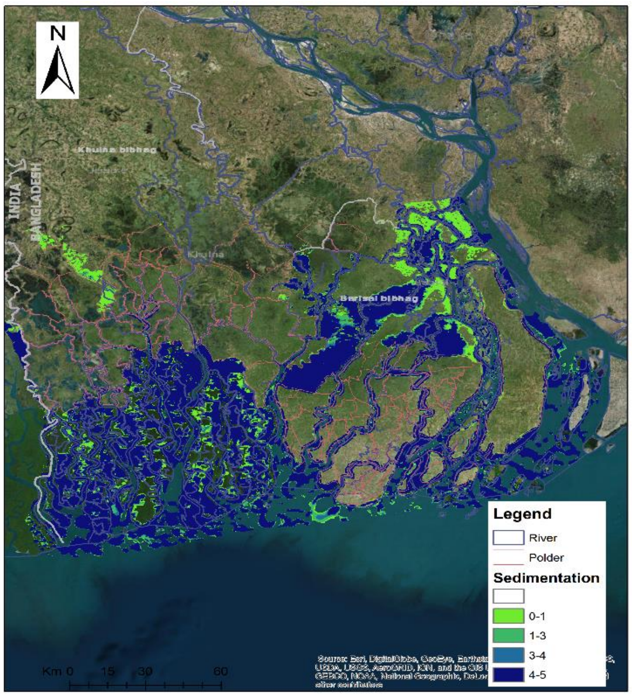
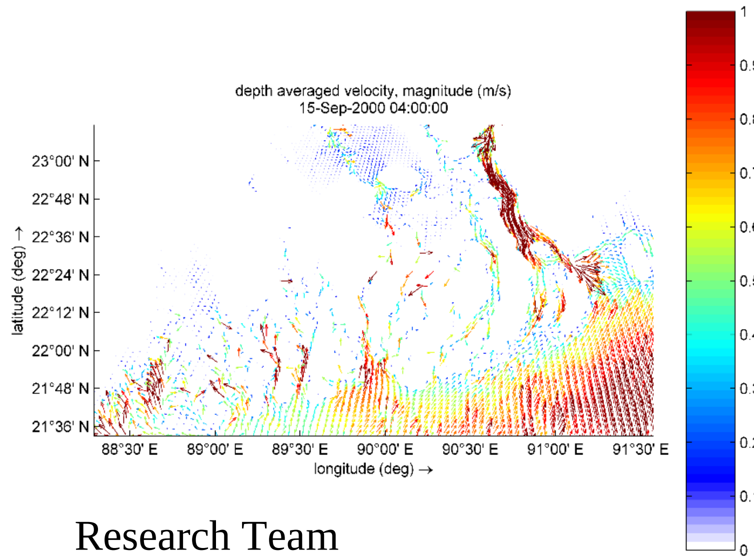
Research on the Morphological processes under Climate Changes, Sea Level Rise and Anthropogenic Intervention in the coastal zone.

Final Report
March 2019





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Executive Summary

Introduction

The patterns of water and sediment flows determine the nature of coastal floodplain sedimentation, and thus, affect the delta building processes in the region. The floodplain sedimentation, in turn, dictates the magnitude and extent of net subsidence and uplift in the GBM delta (Elahi et al., 2015). A number of studies have so far been conducted in the region to determine magnitude of subsidence (Brown et al., 2015). Few studies are performed to study the patterns of water and sediment flows (Haque et al, 2016). Study on future sediment load in the region predicted a possible increase of sediment supply from upstream catchments (Darby et al., 2015), and another study reveals possible impact of sediment load on coastal floodplain sedimentation (Elahi et al., 2015). A recent study reveals the volume of sediment that enters into the region (Rahman et el, 2018). But no study has yet to perform to study re-distribution of these incoming sediments in the coastal floodplain.

Polders are encircled embankment which were constructed in the coastal zone of Bangladesh during early sixties. Polders are generally believed to cause water-logging inside the protected land due to sedimentation in the peripheral rivers. But it is still unknown how these polders affect re-distribution of coastal floodplain sedimentation in the region. Also, a detail understanding of the process of water-logging due to sedimentation of peripheral rivers is also lacking.

Considering all these, this study has two broad objectives: (a) Macro-level study on floodplain sedimentation and (b) Micro-level study on water-logging. The specific objectives are:

1. Sediment distribution on the coastal floodplain due to different flooding scenario
2. Impact of water-logging inside polders due to sedimentation in peripheral rivers

Study Area

For both macro-level and micro-level study, the study area selected is the coastal region of Bangladesh. For the macro-level study on coastal floodplain sedimentation, the entire coastal region of Bangladesh is considered except the eastern part of Lower Meghna estuary. For the micro-level study on water-logging, polders 24 and 25 are selected which is situated on the western part of the coastal region.

Estuarine Systems of the Coastal Region

The discharges coming from the Ganges, Brahmaputra and Upper Meghna rivers drain through the complicated estuarine networks in the south west region of Bangladesh. The combined flows of Ganges and Brahmaputra rivers comes through the Padma river and after joining with Upper Meghna, the bulk of the combined flow discharges through the Lower Meghna estuary. The estuarine systems receive the freshwater flow from the above rivers, mix with saline water due to large tidal prism and eventually discharge into the Bay of Bengal. The eastern part of these estuarine systems is known as Eastern Estuarine System (EES), the central part is known as Central Estuarine Systems (CES) and the western part is known as the Western Estuarine System (WES).

Flow and Sediment Distribution Patterns in the Coastal Zone

Haque et al (2016) made a detailed assessment on the flow and sediment distribution patterns in the coastal zone of Bangladesh (which is the study area in present study). The study shows that Lower Meghna estuary is a predominantly ebb-dominated channel. The rest of the channels of the EES are flood-dominated. For the CES, all the channels are ebb-dominated and for the WES, the channels are flood dominated. These systems have created two clockwise-rotating estuarine circulation patterns. In one system the Lower Meghna and the associated channels of EES makes a clockwise circulation. The other system is the main circulation system that consists of all the three estuarine systems. The flows come down from the Lower Meghna and the CES systems, turn clockwise, and re-enter into WES systems. The dominant contributor of freshwater flow for the EES is the Lower Meghna estuary, for the CES is the Brahmaputra River and for the WES is the Ganges River. The Lower Meghna estuary carries the combined discharge of the Ganges, the Brahmaputra and the Upper Meghna. So, the sediment of the Lower Meghna estuary is the combined sediments from these major river systems. The upstream sediment source of the CES is basically from the Brahmaputra River, whereas, for WES, it is the Ganges River. As most of the sediments are carried during the monsoon and EES receives the maximum amount of share among the three systems, the EES will carry the bulk of the sediments coming from the major river systems of the GBM delta during monsoon. On the other hand, the share of CES increases during the dry period. So, it is expected that, whatever sediments are coming to the system during the dry period, CES carries a significant part of it, specially, the sediments contributed by the Brahmaputra river. These features dictate the nature of sediment circulation pattern in the study area.

Coastal Floodplain Sedimentation

The morphology module of the Delft 3D is applied to compute coastal floodplain sedimentation and associated changes in the flow field. The module of Delft 3D solves the morphological variables which are coupled with the flow parameters (the flow model version of Delft 3D). In this way, any changes in the river and floodplain morphology that affects the flow field and vice versa is simulated.

For sediment inputs to the system, model needs to specify sediment concentration both at upstream rivers and downstream ocean of the model domain. For upstream rivers, measured sediment concentrations (although scattered) are available. But for downstream ocean, no data is available. So, specification of ocean sediment concentration becomes an uncertain parameter for a morphology model application in Bangladesh coast. Sediment composition (percent fraction of cohesive and non-cohesive sediments) is another uncertain parameter for morphology model to be applied in Bangladesh coastal zone. These two uncertain parameters are determined by executing several numerical experiments by comparing the experiment results with available values from literature. Clockwise oceanic circulation in Lower Meghna estuarine systems cause re-entry of oceanic sediments into the estuarine systems. But this circulation does not necessarily drive the sediments further south in the ocean. Numerical experiment results show that ocean sediment concentration in deep ocean far from the coast (near the Sri Lanka coastline) is nearly zero. Numerical experiment results also show that sediment size distribution in the study region is composed with 30% cohesive sediments and 70% non-cohesive sediments. Numerical experiment results also show high spatial variability of sediments on the floodplain in the study region.

Model simulation shows that in an average flood year, about 21.8% of total incoming sediments are deposited on the floodplain. This value is on the lower range of what the secondary literature says (30% to 40% of total incoming sediments are deposited on the floodplain). But it should be noted here that the secondary literature did not consider the spatial variability of floodplain sedimentation and also did not consider the process of sedimentation impacted by polders.

Sedimentation during average flood condition

The flooding considered here is the monsoon flooding during an average flood year which is year 2000 (BWDB, 2015). The main drivers of flooding are the fluvial flow and the tidal flow. The polders in the region has restricted the sediment laden water during monsoon to enter inside the poldered area (except in the central region where there is no polder). Simulation results shows that floodplain sedimentation is mainly confined in the un-protected areas. An average flood condition does not result extensive flooding in the poldered area had there been no polder. Polders restrict the inundation extent but increase the flood depth in unprotected areas. Restricted flooding cause increased sedimentation in unprotected areas. When there is no polder, same volume of flood water is distributed in the entire region causing increase of flood extent but decrease of flood depth. This causes sedimentation in a wider area with decreased sedimentation depth.

Sedimentation during extreme flood condition

Following the BWDB definition (BWDB, 2012), the extreme flood in this case selected as the flood of 1998. During an extreme flood condition, almost all the unprotected region is flooded. This flooding causes sedimentation in the areas which are not protected by polders. When polders are removed, the entire region is flooded. This flooding is associated with the sedimentation in the region. When compared with the average flood condition, areal extents of flooding and sedimentation is significantly larger. This shows the importance of polder in the region when flooding is considered. Polders are effective in protecting the areas which are poldered during an extreme flood. If there were no polders, the entire region would have been flooded during an extreme flood condition. In terms of sedimentation, if polders were not there, sedimentation increases with the increase of flooding intensity.

Sedimentation during end-century flood condition

An end-century flood condition is created for the year 2088 with a sea level rise of 1m. Incoming sediment load into the system is represented by model simulation values (Darby et al., 2015). Inundation scenario during the end-century looks almost similar to an extreme flood scenario but sedimentation (confined within the unprotected land) during end-century scenario is remarkably high compared to extreme flood scenario.

Impact of Polders on Floodplain Sedimentation

Polders restrict the sedimentation within the unprotected lands. The extent and depth of sedimentation depends on the areal extent of inundation during flood and volume of incoming sediments. Had there been no polders in the region, the same volume of flood water and sediments that enter in the region is re-distributed over a wider area. On the western floodplain, where water-logging is believed to be due to restricted sedimentation due to polders, shows that during an average flood year, percentage of sediment retention on the floodplain increases from 11.2% to 14.6% of the total incoming sediments when polders are removed from the system. These values are 49.8% and 59.2% for an extreme flood year. On average, on the western floodplain, polders restrict 14 Million Ton/Year of sediments in an average flood year to 108 Million Ton/Year in an extreme flood year. Without any polder, this additional amount of sediment could contribute to the delta building process and to rise the land elevation alleviating most of the present-day water-logging problems. But at the same time, absence of polders will cause large area of the region to be flooded with fluvial and tidal flows during monsoon.

Seasonal Distribution Patterns of Sediments

Residual flow circulation pattern largely determines the sedimentation in the study area. Residual circulation, on the other hand, depends on the seasonal circulation pattern. It is seen that during pre-monsoon, the flow circulation velocity is low (velocity less than 0.5 m/s). Sediments are yet to start entering in the region. Fluvial inundation is almost non-existent. There is no sedimentation in the floodplain. During monsoon, inundation due to fluvial and fluvio-tidal flood is observed. Both flood and ebb velocity increase (velocity greater than 1m/s). Sediments start to enter in the region from upstream during ebb tide and re-enter in the region during flood tide. In places where velocity is relatively low (north-central), sedimentation starts to occur. The main sedimentation occurs during post-monsoon when sediment laden water velocity in the inundated region is very low (less than 0.5 m/s). This low velocity accelerates the sedimentation process in the floodplain. Inflow of sediments from upstream starts to decrease. In this phase of seasonal circulation, sediments mainly enter from the ocean during flood tide.

Water-Logging in South-West Coastal Region

Water-logging in the western floodplain of the system came into existence during mid 80's. In addition to polder effects, the reason which believed to contribute water-logging are : change at the entrance of Ganges river, death of Mathavanga river, Farakka barrage, encroachment of river banks, poorly aligned roads and unplanned aquaculture. From image analysis and data from secondary sources shows that main cause of water-logging inside Polders-24 and 25 is sedimentation of the peripheral river.

Model Simulation of Water-Logged Scenarios inside Polders-24 and 25

Water-logging is more inside polder-25 compared to polder-24. Sedimentation in Hari river aggravates the water-logging condition. Sedimentation mainly affects the region which is within the floodplain of the Hari river. Dredging in Hari river improves the water-logging condition. Dredging mainly affects the region which is within the floodplain of the Hari river. During monsoon, impact of new polders (at present there is no polder in this region) in south-central region (Barisal-Patuakhali region) inside polders 24 & 25 is not visible. These new polders mainly affect drainage inside polders 24 & 25. Towards the end-century (year 2088) due to 1.48m sea level rise, the entire system becomes insensitive to any physical intervention of peripheral river (sedimentation or dredging).

Acknowledgement

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CHAPTER ONE
Introduction

1.1 Background

The Ganges Brahmaputra Delta (GBD) is formed by the confluence of the Ganges, Brahmaputra, and Meghna Rivers, which together drain nearly 2 million square kilometers of Nepal, Bhutan, China (Tibet), India, and Bangladesh [Kuehl et al., 2005]. This delta was formed by deposition of large volume of sediments coming from the upstream river systems and distributed through the estuarine systems of the coastal zone. The Coastal zone of Bangladesh as a part of the GBD is one of the most significant tide dominated delta of the world (Goodbred and Saito, 2012). The combined seasonal discharge (peaking during the May to November monsoon season) of the Ganges–Brahmaputra river system outputs approximately 1 billion tonnes of sediment per annum, and accounts for approximately 10% of the world's sediment output from rivers to the ocean (Milliman and Meade, 1983; Syvitski et al., 2005; Milliman and Farnsworth, 2011). The process of sedimentation is complicated due to mixing of large volume of freshwater which is often restricted due to upstream withdrawal and saltwater flows influenced by the reduction of fresh water flow and the tidal ranges in the Bay of Bengal.

Sediments in the region mainly come through the flow generated in the upstream basins. These sediments, which are essential for the delta building processes, distributed in the region through the Lower Meghna estuary along with numerous cross-connecting channels/estuaries in the region. After being deposited in the estuaries and estuarine flood plains, these sediments eventually discharge to the Bay of Bengal. Due to oceanic circulation, a fraction of these sediments may re-enter into the estuarine systems (Haque et al., 2016).

These natural processes get intervened due to several climatic and anthropogenic interventions in the region, for example, reduced upstream water flow or changing of flooding patterns due to climate change, construction of dams/ barrages in the upstream region and construction of polders in the coastal region. Reduced upstream flow or changing of flooding pattern will directly change the water distribution in the region (Haque et al., 2016). Construction of dams/ barrages in upstream region will change the sediment supply (Darby et al., 2015). Constructions of polders in the coastal region might have a significant impact on water and sediment flows in the region.

The patterns of water and sediment flows determine the nature of coastal floodplain sedimentation, and thus, affect the delta building processes in the region. The floodplain sedimentation, in turn, dictates the magnitude and extent of net subsidence and uplift in the GBM delta (Elahi et al., 2015). A number of studies have so far been conducted in the region to determine magnitude of subsidence (Brown et al., 2015). Few studies are performed to study the patterns of water and sediment flows (Haque et al, 2016). Study on future sediment load in the region predicted a possible increase of sediment supply from upstream catchments (Darby et al., 2015), and another study reveals possible impact of sediment load on coastal floodplain sedimentation (Elahi et al., 2015). A recent study reveals the volume of sediment that enters into the region (Rahman et el, 2018). But no study has yet to perform to study re-distribution of these incoming sediments in the coastal floodplain.

Polders are encircled embankment which were constructed in the coastal zone of Bangladesh during early sixties. Polders are generally believed to cause water-logging inside the protected land due to sedimentation in the peripheral rivers. But it is still unknown how these polders affect re-distribution of coastal floodplain sedimentation in the region. Also, a detail understanding of the process of water-logging due to sedimentation of peripheral rivers is also lacking.

1.2 Objectives of the Study

Considering all these, this study has two broad objectives: (a) Macro-level study on floodplain sedimentation and (b) Micro-level study on water-logging. The specific objectives are:

3. Sediment distribution on the coastal floodplain due to different flooding scenario
4. Impact of water-logging inside polders due to sedimentation in peripheral rivers

1.3 Organization of the Report

This report has … chapters. Chapter one is about introduction. Chapter two briefly describes the study area. Chapter three is for macro-level study on coastal floodplain sedimentation. This chapter presents the detail methodology and results of the analysis. Chapter four describes the micro-level study on water-logging. This chapter describes the modeling strategy adopted to study the impact of water-logging due to sedimentation in peripheral rivers.

CHAPTER TWO
Study Area

2.1 Introduction

For both macro-level and micro-level study, the study area selected is the coastal region of Bangladesh. For the macro-level study on coastal floodplain sedimentation, the entire coastal region of Bangladesh is considered except the eastern part of Lower Meghna estuary. For the micro-level study on water-logging, polders 24 and 25 are selected which is situated on the western part of the coastal region.

2.2 The Estuarine Systems of the Coastal Region

As shown in Figure-2.1, the discharges coming from the Ganges, Brahmaputra and Upper Meghna rivers drain through the complicated estuarine networks in the south west region of Bangladesh. The combined flows of Ganges and Brahmaputra rivers comes through the Padma river and after joining with Upper Meghna, the bulk of the combined flow discharges through the Lower Meghna estuary. The estuarine systems receive the freshwater flow from the above rivers, mix with saline water due to large tidal prism and eventually discharge into the Bay of Bengal. The eastern part of these estuarine systems is known as Eastern Estuarine System (EES), the central part is known as Central Estuarine Systems (CES) and the western part is known as the Western Estuarine System (WES). These EES, CES and WES are connected through several cross channels. The Ganges, before joining with the Brahmaputra, bifurcates as the Gorai, which is the main flow-carrying channel for the WES. In the same way, the Padma, before joining with the Upper Meghna, bifurcates as the Arial Khan river and acts as a major source of freshwater for the CES. The CES also receives water from the EES through three small spill channels. The Beel Route, a man-made canal excavated from the Arial Khan (Rahman et al., 2014), is also a major source of freshwater from the EES to the CES. Freshwater sources for the WES where the ecologically important Sundarban mangrove forest (Rahman, 2014) is located are much less. The only visible source of freshwater for the WES is the bifurcated branch of the Gorai. The Gorai itself is almost dying due to shortage of flow from the Ganges (Islam and Gnauck, 2011; Mirza, 1998; Bharati, 2011). The other bifurcated branch of the Gorai, named the Madhumati, is acting as a freshwater source for the CES. The other small channels of WES have lost their roles as freshwater source. Among the other estuaries, the Tetulia and Lohalia are the parts of the EES, the Bishkhali, Baleshwar and Burishwar constitute the CES and all other estuaries of the Sundarban system including the Rupsha and Pashur systems are parts of WES. Existing cross channels that connect these estuarine systems are three spill channels of Lower Meghna, Beel Route, Ghashiakhali channel and the Madhumati channel. The roles of these cross channels are vital for facilitating the exchange of flow and sediments from EES to WES. The WES receives a very small amount of freshwater flow from Gorai. On the other hand, the EES receives large amounts of fresh water from the Lower Meghna and supplies some of this to the CES through the spill channels. As there is a very small number of cross channels that connect the WES to the rest of the systems, there is a large difference of water storage among the different parts of the estuarine systems, especially between CES and WES.

The dynamics of these estuarine systems are controlled by the freshwater entering through the Gorai, Arial Khan and Lower Meghna inlets and the seawater entering through the mouths of the estuaries of EES, CES and WES. The large freshwater input and the saline water intrusion due to strong tidal force make these estuarine systems suitable for the existence of diverse ecosystem resources (Miah, 2010). In addition to the tidal force, there are seasonal variations of freshwater flows in different flooding scenarios resulting variation of water storage and its distribution among the different parts of these estuarine systems (Haque et al., 2016). The variations of the hydrodynamic conditions cause different combinations of water balances that ultimately leads to spatial and temporal movement of the sediments within the estuarine systems (Sumaiya et al., 2015; Dasgupta et al., 2014).

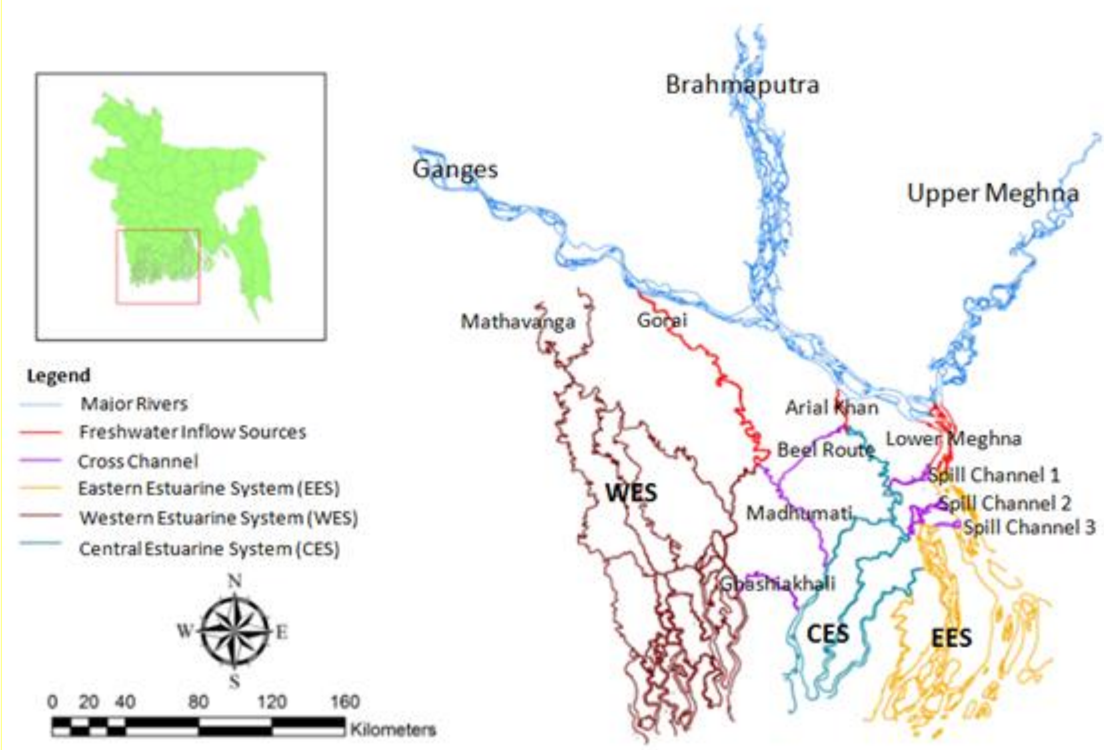

Figure-2.1: Estuarine systems of coastal zone

2.3Flow and Sediment Distribution Patterns in the Coastal Zone

Haque et al (2016) made a detailed assessment on the flow and sediment distribution patterns in the coastal zone of Bangladesh (which is the study area in present study). They used flow parameters as a proxy to sediment transport. The study shows that Lower Meghna estuary is the most dominant channel in the system. During different flooding conditions and tidal instants, high velocity flows (velocity in the order of more than 1 m/s) comes down from the

Lower Meghna. This flow interacts with relatively low velocity flow (in the order of 0.5 m/s) from the sea and the resultant flow, in general, is directed towards the land through the WES outlet. The residual flow circulation pattern over a hydrological year is shown in Figure-2.2.

