Vulnerability of Coatal Region due to Storm Surge Inundation in Changing Climate

Manjur Murshed Zahid Ahmed[1], Zahirul Haque Khan[2], Md. Mobassarul Hasan[3]

[1,2,3]Institute of Water Modelling, House 496, Road 32, New DOHS, Mohakhali, Dhaka-1206, Bangladesh

Keywords
Coastal Region, Cyclone-induced Storm Surge, Mathematical Modelling, MIKE 21, Climate Change, Sea Level Rise, Inundation Risk Map

Abstract

Bangladesh is one of the worst affected countries of climate change impacted by Global warming triggered by Greenhouse Gas emissions. According to the Assessment Report-4 of IPCC, tropical cyclones, storm surges and severe floods are likely to become more frequent and severe in the future as a result of climate change, making Bangladesh even more vulnerable. Institute of Water Modelling (IWM) carried out a study under World Bank, where vulnerability of coastal region of Bangladesh due to cyclone-induced storm surge under climate change condition was assessed and adaptation cost to cope with climate change impacts was estimated. This paper focuses only on the assessment of vulnerability of coastal region of Bangladesh due to cyclone-induced storm surge under climate change.

Under the study inundation in the coastal region due to storm surge under climate change scenario for the projected year 2050 was assessed using existing Bay of Bengal model (which is based on MIKE 21 modelling system). The Bay of Bengal model was applied to simulate 19 major cyclones during the period from 1960 to 2009 to prepare baseline condition for the storm surge inundation. For climate change condition (2050) following assumptions were made:

a) sea level rise of 27cm based on National Adaptation Programme of Action (NAPA);
b) increase in the observed wind speed by 10%; and
c) landfall during high tide.

The inundation risk maps due to storm surge under baseline and climate change conditions were developed based on model results and finally the vulnerability of the coastal region was assessed based on the inundation risk maps under climate change condition for 2050. In this paper the development of inundation risk map of storm surge under climate change condition, application of MIKE 21 modelling system and assessment of vulnerability of the coastal region of Bangladesh based on the inundation risk map have been discussed.

INTRODUCTION

Almost every year cyclones hit the coastal regions of Bangladesh in pre-monsoon (April-May) or post-monsoon season (October-November). Inundation due to cyclone-induced storm surge poses a threat to lives and properties in the coastal region. A recent analysis by UNDP identified Bangladesh as the most vulnerable country in the world to tropical cyclones (UNDP, 2004). More recently tropical cyclone Sidr in Bangladesh (November 2007) provides example of devastating storm-surge impacts in the coast of Bangladesh. According to the Assessment Report-4 of IPCC, tropical cyclones, storm surges and severe floods are likely to become more frequent and severe in the future as a result of climate change, making Bangladesh even more vulnerable. Institute of Water Modelling (IWM) carried out a study under World Bank, where vulnerability of coastal region of Bangladesh due to cyclone-induced storm surge under climate change condition was assessed and adaptation cost to cope with climate change impacts was estimated. This paper focuses only on the assessment of vulnerability of coastal region of Bangladesh due to cyclone-induced storm surge under climate change.

OBJECTIVES OF THIS PAPER

The main objective of this paper is to assess the vulnerability of the coastal region of Bangladesh and map out the risk of inundation due to cyclone-induced storm surge under climate change condition for the projected year 2050.

STUDY AREA

The study area is the coastal region of Bangladesh, shown in Figure 1. The coastal zone covers 19 out of 64 districts (MoWR, 2005). The country has a coastline of 710 km along the Bay of Bengal. The coastal zone constitutes 32 percent of the area of Bangladesh. Sixty-two percent of the land of the coastal zone has an elevation of up to three meters and 86 percent up to five meters (MoWR, 2005).

