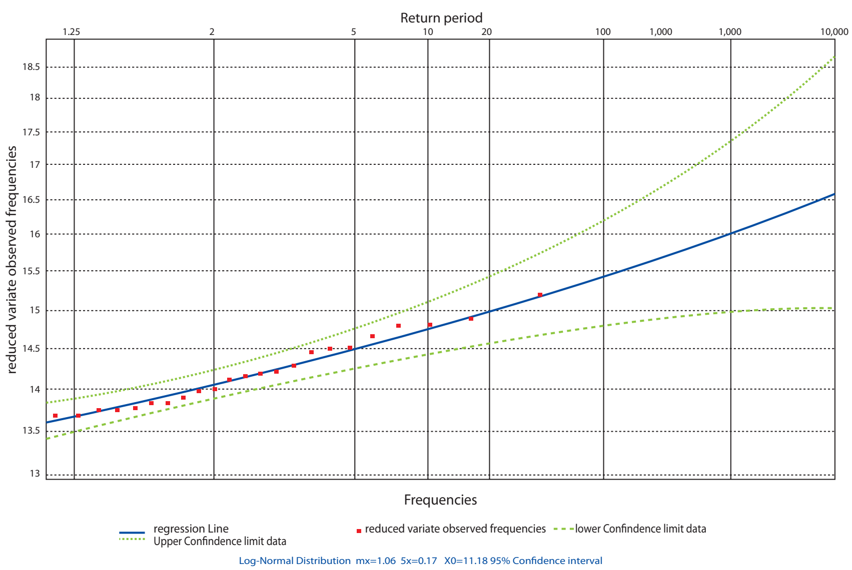


Figure 5.7: Log normal distribution for Hardings Bridge

5.3 Collection of Field Information on Past Severe Flood

Model generated flood information needed verification with existing field condition. For this reason, field verification surveys (Figure 5.8) were carried out in the selected mostly vulnerable flood-prone areas of Bangladesh. In this survey, local union authority and inhabitants were interviewed for collecting flood information. At least one to three households in each union were visited for collecting the flood information. Flood information in the form of flood depth and duration of major floods of 1988, 1998, 2004 and 2007; information about reason and extent of flooding, name of local river and channel etc. have been collected. Hand-held GPS machines have been used to record the survey location. Depths of various major floods occurred in the past were provided by the local people from their experience they suffered. The depths of flood covering the area which includes, in and around 1 km from their homestead, i.e. the survey location, have also been collected. In this connection, a Survey Log sheet in Bangla has been developed as shown in Annexure C.

Figure 5.8: Field verification survey at Paschim Pagla Union under Sunamganj Sadar Upazila

Table 5.4 shows the depths of flooding as revealed from the interviews with the local people at the respective unions of Madarganj and Islampur upazilas under Jamalpur District. The data found from the survey shows the intensity of flooding is observed more than the model results which suggests further study to be carried out in that area. Figure 5.9 shows the sample location against 1998 flood map surveyed in the selected unions of Islampur Upazila under Jamalpur district.

Table 5.4: Field Verification Survey for 1998 Flood

Sample Id [1]	Sample Location			Sample Survey Data					Flood Map 1998	
	Union Name	Easting (m)	Northing (m)	Flood Occurrence Frequency (year)	Flood 1988		Flood 1998		Depth(m)	Class [2]
					Depth(m)	Duration (d)	Depth(m)	Duration (d)		
Mad_1	Balijuri	470884	753027	2	1.83	15	0.98	5	0.00	F0
Mad_15	Balijuri	472960	751777	1	3.05	65	1.52	30	1.01	F2
Mad_2	Char	471312	756267	1	3.05	35	3.05	60	1.50	F2
Mad_3	Char Pakerdaha	471844	759608	1	3.66	30	3.05	35	1.33	F2
Mad_5	CharPakerdaha	476370	755320	3	3.05	15	3.05	17	1.42	F2
Mad_6	Karaichara	476370	755320	1	2.44	20	2.13	30	1.42	F2
Mad_7	Gun aritala	476121	751568	1	2.20	7	1.92	25	2.26	F3
Mad_8	Gunaritala	477942	750790	1	2.13	20	2.07	30	1.83	F3
Mad_9	Adarbhita	477380	748076	1	3.05	20	2.74	30	1.66	F2
Mad_10	Adarbhita	479856	747281	1	3.05	20	1.71	20	1.72	F2
Mad_11	Adarbhita	478878	745817	1	2.44	7	1.52	8	1.53	F2
Mad_12	Sidhli	479003	745817	1	3.66	30	3.05	30	1.52	F2
Mad_13	Sidhli	480705	745602	2	3.66	20	3.05	90	2.19	F3
Mad_14	Jorekhali	475944	747178	5	3.66	15	3.05	30	0.88	F1
Mad_4	Jorekhali	474571	748670	5	2.13	30	1.83	60	2.52	F3
Isl_1	Islampur	480384	773648	2	1.52	12	1.40	20	0.00	F0
Isl_2	Islampur	476246	768788	2	2.13	60	1.83	60	1.48	F2
Isl_3	Patharsi	477051	775528	1	1.52	15	1.52	90	0.00	F0
Isl_4	Patharsi	473667	782843	1	1.28	15	0.91	45	2.37	F3
Isl_5	Kulkandi	471435	782174	1	3.66	20	3.66	30	3.52	F3
Isl_6	Belgachha	471660	776194	1	2.44	30	1.52	90	1.24	F2
Isl_7	Chinadulli	471508	774513	1	4.57	40	3.05	60	4.16	F4
Isl_8	Chinadulli	472944	779869	1	5.18	20	4.57	30	1.91	F3
Isl_9	Noapara	473132	768757	1	2.44	20	1.52	3	1.24	F2
Isl_10	Noapara	474548	768769	1	2.13	20	1.89	30	1.85	F2
Isl_11	Palbanha	481044	775524	5	2.74	15	2.44	30	0.87	F1
Isl_12	Goaler Char	483800	775734	1	3.35	20	1.22	30	1.44	F2
Isl_13	Gaibandha	486031	775204	1	3.05	20	2.13	45	1.47	F2
Isl_14	Gaibandha	486941	773690	1	2.16	20	1.80	30	1.44	F2
Isl_15	Char Putimari	490878	772736	1	2.20	45	1.98	90	0.71	F1
Isl_16	Char Putimari	489507	771890	1	2.44	60	2.13	90	1.52	F2
Isl_17	Char Goalini	487029	771409	1	2.13	30	1.89	45	1.98	F3
Isl_18	Char Goalini	485372	771741	1	2.74	30	2.44	60	1.20	F2

Note:

1: 1st three letters of Upazila Name_Sample No;

2: Flood Depth in m, F0(0.00-0.30), F1(0.31-.90), F2(0.91-1.80), F3(1.81-3.60), F4>3.60

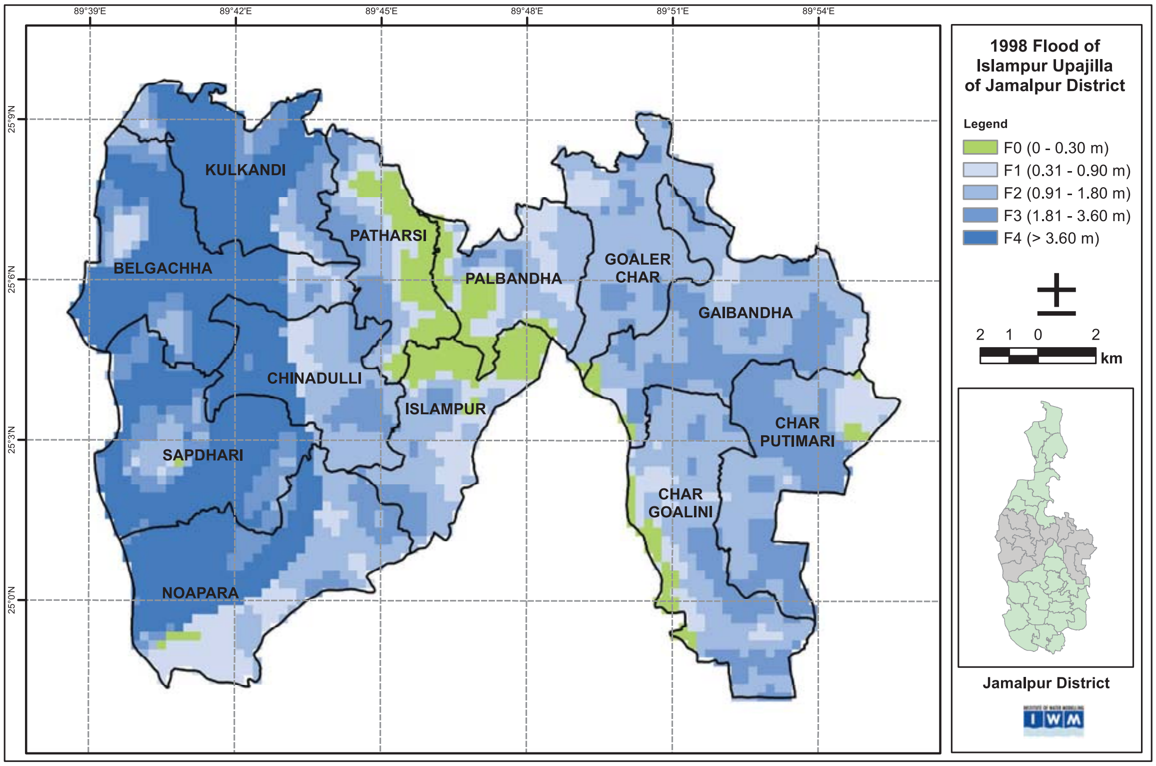


Figure 5.9: Field verification survey sample location in Islampur Upazila against 1998 flood

5.4 Preparation of flood zoning maps

Flood maps were prepared for different characteristics flood event such as 1988, 1998, 2004 and 2007, for different return period such as 10 and 20 year return period and for changing climate. All the maps were produced for 3 hour duration. Results from different regional models and ARC VIEW GIS were used to produce flood zoning maps.

5.4.1 Flood maps for 1988, 1998, 2004 and 2007

The characteristics flood events were selected based on the historical data on maximum water level, maximum flow, duration of flood and amount of damages. Historical maximum water level and flow of three different stations which are representative of three basins are furnished in the Table 5.5. Based on above mentioned parameters four different flood events were selected namely 1988, 1998, 2004 and 2007. Among them inundation depth maps were produced for 34 districts for 1998 and 2004 and the list of districts are furnished in the Table 5.6 whereas inundation maps were produced from 26 districts for 1988 and 2007 and the list of the districts are furnished in the Table 5.7.

Table 5.5: Peak water level at three different stations

Year	Bahadurabad	Bhairab Bazar	Harding Bridge
1970	20.19		
1971	18.75		
1972	19.98		
1973	19.88		
1974	20.25		
1975	19.60		
1976	19.86		
1977	19.99		
1978	19.63		
1979	19.78		
1980	20.10		
1981	19.48		
1982	19.42		
1983	19.92	6.79	14.81
1984	20.10	6.89	14.51
1985	19.61	6.38	14.16
1986	19.15	5.67	14.11
1987	19.71	6.91	14.80
1988	20.62	7.66	14.87
1989	19.58	6.41	13.29
1990	19.39	6.04	13.99
1991	20.08	6.41	14.66
1992	19.20	5.55	13.68
1993	19.90	6.93	13.75
1994	18.75	5.67	14.22
1995	20.36	6.69	13.78
1996	19.99	6.51	14.50
1997	19.94	6.32	13.75
1 998	20.37	7.33	15.19
1999	19.82	6.43	14.45
2000	20.16	6.52	14.20
2001	19.32	6.13	13.90
2002	20.09	6.72	13.53
2003	19.89	6.70	14.28
2004	20.19	7.78	13.69
2005	19.51	6.18	13.83
2006	18.85	5.41	13.34
2007	20.40	6.94	14.00
2008	19.75	6.51	13.83
2009	19.40	6.02	13.36

Table 5.6: List of districts for the characteristics flood event 1998 and 2004

Sl. No.	Districts	Sl. No.	Districts	Sl. No.	Districts
1	Barhmanbaria	13	Rajbari	25	Moulovibazar
2	Dhaka	14	Gaibandha	26	Chandpur
3	Gopalganj	15	Kurigram	27	Pirojpur
4	Shariatpur	16	Sunamganj	28	Barisal
5	Madaripur	17	Sirajganj	29	Bhola
6	Faridpur	18	Khulna	30	Jessore
7	Jamalpur	19	Sathkhira	31	Bagerhat
8	Kishorganj	20	Rangpur	32	Laxmipur
9	Netrokona	21	Nilphamari	33	Pabna
10	Munshiganj	22	Lalmonirhat	34	Rajshahi
11	Tangail	23	Sylhet		
12	Manikganj	24	Habiganj		

Table 5.7: List of districts for the characteristics flood event 1988 and 2007

Sl. No.	Districts	Sl. No.	Districts	Sl. No.	Districts
1	Barhmanbaria	11	Tangail	21	Sylhet
2	Dhaka	12	Manikganj	22	Habiganj
3	Gopalganj	13	Rajbari	23	Moulovibazar
4	Shariatpur	14	Gaibandha	24	Chandpur
5	Madaripur	15	Kurigram	25	Rajshahi
6	Faridpur	16	Sunamganj	26	Pabna
7	Jamalpur	17	Sirajganj		
8	Kishorganj	18	Rangpur		
9	Netrokona	19	Nilphamari		
10	Munshiganj	20	Lalmonirhat		

All the regional river models were simulated for those selected events and flood maps were also produced for selected districts. Sample plots of Barahar union under Ullahpara upazilla of Sirajganj district are shown from Figure 5.10 to Figure 5.12 for the year 1988, 1998, 2004 and 2007.

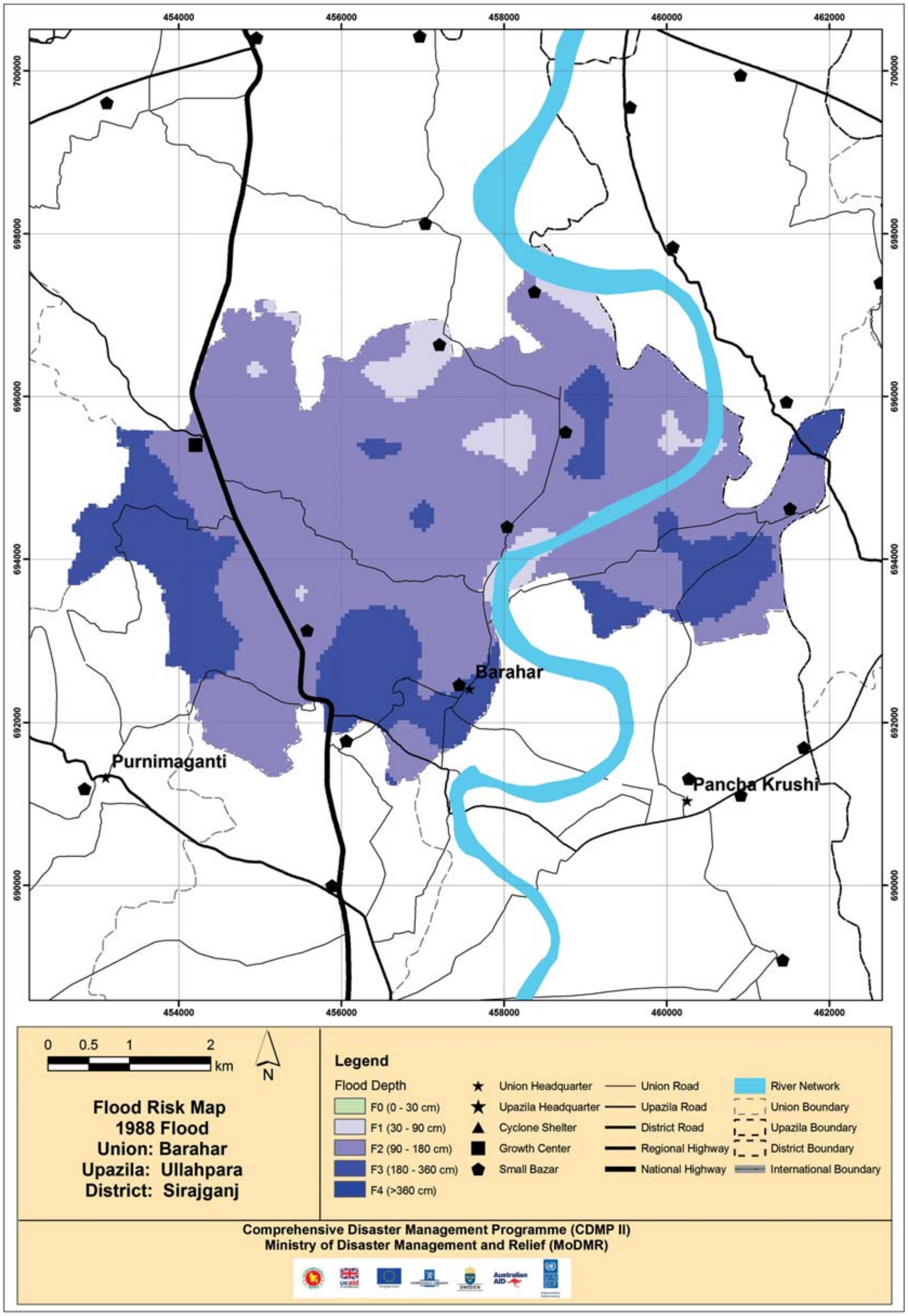


Figure 5.10: Flood map of Barahar Union under Ullahpara Upazila of Sirajganj District for the year 1988