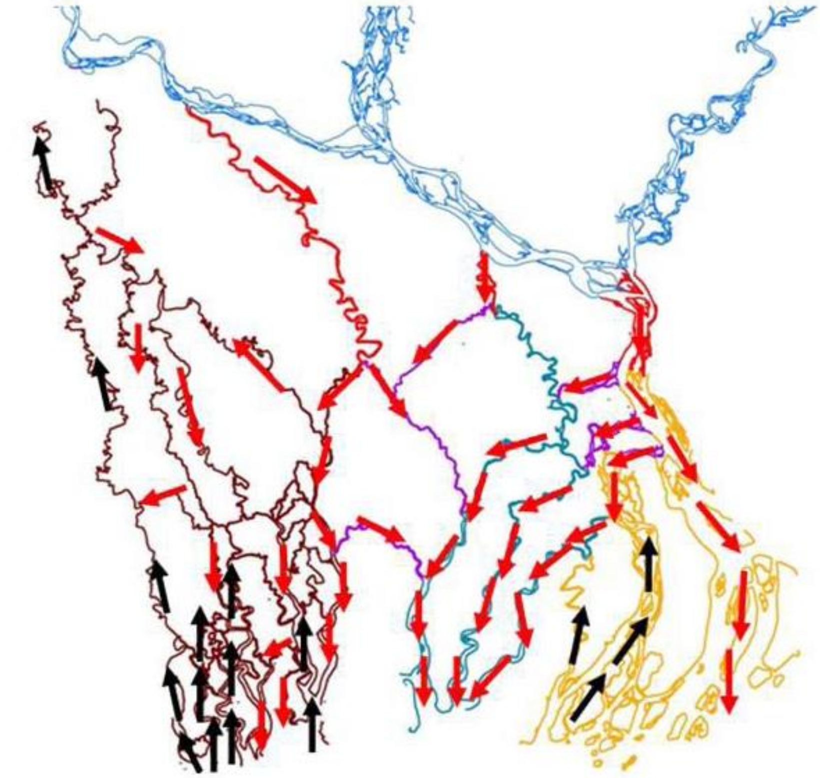

Figure-2.2 : Residual flow circulation pattern in the estuarine systems (Source: Haque et al., 2016)

Figure-2.2 shows that the Lower Meghna estuary is a predominantly ebb-dominated channel. The rest of the channels of the EES are flood-dominated. For the CES, all the channels are ebb-dominated and for the WES, the channels are flood dominated. These systems have created two clockwise-rotating estuarine circulation patterns. In one system the Lower Meghna and the associated channels of EES makes a clockwise circulation. The other system is the main circulation system that consists of all the three estuarine systems. The flows come down from the Lower Meghna and the CES systems, turn clockwise, and re-enter into WES systems. This type of clockwise residual circulation also found elsewhere (Hussain et al., 2009). Analyzing the flow distribution and arrangements of the estuarine systems of the GBM delta, it is obvious that the Meghna estuary is likely to be the main conduit for sediment. As this system is largely ebb dominated, the high tidal excursion during the ebb will drain the incoming sediments to the Bay of Bengal through the mouth of the Meghna estuary. A clockwise residual circulation in the Bay of Bengal near the mouth of the estuaries particularly during the monsoon may drive these sediments in the western direction. With the relatively low freshwater flow contribution of the WES, these sediments may be directed towards the mouth of the estuaries of the WES.

As most of the estuaries of WES can be considered as flood dominated, these sediments will re-enter into WES system. The WES contains the estuaries that feed the Sundarban. Considering this mechanism and remembering the fact that the freshwater inflow of WES is the lowest of the three systems, the sediment feed of this system from the upstream sources (mainly Ganges) must be very low. So, the estuarine systems contributing to the Sudarbans are receiving sediments only from these re-entered sources from the Bay of Bengal. This mechanism is playing a significant role in the sediment dynamics of the study area (Rogers et al., 2013). It is obvious that out of the three estuarine systems, the upstream flow of EES is the maximum among the three. On the other hand, flow from seaward direction is dominantly large in WES system. The inflow of CES is occasionally dominated by either from upstream or from the ocean. As a result, in most of the time in a year, the estuarine environment of EES is 'from upstream' while that for WES is 'from downstream'. The environment for CES is mixed and it varied from 'upstream' to 'downstream' depending on the flooding scenario and seasonality. Sediments in the western system are mainly cohesive sediments ranging from silt to clay (Rajkumar et al., 2012). Saline environment of WES makes the re-entered sediments from the sea to form flocks and results sedimentation in the region. The sediments in these estuarine systems are mainly coming through the Brahmaputra and the Ganges rivers during the monsoon (Rogers et al., 2013). Like water flow, the Brahmaputra sediment is mixed with the Ganges sediment and the combined sediments are discharged through the estuarine systems of the GBM delta to the Bay of Bengal. Most of these sediments flow through the Lower Meghna estuary and through estuaries of CES system to the Bay of Bengal. As described above, part of these sediments may re-enter into WES. The dominant contributor of freshwater flow for the EES is the Lower Meghna estuary, for the CES is the Brahmaputra River and for the WES is the Ganges River. The Lower Meghna estuary carries the combined discharge of the Ganges, the Brahmaputra and the Upper Meghna. So, the sediment of the Lower Meghna estuary is the combined sediments from these major river systems. The upstream sediment source of the CES is basically from the Brahmaputra River, whereas, for WES, it is the Ganges River. As most of the sediments are carried during the monsoon and EES receives the maximum amount of share among the three systems, the EES will carry the bulk of the sediments coming from the major river systems of the GBM delta during monsoon. On the other hand, the share of CES increases during the dry period. So, it is expected that, whatever sediments are coming to the system during the dry period, CES carries a significant part of it, specially, the sediments contributed by the Brahmaputra river. These features dictate the nature of sediment circulation pattern in the study area.

2.4 Study Area for Water-logging

Study area is within polders 24 and 25. Abhaynagar upazila of Jessore district is on the north, Dumuria upazila of Khulna district is on the south, Keshabpur upazila of Jessore district is on the west and Phultala upazila of Khulna district is on the east of the study area. All these upazillas are long been suffering from water-logging problem along with the area within polders 24 and 25. Total 4 upazilas are within the polders area. These are: Phultala, Khan Jahan Ali, Dumiria from Khulna district and Keshabpur from Jessore district. The main river flowing in between these two polders are Hari river which largely dictates the drainage from the polders. Several depressions (beels) work as perennial water bodies within these polders. The study area is shown in Figure-1.

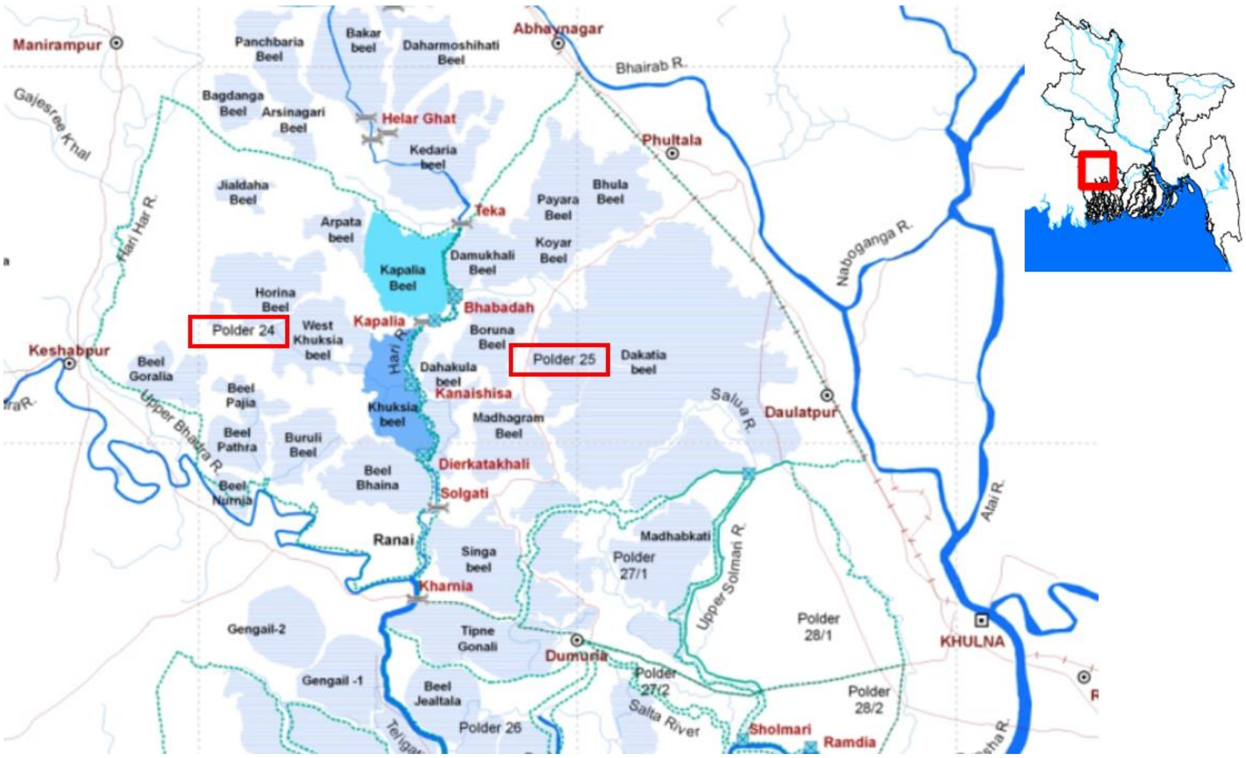

Figure-2.3 : Study area for water-logging

CHAPTER THREE
Coastal Floodplain Sedimentation

3.1 Introduction

This chapter presents results of distribution of sediments on coastal floodplain due to different seasonal and climatic conditions. The seasonal conditions considered is an average flood condition (year 2000) and an extreme flood condition (year 1998). For climatic condition, a future scenario in the year of 2088 is considered with a sea level rise of 1m and predicted sediment load from upstream. The following sections describes the model setup, methodology and results for different scenarios.

3.2 Model Setup

The morphology module of the Delft 3D is applied to compute coastal floodplain sedimentation and associated changes in the flow field. The module of Delft 3D solves the morphological variables which are coupled with the flow parameters (the flow model version of Delft 3D). In this way, any changes in the river and floodplain morphology that affects the flow field and vice versa is simulated. In the Morphology Model, sediment concentration is simulated by solving advection-diffusion equation. The local flow velocities in transport equation comes from the solution of continuity and momentum equations of the hydrodynamic model. The settling velocity appeared in the advection-diffusion equation is computed following the method of Van Rijn. Following Van Rijn, a reference height (named as Van Rijn reference height) is computed. Any sediment above this height is considered as suspended sediment and below this height is considered as bed load. To compute suspended load and bed load transport of sediments, Van Rijn sediment transport formula is used.

The model domain and model bathymetry to study the coastal floodplain sedimentation in the study area is shown in Figure-3.1.

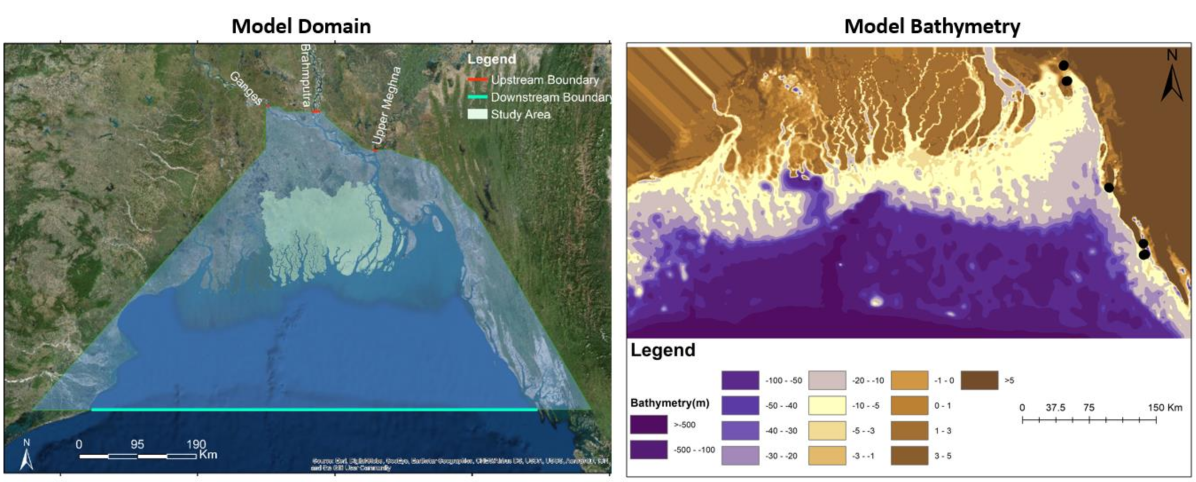

Figure-3.1 : Model domain and model bathymetry

Curvilinear grid is used for spatial discretization. In the ocean grid size is approximately 500 m X 600m, in estuaries and floodplains the grid size is approximately 200 X 300 m. For the river bathymetry, combinations of secondary and primary data are used. Secondary data are collected from BWDB and primary data in 294 locations in the rivers/estuaries of coastal zone are measured in ESPA project of BUET. Ocean bathymetry is provided from the open access General Bathymetric Chart of the Oceans (GEBCO).

The inland ground elevation is provided from available DEM collected from WARPO. DEM is generated from FINNMAP Land Survey 1991 and National DEM from FAP19.

For upstream discharge boundary, measured discharges are collected from Bangladesh Water Development Board (BWDB) at Hardinge Bridge of Ganges, at Bahadurabad of Brahmaputra and at Bhairab Bazar of Upper Meghna. As downstream water level boundaries is in ocean, tides at the sea boundary are generated by using Nao 99b tidal prediction system. For the sediment boundary condition, sediment concentrations are used from the measured data of BWDB at the same locations where discharge boundaries are specified.

The entire coastal zone is embanked with 139 polders of which 103 are in the macro-level model study region. In the macro-scale model, polder locations are specified from the polder map available in the national database of WARPO. Data from 61 polders (some of which are outside the study region) show that actual polder heights vary from 0.75m to 7m (Source: Bangladesh Water Development Board). These heights obviously are not constant for the entire polder embankment. Where actual polder heights are not available, an average design polder height of 4.75m is used in the model (source: Centre for Environmental and Geographic Information Services, CEGIS).

Delft 3D indirectly considers impacts of land use and land cover through resistance in the floodplain. Different resistance values are specified for sea, rivers / estuaries, flood plain and forest (Sundarban). These resistance values are determined during model calibration. Spatially variable resistance coefficients in the model domain vary between 0.00025 in the ocean (considered as large water body), 0.015 to 0.025 in rivers /estuaries (a value generally considered to be valid for rivers / estuaries in the region), 0.025 to 0.040 in the floodplain, and 0.08 to 0.1 in Sundarban.

3.3 Numerical Experiments

Before model calibration and validation, numerical experiments are conducted to understand the model response for some model uncertainty parameters.

3.3.1 Uncertainty in ocean sediment concentration

For sediment inputs to the system, model needs to specify sediment concentration both at upstream rivers and downstream ocean of the model domain (see Figure-3.1). For upstream rivers, measured sediment concentrations (although scattered) are available. But for downstream ocean, no data is available. We have extensively searched for any secondary data or even estimation but found nothing. So, specification of ocean sediment concentration becomes an uncertain parameter for a morphology model application in Bangladesh coast.

As selected location of ocean boundary is far downstream in the deep ocean (see Figure-3.1 for the location of downstream ocean boundary condition), model will 'harmonize' any value specified as the sediment concentration at the ocean boundary with the simulated hydro-morphological parameters inside the coast (which is our study area). So, it was decided to 'estimate' sediment concentration at the ocean boundary which will give the best validation result with the measured sedimentation depth inside the study region.

3.3.2 Uncertainty in sediment composition

Sediment composition (percent fraction of cohesive and non-cohesive sediments) is another uncertain parameter for morphology model to be applied in Bangladesh coastal zone. Similar approach as that of ocean sediment concentration is taken for this parameter also.

3.3.3 Uncertainty in delineation of river / estuary and floodplain

Different methods can be used to compute sediment loads in rivers/ estuaries and in floodplains. In one method (Method-1), sediment loads are calculated by considering all the rivers / estuaries as one unit and all the floodplain as one unit also. In another method (Method-2), sediment loads are calculated separately for individual rivers / estuaries and floodplains are divided into three zones. Before model calibration, validation and application, it is necessary to select one method which will be used in subsequent computation of sediment loads.

3.3.4 Results from the numerical experiments to assess impacts of uncertain parameters

Numerical experiments are performed to study the impact of uncertain parameters as mentioned above. Different combinations of these parameters that are used in the numerical experiment is described in Table-3.1. Different methods to delineate river/estuary and floodplain are added with the uncertain parameters shown in Table-3.1.

Table 3.1: Parameter Values for Numerical Experiments

Sediment Composition	Cohesive 70% + Non-cohesive 30%	Cohesive 30% + Non-Cohesive 70%
Ocean Sediment Concentration (kg/m3)	0.1	0.1
	0.01	0.01
	0	0

Impact of Ocean Sediment Concentration and Sediment Composition on River Sedimentation

In this numerical experiment, sediment composition and ocean sediment concentration as shown in Table-3.1 is used to study impact on net river sedimentation. Positive value represents net sedimentation and negative value represents net erosion. The impacts are shown in Figure-3.2.

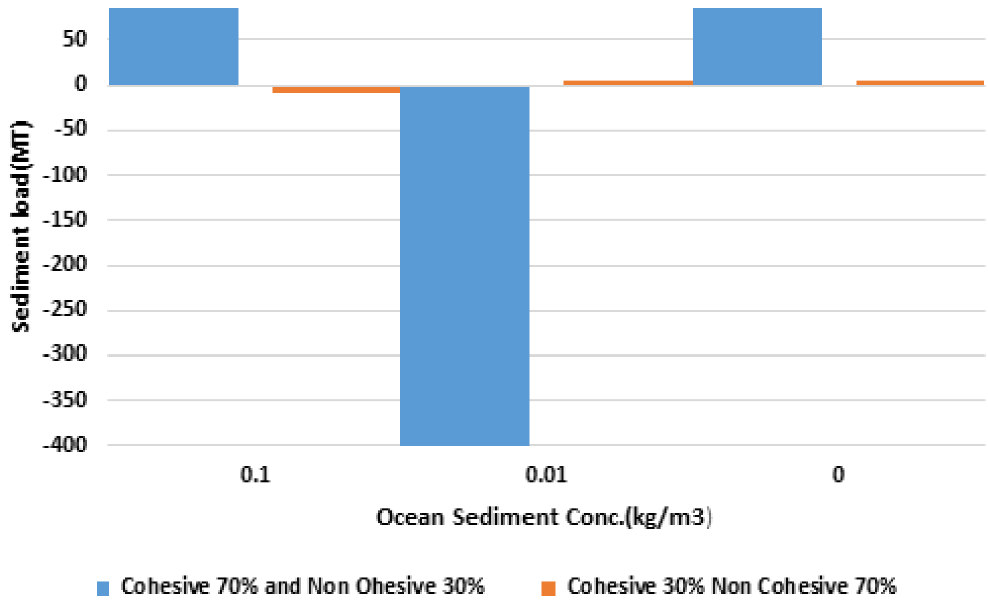

Figure-3.2: Impact of sediment load in the river due to varied sediment concentration in the ocean for different sediment fractions

Figure-3.2 shows the impacts on river sedimentation due to varied sediment concentration in the ocean for different combinations of sediment mixture. The figure shows net sedimentation for all the estuaries of the system. It is seen that sedimentation in the river remains almost same (about 55 million ton) when ocean sediment concentration decreases from 0.1 kg/m^3 to 0.0 kg/m^3. But when the ocean sediment concentration decreases from 0.1 kg/m^3 to an intermediate value, say 0.01 kg/^{3}, instead of decreased sedimentation in the river, erosion is observed in the range of 400 million ton. This distribution is indicative of large spatial variability in the system. Patterns of net sedimentation in the Lower Meghna system (EES) is not the same as that of Pashur-Shibsa system (WES).

Impact of Ocean Sediment Concentration and Sediment Composition on Floodplain Sedimentation

In this case, similar numerical experiments are conducted to study the impact of varying ocean sediment concentration and sediment composition on the net floodplain sedimentation. The results shown in Figure-3.3 shows that for dominantly cohesive sediments floodplain sedimentation decreases with the increase of ocean sediment concentration. When sediment composition is dominantly non-cohesive, a decreasing trend is observed on the floodplain sedimentation due to increased sediment concentration in the ocean. This specific example shows that ocean sediments are largely deposited in the river bed and plays an insignificant role one the overall floodplain sedimentation. This finding is inconclusive. It is necessary to study the spatial distribution of floodplain sedimentation in different estuarine systems due to varying ocean sediment concentration. Due to highly variable hydro-morphological characteristics of the estuaries in the western, central and eastern systems, these systems are likely to respond differently when sediment inputs from the ocean changes.

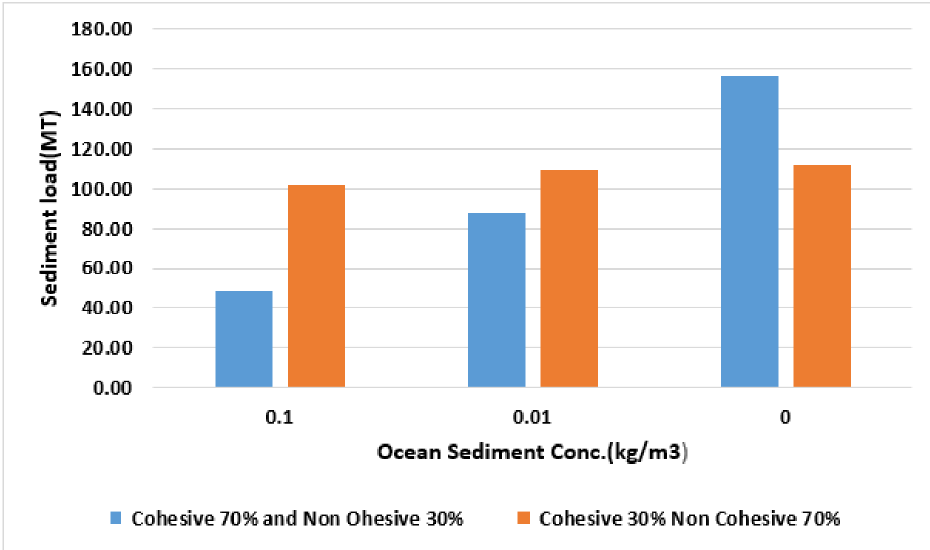

Figure-3.3: Impact of sediment load in the floodplain due to varied sediment concentration in the ocean for different sediment fractions

Spatial Distribution of River-Floodplain Sedimentation due to Varying Ocean Sediment Concentration for different Sediment Fraction

This numerical experiment is conducted to study the spatial distribution of both river and floodplain sedimentation when ocean sediment concentration varies for different sediment size fraction. Figure-3.4 shows the result when sediment size fraction is predominantly cohesive. This result supports what was observed when net impact on river-floodplain sedimentation was studied (see Figures-3.2 and 3.3). Spatial variability of sediment distribution within the estuarine system is clearly visible for predominantly cohesive sediments (see Figure-3.4).

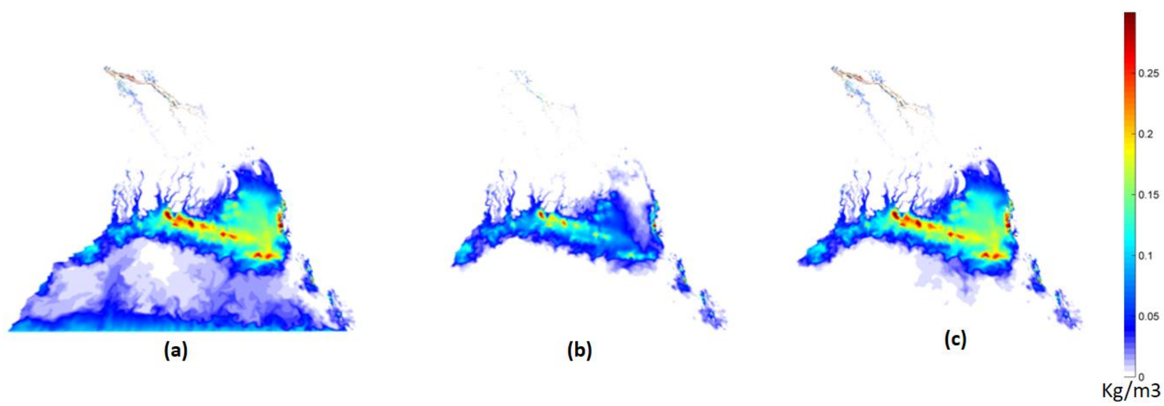

Figure-3.4: Sediment concentration (kg/m3) in the coastal zone of Bangladesh when sediment is pre-dominantly cohesive for different ocean sediment concentration. Ocean sediment concentration is (a) 0.1 kg/m3 (b) 0.01 kg/m3 (c) 0 kg/m3.