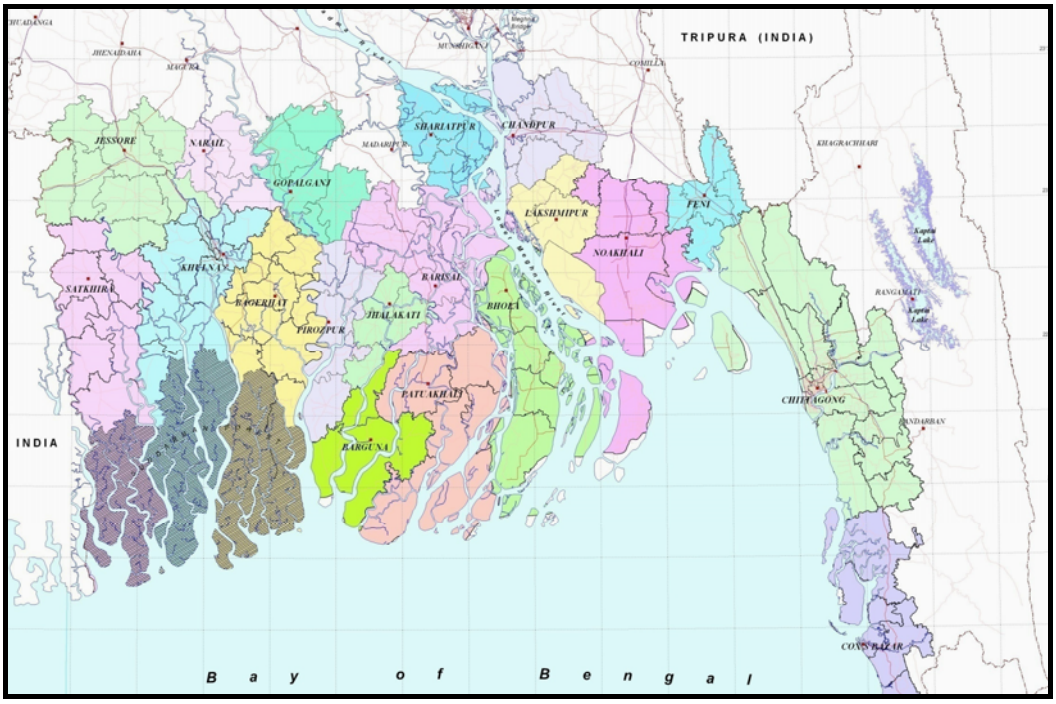

Figure 1: Coastal region of Bangladesh

DATA USED

The study was carried out using secondary data, which are described below.

Cyclones Data

During the period from 1960 to 2009, nineteen (19) cyclones hit the coast of Bangladesh. The most recent one is the Cyclone Aila of 2009. Tracks of major cyclone crossed Bangladesh coast during the period of 1960-2009 is shown in Figure 2 and the information on occurrence month and corresponding maximum wind speed are presented in Table 1. 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 (W_m) and radius to maximum wind (R_m).