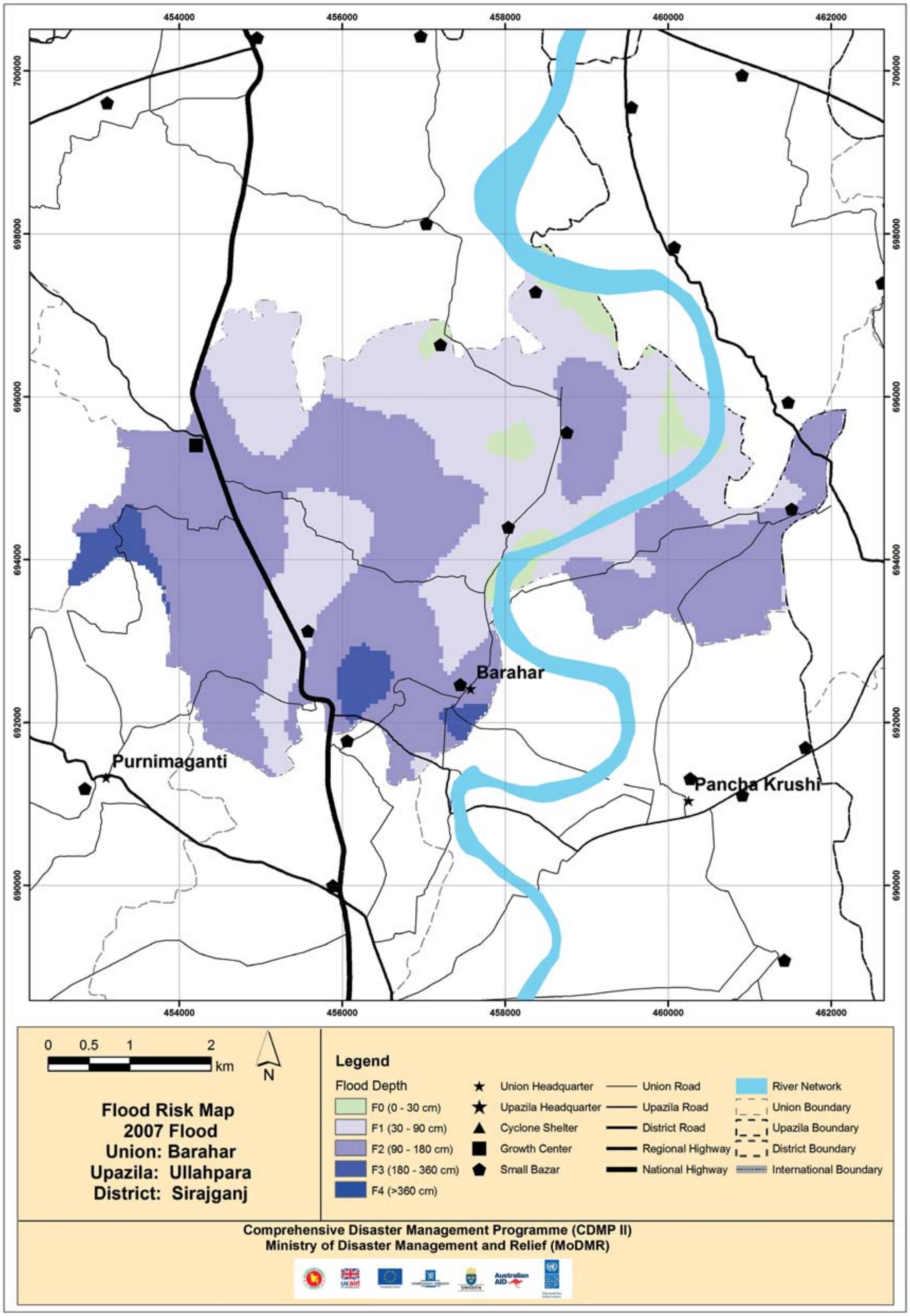


Figure 5.11: Flood map of Barahar Union under Ullahpara Upazila of Sirajganj District for the year 2007

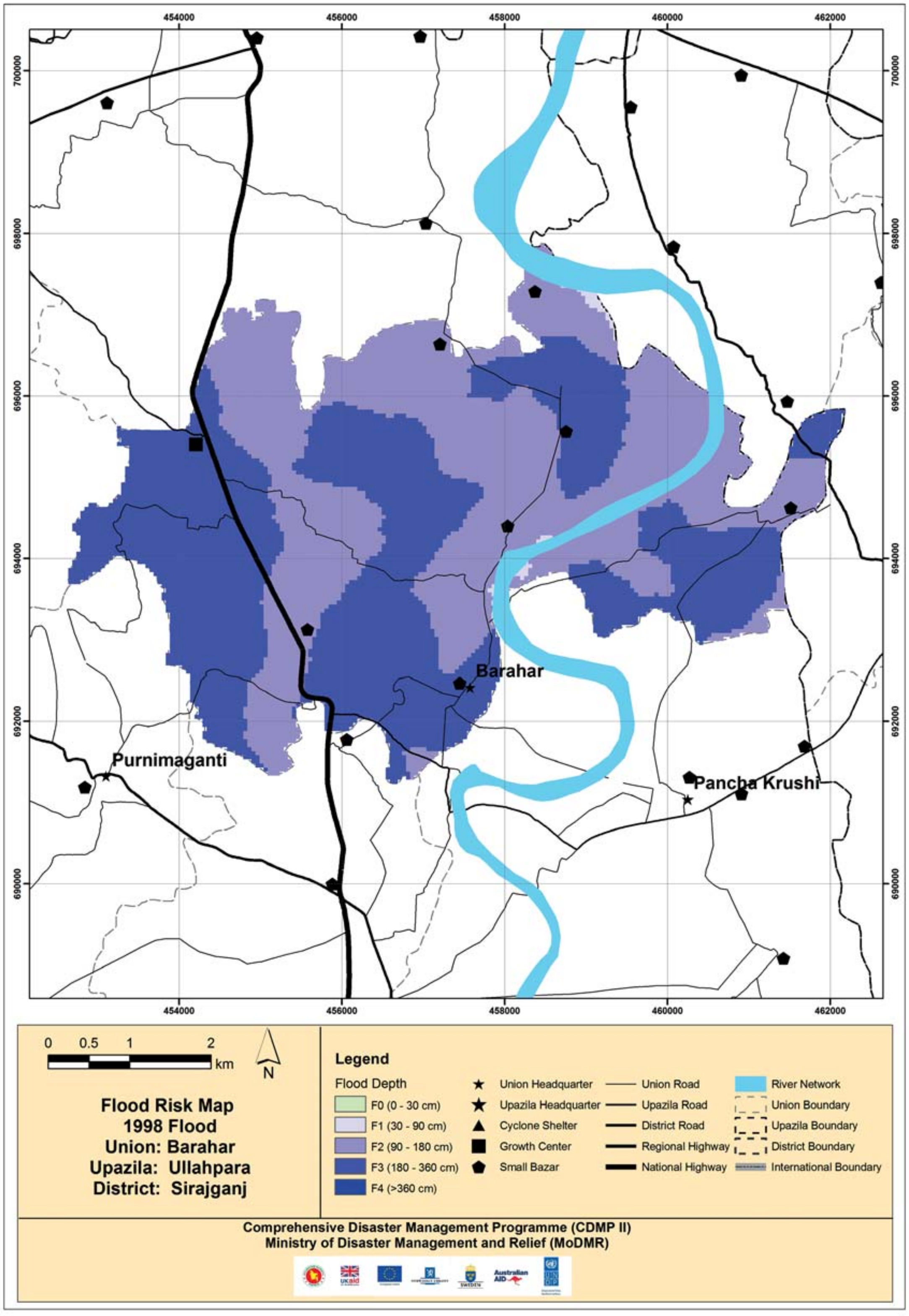


Figure 5.12: Flood map of Barahar Union under Ullahpara Upazila of Sirajganj District for the year 1998

5.4.2 Flood maps for 10 and 20 years return period flood

Flood maps for 10 and 20 years return period were produced based on the results of frequency analysis of historical maximum water level. Three different water level stations were selected from three basins to carry out the frequency analysis. The list of representative year for 10 and 20 years return period flood for three basins is shown in the Table 5.8.

Table 5.8: Representative year for 10 and 20 years return period

River basin	Representative year for 10 years return period flood	Representative year for 20 years return period flood
Brahmaputra	1995	2007
Ganges	1987	1998
Meghna	1998	1988

Regional river models were simulated according to three basins such as for the districts of Brahmaputra basin Northwest and North central regional model were simulated, for the districts of Ganges basin Northwest and Southwest regional models were simulated and for the districts of Meghna basin Northeast and Southeast regional models were simulated. A number of severely flood affected districts are also selected for return period analysis and the selected districts are furnished in the Table 5.9.

Table 5.9: List of Districts for the 10 and 20 years return period flood

Sl. No.	Districts	Sl. No.	Districts	Sl. No.	Districts
1	Dhaka	7	Tangail	13	Sirajganj
2	Gopalganj	8	Jamalpur	14	Rangpur
3	Shariatpur	9	Manikganj	15	Nilphamari
4	Madaripur	10	Rajbari	16	Lalmonirhat
5	Faridpur	11	Gaibandha	17	Chandpur
6	Munshiganj	12	Kurigram		

5.4.3 Flood maps in changing climate

Flood maps were also produced for changing climate under this study. Change in precipitation pattern has been adopted as a basis of climate change as our monsoon flood completely depends on the rainfall intensity. Climate model MIROC was adopted for this assessment and increase of rainfall for all the available rainfall stations for the year 2050 was calculated from the model result. This increase of rainfall was added to each rainfall data and river models were simulated with that increased rainfall data. The increase of rainfall was imposed on and the flood event 1998.

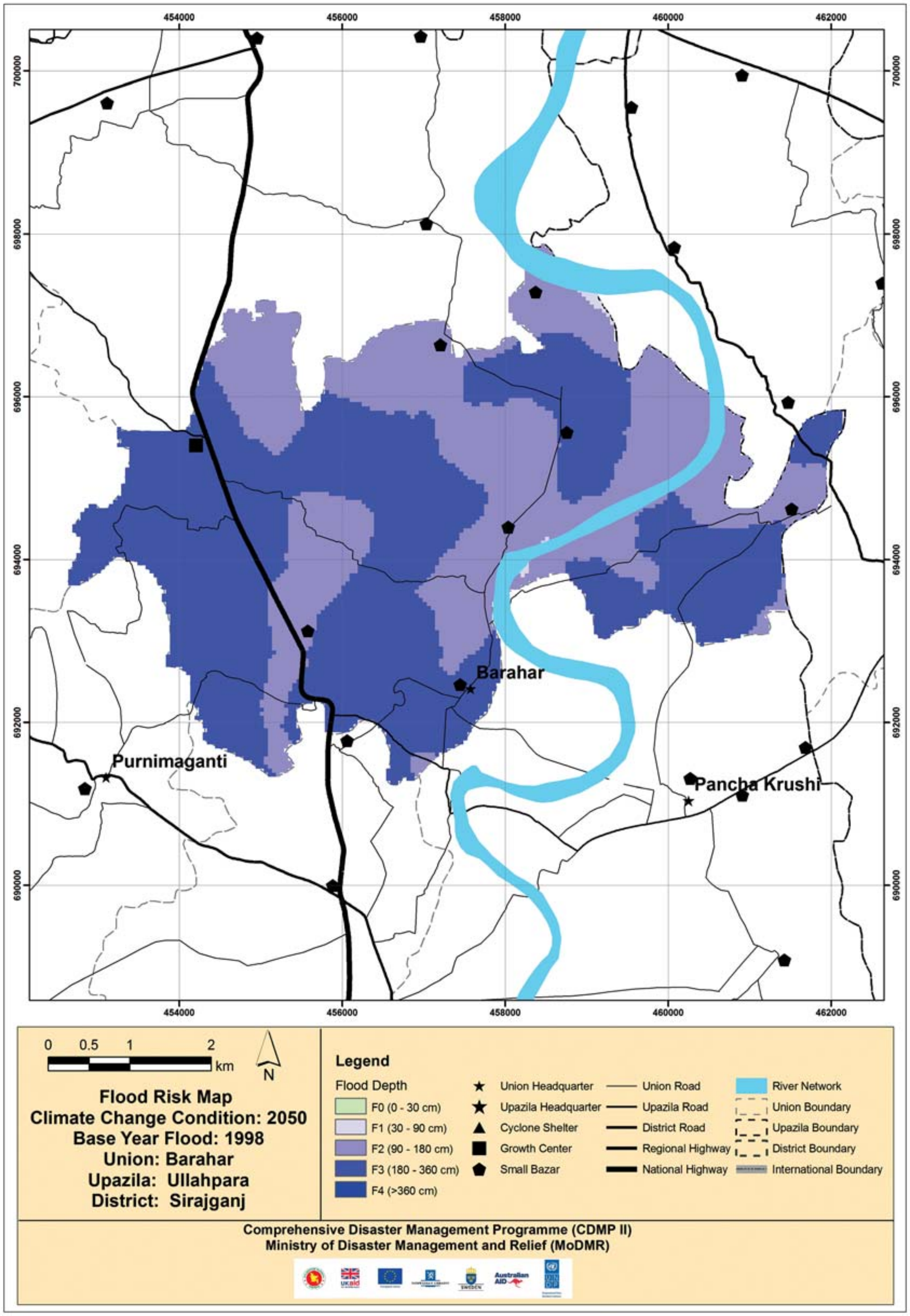


Figure 5.13: Flood map of Barahar Union under Ullahpara Upazila of Sirajganj District for the year 2050

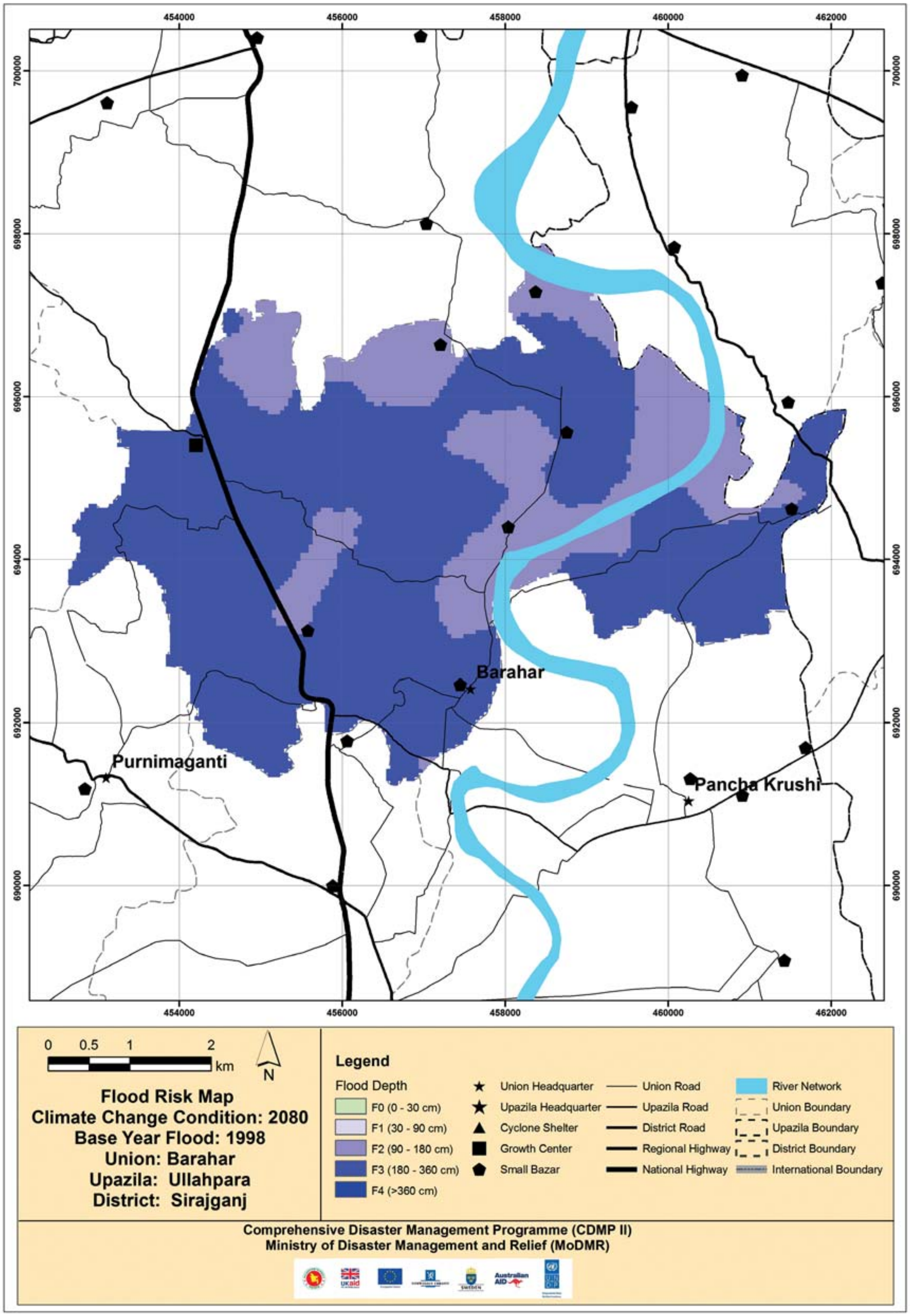


Figure 5.14: Flood map of Barahar Union under Ullahpara Upazila of Sirajganj District for the year 2080

Area under different land types were calculated for Barahar union under Ullahpara upazilla of Sirajganj district for four characteristic flood events and for 2050 and 2080 for changing climate was calculated and furnished in the Table 5.10. It is evident that the union was severely affected in the flood event 1998 and 2004 and the severity will increase in the year 2050 and 2080 due to climate change.

Table 5.10: Area under different land types for all the selected events

Land Type	Class Interval (m)	Area (km^2)					
		1988	1998	2004	2007	2050 (Climate Change)	2080 (Climate Change)
F0	0-0.3	0.06	0.0175	0	1.53	0.01	0
F1	0.31-0.9	2.14	0.26	0.13	12.7625	0.19	0.095
F2	0.91-1.8	22.76	15.6425	19.1125	16.925	13.29	8.8975
F3	1.81-3.6	7.445	16.485	13.1625	1.1875	18.9125	23.4125
F4	>3.6	0	0	0	0	0	0

It is also evident from all the inundation maps that F0 land will drastically reduce due to climate change in the year of 2050 and 2080 compared to the flood event 1998. It is clear from the Table 5.11 that 95% and 96% of F0 land will be lost in the year 2050 and 2080 respectively due to climate change. It is also clear from the Table 5.11 that F0, F1 and F2 land will be decreased and F3 and F4 land will be increased due to changing climate in the near future.

Table 5.11: Percentage change in land type due to climate change

Land Type	% change in 2050	% change in 2080
F0	negligible	negligible
F1	negligible	negligible
F2	-14.8	-43.0
F3	14.5	41.9
F4	0	0

Altogether 17,036 flood maps were produced from 34 different districts for four characteristics flood event, two different return periods and changing climate. The Table 5.12 shows the number of maps that were produced for each flood event.

Table 5.12: List of flood inundation maps

Flood Event	Characteristics Flood				Return Period		Climate Change		Total
	1988	1998	2004	2007	10 yr	20 yr	2050	2080	
Number of Maps	1961	2519	2519	1961	1207	1207	2519	2519	17036

CHAPTER 6

Salinity Zoning Map for Cluster Unions

Salinity distribution in the coastal area has been assessed using existing Bay of Bengal salinity model and three river salinity models. Upazilla-wise salinity map were produced to help the local people to have an overview of existing and future condition of salinity in different areas. The tool that was utilized for generation of maximum salinity maps is ARC GIS, it is a suite consisting of a group of geographic information system (GIS) software products produced by ESRI.