Spatial distribution of river and floodplain sedimentation due to varying ocean sediments when sediment size fraction is dominantly non-cohesive is shown in Figire-3.5.

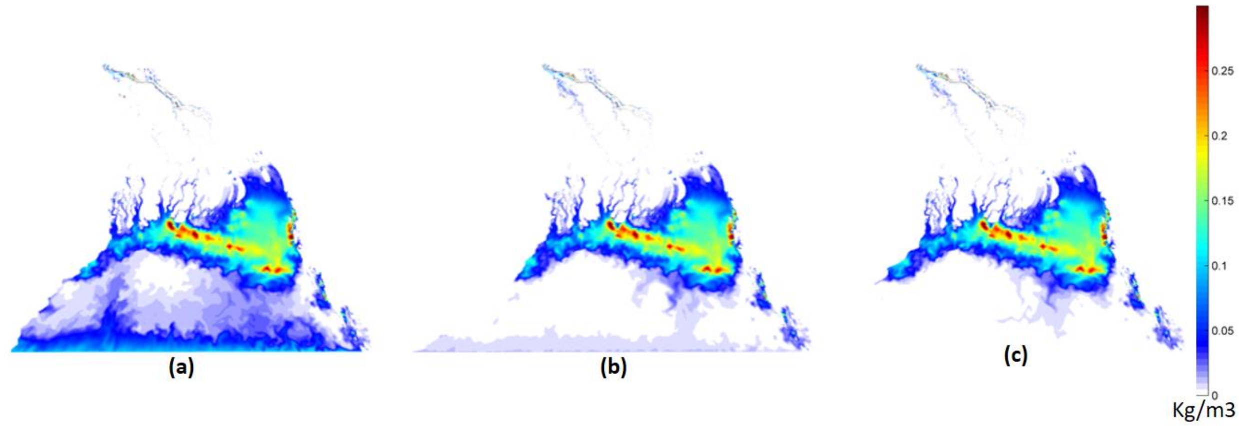

Figure-3.5: Sediment concentration (kg/m^3) in the coastal zone of Bangladesh when sediment is pre-dominantly non-cohesive for different ocean sediment concentration. Ocean sediment concentration is (a) 0.1 kg/m^3 (b) 0.01 kg/m^3 (c) 0 kg/m^3.

Figure-3.5 supports the finding what was observed when net impact on river and floodplain sedimentation was studied (see Figures 3.2 and 3.3). Spatial variability within the estuarine system is visible in Figure-3.5. This distribution is not similar to what was observed when sediment size fraction was dominantly cohesive. This shows the important role of characteristics of sediments on the river and floodplain sedimentation in the delta.

In the study area, net river and floodplain sedimentation is spatially variable within the estuarine systems. In this system, sediment size fraction (dominantly cohesive or non-cohesive) plays an important role on the spatial distribution of net sedimentation.

Delineation of river / estuary and floodplain

To compute sediment load, two methods are used by which rivers/estuaries and floodplains are be delineated in the study region. In Method-1 (Figure-3.6), all the rivers / estuaries in the region is considered as 'river unit' and the rest of the region is taken as the 'floodplain unit'. In Method-2 (Figure-3.6), individual rivers/estuaries are considered as 'separate river unit'. For the floodplain, the entire floodplain is divided into three regions, namely Western Estuarine System (WES), Central Estuarine System (CES) and Eastern Estuarine System (EES). To calculate sediment load, output from Delft-3D is imported to ArcGIS environment. To calculate sediment load by Method-1, study area is clipped out as 'river unit' and 'floodplain unit' whereas, for Method-2, study area is clipped as 'separate river unit' and separate floodplain unit as WES, CES and WES. Inverse Distance Weighted (IDW) interpolation method is applied to translate the non-uniform model grid into a uniform grid. To calculate sediment volume, sediment thickness at each of the grids is multiplied with the grid area. To calculate sediment load (kg), sediment volume is multiplied by specific weight of sediment (2650 kg/m^3).

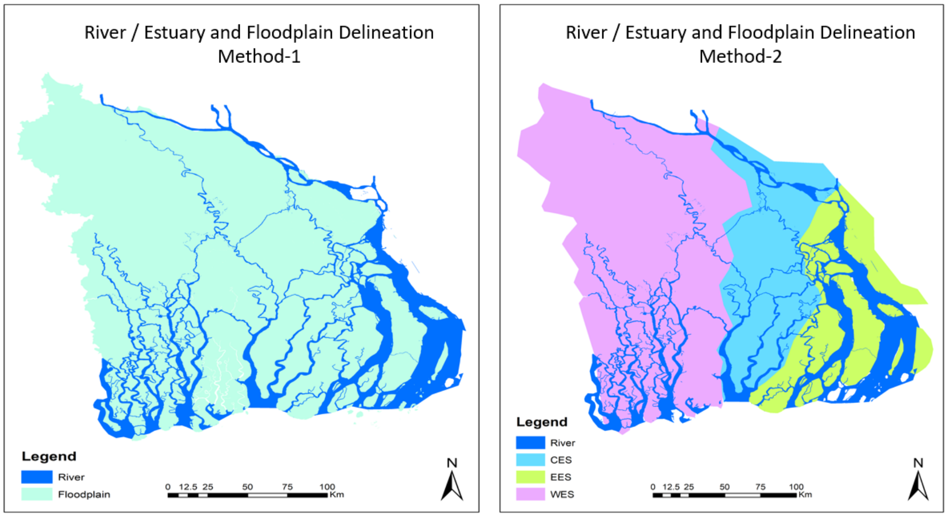

Figure-3.6 : Delineation of rivers/estuaries and floodplains by Method-1 (left) and Method-2 (right)

By applying two different methods (Method-1 and Method-2), sediment loads are calculated in rivers / estuaries. Method-1 takes all the rivers / estuaries as a single unit while Method-2 deals with individual rivers / estuaries in the system. Calculated sediment loads for individual rivers / estuaries (Method-2) is shown in Table-3.2.

Table -3.2: Sediment load calculated by Method-2 for individual rivers / estuaries

	Cohesive30% Non-Cohesive 70%			Cohesive70% Non-Cohesive 30%		
River	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean
Ganges with Padma	138.00	140.36	140.39	174.19	67.35	174.11
Meghna	1.97	1.93	1.90	4.73	--8.01	4.62
Lower Meghna	-33.79	-38.92	-34.09	-2.16	-236.38	-1.4
Tentulia	-12.16	-12.15	-11.73	-6.80	-97.82	-6.32
Arial kha	-0.56	-0.65	-0.64	1.49	-6.92	1.47
Gorai	1.58	1.45	-6.90	5.25	0.52	5.24
Baleswar	-10.24	-10.56	-10.45	-10.28	-14.26	-10.19
Bishkhali	-10.83	-11.31	-11.28	-10.99	-17.31	-11.06

Buriswar	-1.86	-1.86	-1.66	-1.56	-7.13	-1.54
Rupsha_posur	0.54	0.26	-0.76	0.41	0.15	0.15
Sibsa	0.15	-0.46	0.24	0.55	-0.93	0.39
Modhumoti bill	-0.02	0.14	0.02	0.44	-0.51	0.44
Modhumoti river	0.24	0.24	0.05	0.24	-0.58	0.23
Raimongal	-19.95	-19.76	-17.90	-19.31	-20.34	-17.84
Rabnabad	-3.44	-3.66	-3.66	-3.53	-5.28	-3.57
Swarupkathi	0.39	0.39	0.31	0.50	-5	0.46
Kobadak	-0.66	-0.68	-0.63	-0.66	-0.70	-0.63
Jamuna	2.80	2.59	2.61	2.68	2.54	2.67
Malancha	6.92	6.77	6.70	6.94	6.95	6.77
Total Sediment load In Million Ton	58.86	54.23	52.50	142.12	-343.66	144.00

Overall sediment load in rivers / estuaries calculated by Method-1 and Method-2 is shown in Figure-3.7.

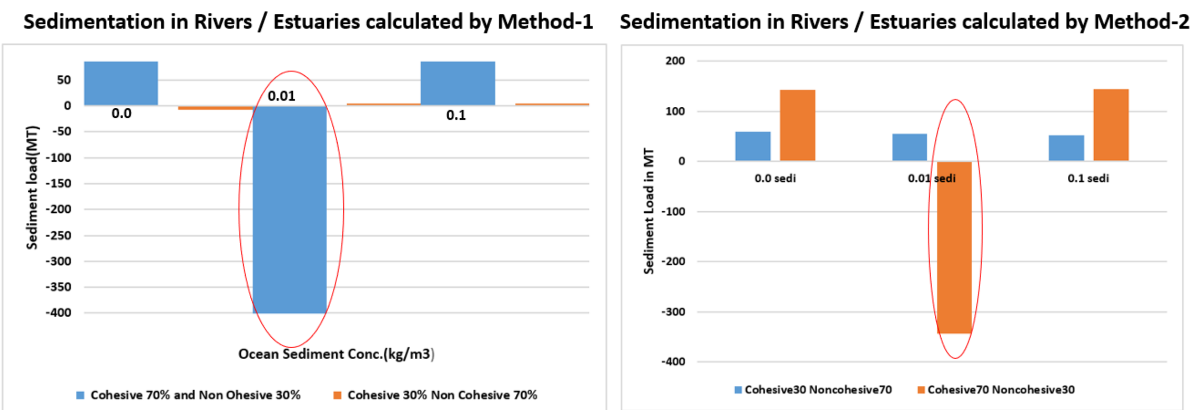

Figure-3.7 : Sedimentation in rivers / estuaries calculated by two different methods.

Table-3.2 and Figure-3.7 show that when ocean sediment concentration is 0.01 kg/m^3, both the methods give unrealistic sediment load distribution in rivers / estuaries. When Method-1 is compared with Method-2, it is found that sediment load distribution calculated by Method-2 is more realistic than Method-1. This proves our previous hypothesis where we assumed that distribution of sediment load in the system is spatially variable. So, the method which considers this spatial variability (each river / estuary as a separate unit) gives more realistic distribution than considering all the rivers / estuaries as a single unit. Figure-3.7 also shows that when size fraction of sediment is considered as '30% cohesive and 70% non-cohesive', this gives better distribution than '70% cohesive and 30% non-cohesive' size fraction assumption. The distribution of sediments in the rivers / estuaries shows that in this system, ocean sediment concentration is very low.

By applying two different methods (Method-1 and Method-2), sediment loads are calculated in floodplains. Method-1 takes all the floodplain as a single unit while Method-2 divides the floodplains into western, central and eastern systems known as WES, CES and EES (see Figure-3.6). Calculated sediment loads for WES, CES and EES (Method-2) is shown in Table-3.3.

Table -3.3: Sediment load in different floodplains

	Cohesive30% Non-Cohesive 70%			Cohesive70% Non-Cohesive 30%		
Floodplain	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean
WES	39.53	38.83	146.61	64.75	-67.016	64.69
CES	28.98	28.94	24.48	62.58	-171.72	62.40
EES	26.11	26.06	25.85	44.64	-107.34	44.24
Total Sediment load In Million Ton	94.62	93.84	196.94	171.97	-346.08	108.93

Overall sediment load in floodplains calculated by Method-1 and Method-2 is shown in Figure-3.8.

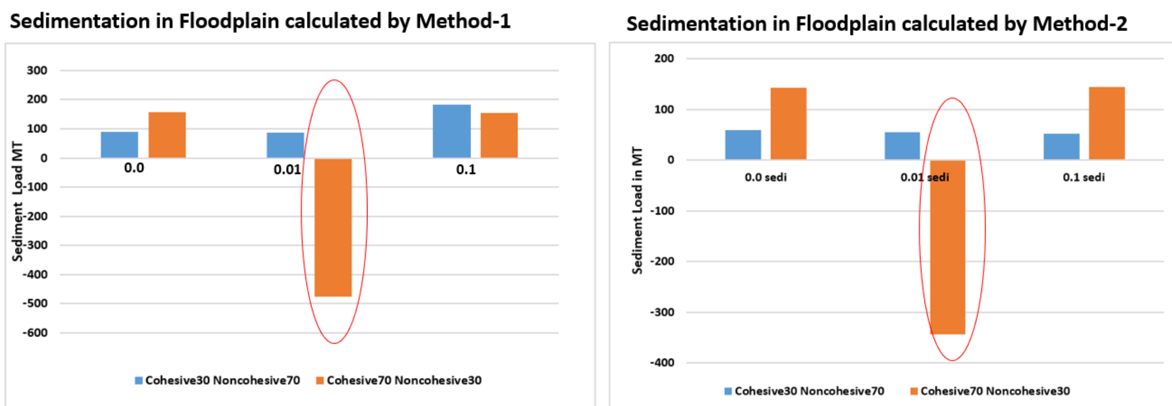

Figure-3.8 : Sedimentation in floodplains calculated by two different methods.

Table-3.3 and Figure-3.8 show that when ocean sediment concentration is 0.01 kg/m^3, both the methods give unrealistic sediment load distribution in floodplains (similar to rivers / estuaries). When Method-1 is compared with Method-2, it is found that sediment load distribution calculated by Method-2 is more realistic than Method-1 (similar to rivers / estuaries). This proves our previous hypothesis where we assumed that distribution of sediment load in the system is spatially variable. So, the method which considers this spatial variability (floodplains are divided into WES, CES and EES) gives more realistic distribution than considering all the floodplains as a single unit. Figure-3.8 also shows that when size fraction of sediment is considered as '30% cohesive and 70% non-cohesive', this gives better distribution than '70% cohesive and 30% non-cohesive' size fraction (similar to rivers / estuaries) assumption. The distribution of sediments in the floodplains shows that in this system, ocean sediment concentration is very low.

Sediment discharge is highly nonlinear with discharge and variable both spatially and temporally. Although there is no accurate estimation about the sediment discharge to the Ganges-Brahmaputra-

Meghna delta, it appears that a large portion of the sediment load entering into the deltaic environment might be deposited. However, very few researchers mentioned some quantitative values pertaining to the floodplain sedimentation. Involving radioisotope testing (137Cs and 210Pb) Goodbred and Kuehl (1998) estimated that more than 30-40% of the total sediments entering into the system are deposited on the floodplain. According to Allison (1998) 1-2% of the total sediment is required for sub aerial delta aggradation and 31-33.5% is for subaqueous delta.

Table-3.4 shows calculated percentage of sediment load distributed in floodplain by two different methods (Method-1 and Method-2) of sediment load calculation. We have already shown that Method-2 gives more realistic result than Method-1 when size fraction of sediment is '30% cohesive and 70% non-cohesive'. If we take 0kg/m^3 as the lower limit of ocean sediment concentration and 0.1kg/m^3 as the upper limit of ocean sediment concentration in this system, we found from Table-3.4 that around 23% to 47% of sediments is deposited in the floodplain. This result supports the results found from secondary source where it is mentioned that 30% to 40% of total sediments coming into the system is deposited in the floodplain (Goodbred and Kuehl, 1998).

Table -3.4: Percentage of Sediment Load Distributed in Floodplain

	Cohesive30% Non-Cohesive 70%			**Cohesive70% Non-Cohesive 30%**		
Floodplain	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean	0 kg/m^3 Sediment at Ocean	0.01 kg/m^3 Sediment at Ocean	0.1 kg/m^3 Sediment at Ocean
Total Deposited Sediment Load (Million Ton) in Floodplain (Method-1)	48.55	86.2	182.01	156.27	-475.31	155.63
Percentage deposited in Floodplain (Method-1)	21 %	20%	44%	37%	-115%	37%
Total Deposited Sediment Load (Million Ton) in Floodplain (Method-2)	94.62	93.82	196.94	171.97	-346.07	108.93
Percentage deposited in Floodplain (Method-2)	**23%**	22%	**47%**	41%	-83%	26%

3.4 Model Calibration

As described in previous sections, sediment concentration in distant sea (not near the coast) in the Bay of Bengal is very low and the size fraction of sediment in this system is '30% cohesive and 70% non-cohesive'. These data are used during calibration and validation of the morphological model. The model is calibrated with available secondary data. Rogers et al. (2013) measured sedimentation in the Sundarbans region (Figure-3.9) from March 2008 to October 2008. Later they converted these 8 months data into sedimentation/year. During model calibration, simulated sedimentation is compared with the measured sedimentation in these four locations. Two different methods of model simulations are performed to calculate sedimentation during calibration:

(a) Method-1: Yearly sedimentation based on simulation from March to October by following Rogers et al. (2013).
(b) Method-2: Yearly sedimentation based on simulation for the whole year covering monsoon and dry season.

Except in location-4, Method-1 performs better than Method-2 (see Figure 3.9). This means that model performs better when same method is applied in the model to that which is used by Rogers et al. (2013) in the field. It is to be noted here that except in location-3, sedimentation is generally low in Method-2 (whole year sedimentation) compared to Method-1 (8 months sedimentation from March to October). Method-2 includes dry period also when erosion is dominated over sedimentation due to low sediment inflow into the system and regular tidal flooding in the floodplain. Location-3 gets more sediments from the system due to clockwise residual circulation pattern in the Bay of Bengal near the coast (Haque et al., 2016).

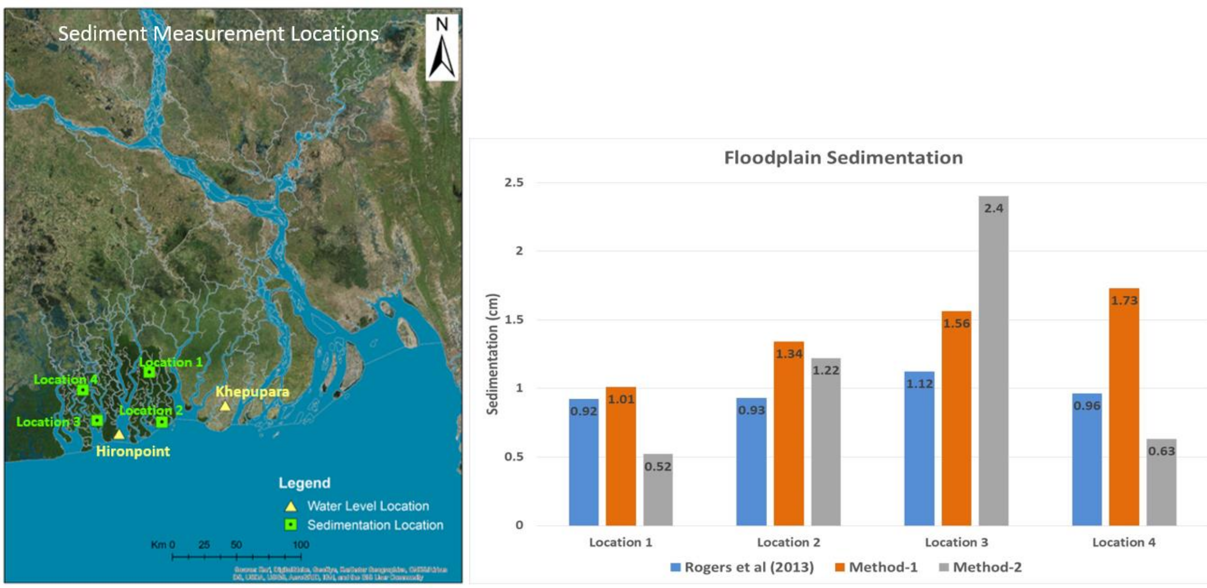

Figure-3.9: Locations where sedimentation was measured in Sundarban (Rogers et al., 2013) and comparison of floodplain sedimentation between the model and the measurement

3.5 Model Validation

To validate the morphology model, model simulated 'percentage of sediment load deposited in the floodplain' is compared with the secondary data (by keeping all other parameters and assumptions unchanged that used during the model calibration). According to Goodbred & Kuehl (1998) and Allison (1998), ~30% - 40 % of total sediment entering into the system is deposited over the floodplain. To compute sediment load distribution in the system, the entire delta is divided into river/estuary and floodplain (see Figure-3.10). Percentage of sediment load deposited over the floodplain computed for the domain (Figure-3.10) is shown in Table-3.5. The results show that out of total sediment load of 412 million ton entering into the system during an average flood year, total of 88.95 million ton of sediment is deposited over the floodplain which is 21.59% of total sediment entering into the system during this time. According to Goodbred & Kuehl (1998) and Allison (1998), this value varies from 123.6 million ton to 164.8 million ton which is about 30% to 40% of total incoming sediment load. Maximum sediment is deposited over the WES system (the Sundarban dominated system) which is about 12% of total sediments entering into the system. Total sediment load distributed over the CES & EES system is about 11% of total incoming sediment load. It is to be noted here that Goodbred & Kuehl (1998) and Allison (1998) did not consider spatial variation of sedimentation among different floodplain systems.

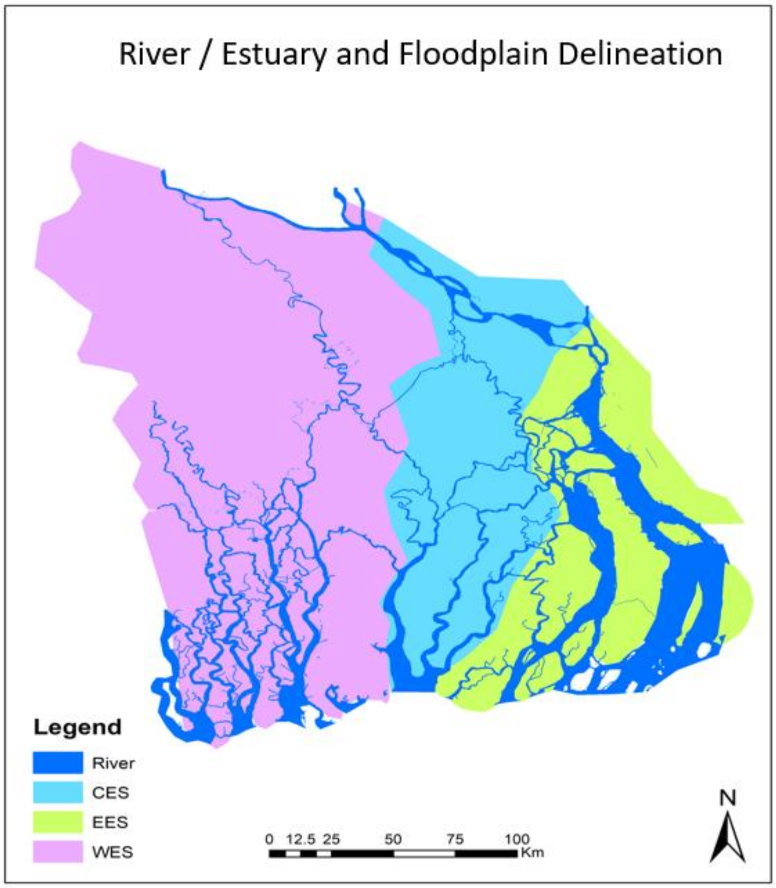

Figure-3.10: Delineation of river / estuary and floodplain

Table-3.5: Comparison of sediment load distribution in floodplain between the model and the secondary data from literature (Goodbred & Kuehl (1998) and Allison (1998))

Total sediment load entering into the system during an average flood year (million ton)		412
Floodplain	Sediment load deposited in the floodplain during an average flood year (million ton)	% of sediment load deposited in the floodplain compared to total sediment load entering into the system during an average flood year
WES	46	11.2
CES+EES	44	10.7
Total Sediment Load (Model)	90	21.8%
Total Sediment Load (Goodbred & Kuehl (1998) and Allison (1998)	124 to 165	30% to 40%

3.6 Flooding and Floodplain Sedimentation

Calibrated and validated morphology model is applied in the study region to study patterns of flooding & sedimentation for different flooding scenarios. An end-century future scenario is also constructed by considering 1m SLR and sediment loads generated by model simulation.

3.6.1 Sedimentation during average flood condition

The main cause of floodplain sedimentation is the flooding in the floodplain due to monsoon flood. Relation between floodplain flooding and floodplain sedimentation is shown in Figure-3.11. The flooding considered here is the monsoon flooding during an average flood year which is year 2000 (BWDB, 2015). The main drivers of flooding are the fluvial flow and the tidal flow. The polders in the region has restricted the sediment laden water during monsoon to enter inside the poldered area (except in the central region where there is no polder). Figure-3.11 shows that floodplain sedimentation is mainly confined in the un-protected areas. It should be mentioned here that the flooding scenario considered here is an average flood condition which may not result extensive flooding in the poldered area had there been no polder. A scenario is constructed assuming ‘no polder in the region’ which is shown in Figure-3.12. This figure shows the relation between floodplain sedimentation and monsoon flooding for the same situation presented in Figure-3.11, but in this case, there is no polder in the entire region.