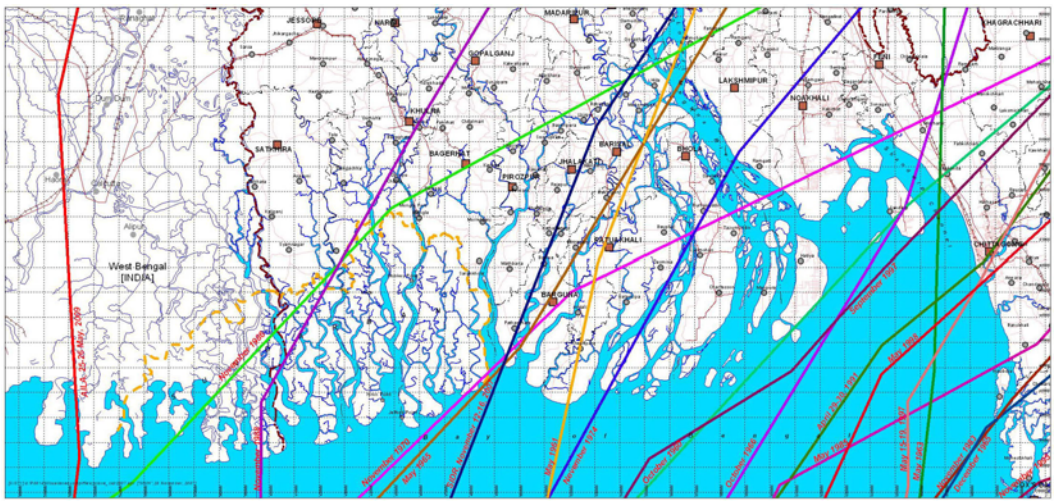

Figure 2: Tracks of major cyclones crossed Bangladeshi coast (1960-2009)

Table 1: Information on historical major cyclones (1960-2009)

Cyclone	Max. Wind Speed (kph)	Loss of Life	Cyclone	Max. Wind Speed (kph)	Loss of Life
Oct-1960	208	5,149	Nov-1986	116	14
May-1961	142	11,468	Nov-1988	150	1,498
May-1963	175	11,520	Apr-1991	224	138,000
May-1965	161	19,270	Nov-1995	110	-
Dec-1965	175	873	May-1997	200	-
Oct-1966	145	850	Sep-1997	150	-
Nov-1970	222	300,000	May-1998	165	-
Nov-1974	161	20	Nov-2007	223	3,363
Nov-1983	122	-	May-2009	95	190
May-1985	145	20			

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

Bathymetry Data
The Bay of Bengal model domain extends from Chandpur to 16º 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.

MODELLING TOOLS APPLIED

The storm surge modelling was done based on the existing two-dimensional Bay of Bengal Model updated, upgraded and calibrated under Comprehensive Disaster Management Programme (CDMP) in 2009.

The storm surge model is the combination of Cyclone and Hydrodynamic models. For simulating the storm surge and associated flooding, the Bay of Bengal model based on MIKE21 hydrodynamic modelling system was adopted. In the hydrodynamic model simulations meteorological forcing like cyclone is given by wind and pressure field derived from the analytical cyclone model. The MIKE 21 modelling 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 two way nested two-dimensional model 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 resolution. Figure 3 shows the nested bathymetry of the Bay of Bengal Model.

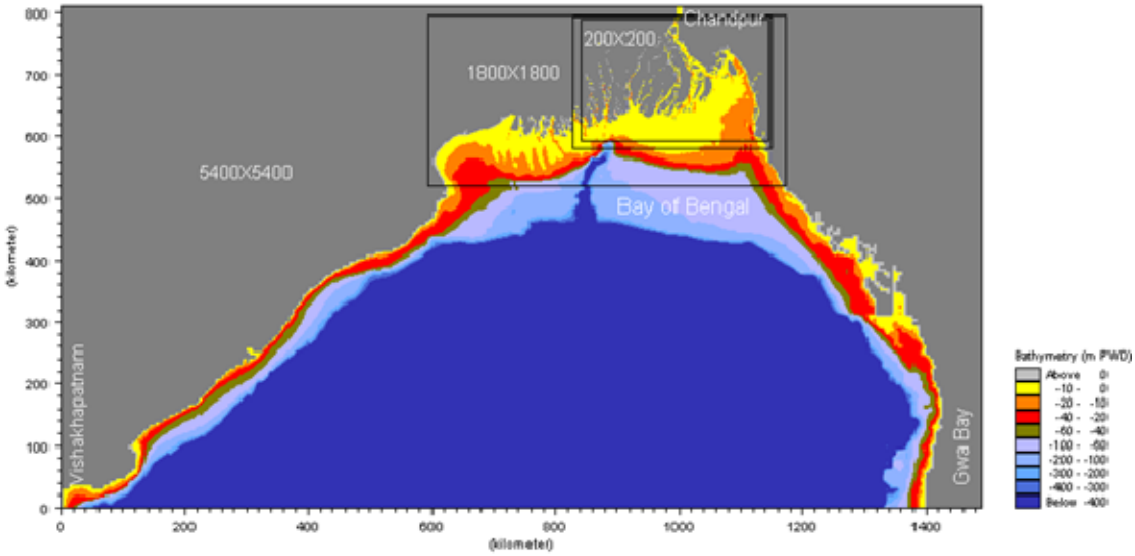

Figure 3: Nested bathymetry of Bay of Bengal Model

A proper cyclone description together with information of land levels is important and essential in order to simulate realistic flood 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.