6.1 Updating and validation of existing salinity models

Salinity data from primary and secondary sources were collected to validate the Bay model and river models to make them more authentic.

6.1.1 Regional Salinity Models

IWM has been maintaining six different regional models for the whole Bangladesh (Figure 5.2). Among them three regional models namely southwest regional model, southeast regional model and eastern hilly regional model fall under the coastal area of Bangladesh. All these salinity models have been updated and validated under this project. Details of these three models are discussed in the section 5.1.2.

Mathematical models are an effective tool to characterize and predict the movement and quality of water. These models provide a means of moving beyond point-based measurements to develop a continuous and comprehensive picture of hydrologic conditions. Salinity modeling aids to assess the salinity intrusion under known boundary conditions without detailed measurements throughout the entire coastal region. To model the salinity variation in the estuary it is very important to have a well calibrated water flow model. The hydrodynamic model will describe the transport and advection of salinity.

The available salinity models for the coastal area of Bangladesh has been developed based on MIKE11 and MIKE 21 FM modeling system and applied for a number of projects over the last 20 years to find the spatial and temporal variation of salinity level over a year and also to examine the effect of climate change on landward movement of salinity front and in assessing the fresh water availability. The models for water flow and salinity for the coastal region of Bangladesh are well calibrated and validated and calibration results showed good agreement with the measured water flow, water level and salinity over the time and space. The models based on MIKE11 modeling system need less time and efforts to update and recalibrate to have quality outputs in comparison of other modeling systems since it has been tested and verified in this region over the years.

Figure 6.1: River System of the South West Region Model

The South West Region Model (SWRM)

The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. The model region is presented in Figure 6.1. Total catchment area and length of rivers/channels of the SWRM are around 37,300 km^2 and 5,600 km, respectively. The Bay of Bengal and the international border with India form the southern and western boundaries, respectively. The rivers of the southwest region of Bangladesh are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal. Freshwater inflows originate from the Gorai, an offtake of the Ganges, and from numerous smaller off takes from the Lower Meghna.

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

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

The South East Region Model (SERM)

Rainfall-Runoff module of MIKE11 has been used to calculate the runoff generated from rainfall occurred in the southeast area along with other parameters for the whole southeast area of Bangladesh. The model comprises an area of 8500 sq. km. The southeast area has been divided into 32 catchments out of which 24 are inside the borders catchments and 8 are cross border catchments for representation of the catchments flows to the rivers. The model has been calibrated and validated against measured groundwater level in 24 catchments.

The southeast region river model covers the river system of the greater Comilla and Noakhali districts of Bangladesh. It comprises a dense network of channels, which ranges from small khals to medium rivers (Figure 6.2). Total length of drainage channels incorporated in the SERM is around 1750 km. The widths of the rivers vary from 50 m to 1000 m and that of khals range from 5 m to 300 m.

There are also hilly streamlines assimilated with the different rivers, however, not incorporated in the model due to unavailability of topographic information. It is surrounded by the Lower Meghna river in the west and the Upper Meghna river as well as Titas river in the north. In the east, it follows the international boundary between India and Bangladesh. Downstream boundaries located in the Lower Meghna river and Sandwip channel are mostly regulated except Noakhali Khal. Flap gate regulators have been incorporated in the model at Rahmatkhali khal, Bamni river and little Feni river, respectively. Char Baggardona area is not included in the model. Flood cells have been incorporated in the model for representation of inundation in the prominent low land areas. The prominent structures, where proper information is available, are included in the model.

Figure 6.2: Southeast region model river network

Salinity intrusion in the south-east region is not very severe and so far has not created many problems because of regulators controlling the flow from the sea. Moreover, salinity is very low in the Lower Meghna River due to huge upstream flow from the entire Ganges-Brahmaputra-Meghna (GBM) basin. No salinity model has thus been initiated for this south-east region. The salinity outside the controlled area can be estimated from the Bay of Bengal model.

The Eastern Hilly Region Model (EHRM)

The Eastern Hilly Region Model covers 8,831 sq. km. of Karnafuli-Halda-Ichamati, Sangu, Matamuhuri and Bankkhali river basins. The region features hilly terrain and foothills and a long strip of coastal plains along the Bay of Bengal. The entire region model has been divided into three sub-models: Karnafuli-Halda-Ichamati sub-model, Sangu sub-model and Matamuhuri sub-model. These sub-models consist of 12 catchments. The model comprises of the entire reach of the Karnafuli River between Kaptai Dam and Khal No. 10, the Halda River downstream of Panchpukuria and the Ichamati River downstream of Thandachari. Measured or rated flow and a zero salinity have been used at the upstream boundaries, while the downstream boundaries are taken from the Bay of Bengal model. The river network of EHRM is presented in Figure 6.3.

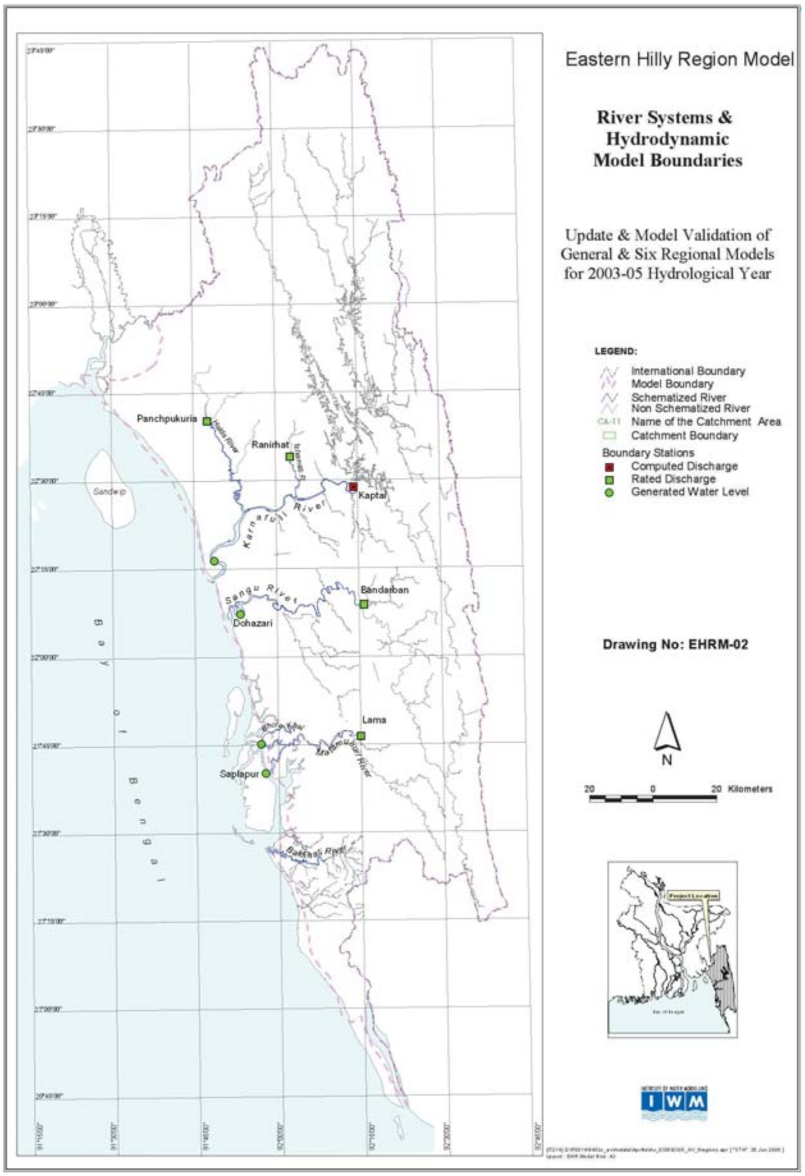


Figure 6.3: Eastern hilly region model river network

6.1.2 Bay of Bengal Salinity Model

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

The BoB model domain extends from Chandpur on Lower Meghna river in the north to 160 Latitude in the Bay of Bengal in the south (Figure 6.4). The model applies PWD datum, i.e. level 0.46m is MSL. The grid or mesh size decreases (or the resolution increases) towards coastlines and islands. Inter-tidal areas are flooded and dried during a tidal cycle, both in nature and in the model.

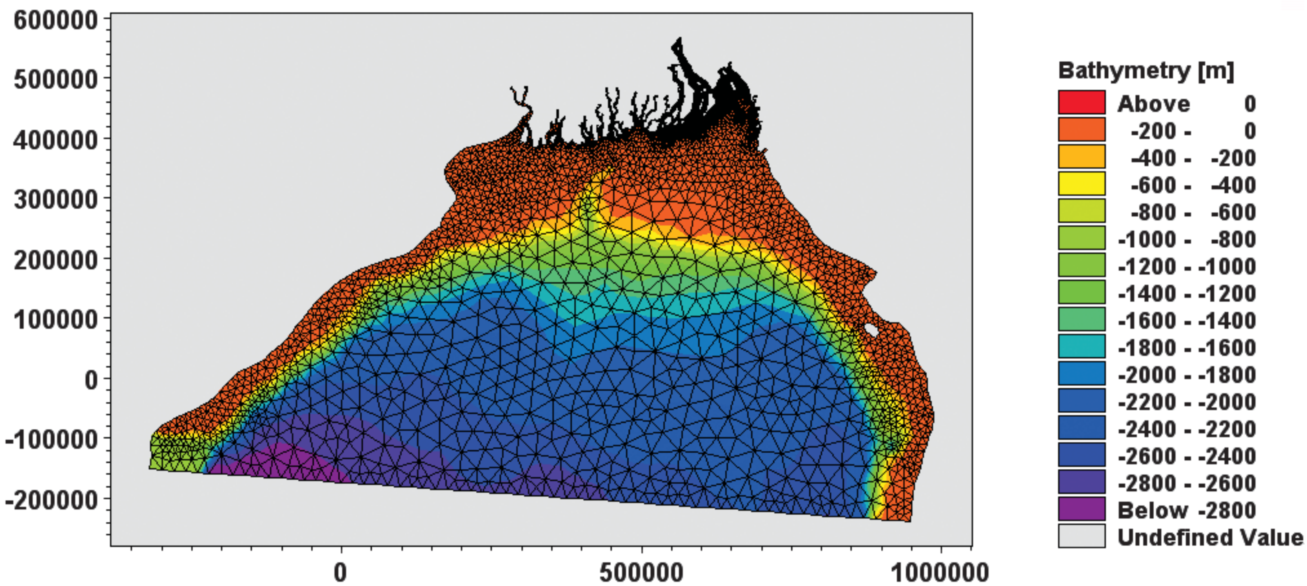


Figure 6.4: Computational mesh of the 2D General Model (Bay of Bengal Model)

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

6.1.3 Validation of Models

Calibration means adjustment of the model parameters so that simulated and observed data will match within the desired accuracy. The southwest region model is being calibrated for the year 2010-2011 and will be validated for the year 2011-12. In order to get a good calibration of salinity, water flow calibration in the branches of the model is very important. Water flow and salinity are being calibrated against measured data in different locations of the coastal region. Following figures (figures 6.5) shows some water flow calibration results.

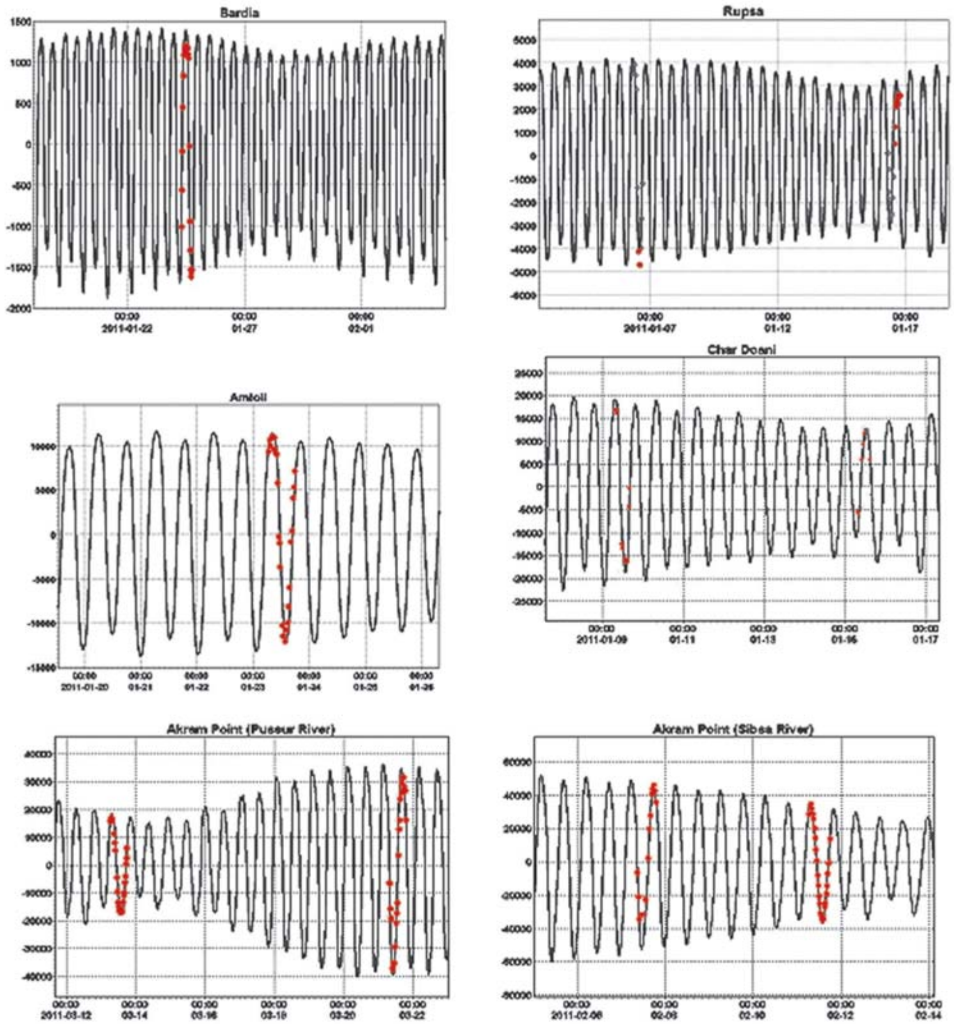


Figure 6.5: Water flow calibration plots

Initial conditions

Initial conditions are essential part of the model and the so-called initialization shock must be absent in the models when different data are using in model as initial conditions. The initialization shock means sharp change of a solution of mathematical model at an initial time interval of its integration. The initialization shock is caused by inconsistence initial conditions. It is accompanied by large gradients of the solution with respect to time and space. That is why especial care was taken during the selection of initial conditions for salinity model. Salinity model is the combination of hydrodynamic model and advection-dispersion processes. In case of hydrodynamic model the initial conditions are water level, water flow and are provided based on available data and judgment based on experience. Historical data from secondary sources and prediction from harmonic constituents were used to settle the initial condition for water level whereas observed data from secondary sources are used for flow/discharge. Simulation of salinity intrusion needs initial condition on water level, water flow and salinity level. Initial condition on salinity level persist long time during simulation and needs to be very accurate at the specific location and time i.e. the time of starting of simulation. In the salinity level simulation initial condition is based on earlier measured data at specific location and time, it has to be space and time specific otherwise simulation may lead huge uncertainty in the results. Details of initial conditions are furnished in Annexure B.

6.2 Spatial distribution of maximum and minimum salinity

Salinity in the Bangladesh coast is completely dependent on the volumes of freshwater flows from the GBM basin. As the tides in the Bay of Bengal are semi-diurnal, the peak in daily salinity generally coincides with the arrival of high water at the coast. The daily range of salinity concentrations at the river entrances varies with the spring-neap tide as well as with the season.

Tidal amplitudes during spring tides are around 2.5 to 3 times higher than the neap tides. The higher water levels occurring at the coastal boundaries cause greater volume of saline water to enter inland during neap tides. The dilution effect of any freshwater flows in the inland rivers is consequently weaker during spring tides. As a result, maximum salinities occurring during spring tides are generally higher than neap tide concentrations.

Average salinity concentrations at the coast are higher in the dry season than in the monsoon because of huge freshwater flow from the upstream. The salinity generally increases almost linearly from October (post-monsoon) to the Late May (pre-monsoon). At the end of May, salinity level sharply drops due to huge upstream flow from GBM basin due to seasonal rainfall. The salinity levels are at the minimum at the end of the wet season, usually during end-September or early-October.

6.2.1 Salinity maps for base condition

Monthly upazilla-wise salinity maps were produced for all the coastal districts from the above mentioned river model results. Figure 6.6 and Figure 6.7 show the maximum salinity for February & March and April & May respectively.

