Impact of Sea level Rise on Coastal Rivers of Bangladesh

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ABSTRACT

Increasing rates of sea level rise caused by global warming are expected to lead to permanent inundation, drainage congestion, salinity intrusion and frequent storm surge inundation. Sea level rise is a growing threat for the coastal regions of Bangladesh. Bangladesh is one of the most densely populated countries of the world where 28% of the population living in the coastal area. Natural disasters have their roots in the nature of its terrain, the physical geographic features, its long coastline and the tropical climate. This study presents an assessment of the expected impacts on inundation, salinity intrusion, cyclone induced storm surge inundation due to sea level rise. The study projects the future sea level rise based on global scenarios and apply them to well proven numerical model to delineate the extent to which Bangladesh coast is vulnerable. The study estimates that about 11% more land will be permanently inundated over the next century. Sundarbans, the Ramsar site will be lost due to high salinity and permanent inundation from projected sea level rise by 2100. An increase of wind speed over 10% of the 1991 severe cyclone will increase the storm surge level by 1.7 m along the eastern coast of Bangladesh.

1.0 INTRODUCTION

Bangladesh is one of the most densely populated countries of the world where 28% of the population living in the coastal area. It is prone to natural disasters, such as cyclone, storm surges, flood etc. On top of these, the zone is vulnerable to earthquake, tsunami and enhanced sea level rise due to climate change. Natural disasters in Bangladesh have their roots in the nature of its terrain, the physical geographic features, its long coastline and the tropical climate.

A significant global-mean sea level rise is expected due to human-induced warming during the 21st century. In the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) the projected rise from 1990 to 2100 was 9 to 88 cm. Sea level rise raises significant concern due to the high concentration of natural and socio-economic assets in the coastal zone of Bangladesh.

Bangladesh has 710 km long coastline. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast is between 37 and 57 km. The coastal zone is low-lying with 62% of the land have an elevation of up to 3 metres and 86% up to 5 metres. The Bay of Bengal is a northern extended arm of the Indian Ocean. In the north of Bay of Bengal, “Swatch of No Ground”, a submarine canyon present at 25 km south of the western coastline of Bangladesh.

The coastal zone has several ecosystems that have important conservation value: mangrove, marine, estuary, islands, coral, sandy beaches which provides habitat for an abundance of plant species as well as an array of fish and wildlife. The world’s largest uninterrupted stretch of mangrove ecosystem, the Sundarbans, has been declared in 1997 as Ramsar Site, a World Heritage needs to be conserved.

The coastal region of Bangladesh has 123 embanked polders, which were constructed in late sixties to protect the land from saline water and to increase the crop production. Figure 1 shows the coastal region of Bangladesh.

A host of descriptive and empirical studies has considered the national and regional impacts of sea level rise in the coastal zone of Bangladesh. In the present paper impact of climate change as sea level rise (SLR) has been assessed using a suite of mathematical models developed for Bay of Bengal and Bangladesh coast. Afterwards, particular impact has been identified on inundation, salinity intrusion, and cyclone and storm surges due to sea level rise. The model is based on MIKE11, MIKE21 software developed by DHI Water & Environment, Denmark.