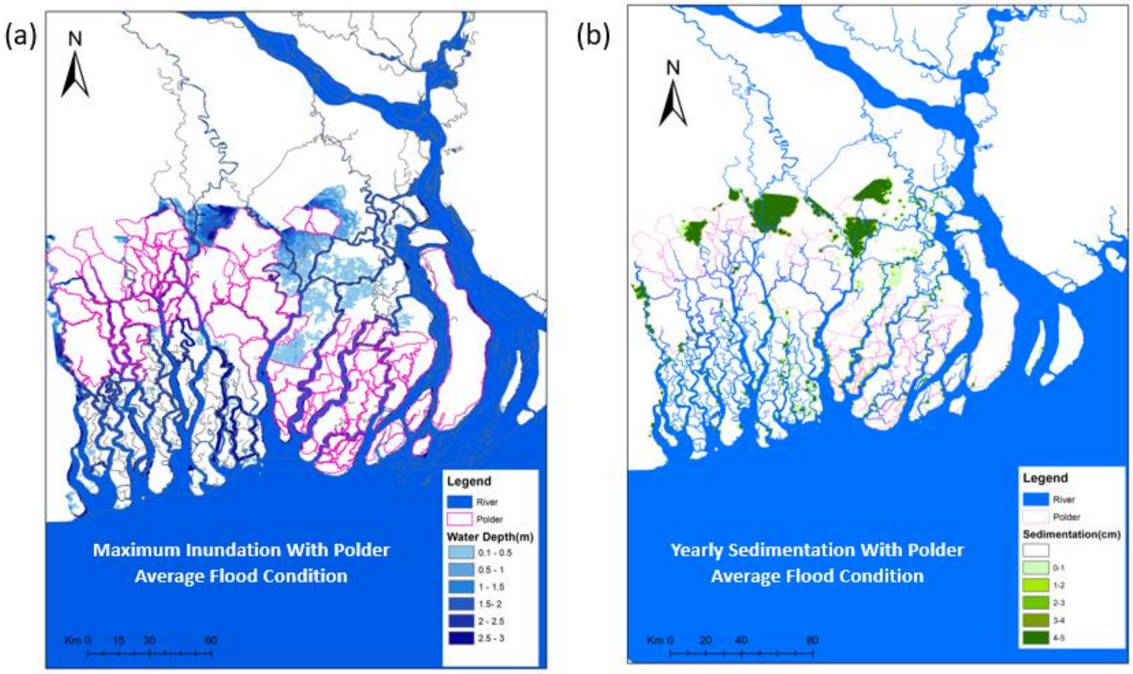

Figure 3.11 : (a) Inundation and (b) sedimentation during an average flood condition. Existence of polders are considered during simulation.

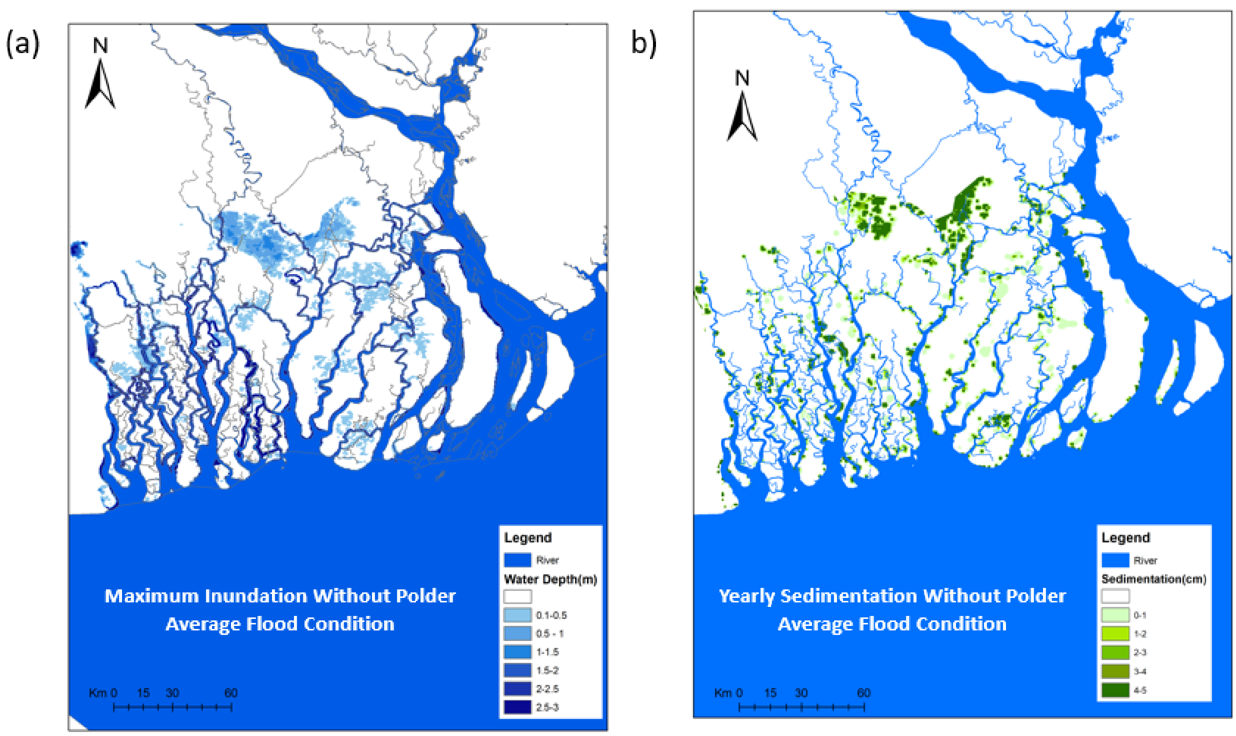

Figure 3.12 : (a) Inundation and (b) sedimentation during an average flood condition. Existence of polders are not considered during simulation.

Polders restrict the inundation extent but increase the flood depth in unprotected areas. Restricted flooding cause increased sedimentation in unprotected areas. When there is no polder, same volume of flood water is distributed in the entire region causing increase of flood extent but decrease of flood depth. This causes sedimentation in a wider area with decreased sedimentation depth.

3.6.2 Sedimentation during extreme flood condition

Following the BWDB definition (BWDB, 2012), the extreme flood in this case selected as the flood of 1998. The flooding during the peak of monsoon of 1998 and yearly sedimentation during the extreme flood year is shown in Figure-3.13. The scenario selected in this case is the existing condition, i.e., the condition when polders are present in the region. Comparison of Figure-3.13 with Figure-3.11 shows an increased flooding in the region when flood condition changes from an average to an extreme. During an extreme flood condition, almost all the unprotected region is flooded. This flooding causes sedimentation in the areas which are not protected by polders.

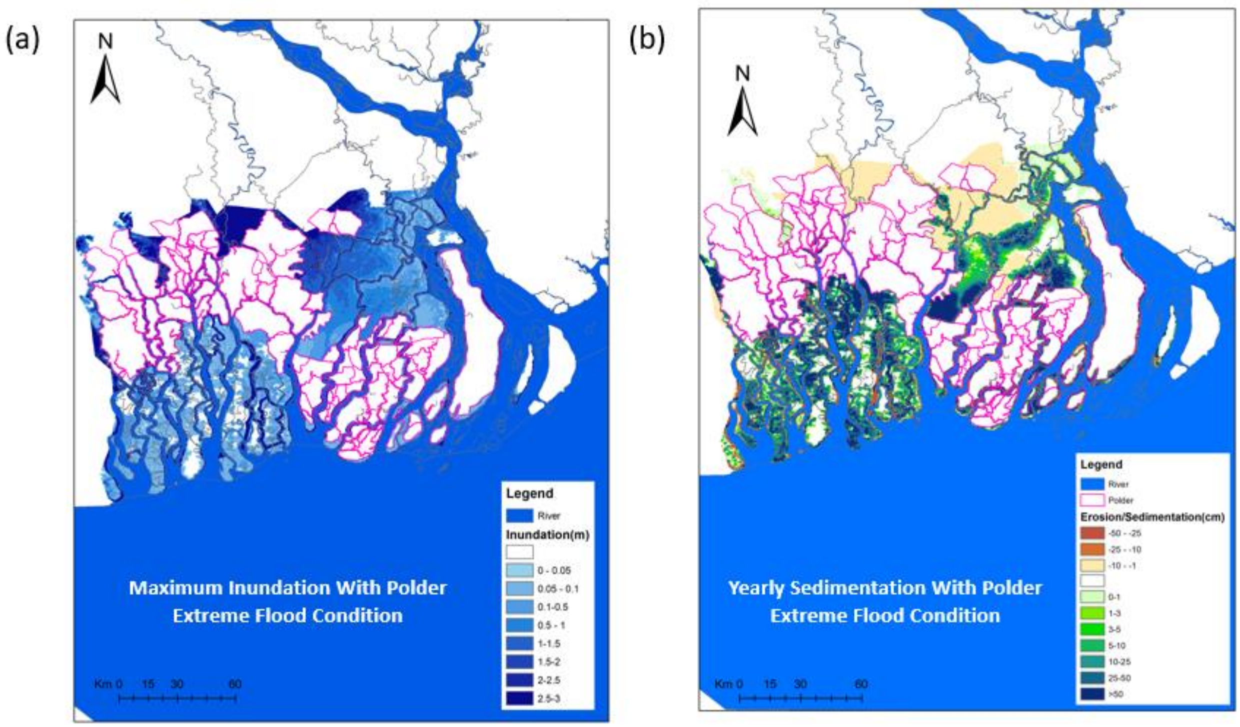

Figure 3.13 : (a) Inundation and (b) sedimentation during an extreme flood condition. Existence of polders are considered during simulation.

When polders are removed, the entire region is flooded as shown in Figure-3.14. This flooding is associated with the sedimentation in the region. When compared with the average flood condition (see Figure-3.12), areal extents of flooding and sedimentation is significantly larger. This shows the importance of polder in the region when flooding is considered. Polders are effective in protecting the areas which are poldered during an extreme flood. If there were no polders, the entire region would have been flooded during an extreme flood condition. In terms of sedimentation, if polders were not there, sedimentation increases with the increase of flooding intensity (Figures 3.12 and 3.14).

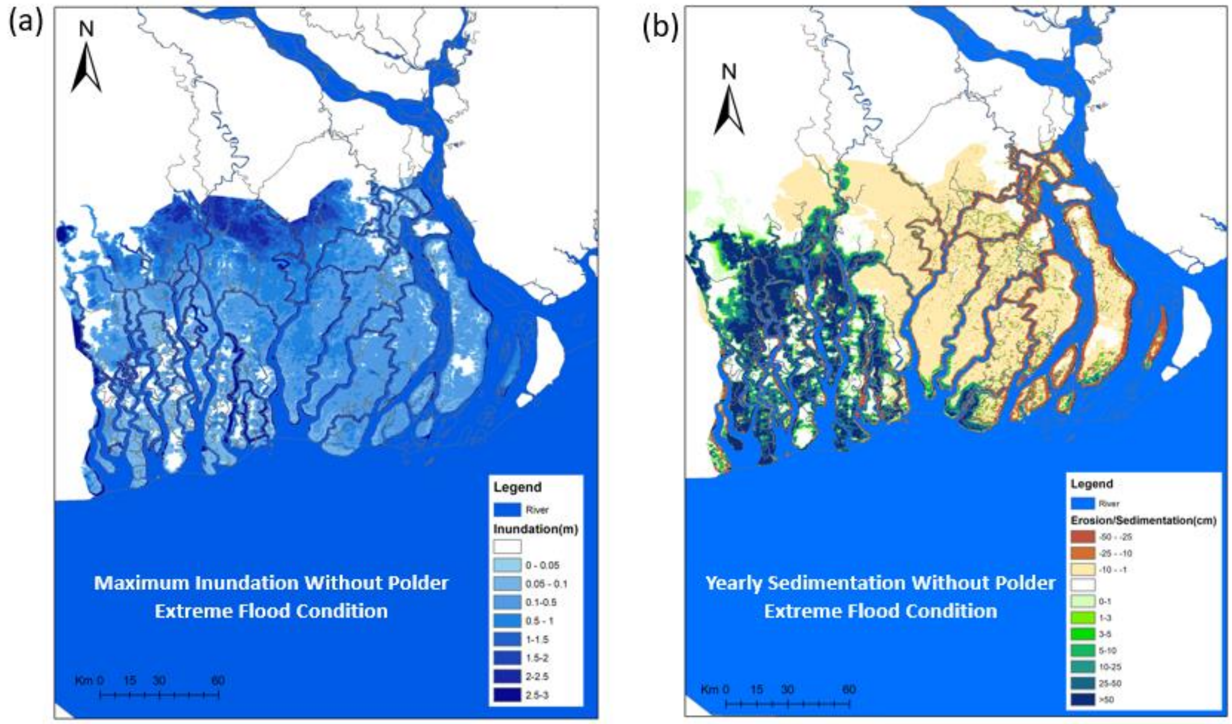

Figure 3.14 : (a) Inundation and (b) sedimentation during an extreme flood condition. Existence of polders are not considered during simulation.

3.6.3 Sedimentation during end-century flood condition

An end-century flood condition is created for the year 2088 with a sea level rise of 1m. Incoming sediment load into the system is represented by model simulation values (Darby et al., 2015). Simulated inundation and sedimentation scenarios are shown in Figure 3.15. Inundation scenario during the end-century looks almost similar to an extreme flood scenario (Figures 3.13a and 3.15a). But sedimentation (confined within the unprotected land) during end-century scenario is remarkably high compared to extreme flood scenario (Figures 3.13b and 3.15b). The main reason behind this is increased sediment load from upstream simulated by the HydroTrend model (Darby et al., 2015).

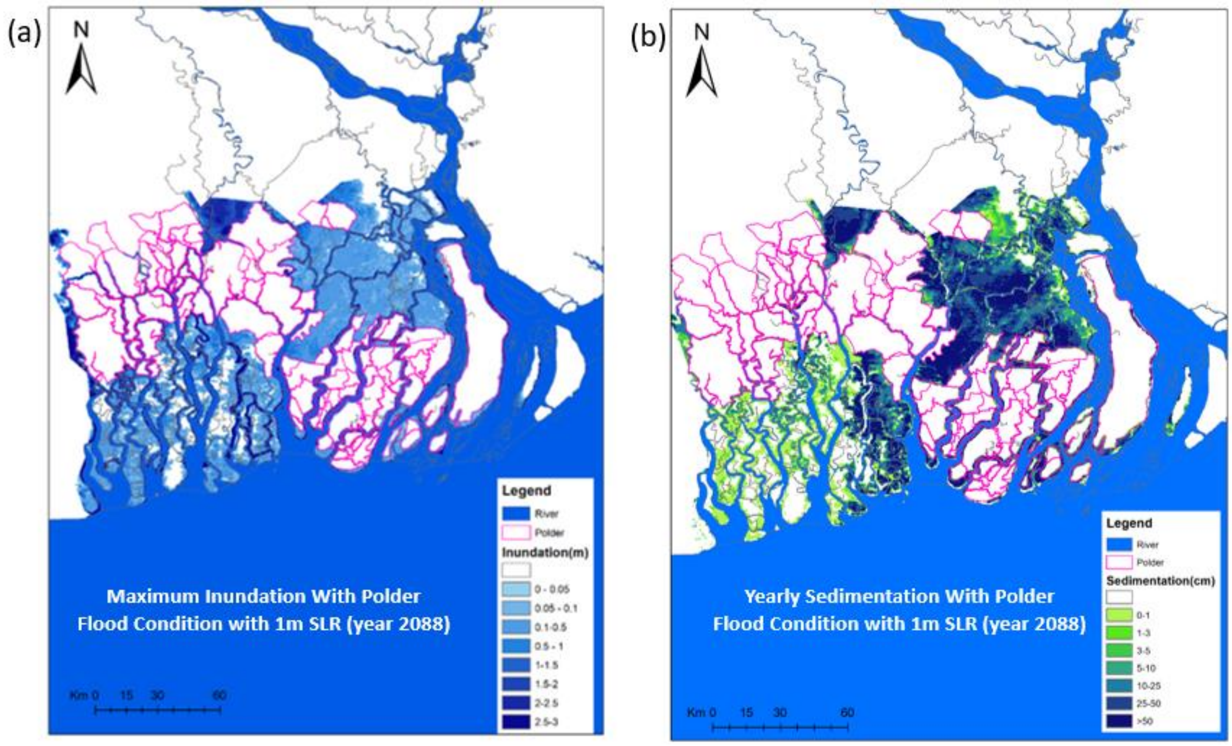

Figure 3.15 : (a) Inundation and (b) sedimentation during an end-century (year 2088) flood condition. Existence of polders are considered during simulation.

3.7 Impact of Polders on Floodplain Sedimentation

There exists a debate that polders restrict floodplain sedimentation and hence are responsible for sedimentation of river bed in the region. So far, there is no computational evidence related to this issue. This study tries an attempt to compute the impact of polders on floodplain sedimentation in the region. Comparison of floodplain sedimentation between 'with polder' and 'without polder' for an average flood condition is shown in Figure 3.16 and for an extreme flood condition is shown in Figure 3.17. Polders restrict the sedimentation within the unprotected lands (Figures 3.16a and 3.17a). The extent and depth of sedimentation depends on the areal extent of inundation during flood and volume of incoming sediments. Had there been no polders in the region (Figures 3.16b and 3.17b), the same volume of flood water and sediments that enter in the region is re-distributed over a wider area. During an average flood condition when polders are present, sedimentation occurs only in the north-central region. Removal of polders re-distributes this sediment in a relatively larger arear of the north-central region with reduced thickness. The process is almost similar during an extreme flood event. In this case, presence of polders cause sedimentation in the south-central region where, at present, there is no polder. Removal of polders cause uniform re-distribution of these sediments in almost the entire coastal region. This clearly shows that polders cause sedimentation to be confined only within unprotected region that results non-uniform land building process which is one of the main reasons of water-logging inside polder. Had there been no polder in the region, sedimentation will be uniform in the entire coastal region.

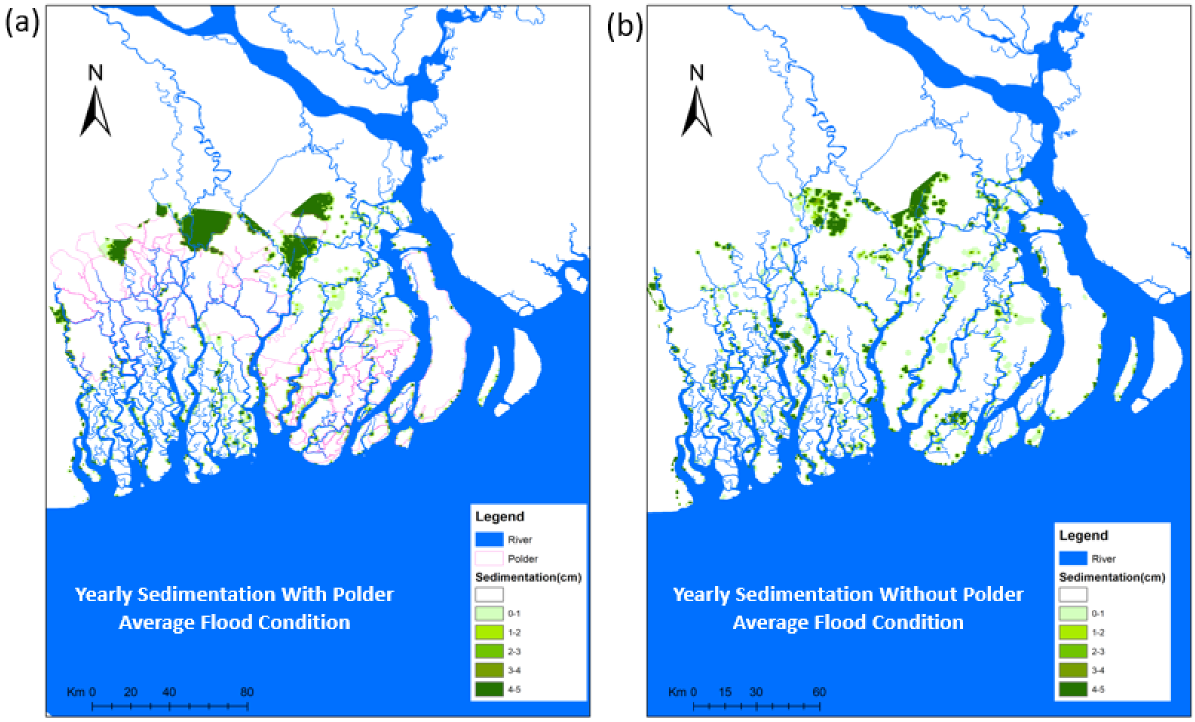

Figure 3.16 : Impact of polder in an average flood condition. Left image (a) shows the sedimentation for 'with' polder condition and the right image (b) shows the condition for 'without' polder condition.

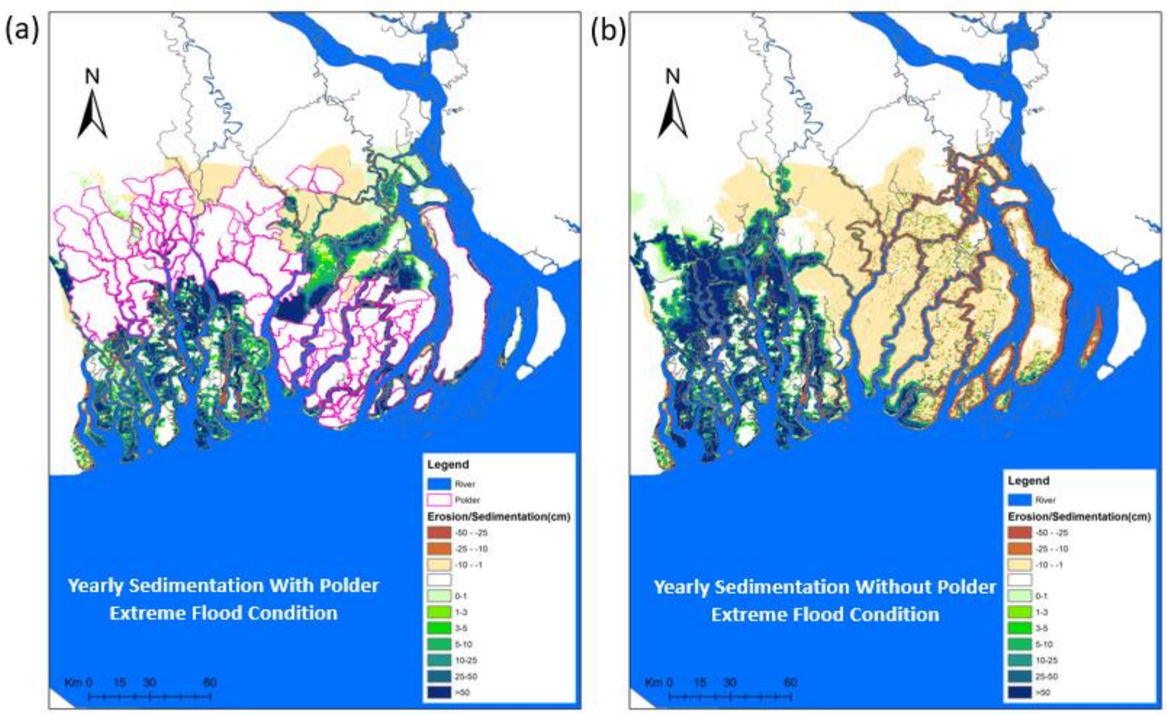

Figure 3.17 : Impact of polder in an extreme flood condition. Left image (a) shows the sedimentation for 'with' polder condition and the right image (b) shows the condition for 'without' polder condition.

Impact of polders on sedimentation is the western region (WES systems, where water-logging is believed to be caused by polders) in terms of total floodplain sediment retention and its percentage of total incoming sediments into the system is shown in Table 3.6. The table shows the values for different flooding conditions, i.e, average flood, extreme flood and an end-century flood of 2088 with a sea level rise of 1m.