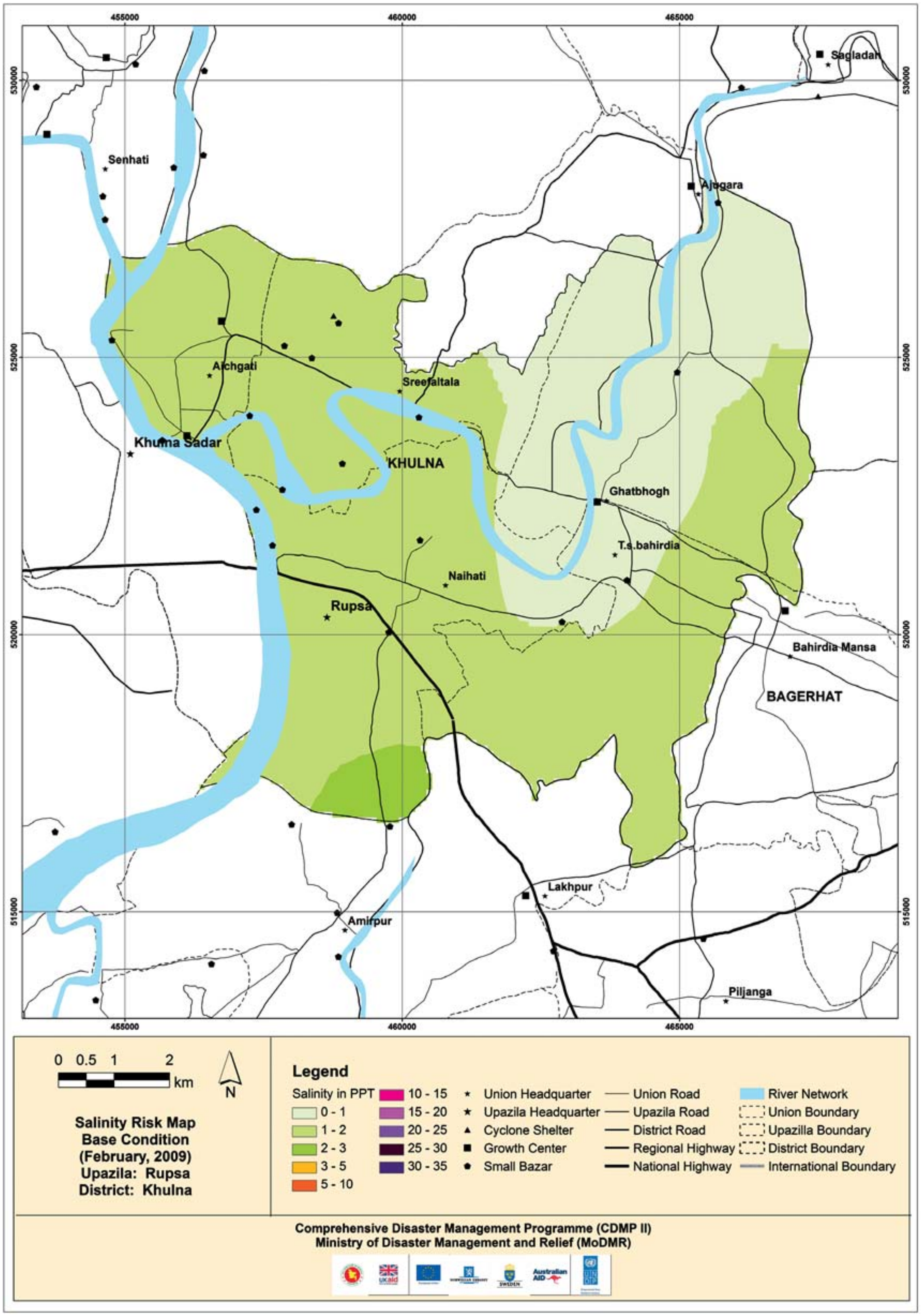


Figure 6.6: Maximum salinity in Rupsa Upazila during the month of February in the base year

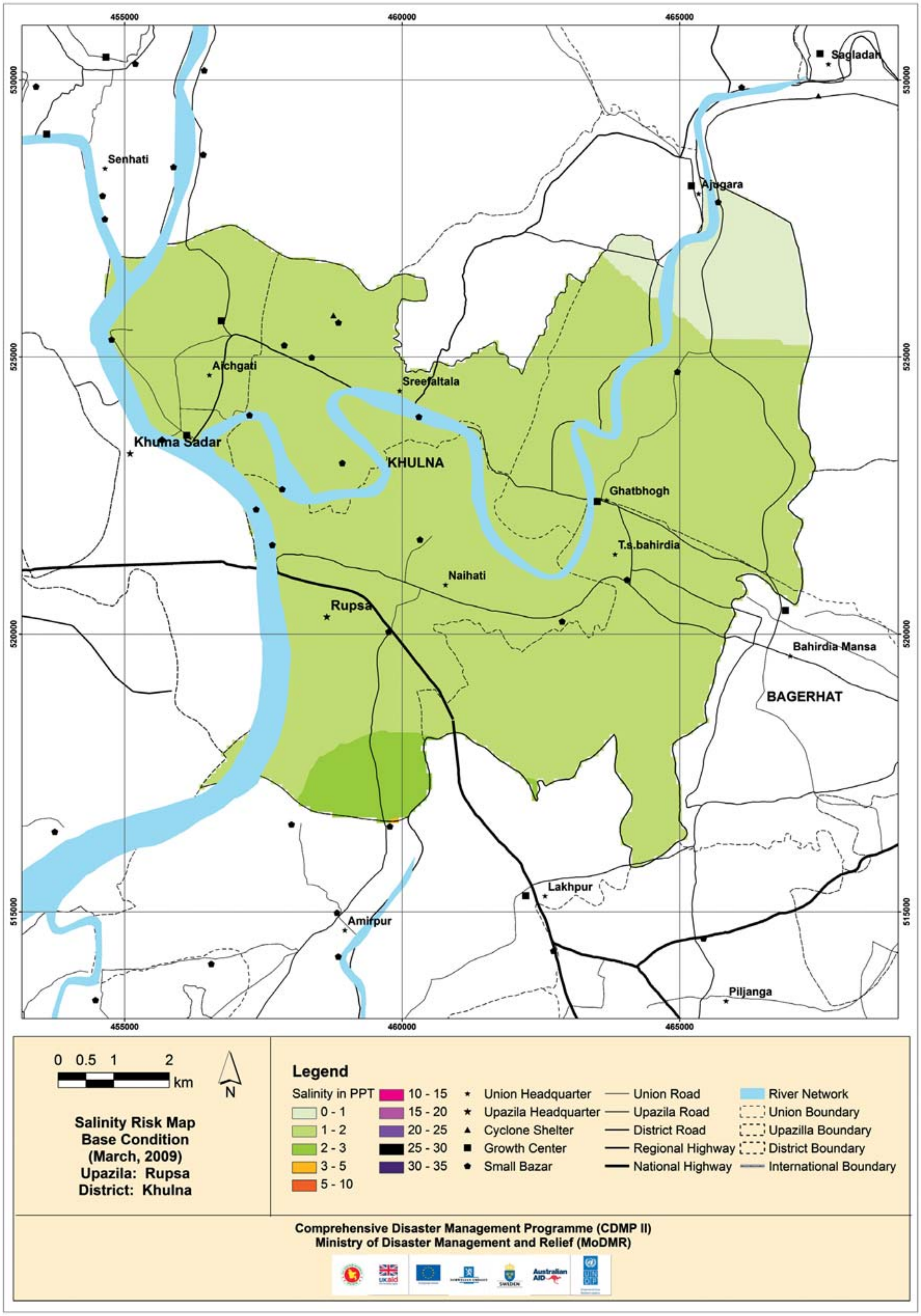


Figure 6.6: Maximum salinity in Rupsa Upazila during the month of March in the base year

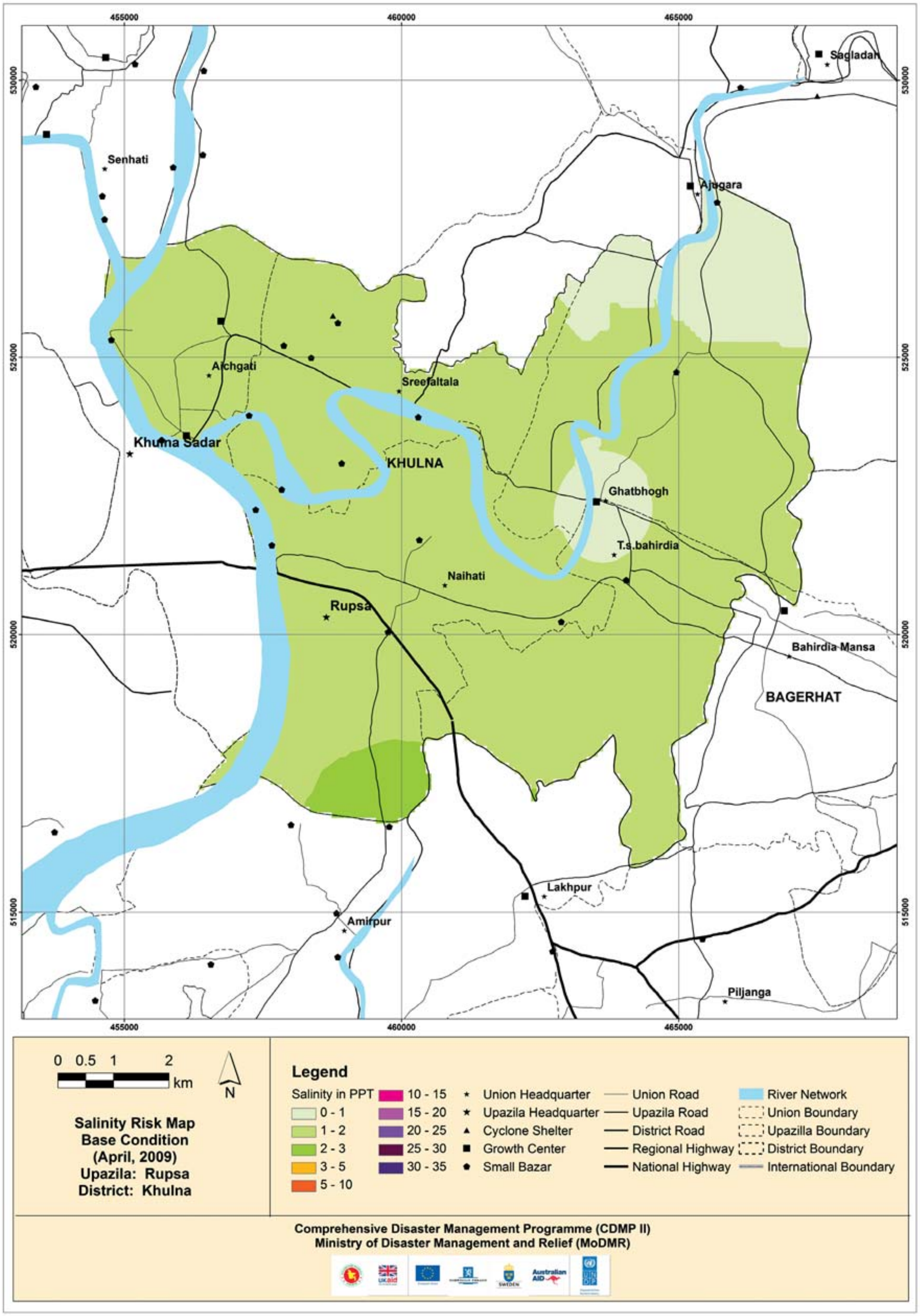


Figure 6.7: Maximum salinity in Rupsa Upazila during the month of April in the base year

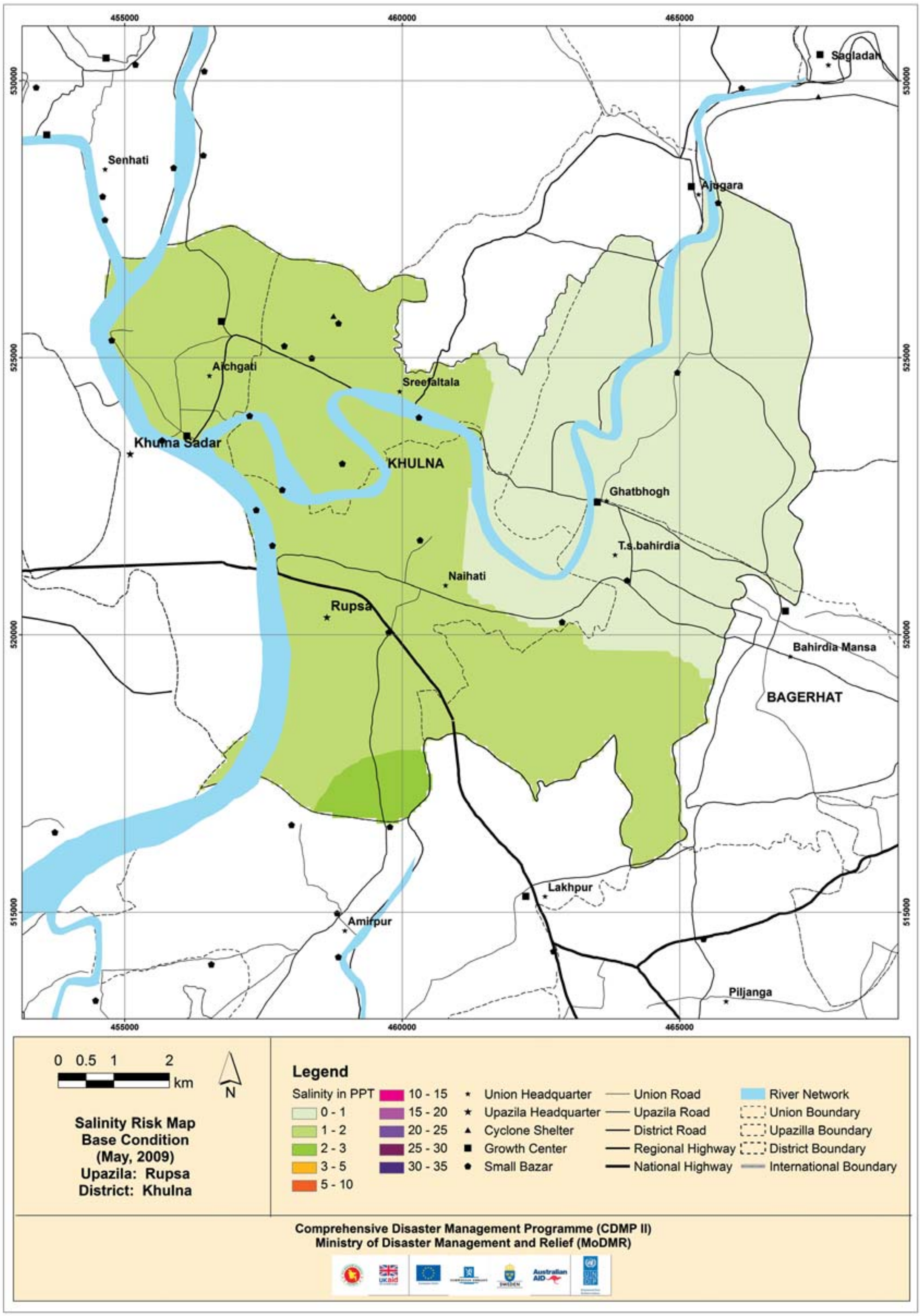


Figure 6.7: Maximum salinity in Rupsa Upazila during the month of May in the base year

6.2.2 Salinity maps for climate change condition

Monthly union-wise salinity maps were produced for all the coastal districts from the above mentioned river model results. Figure 6.8 and Figure 6.9 show the maximum salinity for February & March and April & May respectively in the year 2050 in Rupsa upazilla. Table 6.1 shows the area under different saline interval for February to May both for base and climate change condition. It is evident from the Table 6.1 that the more salinity intrusion will occur for all four months due to climate change and during the month of May 33 km^2 new area will be affected by 1-2 ppt saline range. It is also evident from the model results that more salinity will intrude through Baleswar-Bishkhali river system due to climate change. This is because Pussur-Sibsa river system is already affected by higher salinity as there is no upstream flow for that river system during dry season. It is also evident from the model result that almost all the area under less than 1 ppt of Pirojpur district will be changed to more than 1 ppt due to climate change.

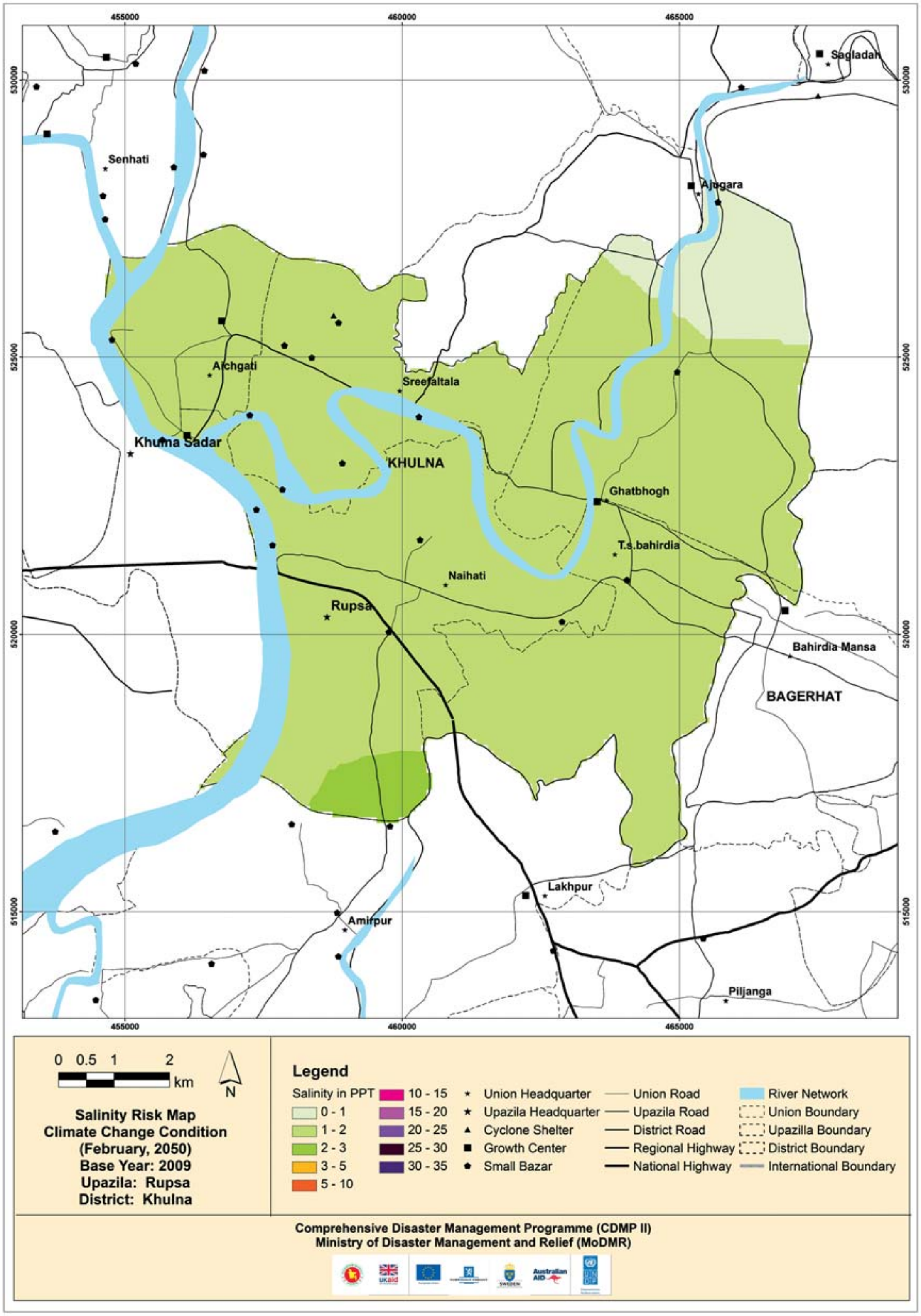


Figure 6.8: Maximum salinity in Rupsa Upazila during the month of February in the year 2050