APPROACH & METHODOLOGY

This study was carried out using the existing data and Bay of Bengal model and the MIKE 21 modelling system. The existing data includes the historical cyclone data, Digital Elevation Model of coastal region of Bangladesh, tide and surge level data and bathymetry of the rivers, the Meghna Estuary and the Bay of Bengal.

Two scenarios wre developed in this study in order to assess the vulnerability: a baseline scenario and climate change scenario for the projected year 2050.

The baseline scenario for cyclone-induced storm surge was developed considering 19 major cyclones making landfall in Bangladesh during the period from 1960 to 2009 together with the corresponding observed wind and pressure fields. The list of cyclones is presented in Table 1.

A second scenario, the climate change scenario, was constructed to assess the combined effect of storm surge and sea level rise for the projected year 2050.

Following assumptions were made in the climate change scenario:

a) sea level rise of 27cm based on National Adaptation Programme of Action (NAPA),
b) increase in the observed wind speed by 10% and
c) landfall during high tide.

The inundation depth and potential vulnerable zone was determined in two steps as follows:

Baseline Scenario:

Firstly, the 19 major cyclones (Table 1) were simulated with the existing the 2D Bay of Bengal model and the maximum inundation map for each cyclone were generated based on the simulation result. The model is based on MIKE 21 hydrodynamic modelling system. Secondly, an inundation risk map was generated based on the simulation results of 19 cyclones using GIS tool. In this scenario, all the cyclone tracks with corresponding observed pressure and wind fields were used.

Climate Change Scenario:

This scenario used 5 potential cyclone tracks consisting of the 4 large cyclones of 1988, 2007, 1974 and 1991- that spans the Sunderban coast, the southwestern coast (Sunderban to Patuakhali), the Bhola and Noakhali coast and the eastern coast (Shitakunda to Bashkhali) respectively – and an artificial cyclone track to cover the coasts located in the central part of the Meghna Estuary. Figure 4 shows the five cyclone tracks considered for the determination of inundation zones due to climate change induced storm surges.

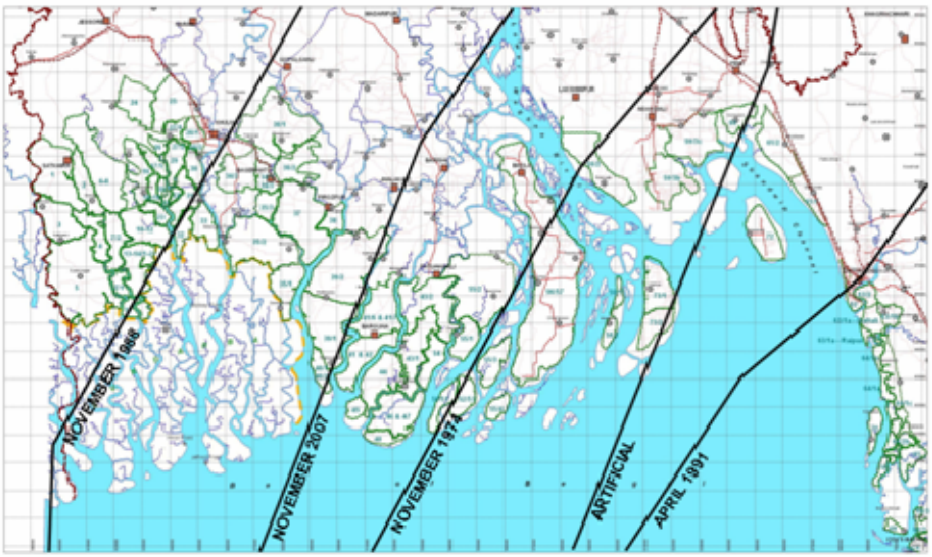

Figure 4: Cyclone tracks considered for assessment of the combined effects of cyclone-induced storm surge and SLR