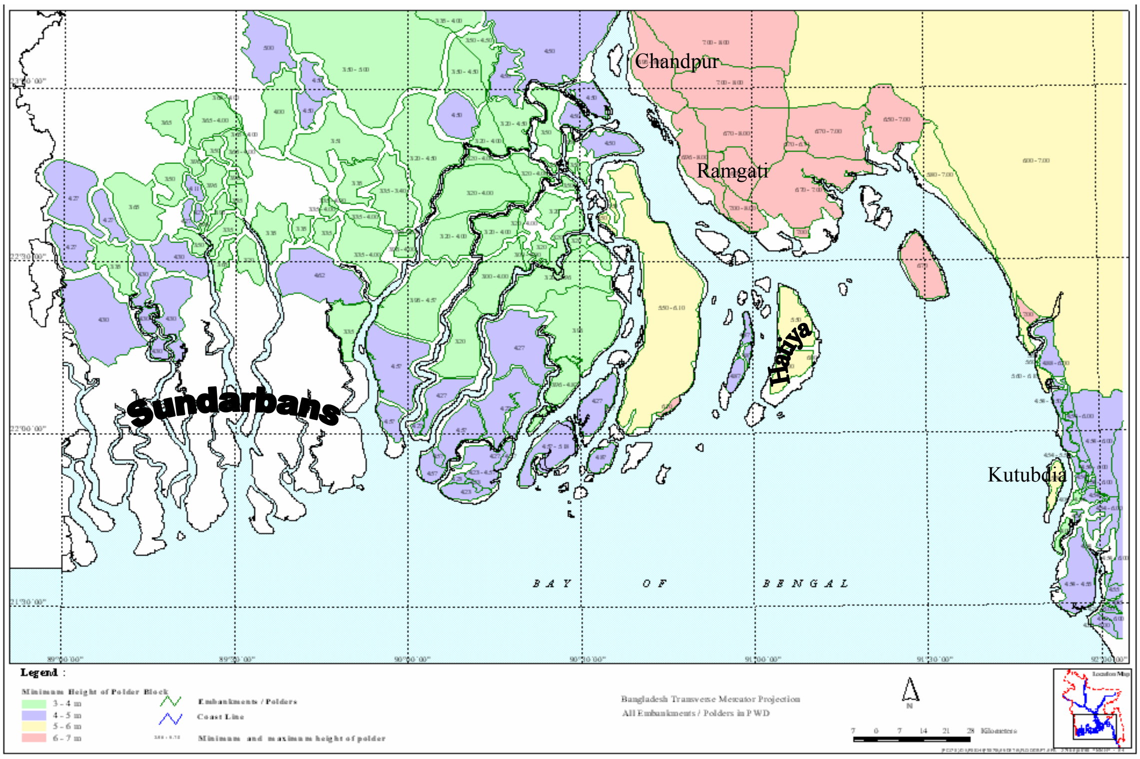

Figure 1. Coastal region of Bangladesh

2.0 METHODOLOGY

2.1 Sea Level Rise Projections

The Third Assessment Report (TAR) of IPCC indicates that the global sea level rise is 9 cm to 88 cm from 1999 to 2100. The SAARC Meteorological Research Centre (SMRC) analysed sea level changes of 22 years historical tide data at three tide gauge locations in the coast of Bangladesh. The study revealed that the rate of sea level rise during last 22 years is many fold higher than the mean rate of global sea level rise over 100 years.

A study by Ahmed and Alam (1998) mentioned one meter change of sea level by the middle of 21st century; it combines a 90 cm rise in sea level and about 10 cm local rise due to subsidence.

Pilot study of Department of Environment mentioned (DOE, 1993) a potential future sea level rise for Bangladesh is 30-50 cm by 2050. An increasing tendency in sea level rise from west to east along the coast has also been found (Singh et al., 2000).

National Adaptation Programme for Action (NAPA, 2005) Team on the basis of 3rd IPCC report and prediction of SAARC Meteorological Research Centre has established the likely climate change and sea level rise scenarios for Bangladesh. Table 1 illustrates those scenarios.

Table 1. Climate Change scenarios for Bangladesh

Year	Temperature change (^{0}C) mean		Precipitation change (%) mean		Sea level rise (cm)		
	Monsoon season	Dry season	Monsoon season	Dry season	3rd IPCC (upper range)	SMRC	NAPA scenario
2030	0.8	1.1	+6.0	-2.0	14	18	14
2050	1.1	1.6	+8.0	-5.0	32	30	32
2100	1.9	2.7	+12.0	-10.0	88	60	88

For the above sea level rise projections, this study focuses its analysis based on 14 cm, 32 cm and 88 cm rise in 2030, 2050 and 2100.