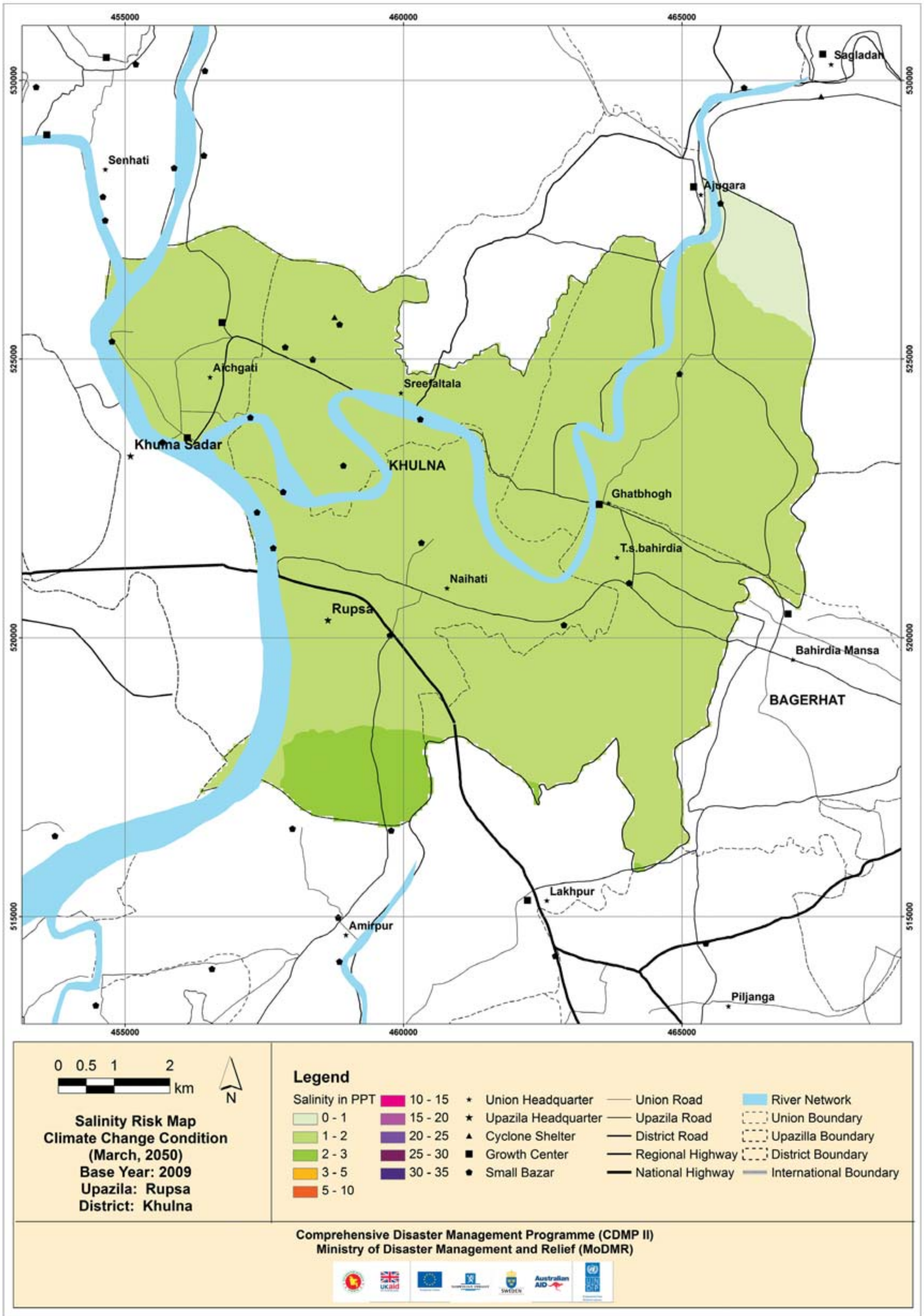


Figure 6.8: Maximum salinity in Rupsa Upazila during the month of March in the year 2050

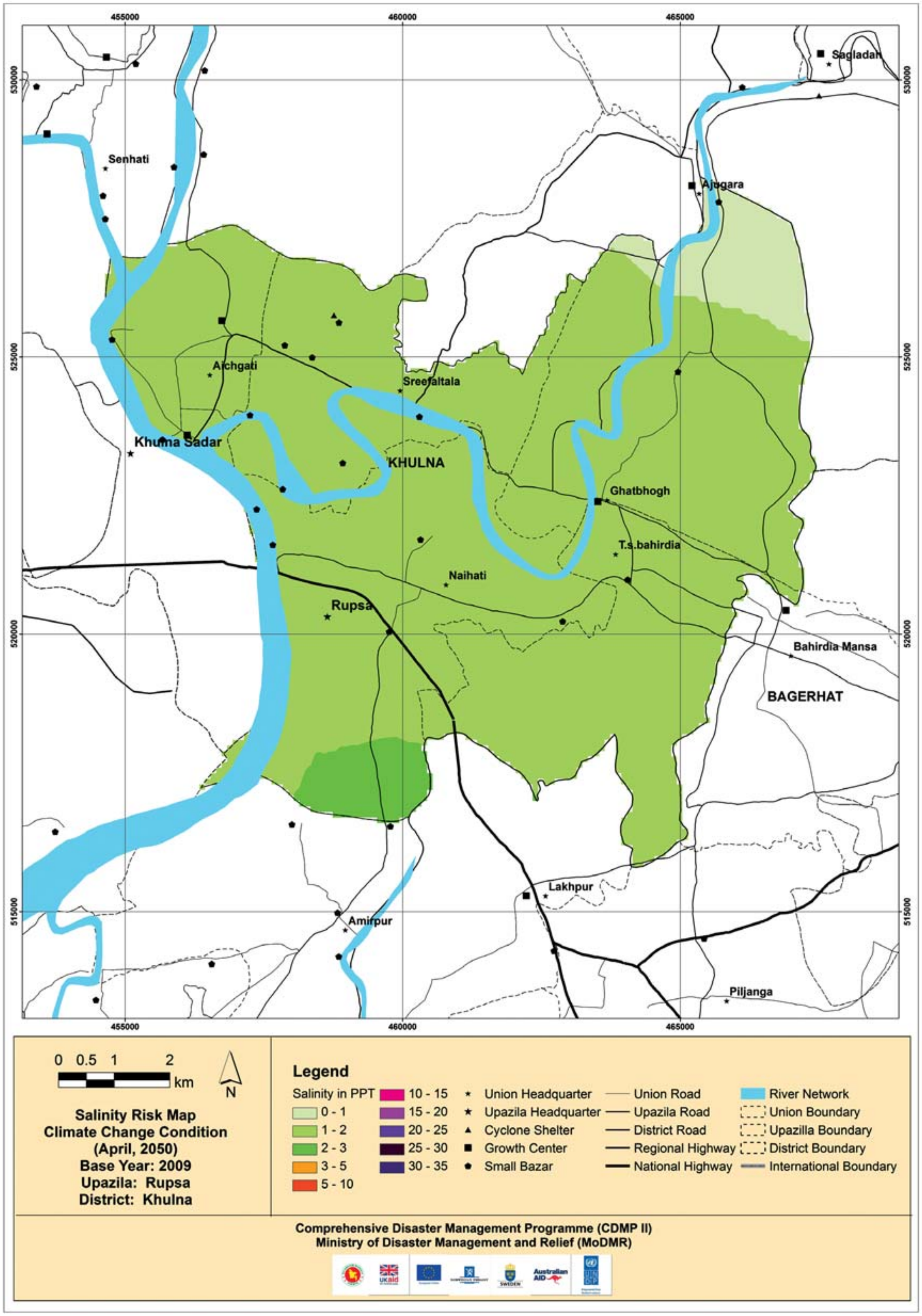


Figure 6.9: Maximum salinity in Rupsa Upazila during the month of April in the year 2050

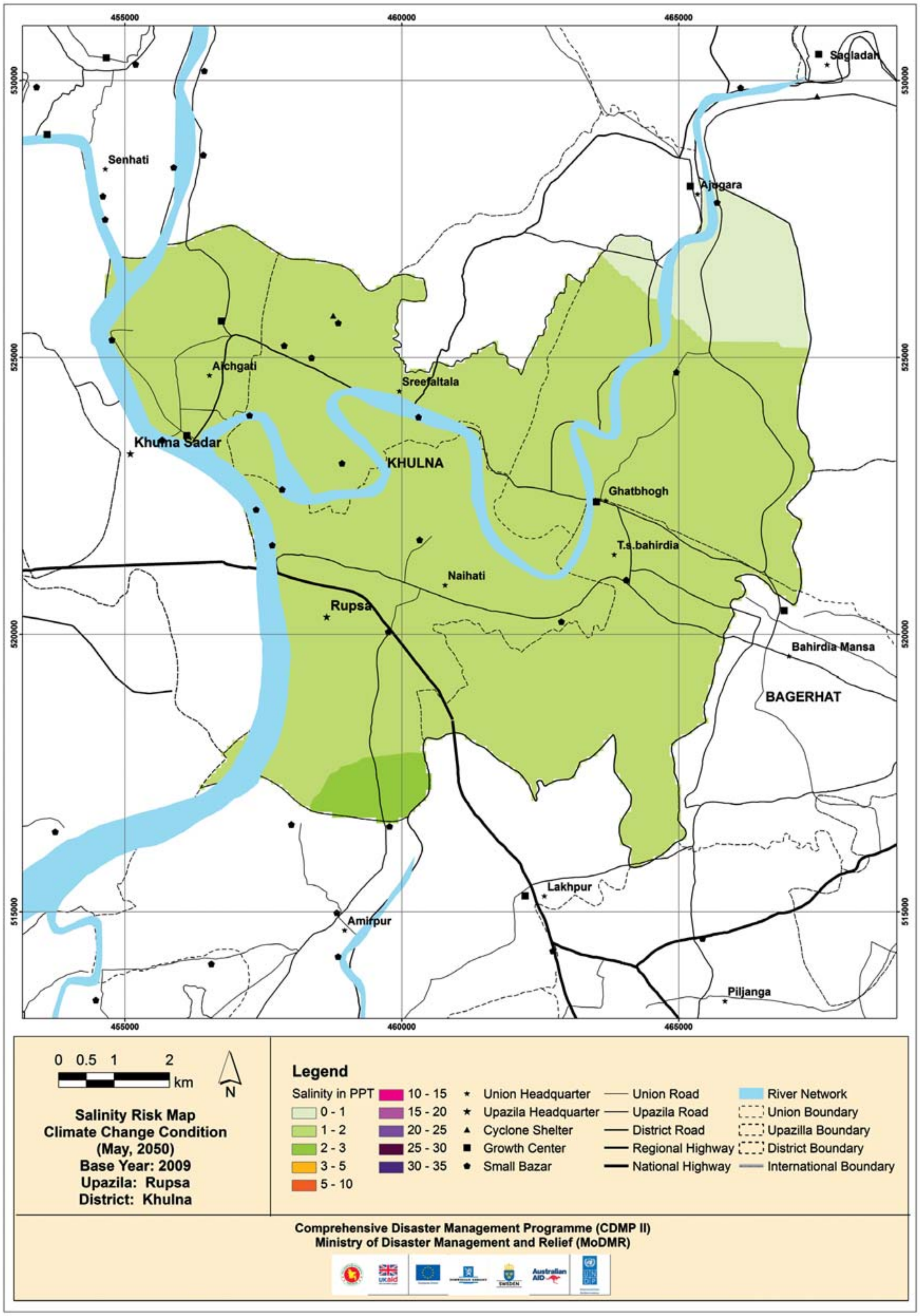


Figure 6.9: Maximum salinity in Rupsa Upazila during the month of May in the year 2050

Table 6.1: Area (km^2) under different saline interval from February to May both for base and climate change condition

Month / Salinity	February		March		April		May	
	Base Condition	Climate Change Condition	Base Condition	Climate Change Condition	Base Condition	Climate Change Condition	Base Condition	Climate Change Condition
0 – 1 ppt	27.11	6.16	6.16	3.04	10.41	4.73	39.14	6.16
1 – 2 ppt	66.11	87.12	86.21	88.18	82.49	87.78	54.28	87.22
2 – 3 ppt	2.16	2.1	2.99	4.16	2.48	2.87	1.96	2
3 – 5 ppt	0	0	0.02	0	0	0	0	0
5 – 10 ppt	0	0	0	0	0	0	0	0
10 – 15 ppt	0	0	0	0	0	0	0	0
15 – 20 ppt	0	0	0	0	0	0	0	0
20 – 25 ppt	0	0	0	0	0	0	0	0
25 – 30 ppt	0	0	0	0	0	0	0	0
30 – 35 ppt	0	0	0	0	0	0	0	0

CHAPTER 7

Conclusions

Bangladesh is one of the most vulnerable countries to natural disasters due to its geographic position. It is located at the confluence of three biggest rivers in the world – Ganges, Brahmaputra and Meghna. That is why it experiences frequent flood during monsoon season as it is located at the downstream part of above mentioned three rivers. On the other hand, the coastal region experiences frequent cyclones and storm surges and salinity intrusion to landward. It is also predicted from different researches and studies that climate change will intensify these natural calamities in near future.

In this study flood inundation Hazard maps for entire country and storm surge Hazard map and salinity distribution map for entire coastal area were prepared at union level. Six regional river models, GBM basin model and Bay of Bengal model were used to produce flood inundation map, Bay of Bengal Storm Surge model was used to produce storm surge inundation map and three regional salinity models and Bay of Bengal salinity model were used to produce salinity distribution map.

Flood Inundation Map

Flood inundation maps were prepared for four characteristic flood event such as 1988, 1998, 2004 and 2007, for two different return periods - 10 years and 20 years and for climate change. All the maps were produced for 3-hr duration and at union level to facilitate the community to get more accurate idea on inundation depth at local level. The following table shows the number of maps that were produced for each flood event.

Table: List of flood inundation maps

Flood Event	Characteristic Flood				Return Period		Climate Change		Total
	1988	1998	2004	2007	10 yrs	20 yrs	2050	2080	
Number of Maps	1961	2519	2519	1961	1207	1207	2519	2519	17036

Field visits were carried out to collect the local inundation depth data for past severe flood and model results were verified with that collected field data to make the model result more authentic for further analysis. It is clear from the model result that the climate change will decrease the F0 & F1 land drastically in the year of 2050 and 2080 which is suitable for T-Aman for all over the country. On the other hand, F3 and F4 land will also increase due to climate change compared to the flood event 1998 in near future.

Strom Surge Inundation Map

Storm surge inundation maps were produced based on the past nineteen (19) severe cyclones and three synthetic cyclone tracks which are considered as base condition. Inundation maps were also produced for climate change condition in the year of 2050 considering sea level rise of 50 cm and 10% increase of wind speed. It is evident from the model results that Bhola, Laxmipur, Chittagong, Noakhali, Bagerhat, Barguna, Patuakhali, Pirojpur, Jhalkathi and Barisal are more vulnerable district for base condition whereas in the climate change condition Khulna, Sathkhira and the rest part of Pirojpur, Barisal, and Jhalkathi will be become vulnerable.

A total of 101 storm surge inundation maps were produced for base and 107 maps were produced for climate change condition. It is also evident from analysis that an area of 20,745 km^2 will be inundated by more than 1m water depth in the year 2050 due to climate change. All of these maps will be helpful for decision makers to go for proper adaptive measures especially the number and design of cyclone shelters and redesign of coastal embankment.

Salinity Distribution Map

Salinity distribution maps were produced both for base year and for climate change. For climate change 50 cm sea level rise was considered to simulate the salinity models. Salinity maps were produced for the affected coastal districts. Both the river and coastal salinity models were verified with the secondary salinity data to make the model results more realistic. A total of 416 salinity distribution maps were produced both for the base and climate change condition which will be useful for the local stakeholders, farmers and fishermen for their future planning. It is evident from the model results that more salinity will intrude through Baleswar-Bishkhali river system due to climate change. This is because Pussur-Sibsa river system is already affected by higher salinity as there is no upstream flow for that river system during dry season. It is also evident from the model result that almost all the area under less than 1 ppt of Pirojpur district will be change to more than 1 ppt due to climate change.

Benefit of Inundation Hazard Maps

The storm surge zoning map can be useful for planning of adequate number and proper location of cyclone shelters, re-engineering of existing coastal infrastructure and planning and design of future infrastructure in the coastal area as well as planning of mangrove afforestation for reduction of surge height and damage of embankment. The study builds upon and strengthens the analytical models and quantitative assessment tools already in use in Bangladesh in support of the research and knowledge management themes. The storm surge inundation maps are useful for (a) assessing community Hazard, (b) examine the potential physical impacts of climate change; (c) assess the associated damages and losses in key economic sectors, on vulnerable populations, and in the overall economy; and (d) estimate spatially disaggregated costs of adaptation options that can reduce these impacts;

Most people living in flood inundated areas, however, are likely to be exposed to higher inundation depths under the climate change scenario. The estimated population exposed to different inundation depths can be estimated using the flood depth maps. These maps will enable to planner to find different elements at Hazard like road, homestead and crop fields. Rural communities can also find adaptation measures for their homesteads based on these flood maps. Cost of potential damages of road infrastructure can be assessed and adaptation measures can be devised. Flood inundation depth maps can be instrumental for awareness building of local communities and assessment of associated Hazards.

Salinity maps are useful to find the water availability in different months for agriculture, drinking, industrial and other household requirement. Adaptation in fisheries sector and crop planning can also be benefitted from salinity zoning maps. Salinity is an important parameter for characterizing the ecosystems and its sustainability in the changing climate. Salinity zoning maps can be used to find the effect of climate change on the coastal ecosystem as well as on bio-diversity.

ANNEXURE A

Global Tide Model

Global Tide Model

The AG06 Global Tide Model developed by Danish National Space Center DNSC is an update of the older AG94 and AG95 with nearly a decade of additional altimetry included. Furthermore the resolution of the model and the quality of the model has been increased. The AG06 ocean tide model is available on a 0.5 degree and 0.25 degree resolution grid for the major 8 constituent in the tidal spectra. These grids are particularly useful for providing boundary information for local models. The provided constituents are for semidiurnal: M2, S2, K2, N2 and for diurnal: K1, O1, P1, Q1.

Below in Figure A-1 is shown the Co-Tidal charts for M2 Constituent showing the phase and amplitude on the same chart.