Table 3.6 : Impact of polders on sediment retention in the western region (WES) for different flood conditions

Flood Condition	Incoming sediment load into the system (Million Ton/year)	Sediment retention in floodplain of western region (Million Ton/year)		Percentage of sediment retention in floodplain of western region with respect to total incoming sediments	
		With Polder	Without Polder	With Polder	Without Polder
Average	412	46	60	11.2	14.6
Extreme	1146	571	679	49.8	59.2
End-century with 1m SLR	2043	600	N/A	29.4	N/A

The results from Table 3.6 show that polders restrict 14 Million Ton/Year of sediments in an average flood year upto 108 Million Ton/Year of sediments in an extreme flood to be deposited on the floodplain in the western region. Had there been no polder in the region, this additional amount of sediment will be used to raise the land elevation in the region. In addition to delta building process, this elevated land would have contributed to reduce water-logging in the area. But at the same time, large area of the coastal region will experience severe flooding during an extreme flood event (Figure 3.14a). Although not explicitly computed, an end-century flood with a sea level rise of 1m would have contributed even more sediments to be deposited in the region, but at the expense of extensive flooding in the area during the peak flood season.

3.8 Seasonal Distribution Patterns of Sediments

As described in section 2.3, residual flow circulation pattern largely determines the sedimentation in the study area. Residual circulation, on the other hand, depends on the seasonal circulation pattern. Sediments in this region enter through inlets of three major rivers, the Ganges, the Brahmaputra and the Upper Meghna. Seasonal variations of inundation, flow circulation and sedimentation patterns in the study region are shown in Figure 3.18 (pre-monsoon), Figure 3.19 (monsoon) and Figure 3.20 (post monsoon). The simulations are made for an average flood condition and the results are shown during flood tide and ebb tide. It is seen that during pre-monsoon, the flow circulation velocity is low (velocity less than 0.5 m/s). Sediments are yet to start entering in the region. Fluvial inundation is almost non-existent. There is no sedimentation in the floodplain.

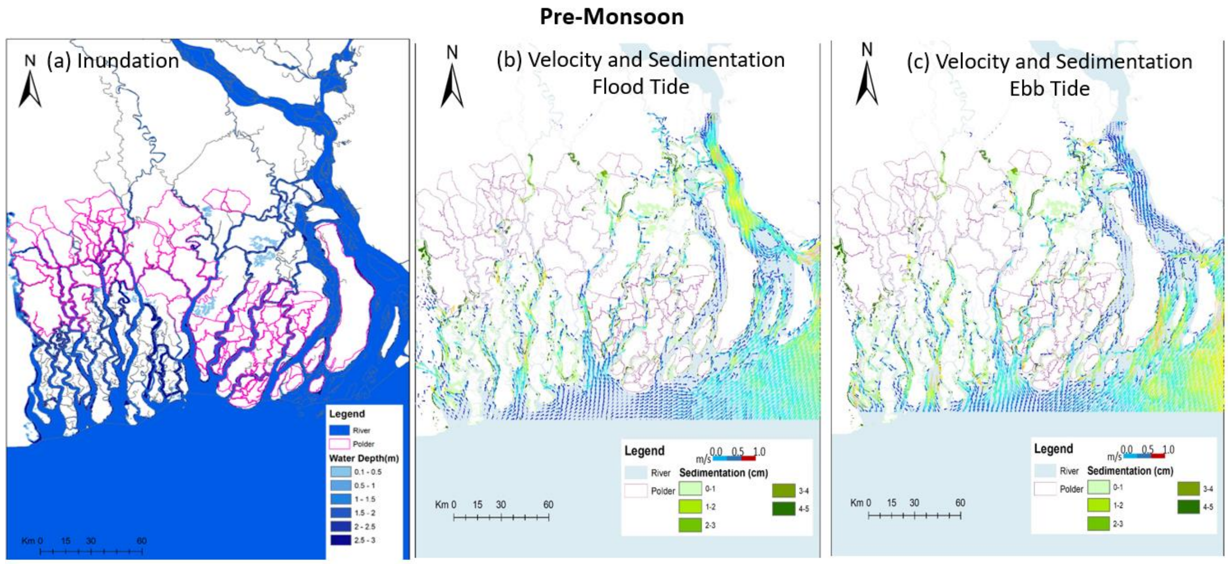

Figure 3.18: Distribution of (a) inundation, velocity and tides during (b) flood tide and (c) ebb tide during pre-monsoon of an average flood condition.

During monsoon, inundation due to fluvial and fluvio-tidal flood is observed (Figure 3.19). Both flood and ebb velocity increase (velocity greater than 1m/s). Sediments start to enter in the region from upstream during ebb tide and re-enter in the region during flood tide. In places where velocity is relatively low (north-central), sedimentation starts to occur.

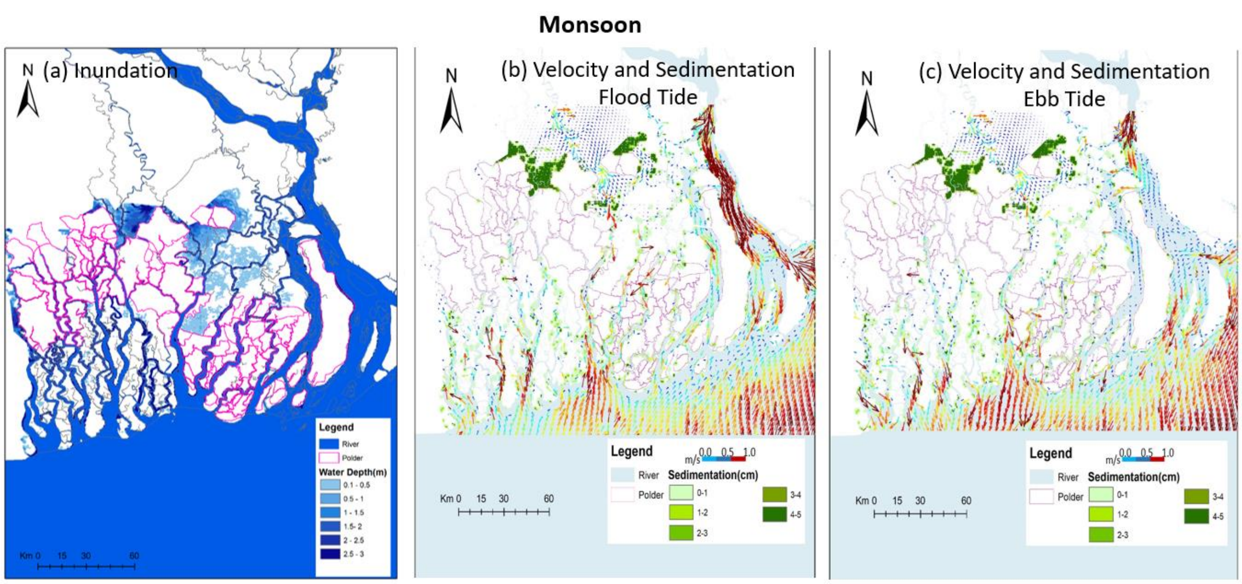

Figure 3.19: Distribution of (a) inundation, velocity and tides during (b) flood tide and (c) ebb tide during monsoon of an average flood condition.

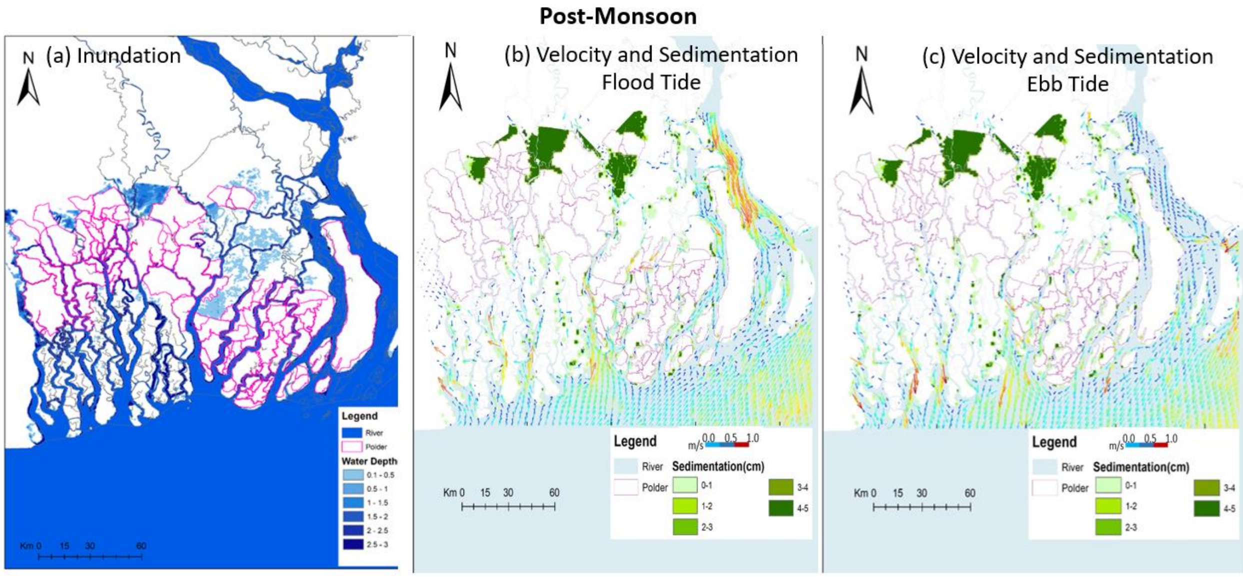

Figure 3.20: Distribution of (a) inundation, velocity and tides during (b) flood tide and (c) ebb tide during post-monsoon of an average flood condition.

The main sedimentation occurs during post-monsoon (Figure 3.20) when sediment laden water velocity in the inundated region is very low (less than 0.5 m/s). This low velocity accelerates the sedimentation process in the floodplain. Inflow of sediments from upstream starts to decrease. In this phase of seasonal circulation, sediments mainly enter from the ocean during flood tide.

CHAPTER FOUR
Water-logging inside Polder

4.1 Introduction

The ecological and geological situation of Southwestern part of Bangladesh is unique in many ways. Southwest coastal region of Bangladesh is a unique brackish water ecosystem comprising the districts of Satkhira, Khulna, Bagerhat and the southern part of Jessore. It is the part of inactive delta of large Himalayan Rivers and located just behind the mangrove forest Sunderban and Bay of Bengal. The large portion of the region is coastal wetland formed by the rivers flowing to the sea. Since the Southwest region is located in the coastal zone, it possesses a fragile ecosystem and is exposed to a number of calamities like cyclones, floods, tidal surges, repeated water logging, and land erosion, degradation etc that shaped the lives and livelihood patterns of people.

Technically water-logging refers to a situation when the level of ground water meets plants' root zone. In some localities, this may last for at least three months, and may prolong up to 8-9 months or even become perennial. The depth of flooding varies, according to the topography of the area, and can reach up to 3m. Soils become highly reduced due to changes in redox potential and undergo changes in physio-chemical properties, thereby supporting certain land usage only. Though such an area would naturally support aquaculture, agriculturally it can also be highly productive (and profitable), depending on the use of certain land management techniques. One of the problems with water logging is to define the limits of water logging – a seasonal drainage problem – as distinct from perennial water bodies in southwestern region of Bangladesh. One way to do this is to compare satellite images at different times of the year/hydrological cycle.

This study is conducted to study the water-logging process by analyzing satellite images and then applying numerical model. As study area for model application, polders 24 and 25 are selected. Eight different scenarios are constructed to study water-logging conditions in different combinations of morphological and climatic variables.

The following sections of this chapter describes the image analysis and model simulation results.

4.2 History of Water-Logging in South-West Coastal Region

After the devastating flood of 1954-1955 an international mission (Crook Mission) was sent under the United Nations to solve the flood problems of the East Bengal (Present Bangladesh) and installment of Coastal Embankment Project (CEP) by Water and Power Development Authority (WAPDA) was an initiative to solve the problem. The project was initiated in 1960 to reclaim all the tidal influence coastal areas that lay below the highest tide levels for periodic inundation by saline water within 136 polders for crop production. In the South-West region alone (Figure 4.1) 1566 km of embankments with 282 sluice gates were constructed. 21 vent Bhabadaha sluice gate one of the important structures of the design which is now the source of the pains for millions people. Within 15 years of the construction of embankments siltation started at the water entrance point of the sluice gates, and rivers & canals beds began to increase. As a result, first Beel Dakatia under polder 25 became water logged. Subsequently, polders 24, 27 and 28 also became water logged one after another.

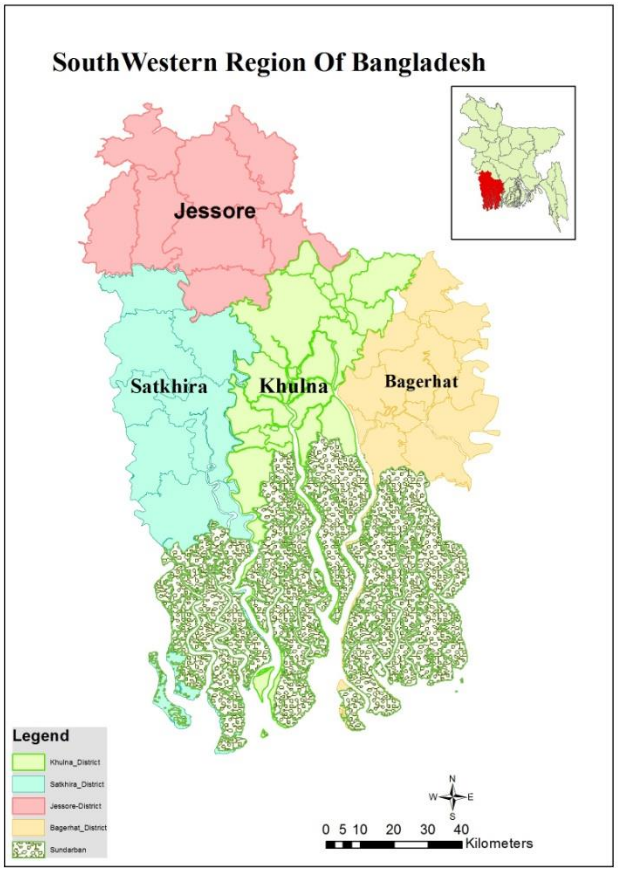

Figure 4.1: South-West coastal region of Bangladesh

From the mid-80s, water-logging becomes a permanent problem because sediments could not be deposited in flat tidal plain due to the polder embankments and began to deposit on the river bed, causing the river bed began to rise. As flat sluice gates became inoperative, water in the polders could not flow out. Through these processes, more than one hundred thousand hectares of land became water-logged in a gradual process.

Then the ill effects of the polder/enclosure system came into surface. Exemplified by deposit of sediments on the riverbed, drainage congestion and water-logging in massive areas creating disastrous consequences for the local communities with inundation of massive areas under stagnant water that seriously exposed livelihood and environment. Due to construction of permanent embankments on both sides of the rivers, tidal flow could not enter in the tidal wetlands. Almost all the estuaries began to silt up at the upper end of the south-west region. In the pre-polder period, the high tides used to deposit sediment on the floodplain during the months of January to June (as shown in chapter three) when local people used to breach the temporary earthen embankments (Ostomasibodh) built for the period from July to December. But after construction of polders sedimentation only took place on unprotected lands including the river channels (as shown in chapter three), causing uneven distribution of sedimentation in protected and unprotected lands. This process ultimately raised the unprotected lands in comparison to adjacent protected lands inside polders. Due to this, the land inside protected land subsided and gradually took the shape of lakes and over 106,000 thousand hectares of land became permanently waterlogged. Major water-logged area based on available online reports are shown in Tables 4.1, 4.2 & 4.3.

Table 4.1: Major Water Logged Area in 2005 (Sep to Nov)

Year	Area affected (District)	Major Cause	Analysis Type
2005 (September to November)	Satkhira	Flooding caused by poor drainage of excessive monsoon rain	Field Assessment
	Jessore		

Silted river with river beds higher than polders preventing natural drainage.

Table 4.2: Major Water-Logged Area in 2013 (July-December)

Year	*Area affected (District)*	*Major Cause*	*Analysis Type*
2013 (July-December)	Khulna	Poor drainage of seasonal rainfall	Field Assessment and image analysis
	Satkhira		
	Jessore		

Major causes of water-logging in 2013 as per FAO report:

- Silted river with river beds higher than polders preventing natural draining out.
- Badly planned or executed infrastructure projects (such as roads) with block drainage.
- Water infrastructure not being properly maintained.
- Agriculture and other economic activities may obstruct drainage.

Table 4.3: Major Water-Logged Area in 2011 (August)

Year	*Area affected (District)*	*Major Cause*	*Analysis Type*
2011 (August)	Khulna	Flooding caused by poor drainage of excessive monsoon rain	Field Assessment
	Satkhira		
	Jessore		

4.3 Reasons Behind Water-Logging

In addition of polder effect, following drivers are believed to act as possible reasons of water-logging in the south-west region:

Change at the entrance of Ganges river

Before 16th century, the main river flow of Ganga River run through Bhagirothi which divided into eight types of flow, it met the sea over the 24 Porogona and Khulna. Basically, Jessore, Khulna, Kushtia, 24 Porogona, Murshidabad, Krisnonagar, Faridpur and Barisal were formed by the alluvial soil from the flow of the Ganges. But after that period it gradually turned towards south-east, the reason is thought to be natural. As a result, the water flow from upstream gradually decreases in the rivers of this region and these rivers began to lost their conveyance capacity. Besides the lack of freshwater flow stared due to change of direction of Ganga River. It also protects the deposition of silt which was brought with the upstream flow. As a result, the land elevation of this region could not rise, and rivers began to dead.

Death of the Mathavanga river

At the period of nineteenth century, rivers of the south-west region was deprived from the upstream flow due to death of the branch river of Ganga named Mathavanga. In the past it was used as a communication route with Kolkata (India), and because of the high flow velocity of water, sometimes river vessel accidents occurred. To control the high flow velocity of Mathavanga River, large boats filled with soil were sunk at the mouth of this river. At the beginning this technique was successful, but later it started to show negative impact at the entrance point of the river (in addition to natural shifting of the Ganges). Gradually this river was disconnected from the main river Ganga. Gradually the other rivers named Kopotakho, Bhairab and Betna (which had link with the Mathavanga River) and the people who were depended on these rivers began to deprive form fresh water flow.

Farakka barrage

Impact of Farakka barrage is devastating for the rivers of whole south-west region. Due to withdrawal of dry season flow of Ganges from upstream by Farakka barrage, freshwater inflows for the rivers of south-west regions decrease. This causes sediment laden saline water from the ocean to intrude into these river/estuarine systems. As type of sediments coming from the sea is mainly cohesive, process of sedimentation in these river systems accelerate due to flocculation and coagulation. This sedimentation process when added to the polder effect, cause rapid rise of bed elevation of the rivers in the south-west region. As described in chapter three, absence of floodplain sedimentation in the protected lands and increased sedimentation in unprotected lands ultimately results drainage congestion which leads to water-logging.

Encroachment of river banks and poorly executed infrastructure

Construction of roads and poorly designed road openings by culverts across the rivers and internal drainage khals without considering the hydrology and hydraulics of the river systems by different government agencies is another cause of water-logging.

Unplanned aquaculture

Unplanned growth of shrimp farming is another reason behind worsening water logging problem.

4.4 River Systems in South-West Region

The major river systems in the south-west region as:

Sholmari-Salta-Lower Bhadra System
Hamkura-Bhadra-Joykhali Catchment System
Hari- Mukteshwari Catchment System
Upper Bhadra- Buri Bhadra- Harihar Catchment System
Teligati-Ghengrile Catchment
Salta- Gunakhali -Haria Catchment System
Kobadak Catchment System
Shalikha Catchment System
Betna Catchment
Atharobaki-Chitra Catchment system
Morirchap and Labonyabati Catchment System
Shapmara- Galgheshiya Catchment

Among these systems, Hamkura, Hapakhali, Teleghati rivers have lost their conveyance and upper Solamari, Hari, Teka, Morirchap and Chitra River are facing severe sedimentation. These rivers are shown in Figure 4.2.

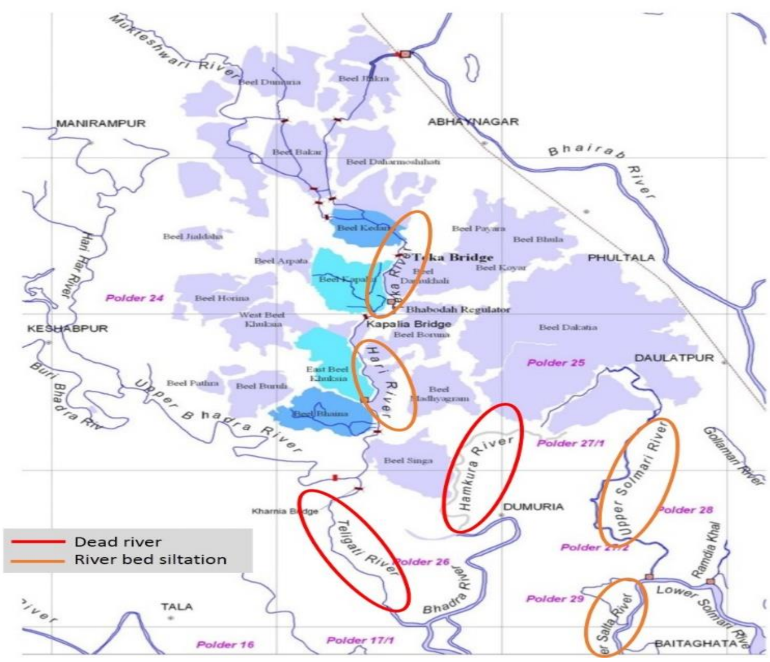

Figure 4.2 : Location of rivers facing loss of conveyance and sedimentation

Ali and Syfullah (2016) reported that sluice gate operation and maintenance play a vital role along with the hydrology and hydraulics of the river system causing water-logging problem in the south-west region. The study stated that non-operational sluice gates are one of the major causes for water-logging in Beel Dakatia (Figure 4.3). In Dacope Upazila, water-logging problem of polder-32 was initiated by polder breaching during cyclone Aila. Breached polder locations are shown in Figure 4.4.

Figure 4.3: Existing condition of three sluice gates of Beel Dakatia (Ali and Syfullah, 2016)

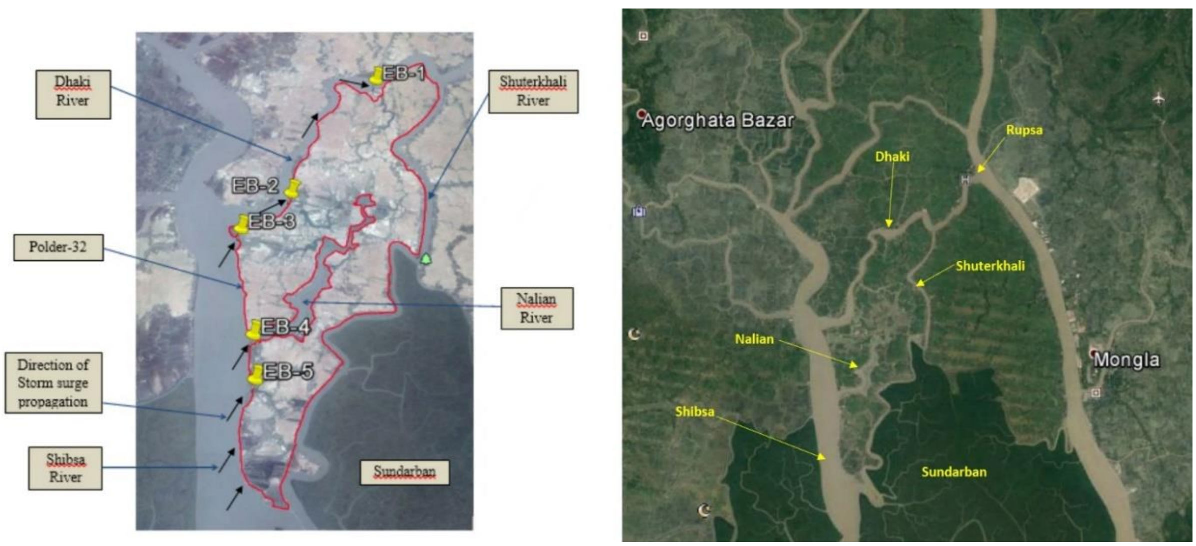

Figure 4.4: Breached polder location during cyclone Aila in Polder-32 and formation of Nalian channel.

4.5 Image Analysis to Locate Water-Logged Areas

Landsat image analysis is made to locate water-logged areas in south-west region. Results of image analysis are shown in Figure 4.5 for Jessore district, in Figure 4.6 for Satkhira district, Figure 4.7 for Bagerhat district and Figure 4.8 for Khulna district.