2.2 Model of Sea Level Rise

A two-dimensional model of the northern Bay of Bengal and Meghna Estuary and the one-dimensional model for the rivers in the coastal area has been used to assess the sea level impact for the present study. The Bay of Bengal model is used to transfer the sea level rise in the deep sea to the coast of Bangladesh whereas the propagation of tide in the rivers and flood plain are modelled using river model.

MIKE21 is used for the two-dimensional modelling and MIKE11 is used for the one-dimensional modelling. The land elevation is based on national digital elevation model (DEM). The DEM were created from FINNMAP surveyed data projected on Bangladesh Transverse Mercator Projection system. The models are referenced vertically to Public Works Datum (PWD).

Applying projected sea level rise as boundary condition in the Bay of Bengal, the corresponding rise along the coast will be propagated through the rivers. The inundation or salinity intrusion over the coastal region is represented by interpolating the adjacent river water level and overlaying on the digital elevation model.

This study was carried out in regional scale and has limitations. First, the models characterize a fixed representation based on land elevation and are not able to represent future shorelines. They do not consider land subsidence, erosion, accretion and other natural adaptations. Nor are they able to incorporate future development or human response to sea level rise. Despite the limitations, the models illustrate the position of land areas susceptible to sea level rise and allow for plausible characterizations of the potential impacts on the Bangladesh coastal zone and rivers.

Bay of Bengal Model (BoBM)

The nature is represented in the model in a simplified way in discrete points at finite distances where flow and transport parameters are calculated/predicted by a mathematical model inside the area of interest (i.e., the discrete description in a model replaces the continuous description in real life) depending on the flow and transport parameters/variables imposed at the boundaries.

This model is founded on a combination of specific information on the region, i.e. bathymetry, topography, wind and water level etc., and a general numerical 2-dimensional model named MIKE21. The governing equations used in MIKE 21 in solving hydraulic problems in coastal areas are:

Conservation of Mass Equation

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0;$$ Inflow- Outflow = Change in control volume

Conservation of momentum equation

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

$$\frac{\partial p}{\partial t}+\frac{\partial\left(p^2/h\right)}{\partial x}+\frac{\partial\left(pq/h\right)}{\partial y}+gh\frac{\partial \varepsilon}{\partial x}+\frac{f}{2}\frac{\sqrt{p^2+q^2}}{h^2}p-\frac{1}{\rho}\frac{\partial \tau_{xy}h}{\partial y}-\Omega q-\frac{\rho_a}{\rho}C_w WW_x+\frac{h}{\rho}\frac{\partial p_a}{\partial x}=0$$

I II III IV V VI VII VIII IX

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

$$\frac{\partial q}{\partial t}+\frac{\partial\left(q^2/h\right)}{\partial y}+\frac{\partial\left(pq/h\right)}{\partial x}+gh\frac{\partial \varepsilon}{\partial y}+\frac{f}{2}\frac{\sqrt{p^2+q^2}}{h^2}q-\frac{1}{\rho}\frac{\partial \tau_{yx}h}{\partial x}+\Omega p-\frac{\rho_a}{\rho}C_w WW_y+\frac{h}{\rho}\frac{\partial p_a}{\partial y}=0$$

I II III IV V VI VII VIII IX

Where,

p and q	flux in x and y directions respectively ($m^3/s/m$).
t	time (s), x and y (m) are Cartesian Co –ordinate (s).
h	water depth (m).
g	acceleration due to gravity (9.81 m^2/s) .
ε	sea surface elevation (m).
ρ_w & ρ_a	air and water density respectively (kg /m^3),
C_w	wind friction factor = 0.0008 + 0.000065W in accordance with Wu (1982).
W	wind speed (m/s).
Ω	Coriolis parameter =$5.2*10^{-5}$ s^{-1} in the Bay of Bengal.
P_a	atmospheric pressure ($kg/m/s^2$).