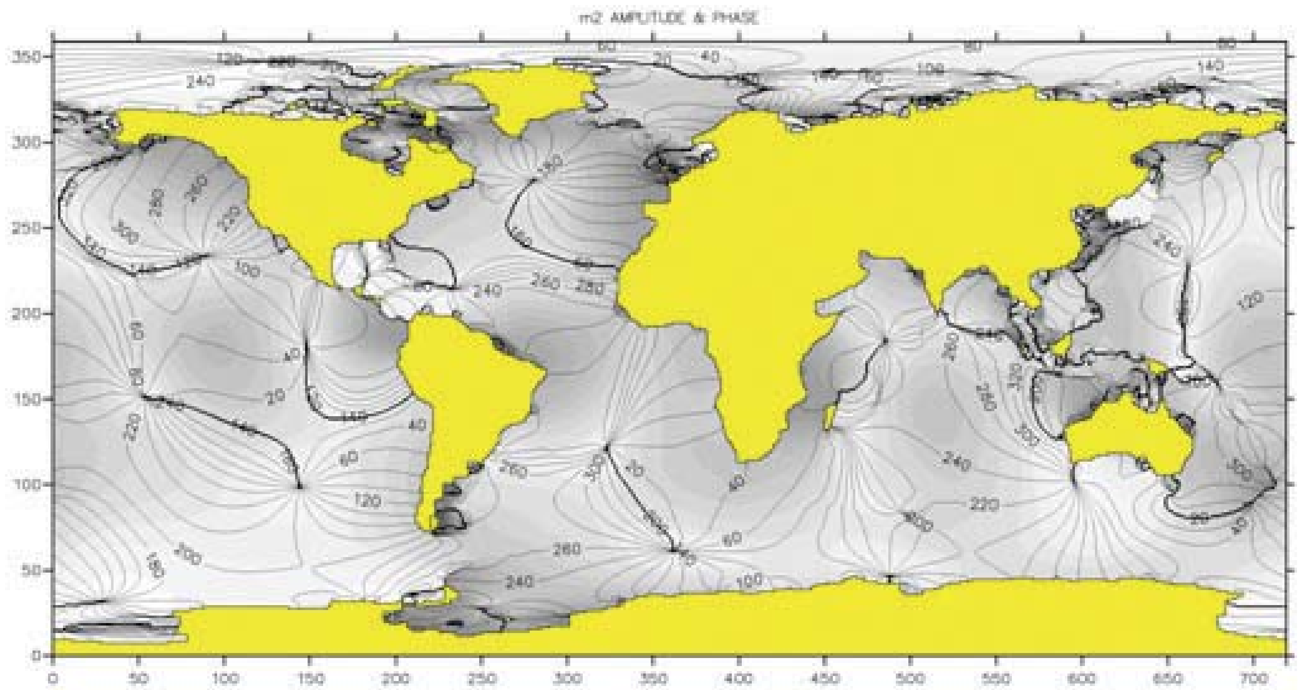


Figure A-1 : Co-Tidal chart of M2

Satellite data used for the Ocean Tide model

Data for the ocean tide model is based on data from 4 altimetric satellites. These are satellite that observes the distance between the satellite and the sea surface averaged over a region of 5 km along pre-selected ground tracks, and have done such for years at regular intervals.

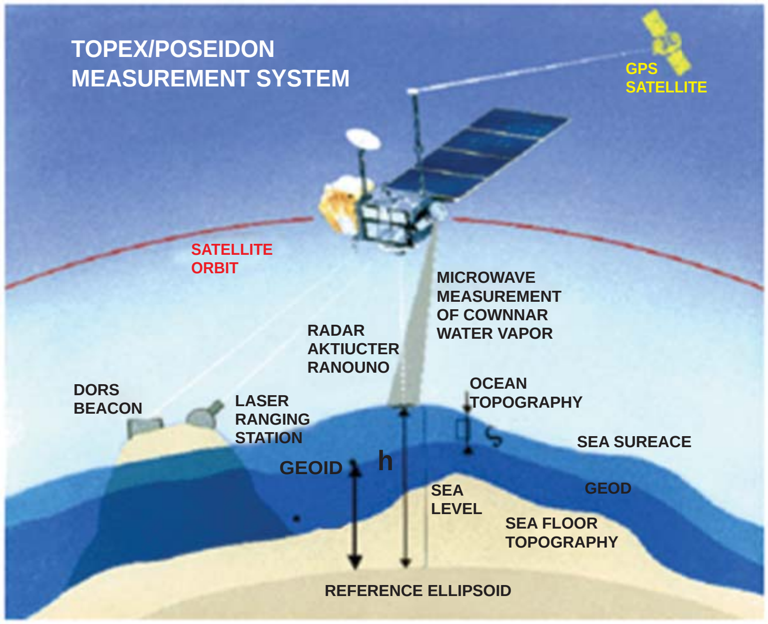


Figure A-2 : Topex/Poseidon measurement system

The TOPEX/POSEIDON (T/P) satellite from 1992-2002 as shown in Figure A-2 is the main satellite. Furthermore data from its interlaced orbit from 2002-2004 have been used. Data from ERS-2 and data from the GFO satellites were used to supplement the satellite data at high latitude where the T/P does not cover (outside the 65 parallel)

The far best satellite to use is the T/P satellite as this satellite was initially designed to map the ocean tides of the world globally at its launch in 1992.

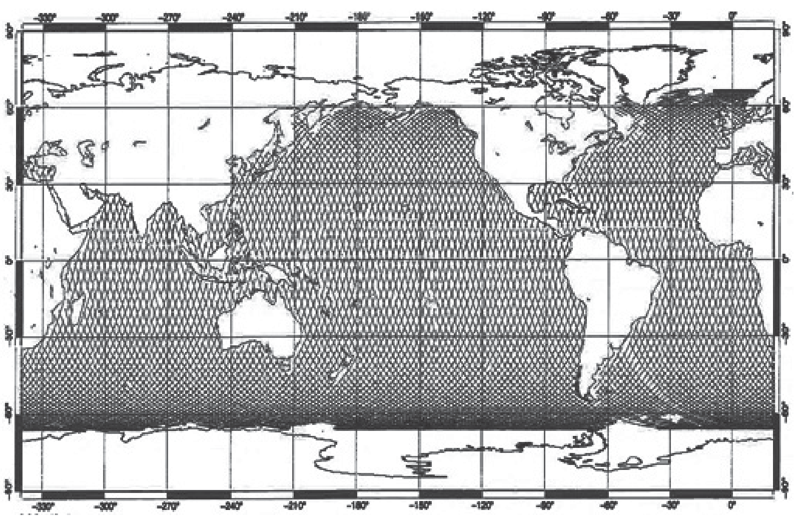


Figure A-3 : Topex/Poseidon track coverage

Due to the relatively coarse track spacing of the T/P satellite (2.9o ≈ 315 km at equator), empirical models from T/P are primarily useful for open ocean tides. On the shelves surrounding the ocean the horizontal extension of the tidal signal is highly reduced, and the track spacing of the T/P satellite becomes critically to resolve especially the high frequency parts of the ocean tide signal properly. Fortunately it was decided to put the TOPEX/POSEIDON (Figure A-3) in an interlaced mission with ground tracks in between the original ground tracks for 2.5 years during the period from 2002-2004 where the TOPEX/POSEIDON follow on called JASON-1 (Figure A-4) was safely launched and calibrated in identical orbits to TOPEX. With these data the track distance is 140 km.

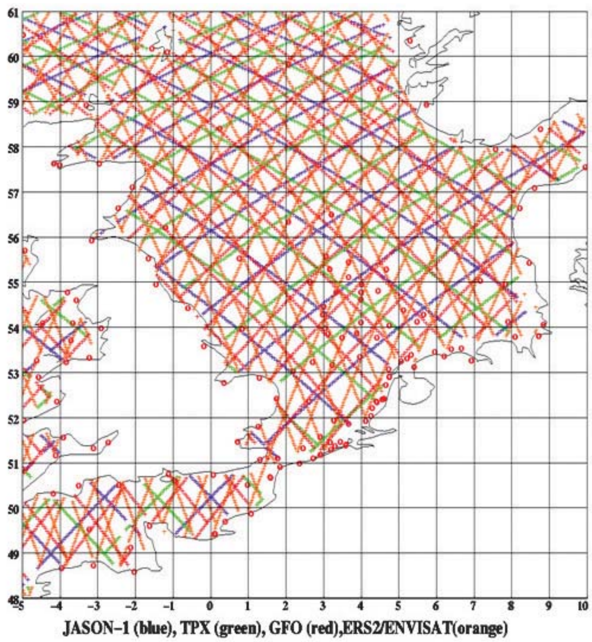


Figure A-4 : Topex/Poseidon tracks and tide gauges on the NW European Shelf

The track spacing of ERS5 1 satellite in the 35-day repeat mission is around 3.6 times better than that of T/P (0.71o ≈ 80 km at the Equator). Similarly the data from the Geosat Follow On (GFO) Mission does also provide valuable supplement to the T/P data when investigating ocean tides in coastal regions (140 km track distance at the Equator).

The empirical T/P derived ocean tide models are limited by the 6o parallel, while ERS 1 provides altimetry all the way up to 820. Therefore the ERS 1 satellite provides observations in roughly all ice-free ocean areas of the world. However, there are several drawbacks to the use of ERS 1 altimetry for tidal analysis. The major drawback is the fact, that ERS 1 is placed in a sun-synchronous orbit (exactly 35 days) so only non-solar constituents can be resolved. Solar constituents are consequently delivered by the apriori hydrodynamic model in this region.

Consequently the following data were used.

- T/P + JASON-1 X-over data within +/- 65 N (465 repeats)
- T/P Along track data (Depth < 1 km) (371 repeats)
- T/P-2 Interlaced mission - Crossover data (Max 90 repeats)
- GFO (various constituents 65N-72N)
- ERS-2/ENVISAT (various non-solar constituents 65N-82N)

All data selection and editing closely follows standard procedures as i.e. documented in Shum et al. 1997 or Andersen, 1995, 1999.

Computation of the Ocean Tide Model

The method used to compute the AG06 ocean tide model is identical to the methodology described in Andersen, (1995, 1999) and the interested user can reference these publications. The model is computed as a long-wavelength adjustment of the FES94.1 pure hydrodynamic model [Le Provost et al., 1994] for all constituents using the altimetry data described above. In the deep ocean only the long wavelength are adjusted as the tidal signal is very long wavelength. Close to the coast the short wavelength part of the tidal signal is also being modelled using satellite data.

Validation against Tide Gauges

The derived amplitudes and phase lags for the major tidal constituents were compared with tide gauges readings by means of bi-linear interpolation within the altimetry derived models using the cosine and sine grids for each constituent. In this comparison the vector difference between the two complex signals are computed and displayed as the values in the Tables below.

A global set of tide gauge readings was defined by C. Le Provost and other members of the T/P ocean tide subcommittee for the investigation of ocean tide models on a common basis. This new set has been constructed from the original 80 tide gauge set selected by Cartwright & Ray [1990, 1991] by various additions, corrections and updates. The new set should have 102 gauges with a more reasonable spatial distribution with 42 tide gauges in the Atlantic Ocean, 18 readings in the Indian Ocean and 42 in the Pacific Ocean. This set of totally 102 tide gauges are shown in Figure A-5

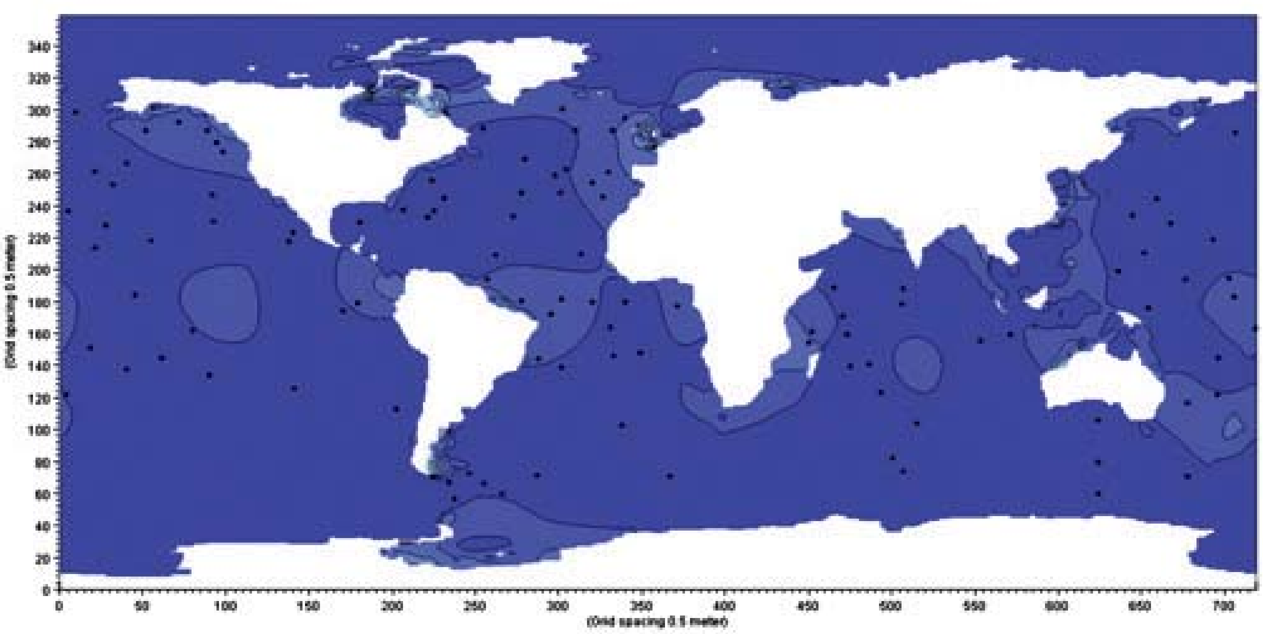


Figure A-5 : Location of 112 high quality global tide gauge station

Extraction from the Global Tide Model

Based on the Global Tide Model users of MIKE21 software can either extract time series of water level for any period and any position on the globe. Furthermore it is possible to extract line series based on either a bathymetry or a mesh file in order to create boundary conditions for local or regional models automatically. It is important to remember that the time zone for the extracted time series is given in UTC or GMT. Normally the user then should adjust the timing to the local time used in the area, where the data is extracted.

ANNEXURE B

Initial Condition

B. INITIAL CONDITION

North-East regional model

Initial conditions for Hydrodynamic Model

River Name	Chainage	Initial h	Initial Q
Angurali_Haor	0	5	1
Angurali_Haor	4000	5	1
Baram_Haor	0	2.7	1
Baram_Haor	4000	2.7	1
Bhanda_Haor	0	2.2	1
Bhanda_Haor	4500	2.2	1
Chandrosonar_Thal_Haor	5000	0.2	1
Chandrosonar_Thal_Haor	9000	0.2	1
Chaptir_Haor	0	2.3	1
Chaptir_Haor	6000	2.3	1
Dhankunia_Haor	0	1	1
Dhankunia_Haor	5000	1	1
Gurmar_Haor	0	0.8	1
Gurmar_Haor	5000	0.8	1
Haijda_Haor	5000	2	1
Haijda_Haor	13000	2	1
Halir_Haor	0	1	1
Halir_Haor	4000	1	1
Jamkhola_Haor	0	3.1	1
Jamkhola_Haor	4500	3.1	1
Joal_Bhanga_Haor	0	3	1
Joal_Bhanga_Haor	7000	3	1
Joydhona_Haor	0	2	1
Joydhona_Haor	2000	2	1
Kalikota_Haor	8000	1	1
Kalikota_Haor	14000	1	1
Kalner_Haor	0	5	1
Kalner_Haor	7000	5	1
Karchar_Haor	0	1.52	1
Karchar_Haor	7000	1.52	1
Matian_Haor	0	1	1
Matian_Haor	5000	1	1
Mohalia_Haor	0	1.5	1
Mohalia_Haor	1500	1.5	1
Naluar_Haor	0	2.5	1
Naluar_Haor	11000	2.5	1
Pagner_Haor	7000	1	1
Pagner_Haor	12000	1	1
Shanghair_Haor	5000	3.7	1
Shanghair_Haor	8000	3.7	1
Safique_Haor	0	11	1
Safique_Haor	4000	11	1
Shanir_Haor	0	1	1
Shanir_Haor	7000	1	1
Sonamoral_Haor	0	1	1
Sonamoral_Haor	4000	1	1
Tanguar_Haor	0	2	1
Tanguar_Haor	4000	2	1

River Name	Chainage	Initial h	Initial Q
Udgal_Haor	8000	2.7	1
Updkhal_Haor	5000	1.5	1
Updkhal_Haor	7000	1.5	1
Zilkar_Haor	0	6	1
Zilkar_Haor	2500	6	1
Khai_Haor	5000	2.6	1
Khai_Haor	9000	2.6	1
Patharchuri_Haor	0	4.5	1
Patharchuri_Haor	4000	4.5	1
Shanghair_Haor	10000	5	1
Surma	201400	3.5	1
Jadukata	7000	5	1
Up_khowai	17000	7	10

Here,

Initial h is water level
Initial q is discharge

Initial conditions for Rainfall-runoff model

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
NE-3	1.00E+03	65	0.5	25	50	0	0
NE-7	1000	65	0.5	50	300	0	0
NE-11A	1000	65	0.5	25	50	0	0
NE-13A	1000	65	0.5	50	300	0	0
NE-15A	1000	65	0.5	25	50	0	0
NE-19	1000	65	0.5	50	75	0	0
NE-21	1000	65	0.5	25	50	0	0
NE-22	1000	65	0.5	50	24	0	0
NE-23	1000	65	0.5	50	24	0	0
NE-25	1000	65	0.5	50	30	0	0
NE-33	1000	65	0.5	50	50	0	0
NE-33A	1000	65	0.5	50	50	0	0
NE-35	1000	65	0.5	50	30	0	0
NE-35A	1000	65	0.5	50	24	0	0
NE-36	1000	65	0.5	50	24	0	0
NE-37	1000	65	0.5	50	24	0	0
NE-37A	1000	65	0.5	50	24	0	0
NE-37B	1000	65	0.5	50	300	0	0
NE-46	1000	65	0.5	50	400	0	0
NE-47	1000	65	0.5	25	50	0	0
NE-47A	1000	65	0.5	50	100	0	0
NE-48A	1000	65	0.5	25	50	0	0
NE-51	1000	65	0.5	50	24	0	0
NE-51A	1000	65	0.5	50	400	0	0
NE-52	1000	65	0.5	50	400	0	0
NE-52A	1000	65	0.5	50	24	0	0
NE-54	1000	65	0.5	50	24	0	0
NE-57	1000	65	0.5	50	200	0	0