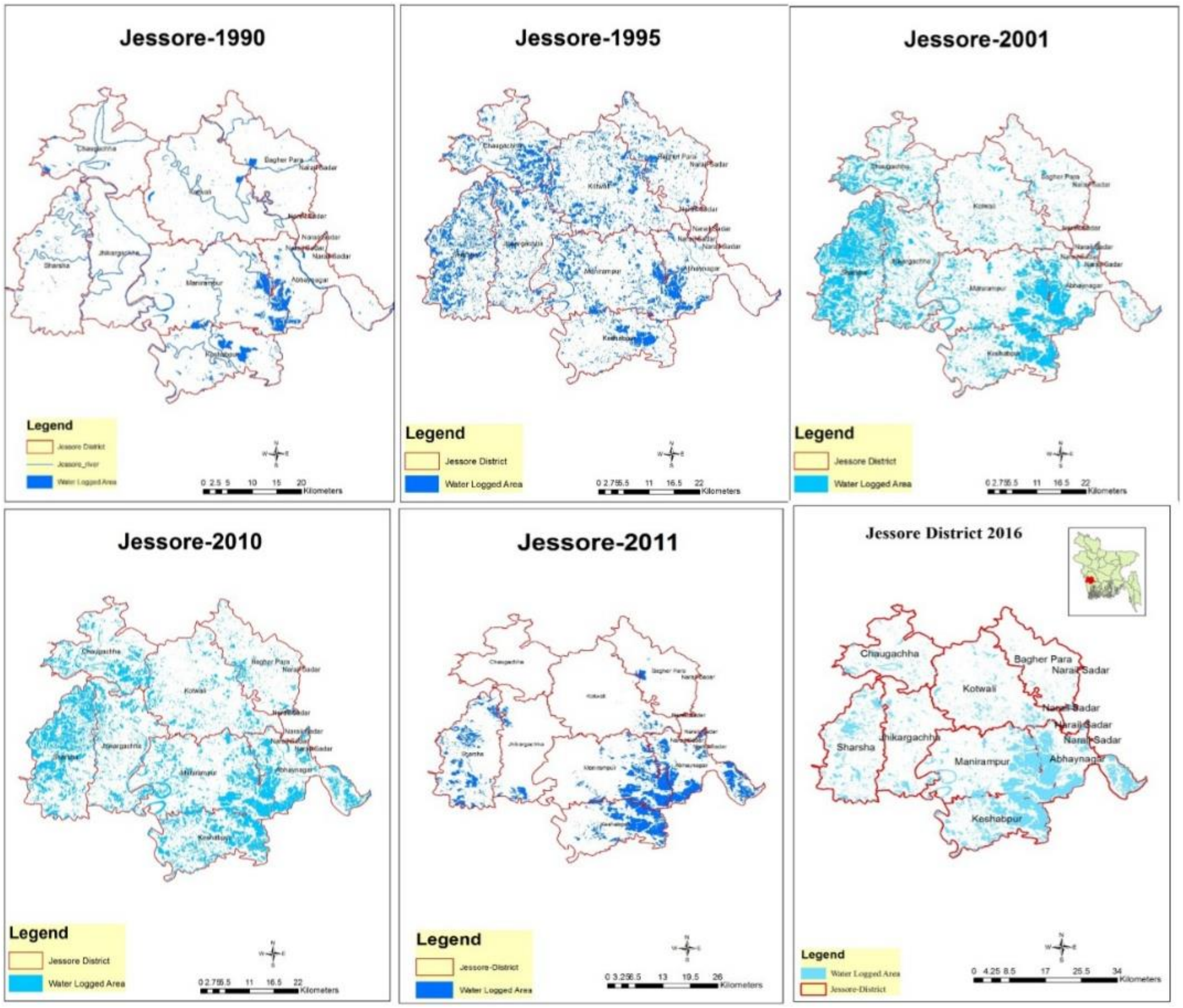

Figure 4.5: Landsat image shows water-logged areas of Jessore district.

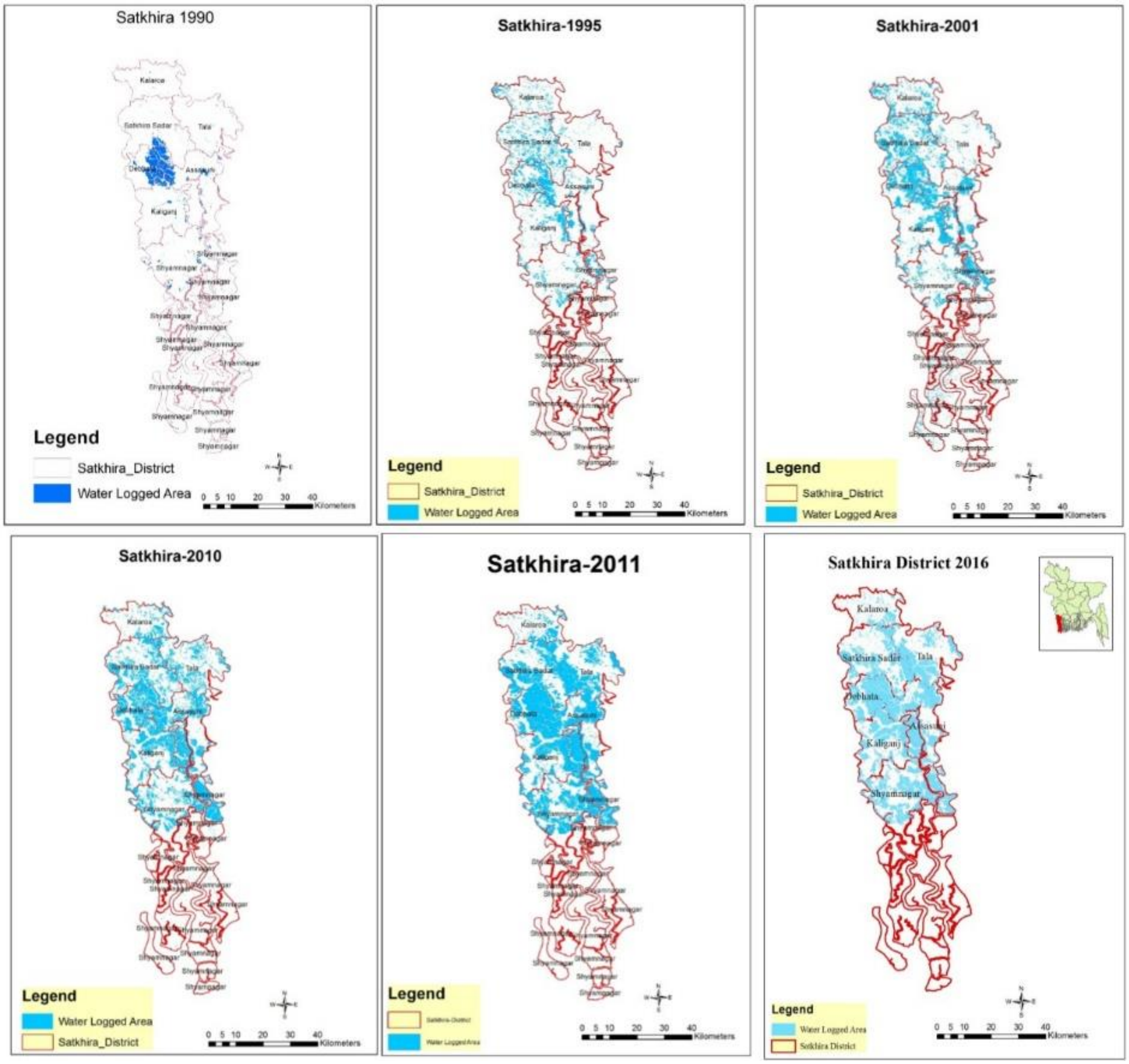

Figure 4.6: Landsat image shows water-logged areas of Satkhira district.

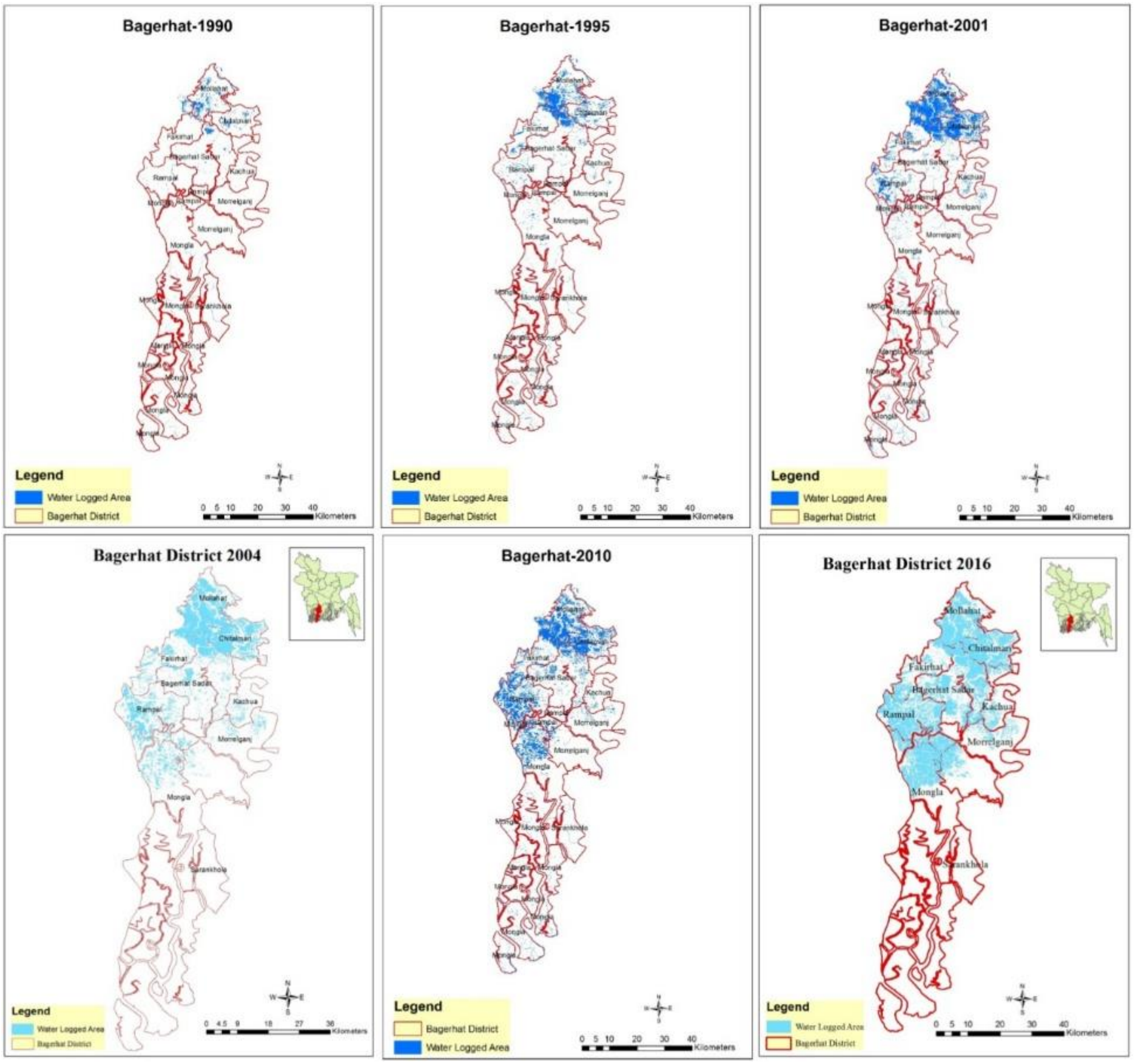

Figure 4.7: Landsat image shows water-logged areas of Bagerhat district.

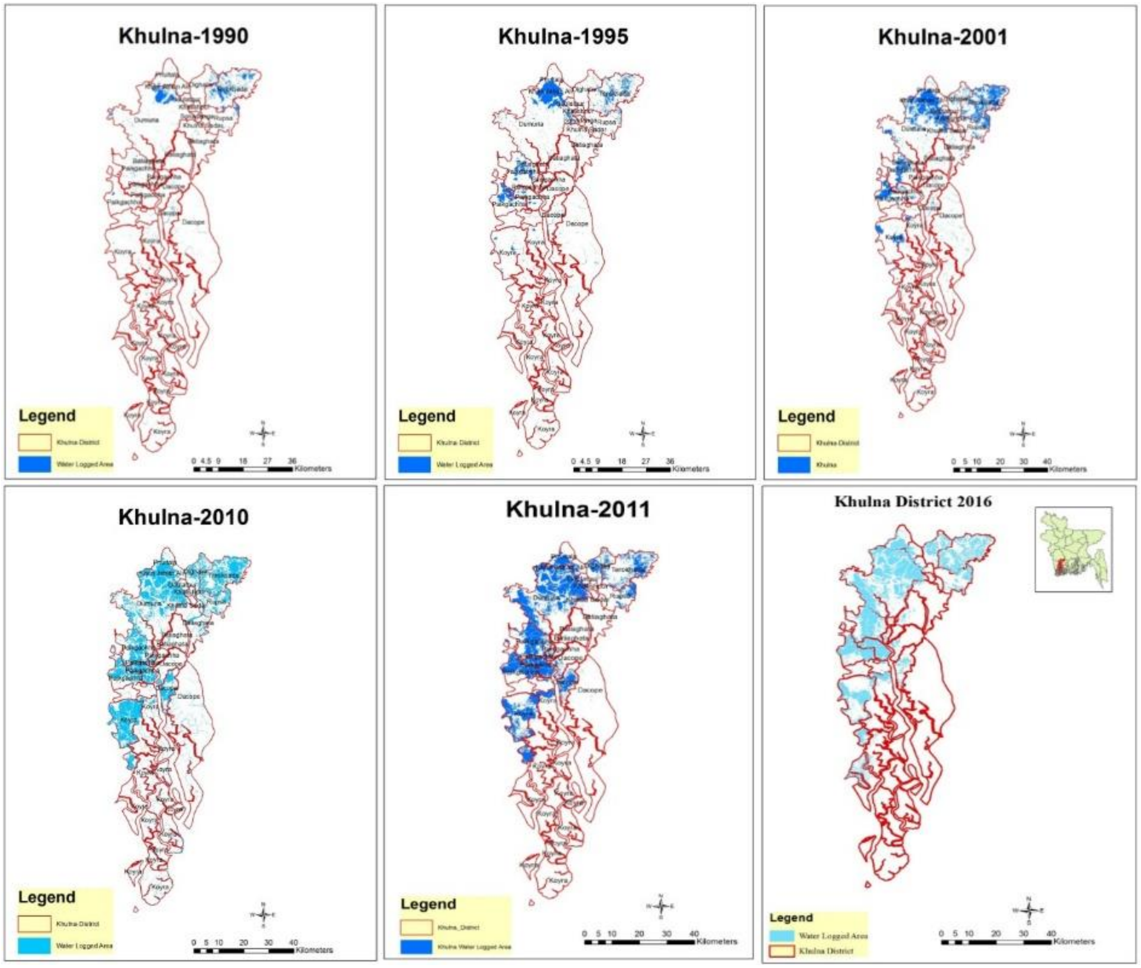

Figure 4.8: Landsat image shows water-logged areas of Khulna district.

From the Landsat image analysis, major water-logged areas for the last 25 years are identified and listed in Table 4.4.

Table 4.4: Major water-logged areas for last 25 years

Districts	Upazila	Total Upazila
Khulna	Dumuria, Phultala, Paikgacha, Terokhada, Batiaghata, Daulatpur, Dacope, Koyra	8
Jessore	Abhaynagar, Keshabpur, Manirampur, Jhikargacha, Sarsha	5
Satkhira	Kalaroa, SatkhiraSadar, Tala,Debhata, Asasuni	5

4.6 Projects Taken up by Different Organizations to Solve Water-Logging Problem

Numbers of government organizations like Bangladesh Water Development Board (BWDB), Local Government Engineering Department (LGED), Department of Fisheries (DoF), Department of Disaster Management (DDM), Bangladesh Agricultural Development Corporation (BADC) etc. and non-governmental organizations are working to solve water-logging problem in south-west region. In this regard, lists of different projects taken by BWDB and by LGED are shown in Table 4.5 and Table 4.6.

Table 4.5: Projects taken by BWDB related to water-logging problem

SL No	Name of the project	District covers	Implementing year	Funding source	Status
1	Khulna Jessore Drainage Rehabilitation Project	Khulna Jessore	1994-2002	ADB	Completed
2	Operation & Maintenance in KJDRP area	Khulna Jessore	2006 to present	GoB	Ongoing
3	Drainage improvement of Kobadak river basin	Khulna Jessore, Satkhira	2010 to present	GoB	Ongoing
4	Drainage improvement of polder 34/2	Khulna, Bagerhat	2011	GoB	Ongoing
5	Drainage improvement of BhitiarBeel Project	Khulna, Narail	2012 to present	GoB	Ongoing
6	Drainage improvement of polder 36/1	Khulna, Bagerhat	2013	GoB	Proposed
7	Drainage improvement of polder 1,2,6-8 project	Satkhira, Khulna	2013	GoB	Proposed
8	Re-Excavation of Betna River for mitigation of drainage congestion in Satkhira District	Satkhira, Kolaroa, Tala and Assasuni	2012-2014	Climate Change Trust Fund	Completed

Table 4.6: Projects taken by LGED related to water-logging problem

SL No	Name of the project	District covers	Duration	Funding source
1	Project for improvement of Rural Road, Hat-Bazar, Bridge/Culvert,Infrastructure	Khulna, Satkhira	July-2008 June-2013	GOB
2	Emergency 2007 Cyclone Recovery and Resortoration project (ECRRP), school	Khulna Satkhira	Aug-2008 Dec-2017	World Bank
3	Important Rural Infrastructure Development project (Roads/Bridge/Culvert/Market/Bazar)	Khulna Jessore, Satkhira	Jan-2010 Dec-2014	GoB

SL No	Name of the project	District covers	Duration	Funding source
4	South-west Bangladesh Rural Infrastructure Development project (Roads/Market/Bazar&GCS)	Khulna, Narail	Jul-2010 June-2013	JACA
5	Union Infrastructure Development (Khulna, Bagerhat&Satkhira District) Project, ROad, Bridge/Culver & GC-RM	Khulna, Satkhira	Jul-2010 June-2013	JACA
6	Construction/Reconstruction of upazila& union roads bridges/culvert project	Satkhira, Khulna, Jessore	Jan-2009 Jan-2014	GoB
7	City Region Development Project (Road construction, Drain, River Dredging and Rehabilitation)	Khulna	2011-2016	ADB,SIDA,Kfw
8	Rural Infrastructure Development	Jessore, Satkhira	2010-2015	GOB
9	Maintenance of Rural infrastructure Rural road and culvert maintenance	Satkhira	2012-2013	GOB
10	Development of Public priority upazila Road, Bridge/Culvert	Satkhira	2014-2013	GOB

4.7 Selection of Study Area for Model Application

Based on the synthesis and discussion above, reasons of water-logging inside different polders are summarized as:

- River bed siltation / non-functioning of rivers (Polder- 24, 25, 27)
- Embankment breaching (Polder-29,32)
- Rainfall flooding (Polder- 29, 32)
- Manmade interventions: (Polder-24, 25, 29)
  - Obstruction of natural drainage due to construction of infrastructure
  - Shrimp culture
  - Non-operational sluice gates

As focus of this study is the impact of river sedimentation on water-logging, Polder-24 and 25 are selected as the study area for model application.

4.8 Model Setup

The flow module of Delft 3D modeling suite is applied to study the water-logging inside polders 24 and 25. The model setup for the morphology model described in chapter three is in macro-scale whereas, water-logging model is in micro-scale. This model requires a detail description of river and canal network, road network, depression (beels) and sluices that connects the main river with the polder domain inside. This needs a very fine-grid model within a coarse-grid domain. For the coarse grid domain, model grid size varies from 243m to 1164m in longitudinal direction and 186m to 1704m in lateral direction. For the fine grid model, the grid resolution is approximately 150m x 110m. Total number of grid points in the entire model domain is about 1.7 million. The boundary of the coarse grid model is : border with India in the west (type of boundary is not fixed), Lower Meghna estuary in the east, three major rivers (Ganges, Brahmaputra and Upper Meghna) in the north and Bay of Bengal in the south (see Figure-4.9). The boundary of the fine grid model is driven by the boundary of the coarse grid model (Figure-4.9). Details of polder network, polders 24 and 25 for which the fine grid model is constructed, all the major rivers including the Hari river is shown in Figure-4.10. Details of the Water-logging model that shows canal network, road network, sluices is shown in Figure-4.11 and in Figure-4.12.

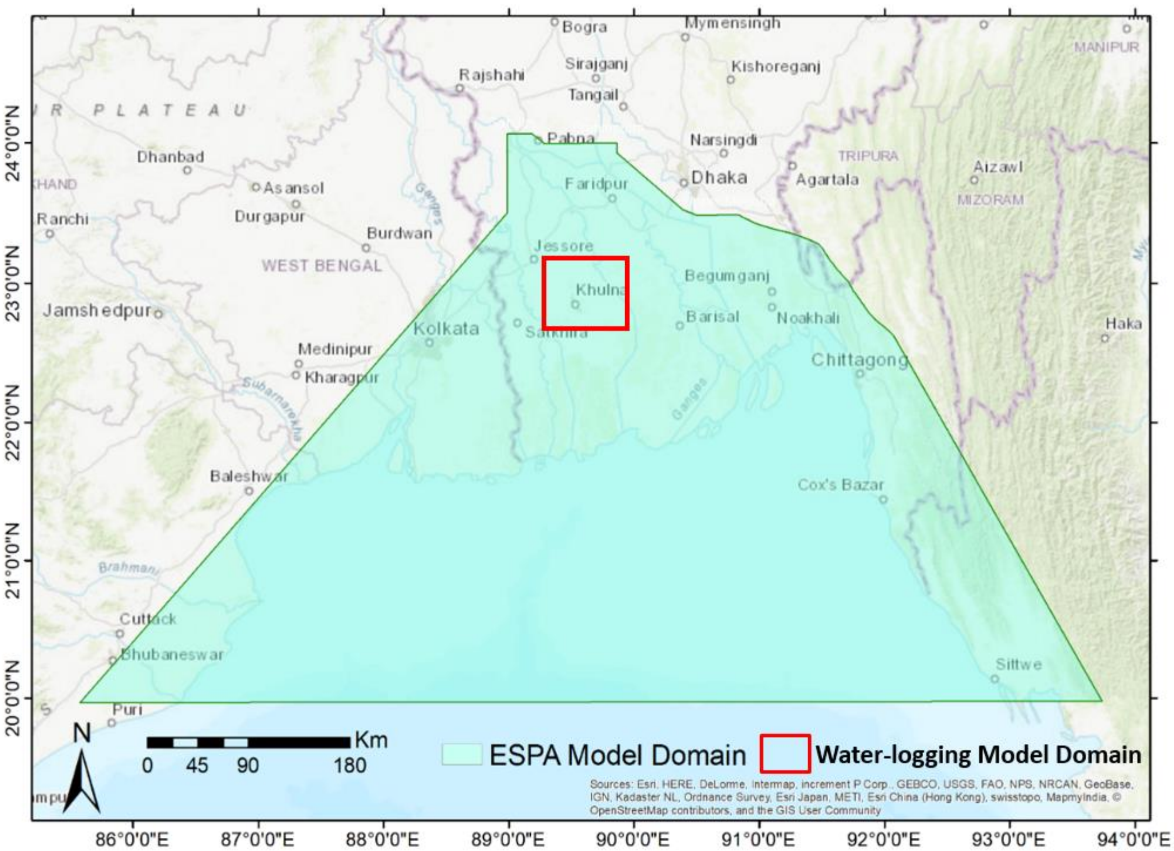

Figure-4.9: Model domains of ESPA model and Water-logging model.