The following terms in equations implies:

I	local acceleration
II & III	advection
IV	pressure gradient
V	bed friction
VI	shear stress
VII	Coriolis force
VIII	wind friction
IX	air pressure gradient

The BOB model has been calibrated for 1996, 1997 dry, monsoon season and validated for 1999, 2000 dry and monsoon season. The model has been calibrated and validated against measured water level and discharge and sample plot is presented in **Figure 2**. This calibrated model has been used to simulate the impact for 14 cm, 32 cm and 88 cm sea level rise on inundation, drainage congestion, salinity intrusion and storm surge.

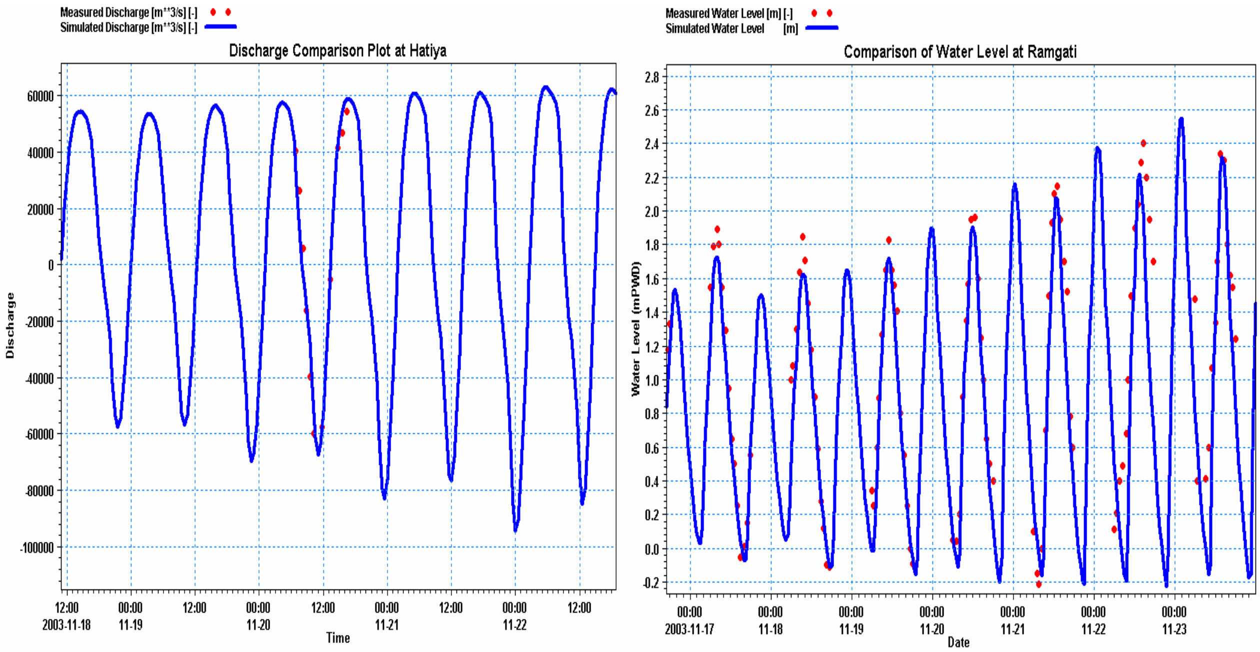

Figure 2. Calibration of the model against flow and water level

3.0 EFFECTS OF SEA LEVEL RISE

3.1 Coastal Inundation

The most obvious outcome of sea level rise is the permanent inundation of coastal areas. Inundation refers to the shoreline retreats as low-lying areas are gradually submerged by ocean waters. Over time inundation changes the coast line and drowns natural habitats and human structures. Mathematical models of the Bay of Bengal have been used to translate SLR of the deep sea, to the inland tidal river network and the Meghna Estuary region. One-dimensional model for inland tidal rivers and two-dimensional model for Meghna Estuary have been used to generate data for analysis of the existing and different SLR scenarios in the coast.