In this scenario, the meteorological parameters of cyclone Sidr (2007) was used in all the cyclones and the landfall was considered during High Tide.

Inundation risk maps for climate change condition was generated based on the simulation results of the 5 cyclones taking into account the maximum level of inundation at every grid points of the model using GIS tool.

Finally, the vulnerability of the coastal region of Bangladesh due to storm surge under climate change condition was assessed based on the inundation risk maps.

ASSESSMENT OF VULNERABILITY USING MODEL RESULTS

Two scenarios were considered for the assessment of vulnerability of the coastal region of Bangladesh due to storm surge under climate change condition:

> *Baseline Scenario:* 19 historical cyclone tracks with actual observed meteorological parameters (Maximum wind speed; radius of influence, cyclone tracks, forward speed and direction and central and neutral pressure).
>
> *Climate Change Scenario (Projected year 2050):* Five cyclone tracks to span the coast line, meteorological parameters of cyclone Sidr, 10% increase in wind speed, 27 cm sea level rise, Land fall at high tide.

In the baseline scenario 19 cyclones were simulated with the Bay of Bengal model using MIKE 21 modelling system. Based on the simulation results of 19 cyclones an inundation risk map for the baseline scenario was generated. The method has been discussed in the previous section. In the climate change scenario, five cyclone tracks were simulated with the meteorological parameters of cyclone Sidr increasing wind speed by 10%, landfall time during high tide and incorporating climate change condition for 2050. Maximum inundation maps for all the cyclones were prepared using MIKE 21 modelling system. Then those maps were combined together using GIS tool to prepare inundation risk map for climate change condition (2050).

The inundation risk maps for baseline scenario and climate change scenario (2050) are presented Figure 5 and Figure 6.

In the figures the inundation depths are presented in two classes: low risk area, which is less than 1m inundation depth and shown in blue colour and high risk area, which is equal to or greater than 1 m inundation depth and shown in red colour.

According to the past study titled "Multipurpose Cyclone Shelter Programme", the high risk area extends from the coastline up to a limit where the depth of storm surge inundation may reach one metre (MCSP, 1993). In this study same definition has been used.