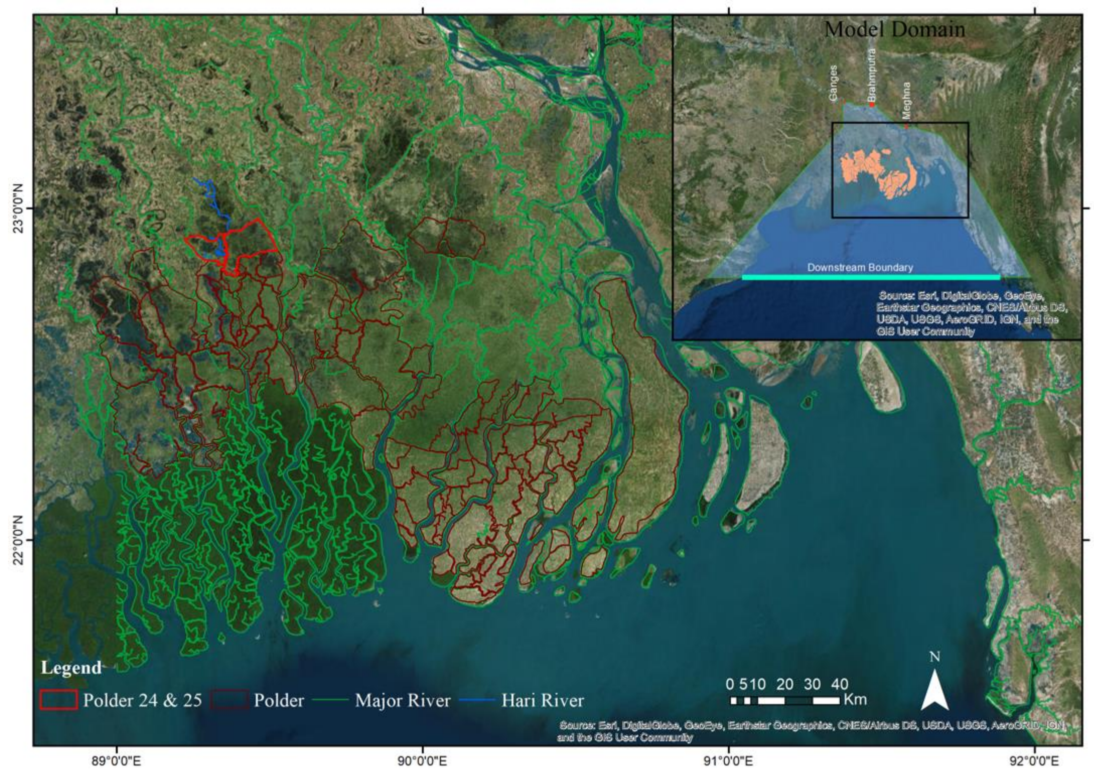

Figure-4.10: Details of the ESPA model domain along which polders 24 & 25.

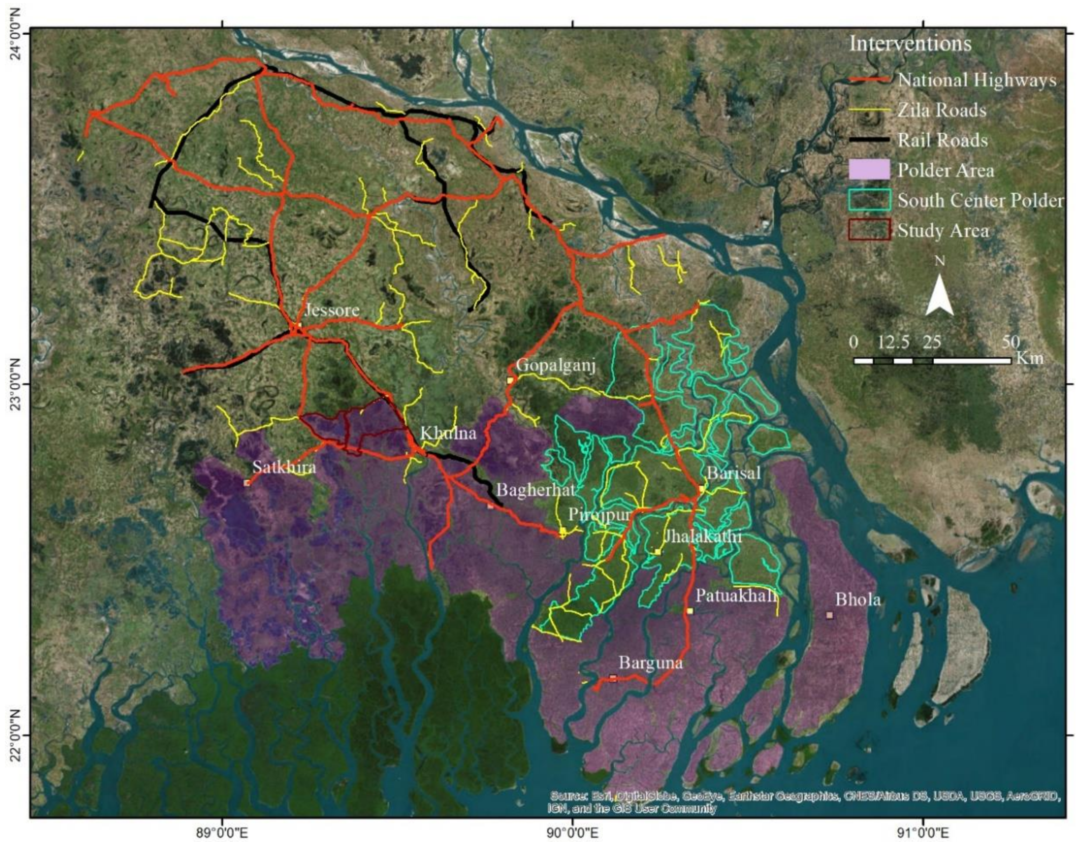

Figure-4.11: Details of Water-logging model.

Model receives fluvial flows from three major rivers in the region – the Ganges, Brahmaputra and Upper Meghna. For all the scenario runs – model simulated daily discharges from INCA hydrological model (Whitehead et al., 2015) are used as discharge boundary conditions. Tidal forcing in the model is provided by sea surface elevation in the Bay of Bengal. For all the scenarios runs – model simulated hourly sea surface by GCMOS ocean model (Kay et al., 2015) is provided as the downstream sea level boundary. In micro-scale model, morphological changes are considered static (except subsidence) – so no additional sediment input is provided.

Land topographic input in the model is provided from Digital Elevation Model (DEM) currently available in Bangladesh. DEM data is collected from the National Database of Water Resources Planning Organization (WARPO), Bangladesh. DEM in its current form has a 50m X 50m resolution.

For the river bathymetry, combinations of secondary and primary data are used. Secondary data are collected from BWDB and primary data in 294 locations in the rivers/estuaries of coastal zone are measured in ESPA project of BUET. Ocean bathymetry is provided from the open access General Bathymetric Chart of the Oceans (GEBCO).

Channel planforms are assumed to remain the same over the model simulation period. Similar assumption is made for channel bed level and floodplain levels of rivers / estuaries.

Subsidence is considered as a spatially static parameter. A rate of 2.6 mm/yr of subsidence is considered in the area bounded by the polders including the polder itself. Subsidence in the areas outside the polders, which are basically floodplain of rivers / estuaries, are assumed to be compensated by sedimentation and a zero subsidence is assumed in these areas.

4.9 Model Validation

The water-logging model comprising polders 24 & 25 is validated for dry season scenario by comparing the model simulation with the MODIS satellite image. The dry season of year 2001 (which is also the base year) is selected for model validation. The two model parameters used for model validation are Manning's roughness coefficient and eddy viscosity. The calibrated roughness coefficient was spatially variable having a values of 0.00025 in the ocean, 0.015 to 0.025 in the estuaries, 0.025 to 0.040 in the floodplain and 0.08 to 0.10 in Sundarban. Horizontal eddy viscosity has a constant value of 1 m^2/s. Comparison of model simulation in the dry season of year 2000 with MODIS satellite image is shown in Figure-4.12.

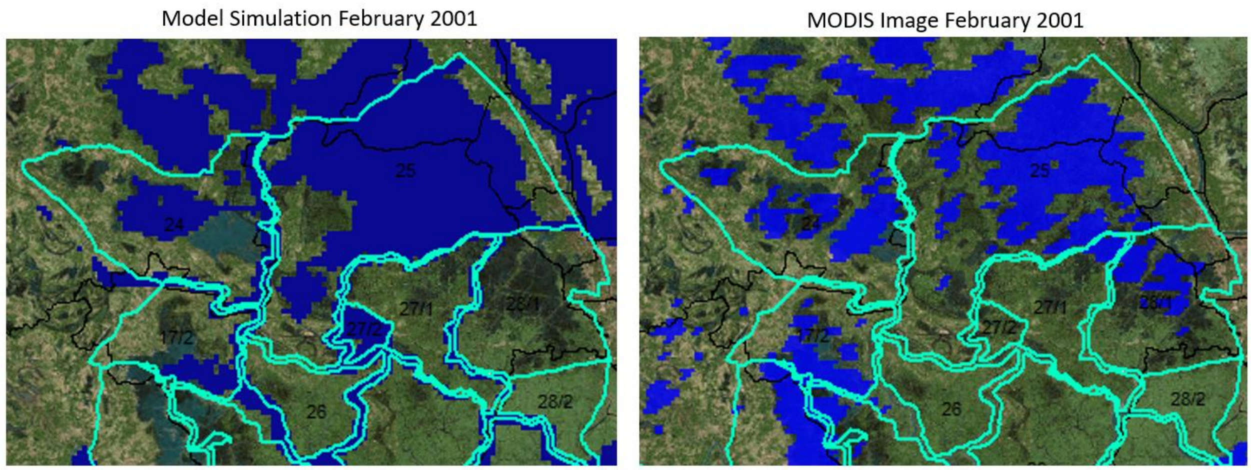

Figure-4.12 : Comparison of inundation extent between model simulation (left) and MODIS Image (right) during dry season (February) of the year 2001. The comparison shows inundation inside polders 24 and 25.

4.10 Scenario Description

Total 8 scenarios are constructed to study the water-logging process and impact in the study region. Out of these 8 scenarios, 4 are for base condition and 4 are for future. Year 2000-2001 is used as the base year and end-of-century is used as the future scenario. For end-century scenario, a sea level rise of 1.48m is used as sea level condition and a warmer & wetter climate is used as the climatic condition. A warmer and wetter climate increases the precipitation in the upstream basins during the monsoon and affects the upstream discharges of the major river systems. These combined effects are taken into considering during simulation of water-logging condition during end-century. Four base and future scenarios are constructed by considering (1) no intervention (2) sedimentation in the Hari river which is the main river system in the study region (3) dredging of the Hari river and (4) construction of new polders in the south-central region. New polders in south-central region is introduced by considering the fact that this region is flooded during the sea level rise and currently there is no polder in this region (see Figure-13). 24 new polders are introduced in this region as shown in Figure-14.

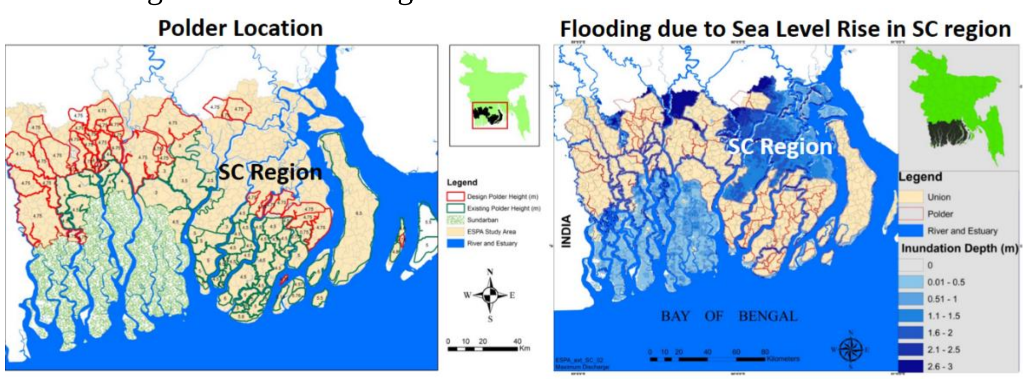

Figure-4.13 : Polder map (without any polder in the SC region) and inundation in the SC region during SLR of 1.48m.

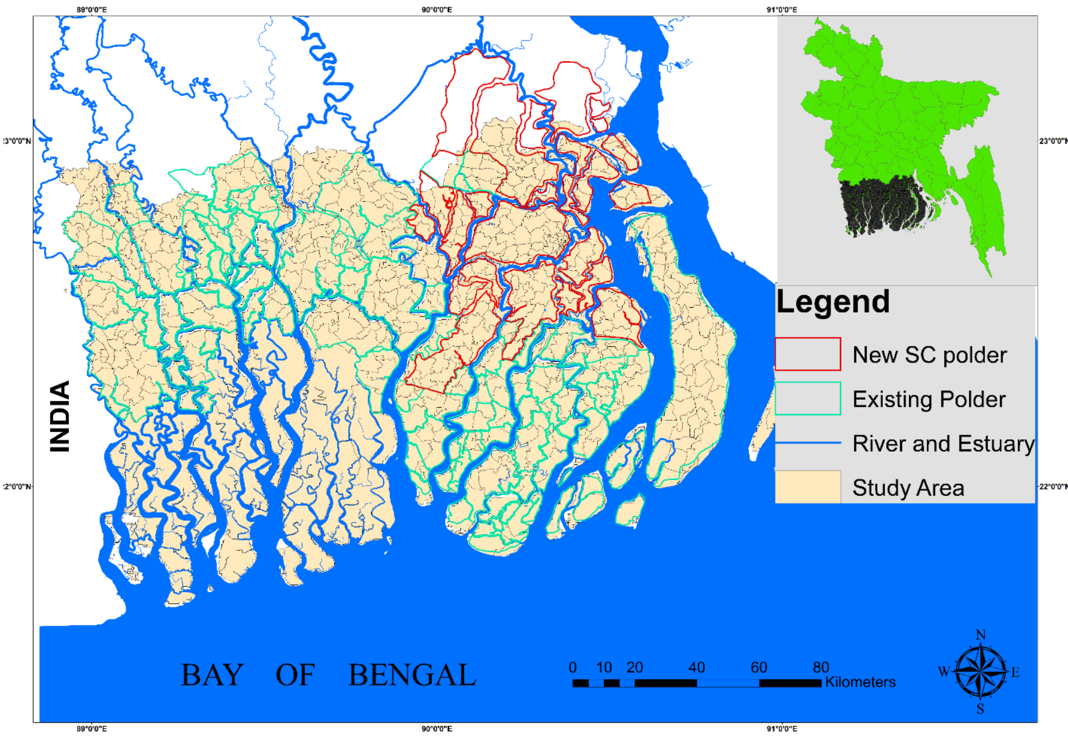

Figure-4.14 : New polders in the south central region.

All the 8 scenarios are summarized in Table-4.7.

Table-4.7 : Scenarios used in the water-logging model

Scenario No.	Scenario Description
1	Base scenario. Base condition in year 2000. Sea level rise is zero. The scenario is driven by the discharges of year 2000. To capture the complete drainage condition, model run is extended till March 2001.
2	Base scenario. Sedimentation in the Hari river (which is the main river between polders 24 & 25) is considered in base condition.
3	Base scenario. Dredging in the Hari river (which is the main river between polders 24 & 25) is considered in base condition.
4	Base scenario. New polders (SC polders) are introduced in south-central region in base condition.
5	End-century scenario. The snapshot selected for end-century is the year 2088-2089. Sea level rise is 1.48m. Warmer and wetter climate drives increased inflow into the system.
6	End-century scenario. Sedimentation in the Hari river is considered in end-century.
7	End-century scenario. Dredging in the Hari river is considered in end-century.
8	End-century scenario. New polders in south-central region is considered in end-century.

4.11 Model Simulations

Model simulation is made for all the 8 scenarios shown in Table-4.7. For base condition, simulation is made from the dry season of 2000 to the dry season of 2001. For the end-century scenario, total simulation period is from dry season of 2088 to dry season of 2089. The year 2088 is selected based on the maximum discharge condition in end-century.

<u>Scenario-1</u>

In this scenario, no physical intervention is made. This is the base scenario for years 2000-2001. Inundation during monsoon and dry season is shown in Figure-15. The main features from this result are:

- Flooding is mainly concentrated in the depression region.
- Flooding is more pronounced inside polder-25 compared to polder-24.
- After drainage during the entire dry season, water-logged condition is observed in most of the depressions inside polders 24 & 25.

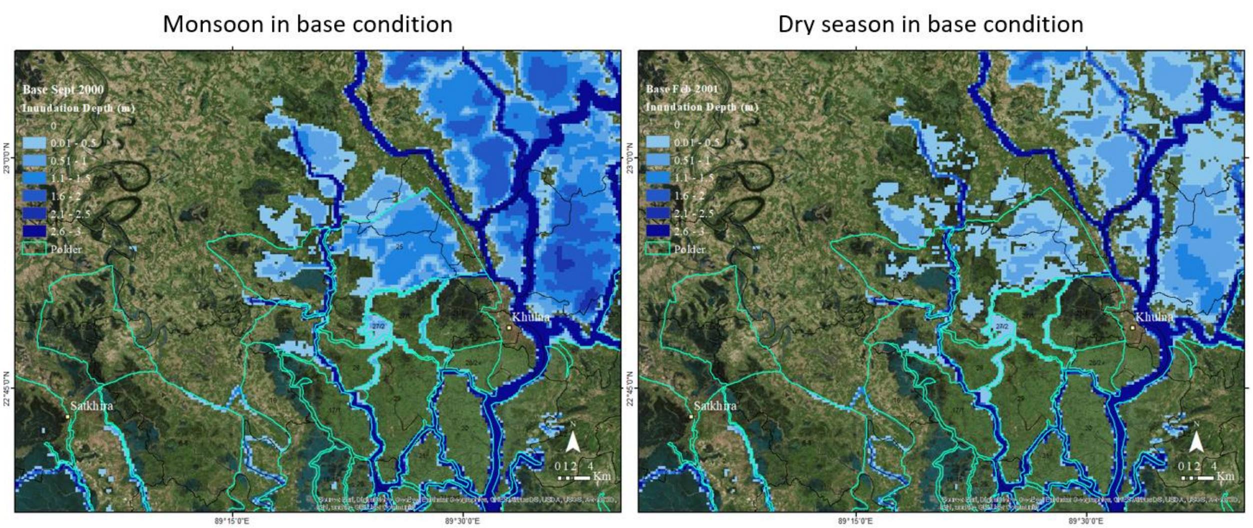

Figure-4.15: Inundation in base condition during monsoon and dry season

<u>Scenario-2</u>

This is base scenario where sedimentation is introduced in the Hari river. It is assumed that sedimentation reach that has decreased conveyance of the Hari river which has a length of about 30 km (see Figure-16). The sedimentation has filled the river bed to a maximum of 1.5m. The sediment volume that has deposited inside the river is about 6750 ton.

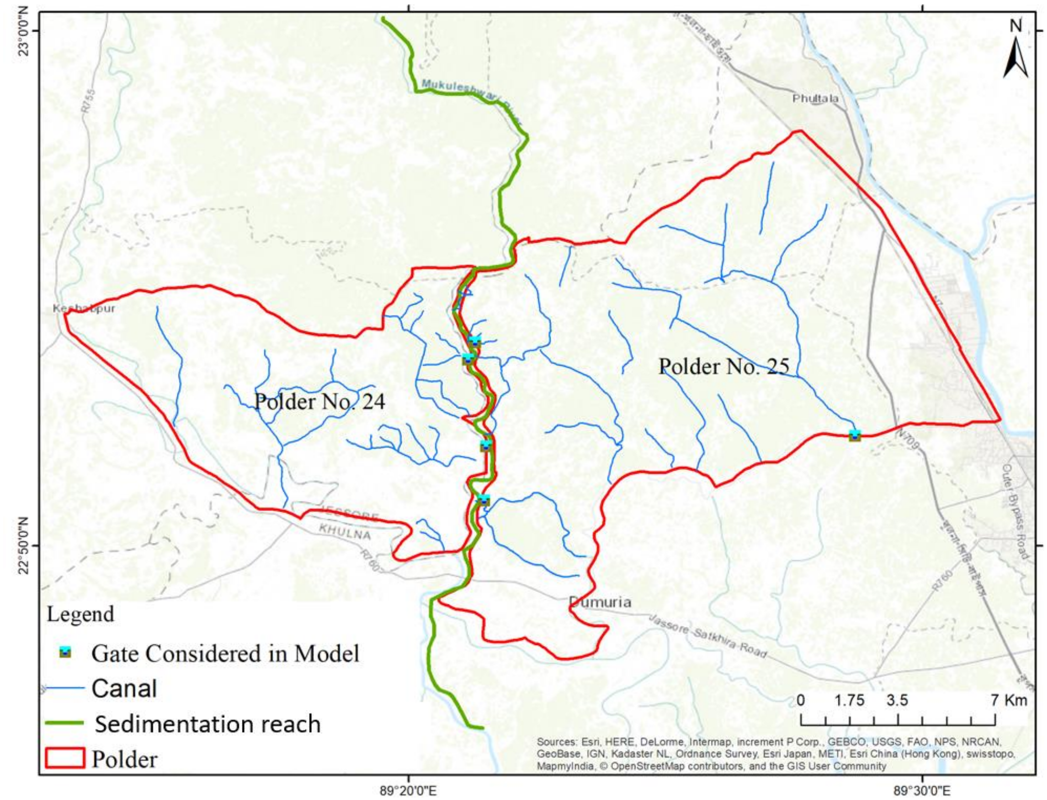

Figure-4.16 : Sedimentation reach in the Hari river.

Comparison of inundation patterns during monsoon when Hari river is sedimented and when it is not sedimented is shown in Figure-17. This comparison is for base condition. Figure-18 shows impact of sedimentation of Hari river on water-logging in base condition.

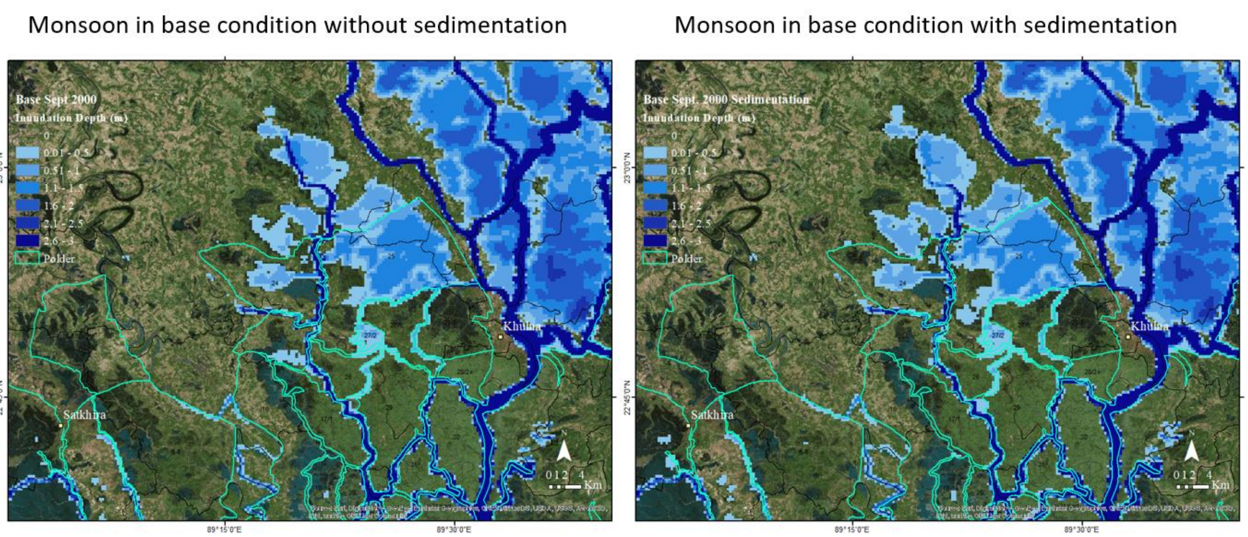

Figure-4.17 : Inundation during monsoon when Hari river is not sedimented (left) and when it is sedimented (right). This scenario is for base condition.

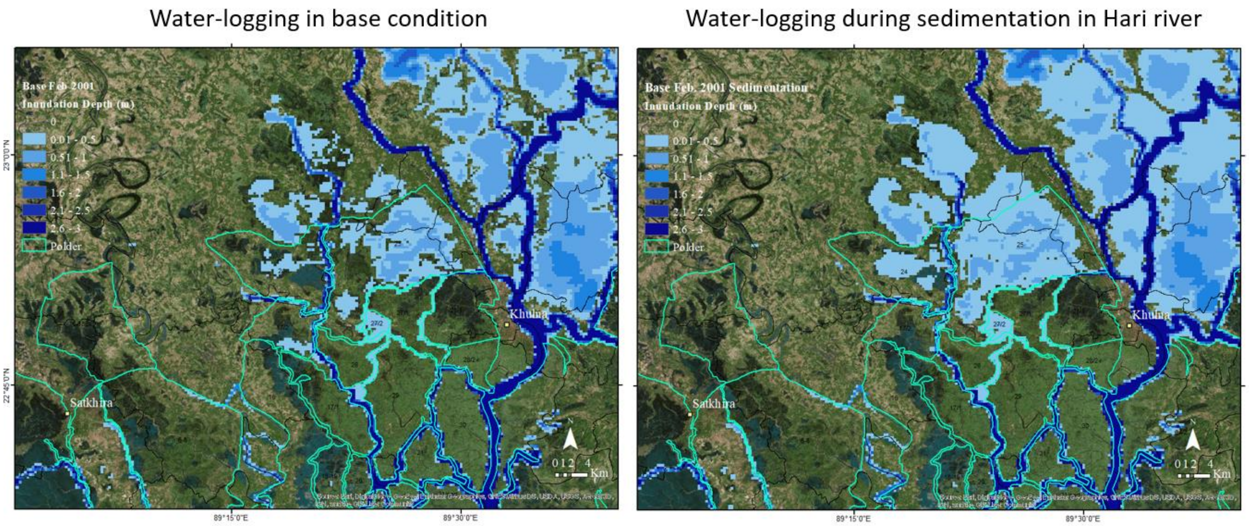

Figure-4.18: Water-logging in the study area. Water-logged condition is created during dry season of base condition. The left image shows when there is no sedimentation in Hari river. The right image shows when Hari river is sedimented.