The result shows that, in the year 2100 at 88 cm SLR, about 11% area (4,107 km^2) of the coastal zone will be inundated in addition to the inundated area in the year 2000 under same upstream flows. It is found that most of the increases in the flooded area are in the shallow land. Seawater will enter at Chandpur, about 80 km upstream from estuary. This rise will be about 50 cm for 88 cm SLR and 15 cm for 32 cm SLR (Figure 3). Due to 32 cm SLR, 84% of the Sundarbans (the Ramsar site) will be deeply inundated 2050 and in 2100, for 88 cm SLR the whole of Sundarbans will be lost. The forest floor, however, may be experiencing a natural uplift at a rate similar to the anticipated rate of sea level change. Whether natural uplift is strong enough to counterbalance sea level rise is very uncertain.

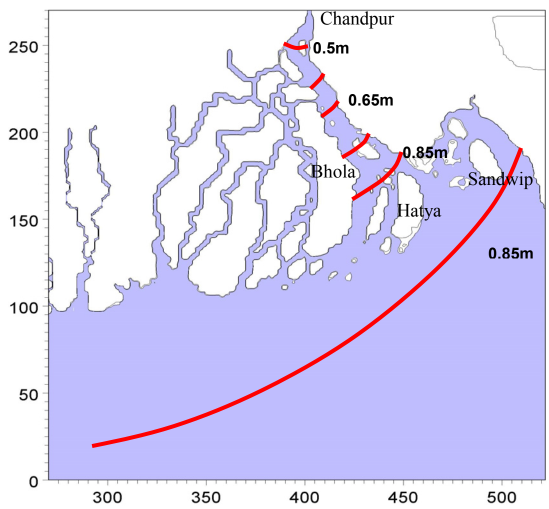

Figure 3. Rise of water level due to 88 cm SLR

3.2 Salinity Intrusion

As sea level continues to rise the associated effects of permanent inundation is likely to increase the salinity near coastal areas. The study also shows that 5 ppt saline front will penetrate about 40 km inland for SLR of 88 cm which is going to affect the only fresh-water pocket of the Tentulia River in Meghna Estuary as shown in Figure 4. A big chunk of the fresh-water zone that will be disappearing due to sea level rise near to the estuary will have a far reaching effect on the country's ecology and will extinct some of its endangered species (marked by IUCN) for ever.