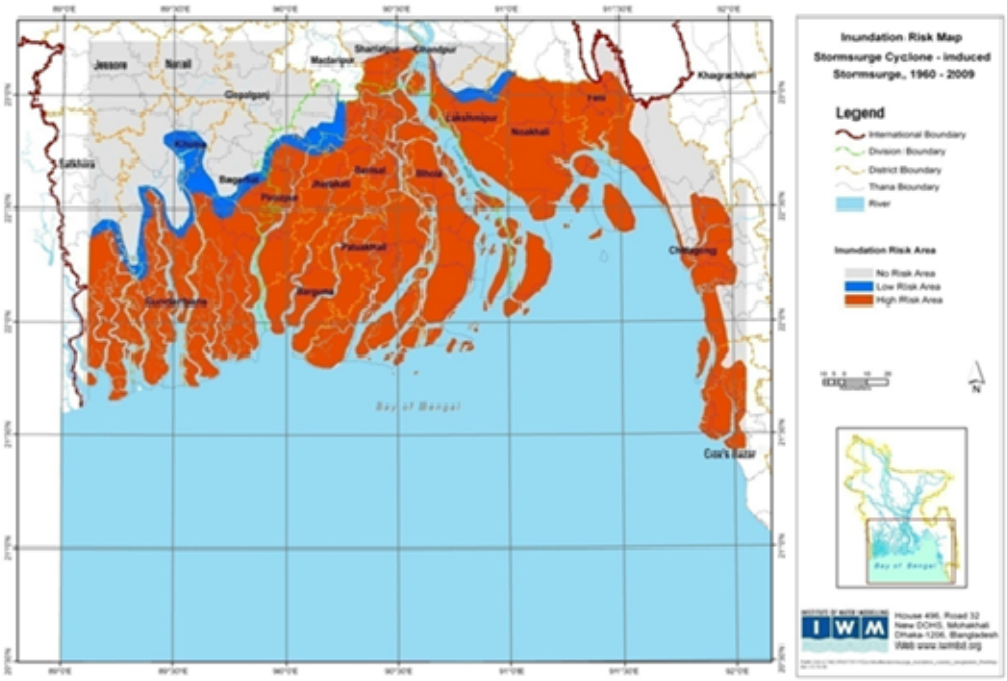

Figure 5: Inundation risk map for baseline condition.

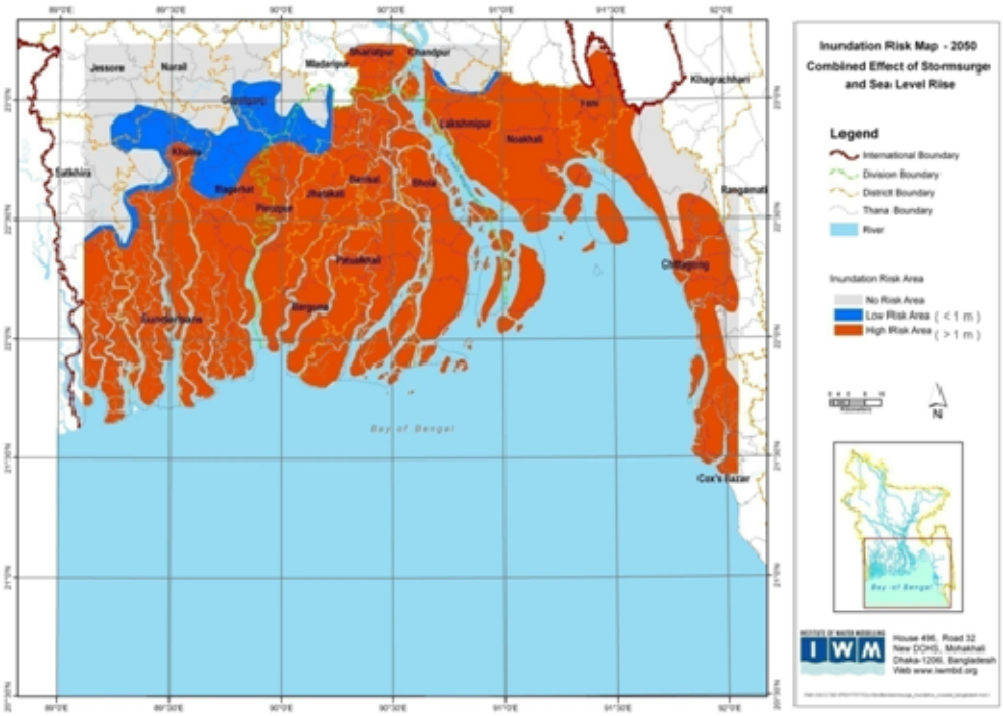

Figure 6: Inundation risk map having two inundation class for combined effect of storm surge and sea level rise for the projected year 2050

A comparison is made between the two inundation risk maps and the difference in high risk area between the two maps are presented in Table 1. It shows that the high risk area (i.e. greater than 1 meter) under climate change condition (2050) is 2,376,362 ha, which is 14% greater than the baseline scenario. The

very high risk area (i.e. inundation depth greater than 3 m) under climate change condition (2050) is 1,719,275 ha, which is 69% greater than the baseline scenario.