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
NE-58	1000	65	0.5	50	200	0	0
NE-59A	1000	65	0.5	50	400	0	0
NE-59B	1000	65	0.5	50	175	0	0
NE-60	1000	65	0.5	50	24	0	0
NE-60A	1000	65	0.5	50	24	0	0
NE-67	1000	65	0.5	50	400	0	0
NE-67A	1000	65	0.5	50	400	0	0
NE-68	1000	65	0.5	50	400	0	0
NE-68A	1000	65	0.5	50	400	0	0
NE-3A	150	65	0.5	100	12	0	0
NEX-40-IRRI	10.3	104	0.6	111.9	26.7	0.9	0.108
NE-15	1000	65	0.5	25	50	0	0
NEX-40-NOIRRI	10.3	104	0.36	111.9	26.7	0.255	0.108
NEX-1	30	200	0.8	100	18	0.9	0
NEX-1A	30	200	0.6	100	6	0.9	0.5
NEX-2	30	200	0.8	100	24	0.9	0
NEX-26	30	200	0.6	100	300	0.9	0
NEX-27	30	200	0.6	100	36	0.9	0
NEX-53	30	200	0.6	100	24	0.9	0
NEX-6	30	200	0.8	100	12	0.9	0
NEX-11	30	200	0.6	100	6	0.9	0.5
NEX-28	17.5	221	0.364	201.8	25.5	0.00743	0.244
NEX-29	17.3	296	0.374	235.5	22.7	0.0255	0.8
NEX-19A	10.2	299	0.989	231.5	22.2	0.987	0.437
NEX-19B	10.1	102	0.989	242.7	25.9	0.7	0.152
NEX-48	18.9	299	0.598	287.2	26.3	0.0725	0.257
NEX-20	10.5	102	0.546	159.4	28.8	0.181	0.713
NEX-16A	12.1	114	0.865	101.1	11.7	0.832	0.123
NEX-38	11.5	100	0.623	102.8	23.8	0.0339	0.124
NEX-39	11.1	133	0.998	946	49.8	0.0145	0.724

Here,

Umax is Maximum water content in surface storage
Lmax is Maximum water content in root zone storage
CQOF is Overland flow runoff coefficient
CKIF is Time constant for interflow
CK1, 2 is Time constants for routing overland flow
TOF is Root zone threshold value for overland flow
TIF is Root zone threshold value for inter flow

North-West Regional Model

Initial conditions for Hydrodynamic Model

River name	Chainage	Initial h	Initial Q
Akhira	0	20.5	0
Akhira	39500	16	0
Alai	0	19	0
Alai	35000	15	0
Alaikumari	0	26.5	0
Alaikumari	32000	23.39	0
Atrai	3170	13	0
Atrai	26170	11.5	0
Atrai	43000	9	0
Atrai	59200	8.5	0
Atrai	83420	8	0
Atrai	101490	7	0
Atrai	110420	6	0
Atrai	128170	5.5	0
Atrai	148670	5.4	0
Atrai	167170	5	0
Atrai_l050	0	11	0
Atrai_l050	10000	11	0
Atrai-india	0	36	0
Atrai-india	78800	13.5	0
Bangali	42500	14	5
Bangali	67420	13	5
Bangali	87240	11.8	5
Bangali	106500	11	5
Bangali	144180	8	5
Bangali	166500	8	5
Bangali	205780	5.5	5
Bangali	233250	5.5	5
Baral	0	5	0
Baral	0	12	0
Baral	700	11.8	0
Baral	39390	5.5	0
Barnai	0	8	0
Barnai	25500	6	0
B-chikly	0	34	0
B-chikly	41100	27.06	0
Breach2-94	0	14.1	0
Breach2-94	2900	14	0
Breach3x	0	14	0
Breach3x	13000	10	0
Breach5x	0	8	0
Breach5x	29000	6.5	0
Breach7x	0	13.5	0
Breach7x	23000	12	0

River name	Chainage	Initial h	Initial Q
Bullai	19000	34.35	0
Bullai	30500	27.65	0
Buriteesta	0	47.7	0
Buriteesta	35000	43.7	0
Cjamuneswari	100	50	0
Cjamuneswari	48950	40.25	0
Cjamuneswari	74250	32.3	0
Cjamuneswari	100750	27.6	0
Cjamuneswari	146000	22	0
Dharla	0	27.5	0
Dharla	48000	19.8	2
Dhepa	0	40.2	0
Dhepa	43000	29.3	0
Dudkumar	508	26.5	1
Dudkumar	46453	21	1
Dur-ban	0	7	0
Dur-ban	2500	7	0
Durgadah	0	8	0
Durgadah	50500	6	0
Fakirni	0	11.5	0
Fakirni	10000	10.5	0
Fakirni	29500	10.5	0
Ganges	32500	7.5	0
Ganges-ext	0	10	0
Ghaelgurhari_k	0	30	0
Ghaelgurhari_k	10600	16.2	0
Ghaelgurhari_k	20000	12	0
Ghagot	73500	23.82	0
Ghagot	120250	21.73	0
Ghagot	136000	14.93	0
Ghagot-at	0	18	0
Ghagot-at	5000	18	0
Gorai	11900	4.5	0
Gorai	5	10	0
Hurasagar	0	5	0
Hurasagar	10500	4.8	0
Ic-bg1	0	8	0
Ic-bg1	2500	8	0
Ic-bg2	0	10	0
Ic-bg2	2500	10	0
Ichamati-nw	0	12	0
Ichamati-nw	23000	10	0
Ichamati-nw	62000	9	0
Ich-jamuna	29500	34	0
Ich-jamuna	58500	27	0
Ich-jamuna	147250	12.5	0

River name	Chainage	Initial h	Initial Q
Ich-jamuna	167250	10.5	0
Jamuna	8000	18	20
Jamuna	37100	17	20
Jamuna	235650	2.65	30
Kala	0	25	0
Kala	7200	25	0
Kala	47500	24	0
Karatoya	261	22	0
Karatoya	72500	14.5	0
Karatoya-gag	0	17	0
Karatoya-gag	61250	12	0
Kharkharia	0	36.1	0
Kharkharia	8750	35	0
Kharkharia	33000	27	0
L-jamuna	12200	10.5	0
L-jamuna	22810	12.5	0
L-jamuna	39700	9.5	0
Lkaratoya	0	11.5	0
Lkaratoya	43300	8.5	0
Lnagor	0	11	0
Lnagor	54200	9	0
Lnagor	56900	9	0
Mohananda	6500	12	0
Mohananda	6500	12	0
Mohananda	45375	12	0
Mohananda	45875	12	0
Nadar	0	11	0
Nadar	30000	11	0
Nagor	0	14.4	0
Nagor	36450	11.5	0
Nandakuja	39390	9.8	0
Nandakuja	68120	7.5	0
Nandakuja	85550	7	0
Naotara	0	47	0
Naotara	10000	47	0
Nemaichari	0	5	0
Nemaichari	300	5	0
Polc_art	0	10.5	0
Polc_art	39350	9	0
Pold_art	0	10	0
Pold_art	17250	10	0
Punarbhaba	0	39.4	0
Punarbhaba	0	39.5	0
Punarbhaba	50000	28.4	0
Punarbhaba	50000	28.6	0
Sib-barnai	9650	11	0

River name	Chainage	Initial h	Initial Q
Sib-barnai	68290	10	0
Sib-barnai	93150	10	0
Sib-barnai	150150	7.5	0
Tangon	33000	47.5	1
Tangon	47500	30.8	1
Teesta	8000	53	0
Teesta	14000	53	0
Teesta	79790	33	0
Teesta	121000	30	0
Tulshiganga	0	16.3	0
Tulshiganga	39000	11	0
Tulshiganga	57000	12	0
Uatrai	123500	42	0
Uatrai	176000	35.7	0
Ukaratoya	41500	69	0
Ukaratoya	90000	52	0
Ukaratoya	123500	45	0
Monohorganga_k	0	22	0
Monohorganga_k	49000	11.8	0
Joaikhari	0	23	0
Joaikhari	16000	14	0
Joaikhari	33000	10.8	0
Rasulpur_k	0	31	0
Rasulpur_k	25000	11.5	0

Here,

Initial h is water level

Initial q is discharge

Initial conditions for Rainfall-runoff model

Catchment Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
NW-19	1.00E+03	65	0.9	200	30	0.85	0.5
NW-5	1000	85	0.9	125	24	0.85	0.7
NW-12U	1000	65	0.9	125	24	0.85	0.5
NW-13	1000	65	0.9	100	75	0.85	0.5
NW-4	1000	65	0.9	48	24	0.85	0.5
NW-12L	1000	65	0.9	100	60	0.85	0.5
NW-11	1000	65	0.9	100	75	0.85	0.5
NW-10	1000	65	0.9	100	48	0.85	0.5
NW-15	1000	65	0.9	75	6	0.85	0.5
NW-21	1000	65	0.9	100	24	0.85	0.5
NW-22	1000	65	0.9	100	24	0.85	0.5
NW-23	1000	65	0.9	100	24	0.85	0.5
NW-7	1000	65	0.9	75	24	0.85	0.7
NW-17	1000	65	0.9	48	24	0.85	0.7
NW-3	1000	85	0.9	150	24	0.85	0.8
NW-27	1000	65	0.9	120	24	0.85	0.6
NW-26	1000	65	0.9	200	48	0.85	0.6
NW-34	1000	65	0.9	100	24	0.85	0.5
NW-33	1000	65	0.9	75	24	0.85	0.5
NW-24	1000	65	0.9	100	24	0.85	0.5
NW-32U	1000	65	0.9	100	24	0.85	0.5
NW-32L	1000	65	0.9	75	24	0.85	0.5
NW-30	1000	65	0.9	100	24	0.85	0.5
NW-31	1000	65	0.9	100	24	0.85	0.5
NW-39	1000	65	0.9	100	24	0.85	0.5
NW-35	1000	65	0.9	100	24	0.85	0.5
NW-40	1000	65	0.9	100	24	0.85	0.5
NW-38	1000	65	0.9	120	24	0.85	0.5
NW-14	1000	65	0.9	200	75	0.85	0.5
NW-1U	1000	65	0.9	150	18	0.85	0.5
NW-1M	1000	65	0.9	150	18	0.85	0.5
NW-1L	1000	65	0.9	150	18	0.85	0.5
NW-2U	1000	65	0.9	140	24	0.85	0.7
NW-16U	1000	65	0.9	75	24	0.85	0.7
NW-16L	1000	65	0.9	75	24	0.85	0.7
NW-32M	1000	65	0.9	75	24	0.85	0.5
NW-2L	1000	65	0.9	140	24	0.85	0.7

Here,

Umax is Maximum water content in surface storage

Lmax is Maximum water content in root zone storage

CQOF is Overland flow runoff coefficient

CKIF is Time constant for interflow

CK1, 2 is Time constants for routing overland flow

TOF is Root zone threshold value for overland flow

TIF is Root zone threshold value for inter flow

North Central Regional Model

Initial conditions for Hydrodynamic Model

River name	Chainage	Initial h	Initial Q
Balu	30000	1	5
Bangshi	37000	7.75	1
Bangshi	95000	6.25	1
Bangshi	148000	3	5
Bangshi	166000	3	5
Bangshi	192000	2	3
Bangshi	202000	2	1
Buriganga	29500	1.5	10
Buriganga	40000	1.25	10
Chatal	24000	12	0.5
Dhaleswari	21000	5	2
Dhaleswari	52000	4	2
Dhaleswari	74000	3	0
Dhaleswari	120000	1.75	10
Dhaleswari	135000	1.5	10
Dhaleswari	170500	1.25	10
Futikjani	12500	8	0.5
Ghior_k	0	2.5	1
Ghior_k	200	2.5	1.5
Ichamati	36500	1	1
Jhenai	5000	12	0.5
Jhenai	35001	9.5	1
Jhenai_east	0	11.6	1
Jhenai_east	36800	8.4	1
Kaliganga	15000	2	10
Lakhya	96500	1.25	5
Louhajang	1000	5.5	1
Louhajang	53000	4.5	1
O_bramaputra	0	15	1
O_bramaputra	56750	11.5	1
O_bramaputra	111500	7	1
O_bramaputra	125500	6.5	1
O_bramaputra	257500	2	1
Pungli	3000	7.5	1
Tongi_k	9000	2	1
Turag	64000	1.5	5
Ichamati	0	4	0

Here,

Initial h is water level

Initial q is discharge

Initial conditions for Rainfall-runoff model

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
NC-1	1.00E+03	65	0.9	600	24	0.85	0
NC-2	1000	65	0.9	500	24	0.85	0
NC-3	1000	65	0.9	400	24	0.85	0.5
NC-5	1000	65	0.9	450	24	0.85	0
NC-6	1000	65	0.9	300	24	0.85	0
NC-7	1000	65	0.9	500	24	0.85	0
NC-8	1000	65	0.9	600	24	0.85	0
NC-9	1000	65	0.9	600	24	0.85	0
NC-10	1000	65	0.9	500	24	0.85	0
NC-11	1000	65	0.9	600	24	0.85	0
NC-12	1000	65	0.9	500	24	0.85	0
NC-13	1000	65	0.9	600	24	0.85	0
NC-14	1000	65	0.9	600	24	0.85	0
NC-15	1000	65	0.9	500	24	0.85	0
NC-16	1000	65	0.9	800	24	0.85	0
NC-17	1000	65	0.9	500	24	0.85	0
NC-18	1000	65	0.9	500	24	0.85	0
NC-19	1000	65	0.9	600	24	0.85	0
NC-4	1000	65	0.9	200	24	0.85	0
NC-4A	1000	65	0.9	200	24	0.85	0

Here,

Umax is Maximum water content in surface storage

Lmax is Maximum water content in root zone storage

CQOF is Overland flow runoff coefficient

CKIF is Time constant for interflow

CK1, 2 is Time constants for routing overland flow

TOF is Root zone threshold value for overland flow

TIF is Root zone threshold value for inter flow

South-East Regional Model

Initial conditions for Hydrodynamic Model

River name	Chainage	Initial h	Initial Q
Kakri	0	8	5
Kakri	8001	6.25	5
Little feni	34182	3	20
Little feni	89680	3	20
Kakri	13000	6	10
Sonaichari	0	6.5	2
Pagli	0	5.5	2
Salda	5000	3.5	15
Howra	21700	6	5
Dakatia	5700	6	20
Dakatia	15000	5.8	20
Dakatia	43900	5	30
Dakatia	79200	2	30
Titas upper	43800	1.75	3
Gumti	210	8	40
Gumti	25300	5	45
Gumti	41000	4	50
Boaljor nadi	0	5.5	0.5
Lateral-4	0	5.5	0.5
Lateral-5	0	5.5	0.5
Art-sonaichari	0	5.5	0.5
Art-l_feni1	0	6	0.5
Art-l_feni2	0	5	0.5
Art-l_feni3	0	5	0.5
Feni-river	39700	5	30
Muhuri	0	10.5	20
Gumti	4420	8	15
Gumti	5020	8	15
Gumti	5590	8	15
Gumti	6090	8	15
Gumti	6590	8	15
Art-dakatia1	4000	1.5	2
Art-dakatia2	4000	1.5	2
Art-dakatia3	4000	1.5	2
Art-noa-l1	4000	3	2
Art-noa-l2	4000	3	2

River name	Chainage	Initial h	Initial Q
Art-noa-l3	4000	3	2
Art-noa-l4	4000	3	2
Art-noa-l5	4000	3	2
Art-noa-r2	4000	3	2
Art-noa-r3	4000	3	2
Dakatia	29600	1.5	2
Dakatia	29601	1.5	2
Dakatia	43900	1.5	2
Dakatia	54700	1.5	2
Dakatia	62200	1.5	2
Dakatia	72700	1.5	2
Dakatia	79200	1.5	2
Dakatia	88700	1.5	2
Dakatia	94900	1.5	2
Dakatia	94901	1.5	2
Noakhali khal	43000	3.6	2
Noakhali khal	46807	3.6	2
Noakhali khal	51111	3.6	2
Noakhali khal	51176	3.6	2
Noakhali khal	57118	3.6	2
Noakhalkhal	57193	3.6	2
Noakhali khal	57672	3.6	2
Noakhali khal	60220	3.6	2
Noakhali khal	23520	1.5	2
Noakhali khal	24662	1.5	2
Noakhali khal	25624	1.5	2
Noakhali khal	28513	1.5	2
Noakhali khal	29256	1.5	2
Noakhali khal	29840	1.5	2
Noakhali khal	31826	1.5	2
Noakhali khal	32226	1.5	0
Noakhali khal	33851	1.5	2
Noakhali khal	34089	1.5	2
Noakhali khal	36651	1.5	2
Noakhali khal	36711	1.5	2
Art- Sonaichari2	2000	5.5	1

Here,

Initial h is water level

Initial q is discharge

Initial conditions for Rainfall-runoff model

Catchment Name	U	L	QOF	QIF	BF	BFlow	Snow stor.
SE-03	0	40	0	0	0	0	0
SE-02	0	40	0	0	0	0	0
SE-01	0	40	0	0	0	0	0
SE-04	0	40	0	0	0	0	0
SE-05	0	40	0	0	0	0	0
SE-06	0	40	0	0	0	0	0
SE-07	0	40	0	0	0	0	0
SE-08	0	40	0	0	0	0	0
SE-09	0	40	0	0	0	0	0
SE-10	0	40	0	0	0	0	0
SE-11	0	40	0	0	0	0	0
SE-12	0	40	0	0	0	0	0
SE-13	0	40	0	0	0	0	0
SE-14	0	40	0	0	0	0	0
SE-15	0	40	0	0	0	0	0
SE-16	0	40	0	0	0	0	0
SE-17	0	40	0	0	0	0	0
SE-18	0	40	0	0	0	0	0
SE-19	0	40	0	0	0	0	0
SE-20	0	0	0	0	0	0	0
SE-21	0	0	0	0	0	0	0
SE-22	0	0	0	0	0	0	0
SE-23	0	0	0	0	0	0	0
SE-24	0	0	0	0	0	0	0
SE-25	0	0	0	0	0	0	0
SE-26	0	0	0	0	0	0	0
SE-27	0	20	0	0	0	0	0
SE-28	0	20	0	0	0	0	0
SE-29	0	20	0	0	0	0	0
SE-30	0	20	0	0	0	0	0
SE-31	0	20	0	0	0	0	0
SE-32	0	20	0	0	0	0	0
SE-36	0	20	0	0	0	0	0
SE-37	0	20	0	0	0	0	0
SE-38	0	20	0	0	0	0	0
SE-39	0	20	0	0	0	0	0
SE-40	0	20	0	0	0	0	0
SE-41	0	20	0	0	0	0	0
SE-42	0	20	0	0	0	0	0
SE-44	0	20	0	0	0	0	0
SE-46	0	20	0	0	0	0	0
SE-27A	0	20	0	0	0	0	0
SE-33	0	40	0	0	0	0	0
SE-34	0	40	0	0	0	0	0
SE-35	0	40	0	0	0	0	0
SE-47	0	40	0	0	0	0	0
SE-48	0	40	0	0	0	0	0
SE-49	0	40	0	0	0	0	0