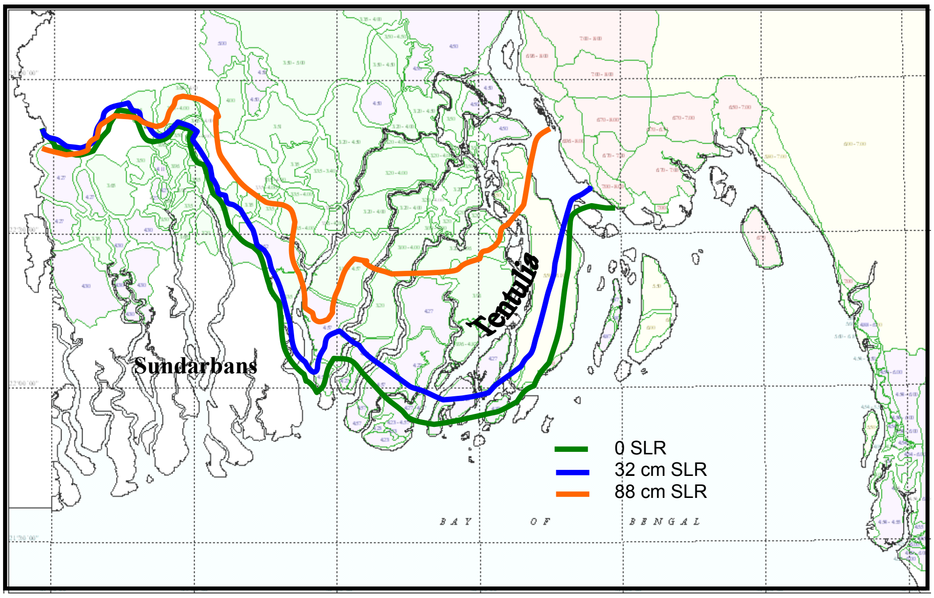

Figure 4. Five ppt line for different sea level rise in dry season

Increased salinity intrusion due to sea level rise poses great threat to the Sundarbans. The Sundarbans has already been affected due to reduced freshwater flows through Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing the different species of plants and animals to be adversely affected. Increased salt water intrusion is considered as one of the causes of top dying of Sundari trees. The impact of sea level rise will further intrude the saline water to landward. Sea level rise of 32 cm will intrude 10 to 20 ppt salinity level more in the Sundrabans. The rate of salt water intrusion will also affect the ability of the ecosystem to adapt.

3.3 Drainage Congestion

The drainage of coastal polders mainly depends on the tidal characteristics of the surrounding rivers and degree of siltation of these rivers. Present study mainly focussed the change in the tidal characteristics of the surrounding rivers due to sea level rise and its impact on inundation area of the polder.

The result shows (Figure 5) that high water level at the surrounding rivers of polders increases in the range of 30-80 cm for sea level rise of 32 cm and 88 cm respectively. This rise will eventually hamper the smooth drainage of a number of polders. Inundation area in few polders causing drainage congestion due to sea level rise is presented in Table 2.

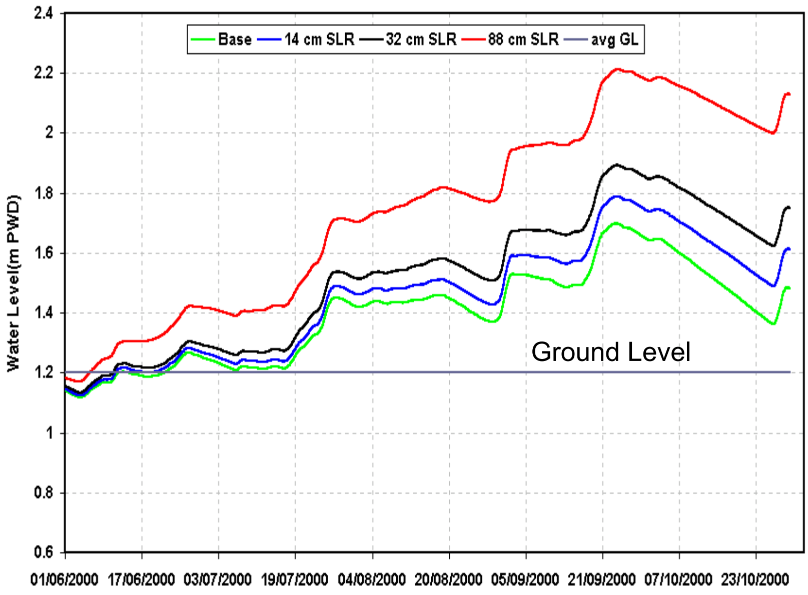

Figure 5. Performance of polder 36/2 for Sea Level Rise

Table 2. Maximum inundation Area (3 day duration) above 30 cm in October

Polder No.	Total area [ha]	Area [ha] SLR 0 cm	Area [ha] SLR 32 cm	Area [ha] SLR 88 cm
P-25	17,594	600	1,600	2,800
P-36/2	13,322	3,000	5,300	whole area inundated
P-37	36,539	0	4,500	10,000

Sea level rise will deteriorate drainage conditions to a large extent. 17 polders out of 35 will be facing acute drainage congestion where present performance of these polders is satisfactory. Figure 6 shows these vulnerable polders for sea level rise.