Table 1: Comparison of high risk area between two scenarios

Inundation Depth (m)	High Risk Area of Inundation (ha)		
	Baseline Scenario (without climate change)	Climate Change Scenario (2050)	% Increase
More than 1 m	2,087,607	2,376,362	+14 %
More than 3 m	1,016,298	1,719,275	+69 %

In order to assess the vulnerability of the coastal region, the inundation risk map for climate change condition (2050) is presented again in Figure 4 with three diffrent classes of inundation depth: 1- 3m , 3-6 m and more than 6 m. The figure shows that the Meghna estuarine region is the area where most of the surge amplification occurs, which includes Noakhali coast, part of Bhola island, Sandwip and other islands in the Meghna estuary, Shitakunda coast, Kutubdia island, Anwara and Bashkhali. This area experiences maximum inundation depth, which is greater than 6 m due to cyclone-induced storm surge under climate change condition (2050).

The maximum inundation depth varies from 3m to 6m in the western coast and Cox's Bazar area. The extend of high risk area (i.e. > 1 m) moves further inland under climate change condition.

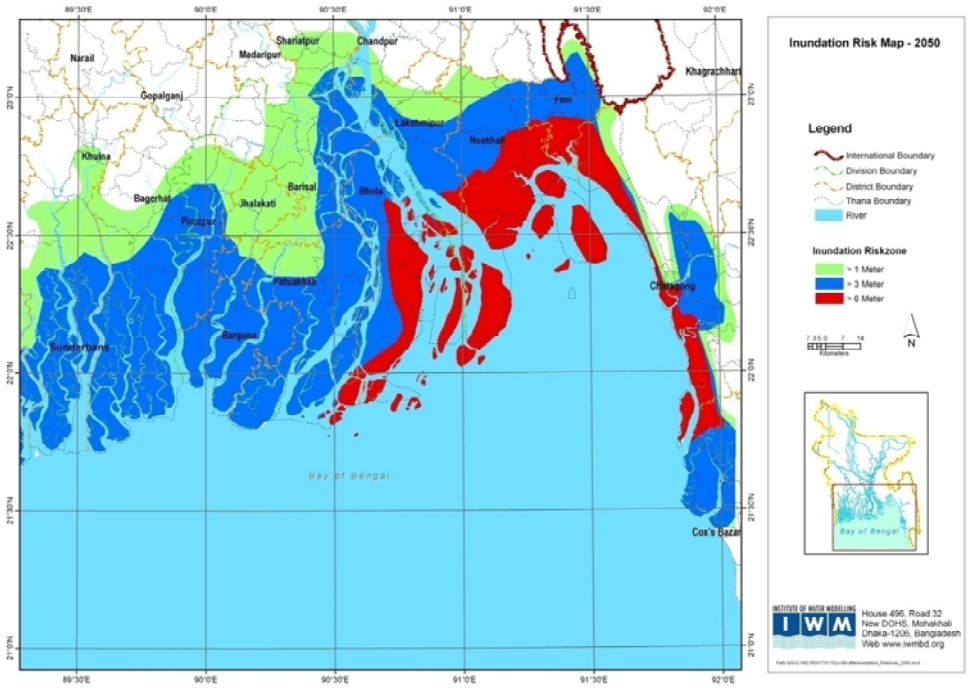

Figure 4: Inundation risk map (in three categories) for combined effect of storm surge and sea level rise for the projected year 2050

CONCLUSIONS

The model results clearly show that the vulnerability of the coastal region of Bangaldesh due to cyclone-induced storm surge increases under climate change condition (2050). The most affected area is the Meghan Estuary region.

The high risk area (i.e. greater than 1 meter) under climate change condition (2050) increases by 14% and the very high risk area (here considered greater than 3 m inundation depth) under climate change condition (2050) increases by 69% with respect to baseline scenario.

These findings may be used in formulating future adaptation measure for reducing the vulnerability of the coastal region of Bangladesh due to storm surge under climate change condition.

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