Here,

Umax is Maximum water content in surface storage

Lmax is Maximum water content in root zone storage

CQOF is Overland flow runoff coefficient

CKIF is Time constant for interflow

CK1, 2 is Time constants for routing overland flow

TOF is Root zone threshold value for overland flow

TIF is Root zone threshold value for inter flow

South Western Regional Model

Initial conditions for Hydrodynamic Model

River Name	Chainage	Initial h	Initial Q
Padma	12000	2	55000
Padma	100000	1.8	55000
Upper_meghna	0	2	10000
Upper_meghna	110000	1.8	10000
Harihar	0	2.8	0
Harihar	39500	2.8	0
Buri-bhadra	0	2.8	0
Buri-bhadra	7500	2.8	0
U-bhadra	1000	3.05	0
U-bhadra	16000	1.5	0
U-bhadra	16500	1	0
Madhumati	182000	4	0
Kaliganga_u	5000	7	0
Kaliganga_u	41000	6.5	0
Kumark	22000	6.5	0
Kumark	116000	3.6	0
Nabaganga_u	42000	5	0
Nabaganga_u	98000	3.6	0
Nabaganga_u	144000	3	0
Nabaganga_u	178000	2	0
Chitra	50000	4	0
Chitra	108000	3.5	0
Chitra	120000	3	0
Chitra	160000	2	0
Begabati	48000	3.6	0
Begabati	74000	3	0
Bhairab_u	0	3	0
Bhairab_u	137000	1.5	0
Afrakhal	0	2	0
Afrakhal	36000	2	0
U-solmari	0	0.72	0
Chandana	0	4	0
Chandana	45000	3	0
Kumar	9000	3	0
Kumar	19400	4.5	0
Kumarf1	26000	4	0

River Name	Chainage	Initial h	Initial Q
Kaliganga_u	5000	7	0
Kaliganga_u	41000	6.5	0
Kumark	22500	6.5	0
Kumark	116000	4.5	0
Nabaganga_u	42000	5	0
Nabaganga_u	98000	3	0
Nabaganga_u	144000	2	0
Nabaganga_u	157000	1	0
Chitra	50000	4	0
Chitra	108000	3.5	0
Chitra	120000	2.5	0
Chitra	143000	2.4	0
Begabati	48000	3.6	0
Begabati	74000	3	0
Mbr	0	2.5	0
Mbr	30000	2.5	0
Kumar	19400	1	0
Kumar	108600	0.75	0
Kumar_nadi	0	4	0
Kumar_nadi	46050	4	0
Sitalakhya	0	2	0
Sitalakhya	46000	1	0
Sitalakhya	69400	1	0
Gorai	11901	4.5	0
Kobadak	0	3	0
Kobadak	44500	1.5	0

Here,

Initial h is water level

Initial q is discharge

Initial conditions for Rainfall-runoff model

Catchment Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
SW-1	1.00E+03	65	0.8	800	24	0.7	0
SW-2	1000	65	0.8	600	24	0.7	0
SW-3	1000	65	0.8	800	24	0.7	0
SW-4	1000	65	0.7	800	24	0.7	0
SW-5	1000	65	0.8	1000	24	0.7	0
SW-6	1000	65	0.8	800	24	0.7	0
SW-7	1000	65	0.8	800	24	0.7	0
SW-8	1000	65	0.8	1000	24	0.7	0
SW-9	1000	65	0.8	1000	24	0.7	0
SW-10	1000	65	0.8	1000	24	0.7	0
SW-11	1000	65	0.9	1000	24	0.7	0
SW-12	1000	65	0.9	1000	24	0.7	0
SW-13	1000	65	0.9	1000	24	0.7	0
SW-14	1000	65	0.9	1000	24	0.7	0
SW-15	1000	65	0.9	1000	24	0.8	0
SW-16	1000	65	0.9	1000	24	0.7	0
SW-17	1000	65	0.9	1000	24	0.7	0
SW-18	1000	65	0.7	1000	24	0.9	0
SW-19	1000	65	0.7	1000	24	0.9	0
SW-20	1000	65	0.8	1000	24	0.7	0
SW-21	1000	65	0.8	1000	24	0.7	0
SW-22	1000	65	0.8	1000	24	0.7	0
SW-23	1000	65	0.9	1200	24	0.7	0
SW-24	1000	65	0.8	800	24	0.9	0
SW-25	1000	65	0.7	1000	24	0.8	0
SW-26	1000	65	0.7	1000	24	0.7	0
SW-27	1000	65	0.8	1000	24	0.8	0
SC-1	1000	65	0.9	1000	24	0.7	0
SC-2	1000	65	0.9	1200	24	0.7	0
SC-3	1000	65	0.85	1200	24	0.7	0
SC-4	1000	65	0.85	800	24	0.7	0
SC-5	1000	65	0.9	800	24	0.7	0
SC-6	1000	65	0.85	1000	24	0.7	0
SC-7	1000	65	0.85	800	24	0.7	0
SC-8	1000	65	0.95	800	24	0.7	0
SC-9	1000	65	0.85	1000	24	0.7	0
SC-10	1000	65	0.85	800	24	0.7	0
SC-11	1000	65	0.85	800	24	0.7	0
SC-12	1000	65	0.85	800	24	0.7	0
SC-13	1000	65	0.85	600	24	0.7	0
SC-14	1000	65	0.9	1200	24	0.7	0
SC-15	1000	65	0.85	1200	24	0.7	0
SC-16	1000	65	0.9	800	24	0.7	0
SC-17	1000	65	0.9	1000	24	0.7	0

Here,

Umax is Maximum water content in surface storage

Lmax is Maximum water content in root zone storage

CQOF is Overland flow runoff coefficient

CKIF is Time constant for interflow

CK1, 2 is Time constants for routing overland flow

TOF is Root zone threshold value for overland flow

TIF is Root zone threshold value for inter flow

Eastern Hilly Regional Model

Initial conditions for Hydrodynamic Model

River Name	Chainage	Initial H	Initial Q
Bank Khali	0	9.71	0
Bank Khali	33850	0.83	0
Halda	0	4.75	0
Sangu	0	4.75	0

Here,

Initial h is water level

Initial q is discharge

Initial conditions for Rainfall-runoff model

Catchment Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
CA-01	20	200	0.4	1000	36	0	0
CA-02	20	200	0.6	1000	15	0.8	0.8
CA-03	20	200	0.4	1000	36	0	0
CA-04	20	200	0.4	1000	36	0	0
CA-05	20	200	0.4	1000	36	0	0
CA-06	20	200	0.6	1000	15	0.8	0.8
CA-07	20	200	0.6	1000	15	0.8	0.8
CA-08	20	80	0.5	75	36	0	0
CA-09	20	80	0.5	75	36	0	0
CA-10	20	80	0.5	75	36	0	0
CA-11	20	80	0.5	75	36	0	0
CA-12	20	200	0.6	1000	15	0.8	0.8
CA-13	20	80	0.5	75	36	0	0
CA-14	20	80	0.5	75	36	0	0

Here,

Umax is Maximum water content in surface storage
Lmax is Maximum water content in root zone storage
CQOF is Overland flow runoff coefficient
CKIF is Time constant for interflow
CK1, 2 is Time constants for routing overland flow
TOF is Root zone threshold value for overland flow
TIF is Root zone threshold value for inter flow

ANNEXURE C

Survey Logsheet

Questionnaire Survey for Comprehensive Disaster Management Program

Union-wise Flood Mapping For Flood-prone Areas to Facilitate Community Hazard Assessment (CRA)

SURVEY LOGHEET

১. Latitude: Longitude: ২. স্যাম্পল নংঃ ৩. তারিখঃ

৪. নামঃ ৫. পুরুষ/মহিলা

৬. জরিপ স্থানের ঠিকানা (ইউনিয়ন/উপজেলা/জেলা)ঃ

৭. বয়সঃ

৮. পেশাঃ ৯. বন্যাক্রান্ত হয়ঃ ১/২/৩/৪/৫ বছর পরপর

১০. বন্যার তথ্যের ছকঃ

বছর	মাস	বন্যার পানির সর্বাধিক গভীরতা/সময়কাল							মানচিত্রে বন্যার পানির গভীরতা (Fo/F1/F2/F3/F4)
		বাড়ির ভিটায় (ফুট/সময়)	বাড়ির উঠানে (ফুট/সময়)	বাড়ির পাশে মাঠে (ফুট/সময়)	বাড়ির পাশে ১ কিমি দূরুত্বের কৃষি জমিতে				বাড়ির ভিটায়
					উত্তর (ফুট/সময়)	দক্ষিন (ফুট/সময়)	পূর্ব (ফুট/সময়)	পশ্চিম (ফুট/সময়)	
২০০৭									
২০০৪									
১৯৯৮									
১৯৮৮									
স্বাভাবিক বন্যা									

মন্তব্যঃ ....

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সার্ভেয়রের নাম ও স্বাক্ষর

Questionnaire Survey for Comprehensive Disaster Management Program

Union-wise Flood Mapping For Flood-prone Areas to Facilitate Community Hazard Assessment (CRA)

SURVEY LOGHEET

১১. আপনার বাড়ীর পাশের নদীগুলোর অবস্থাঃ

১১.১ বড় নদীর নামঃ

১১.২ বাড়ী থেকে বড় নদীর দূরুত্বঃ

১১.৩ ছোট খাল/নদীর নামঃ

১১.৪ বাড়ী থেকে ছোট নদীর দূরুত্বঃ

১১.৫ ছোট নদীর সাথে বড় নদীর সংযোগ অবস্থাঃ

- ☐ সংযুক্ত/বিচ্ছিন্ন
- ☐ অন্যান্যঃ

১১.৬ ছোট খাল/নদীর তলদেশঃ

- ☐ গভীর/অগীর/ভরাট
- ☐ অন্যান্যঃ

১২. বন্যার কারণ ক্ষতিসাধন হয়ঃ

- ☐ ফসলের/রাস্তাঘাটের/ব্রীজ-কালভার্টের
- ☐ অন্যান্যঃ

১৩. স্বাভাবিক বন্যায় অত্র এলাকার যেসব অংশ ডুবে যায়ঃ

- ☐ উত্তারাংশ/দক্ষিনাংশ/পূর্বাংশ/পশ্চিমাংশ/পঁরো এলাকা
- ☐ অন্যান্যঃ

১৪. এই এলাকার বন্যার কারণঃ

- ☐ বড়/ছোট খাল/নদীর পানি বেড়ে গেলে দুকুল বুপচিয়ে যাওয়া
- ☐ বৃষ্টির পানি বের হওয়ার খাল/নদী ভরাট/বন্ধ
- ☐ অন্যান্যঃ

১৫. এই ইউনিয়নের চেয়ারম্যান/মেম্বার/স্কুল শিক্ষক/গন্য-মান্য বক্তির সাথে সাক্ষাতে প্রাপ্ত বন্যার তথ্য

১৫.১ নামঃ ১৫.২ বয়সঃ

১৫.৩ ইউনিয়ন/স্কুলঃ

১৫.৪ স্বাভাবিক বন্যায় ডুবে যায় এই ইউনিয়নের	%
১৫.৫ বড় বন্যায় ডুবে যায় এই ইউনিয়নের	%

১৬. ছোট/বড় নদীসহ এলাকার আনুমানিক সেচ

ANNEXURE D

Comments & Responses

(Comments and responses from the validation workshop on draft final report)

1. Dr. Ainun Nishat, Vice Chancellor, BRAC University

Sl No.	Comments	Responses
1.	The map needed to be produced in Bangla for community.	It is a very good suggestion and essential to prepare it. Considerable numbers of maps were produced for flood inundation, storm surge inundation and salinity distribution in English and it took quite long time to produce all of those maps. It will take almost the same time to produce all of the maps in Bangla. CDMP can take over the task to produce these maps in Bangla.
2.	The maps produced need to be validated in field with community.	Agreed and already validated through a number of field visits.
3.	Explanation of using specific models should be presented.	Explained in the previous section.
4.	Literature review of related works need to be included.	Agreed.
5.	Any available information on SLR in Bangladesh needs to be included.	Agreed.
6.	Comparison of model outputs with some earlier works.	It has done in the KJDRP area.
7.	Such consultation workshop should be organized at the beginning of the study as well.	Agreed.
8.	Mention if flood embankments are considered or not in predicting flood inundation maps.	Flood embankment is considered.
9.	Rationale of selecting study areas for flood inundation should be explained.	Agreed.
10.	The study would serve as baseline for any future studies.	Agreed.
11.	Should produce global level publication based on the study findings.	Agreed.

2. Tarik-ul Islam, Assistant Country Director, UNDP

Sl No.	Comments	Responses
1.	Share the full report with the stakeholders, rather than the summary.	Agreed.
2.	The study is strategically important for the policy makers, planning people as well useful for the community.	Agreed.
3.	Too many maps will confuse community, provide them with the important one (i.e., maximum risk level); translate the maps in Bangla.	Agreed.
4.	Explain the reason behind selecting the flood-prone districts.	The districts for flood mapping have been selected in consultation with officials of CDMP. The districts other than flood-prone are not likely to be affected by high flood inundation in the changing climate.
5.	Need to be careful about predictions based on the IPCC, they might lead to expensive development.	It is important to have local projection and to investigate risk to moderate and high emission scenarios.
6.	Need clarification on selection of models, provide comparison with other available ones.	These models have been tested in the rivers and Bay of Bengal for the last twenty years and applied in many projects.
7.	The reports lack long-term strategy (such as update frequency).	The TOR does not stipulate to do the long-term strategy.

3. Md. Mahfuzur Rahman, Project Director, CDSP and Superintending Engineer, BWDB

Sl No.	Comments	Responses
1.	Value for 2080?	10% wind speed is selected for the year 2050. According to the prediction of IPCC 10% and 20% increase of wind speed may occur due to increase of 2^0C and 4^0C temperature. In this study 2^0C increase of temperature was elected for the year 2050. The value of percentage increase.
2.	Is it possible to use trend of wind speed increase using our cyclone data instead of IPCC.	Cyclone is a discrete event and it is difficult to go for any frequency analysis with this kind of discrete data. Even if we find the increase of wind speed but we can't extrapolate it for 2050 since future driving forces and temperature will be different. That is why predictions from IPCC is considered.
3.	The coastal area is protected with polders, so inundation will be after overtopping or by breach of embankment.	Coastal polders have already been incorporated in the costal model but breach of embankment was not incorporated in the model due to the limitation of model.
4.	Incremental area of salinity need to be elaborated.	Agreed.
5.	The user of the finding will be all sectors rather than re-design of embankment as stated in the report.	Agreed.
6.	Need to prepare a national baseline with downscaling of IPCC predictions.	Agreed.

4. Md. Sabbir Mostafa Khan, Professor, Department of Water Resources Engineering, BUET

Sl No.	Comments	Responses
1.	Could have a note on CRA in the report.	
2.	In working with synthetic cyclone model, high tide - low tide need to be considered with care.	Agreed both low tide and high tide were considered in the study.
3.	Use of storm surge inundation would be better instead of storm surge height.	Agreed.
4.	Caution should be made in considering return period of cyclone.	Agreed. Inundation risk map have been prepared and no statistical analysis was carried out.
5.	Effect of El-Nino and La-Nina was mentioned in the report.	We are in agreement to investigate this issue and in future study needs to be designed on this basis......
6.	The information in table at page 16 need to be checked.	Checked and corrected.
7.	Use of representative year (page 52) should be re-considered.	It is not a representative year, rather a flood event with a frequency of occurance.

5. Mr. Saiful Alam, Principal Scientific Officer Water Resources, WARPO

Sl No.	Comments	Responses
1.	Some of the data used in the report are not updated.	Secondary data was used for all kind of analysis under this study and recent hydrometric, salinity and flow data were used, but some cross-section are few years old and recent data are not available.
2.	The selection of base year of 5, 10, 20 and 50 years return period as agreed in the ToR was not followed; instead only 10 and 20 years return period was considered, need rationale.	The flood events and return period have been selected in consultation with the officials of CDMP.
3.	No calibration and validation of basin model, surge, salinity model and hydrodynamic model of other regions has been incorporated in the report.	All the models were calibrated and validated for several years in Institute of Water Modelling. Some sample plots have been incorporated in the report.
4.	Presentation of the maps could be more explicable with better color scheme.	Agreed.

6. Open discussion

Sl No.	Comments	Responses
1.	Duration of inundation should be provided.	Agreed and incorporated.
2.	The study findings need to be made accessible to all stakeholders.	Agreed.
3.	Only surface water salinity map is developed, no map for ground water and soil salinity.	There was no provision for ground water salinity and soil salinity in the Terms of Reference, but these can be done considering the ground water salinity and soil salinity through further study.
4.	The maps need to be made user-friendly, useable by local community.	Agreed.
5.	Need study on impact of surface water salinity on soil salinity.	It is an excellent suggestion and needs urgent attention of CDMP.
6.	Salinity data should be of mouza-level rather than union-level.	We are providing in UZ.
7.	Compare the maps prepared by model with remote sensing maps.	This is no doubt an excellent validation. Calibration also made using satellite images on flood extent.
8.	Development of models based on extreme conditions may lead to excessive scenario with higher development cost, use of average condition along with extreme one should be used.	Agreed.

6. Open discussion

Sl No.	Comments	Responses
9.	The maps could be used for awareness purpose in the community level.	Agreed.
10.	Evaporation, sunshine data should be considered for salinity model.	Evaporation data was already used in the models. Evaporation has effect on water salinity, but there is no direct formulation to assess the effect of sunshine on water quality.
11.	Use of higher resolution model would produce better result.	Agreed but for union-level output existing grid size is OK.
12.	There is need for guideline for interpretation of the maps.	Agreed.
13.	The study should contain limitations of prediction.	Agreed and incorporated the methodology of interpolation.
14.	The findings of the study need wider dissemination.	Agreed.
15.	There is need for national Sea Level Rise data for better prediction of future inundation.	Agreed.
16.	It would be better if we have seasonal salinity scenarios for each union.	We have given monthly variation of salinity for each upazila from February to May. However, it will be very useful if unionwise seasonal salinity can be prepared, which may be done in future.
17.	Salinity situation of the Sunderbans should be highlighted.	Agreed.
18.	Stakeholders consultations during the study period might be helpful in such studies.	Agreed and have already done.
19.	Feedback and regular update of the results of this study should continue.	Agreed.
20.	The presentations of the maps need to be more user-friendly.	Agreed.
21.	Limitations and assumptions could be embedded in the maps.	These limitations are given in the report.
22.	There is a demand for producing the maps in an ATLAS format.	This is a very good suggestion. CDMP can take over it in future studies.

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