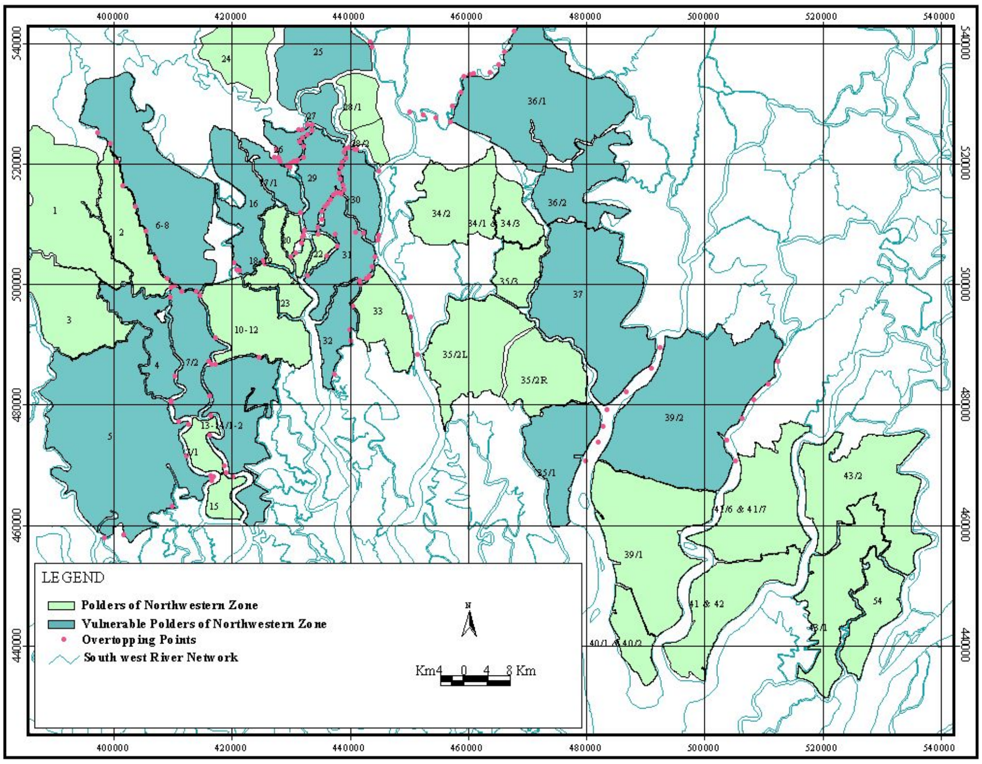

Figure 6. Drainage congestion affected polders due to sea level rise

3.4 Cyclone Storm Surge

This study finds that for the cyclone induced storm surges along with sea level rise (32 cm) inundated delta area would increases from 42% to 51.2% in case of occurrence of 1991 cyclone, which had erased about 150,000 people from its coastal region.

A 10% increase in wind speed of 1991 cyclone along with 32 cm SLR, will increase the surge height by 1.2-1.7 m near Kutubdia-Cox's Bazar, eastern coast of Bangladesh. The population and area inundated rise significantly when considering increased flood risk due to storm surge.

4.0 CONCLUSIONS

Accelerated sea level rise, driven by global climate change, will continue to affect Bangladesh coast through permanent inundation, drainage congestion in the polders, storm surge inundation and increased salinity intrusion of low-lying areas. As a result, a wide range of impacts on socio-economic and natural systems is anticipated, including increased damage to property and infrastructure, net loss of coastal wetlands and coastline, declines in coastal bird and wildlife populations.

The study of sea level rise and its impact on coastal zone in Bangladesh and the world remains limited due to the low resolution of digital elevation data for coastal regions.

However, the past and current affect of sea level rise along the Bangladesh coast are apparent. What is much less obvious and more difficult to predict is the future impact of increasing rates of sea level rise and climate change on the country's valuable socioeconomic and natural systems. This study, based on plausible projections, has assessed the susceptibility of the country's coastal areas to the effects of inundation, flooding and saline intrusion. What is evident from the study is that action needs to be taken immediately and at many levels. Strategies and initiatives which address coastal management at the state and national level are vital.

Acknowledgment

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