Results from scenario-2 shows:

- During monsoon, inundation inside polders 24 & 25 increases due to sedimentation of the Hari river.
- Sedimentation in Hari river aggravates the water-logging condition.
- Sedimentation mainly affects the region which is close to the Hari river.

Scenario-3

This is the base scenario where Hari river is dredged to improve the water-logged condition. The reach of the Hari river which is dredged is shown in Figure-19. A total of 30 km reach of the Hari river is dredged to a depth of 1.5m from its present bed level. Dredging is made uniformly keeping the bed slope same before and after dredged condition. In this way, a total of 6750 ton of soil is dredged from the river bed.

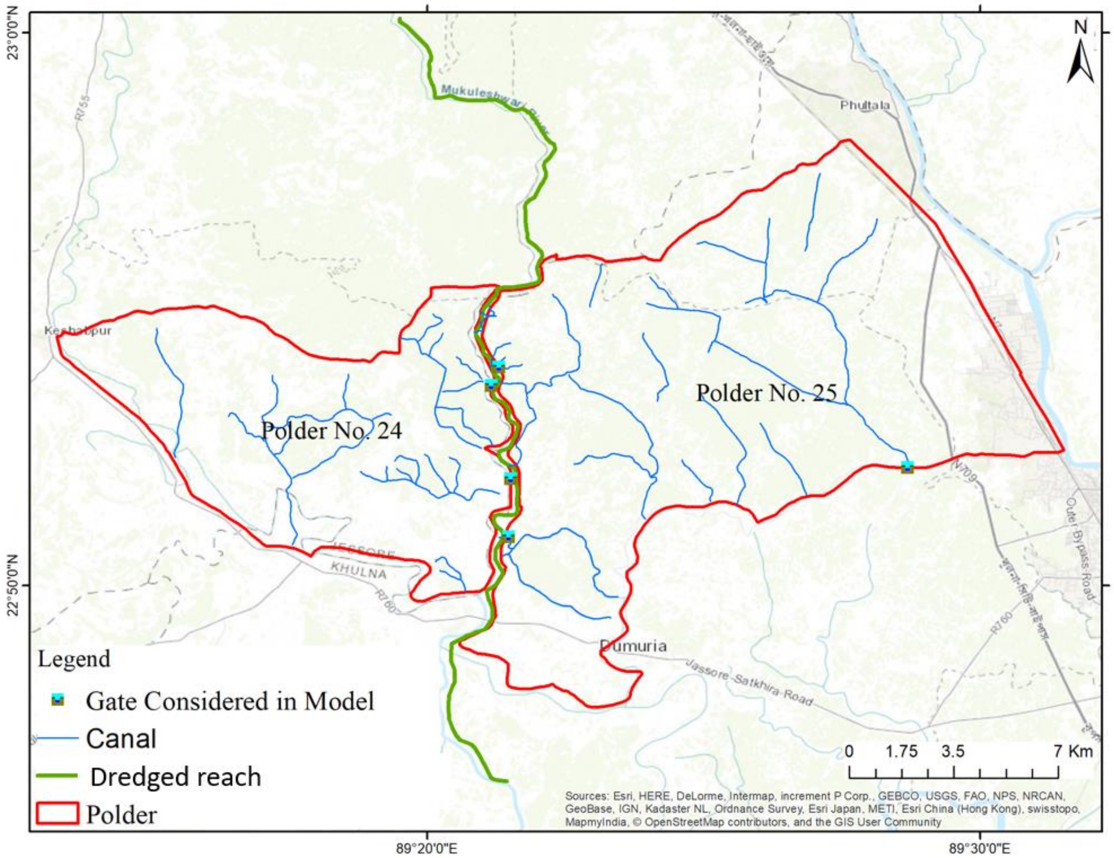

Figure-4.19 : Dredged reach of Hari river.

Comparison of inundation patterns during monsoon when Hari river is not dredged and when it is dredged is shown in Figure-20. This comparison is for base condition. Figure-21 shows impact of dredging of Hari river on water-logging in base condition.

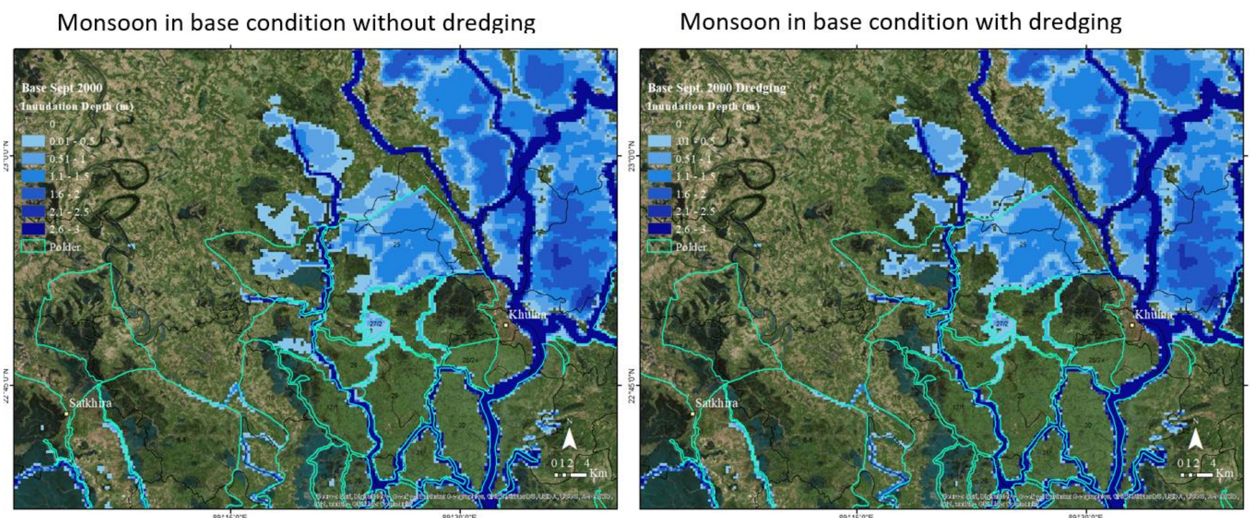

Figure-4.20 : Inundation during monsoon when Hari river is not dredged (left) and when it is dredged (right). This scenario is for base condition.

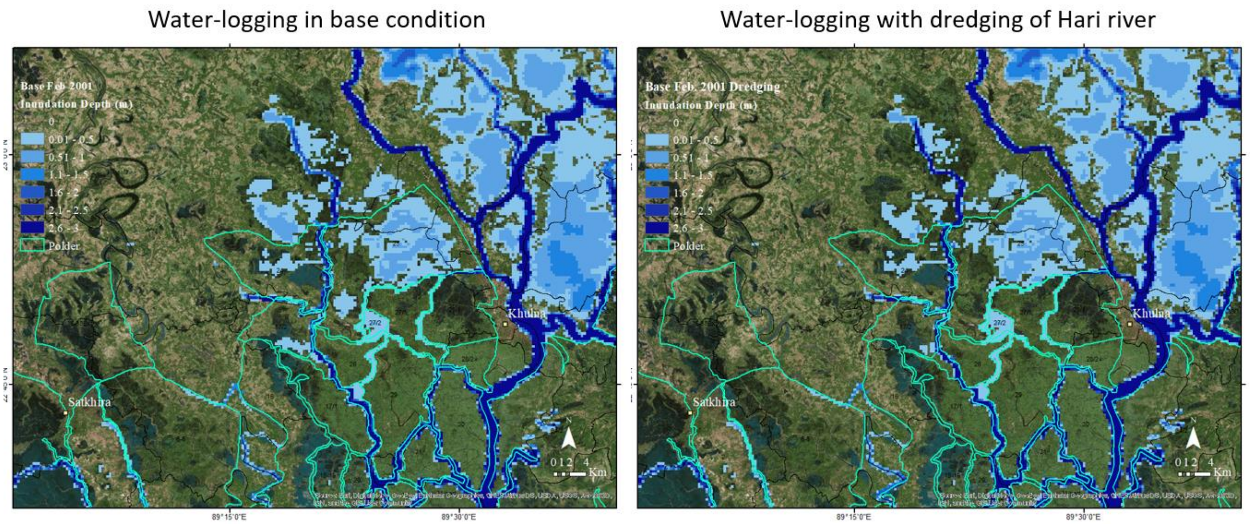

Figure-4.21: Water-logging in the study area. Water-logged condition is created during dry season. The left image shows when there is no dredging in Hari river. The right image shows when Hari river is dredged.

Results from scenario-3 shows:

- During monsoon, inundation inside polders 24 & 25 decreases when Hari river is dredged.
- Dredging in Hari river improves the water-logging condition.
- Dredging mainly affects the region which is close to the Hari river.

Scenario-4

In this scenario, new polders are introduced in south-central region in base condition. Location of south-central polders are shown in Figure-14. At present, there is no polder in south-central region and the region will be flooded during sea level rise (Figure-13). With the introduction of new polders in this region, the south-central region will be flood-free (Figure-22). But this intervention shifts the flood hazard to further west (Figure-22) where polders 24 and 25 (study area of present study) are situated. Water has not entered inside these polders but affects the flooding in surrounding region. This might have some impact on the water-logging condition inside polders 24 and 25.

Comparison of inundation patterns during monsoon when SC polders is absent and when it is present is shown in Figure-23. This comparison is for base condition. Figure-24 shows impact of SC polders on water-logging in base condition.

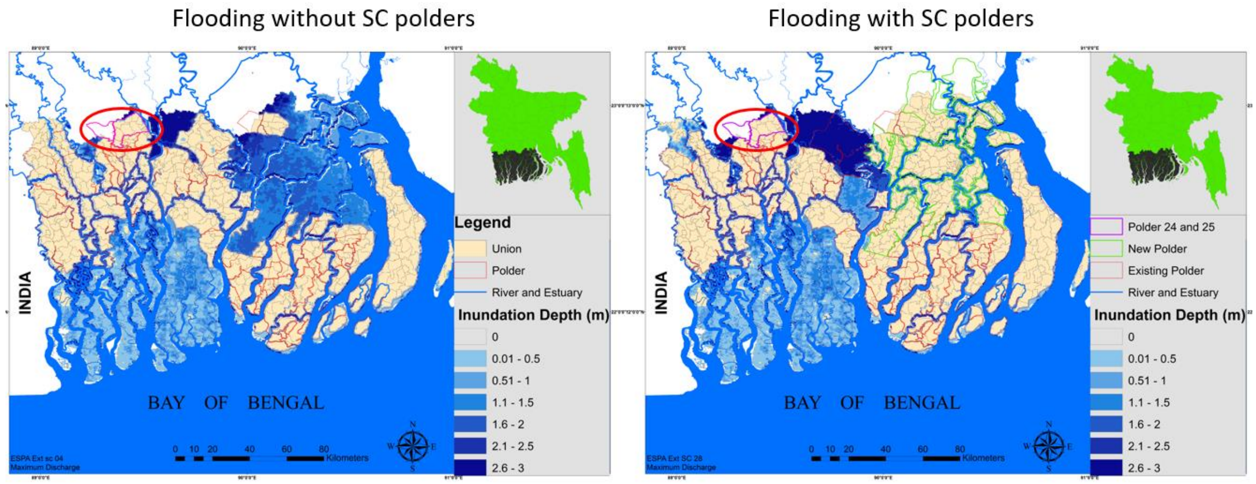

Figure-4.22 : Change of flooding pattern due to construction of new polders in south-central region. The red circled region shows polders 24 & 25 which is the study area of present study.

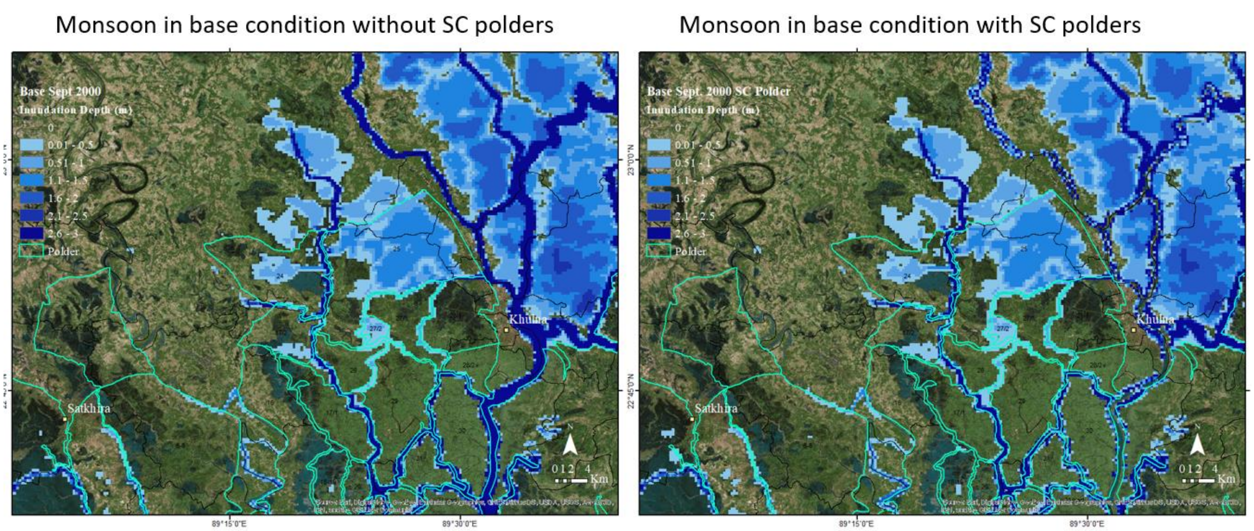

Figure-4.23 : Inundation during monsoon without SC polders (left) and with SC polders (right). This scenario is for base condition.

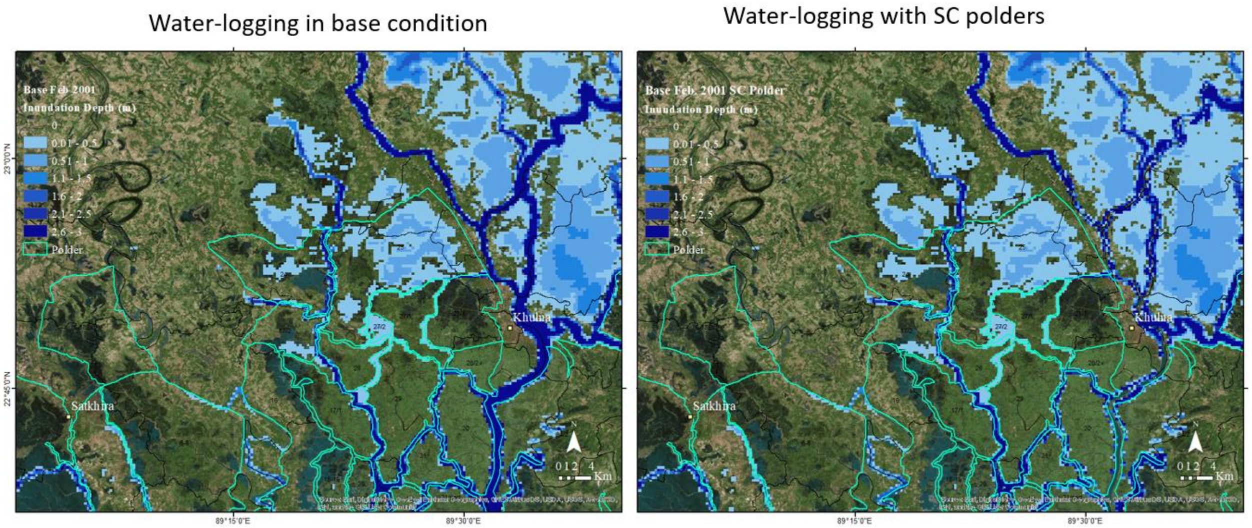

Figure-4.24: Water-logging in the study area. Water-logged condition is created during dry season. The left image shows without SC polders. The right image shows with SC polders.

Results from scenario-4 shows:

- During monsoon, impact of SC polders inside polders 24 & 25 is not visible.
- SC polders slightly aggravates water-logging condition. This shows SC polders mainly affects drainage.
- Impact of SC polders are visible close to eastern border of polder 25. This border directly feels the shift of flood hazard due to construction of SC polders (see Figure-22).

Scenario-5

This is the end-century scenario where sea level rise is 1.48m and flooding is driven by a warmer and wetter climate. The end-century scenario is represented by snapshot of the year 2088-2089. In this scenario, no intervention is considered. Comparison of inundation between monsoon and dry season is shown in Figure-25.

Results from scenario-5 shows:

- Both the polders 24 & 25 are completely inundated.
- During dry season, inundation depth decreases but the extent of inundation remains the same.
- The entire region becomes perennial water body.

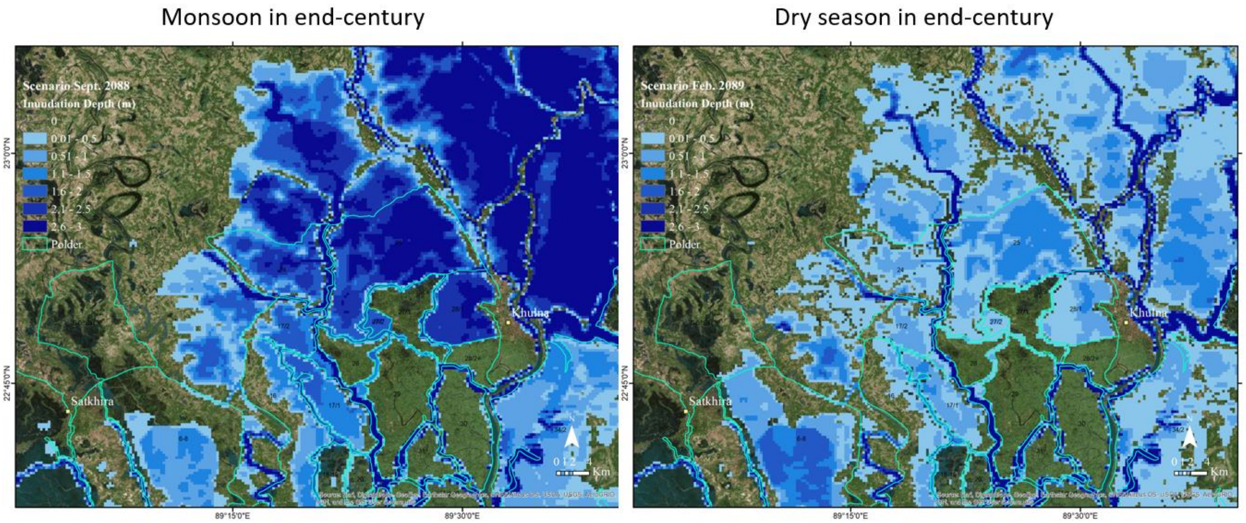

Figure-4.25: Inundation in end-century during monsoon and dry season

<u>Scenario-6</u>

This is the end-century scenario when the Hari river is sedimented. The reach of the Hari river which is sedimented is shown in Figure-16.

Comparison of inundation patterns during monsoon when Hari river is sedimented and when it is not sedimented is shown in Figure-26. This comparison is for end-century. Figure-27 shows impact of sedimentation of Hari river on water-logging in end-century.

Results from scenario-6 shows:

- Impact of sedimentation is not visible in monsoon. The entire area is completely inundated.
- Water-logging remains almost same both for with and without sedimentation of the Hari river.

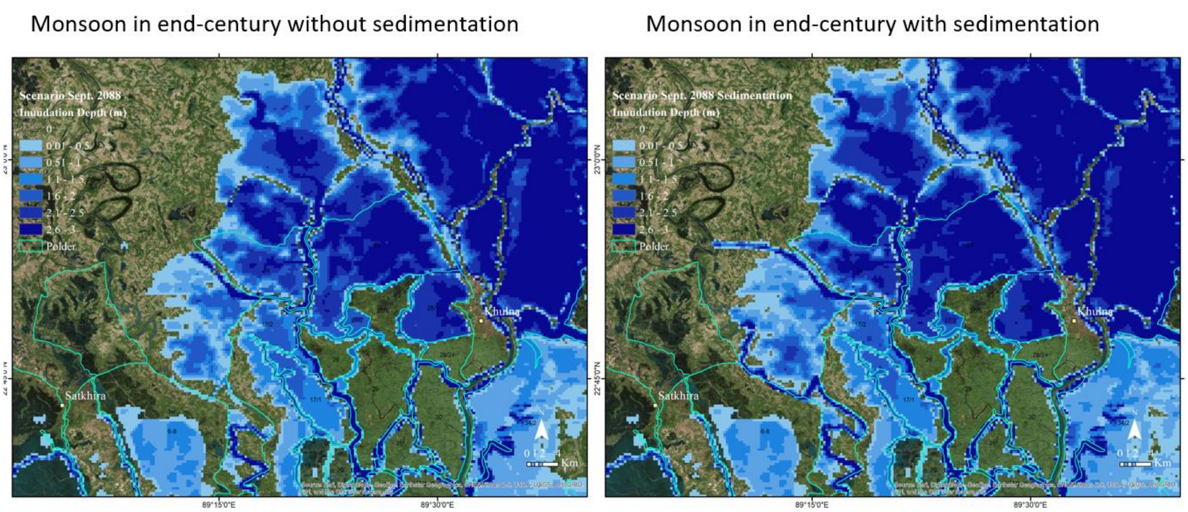

Figure-4.26 : Inundation during monsoon when Hari river is not sedimented (left) and when it is sedimented (right). This scenario is for end-century.

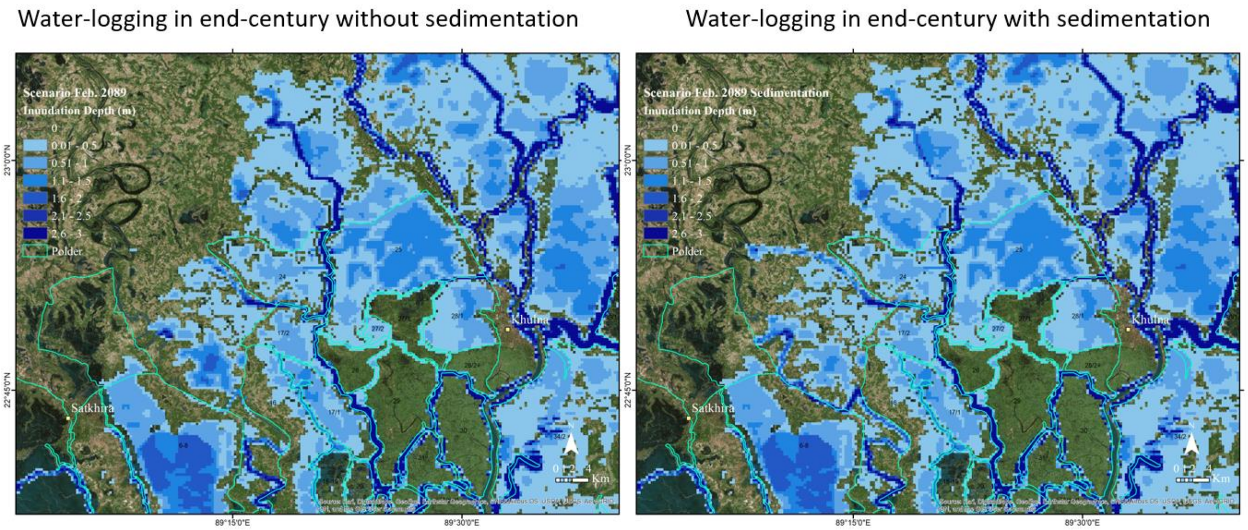

Figure-4.27: Water-logging in the study area. Water-logged condition is created during dry season. The left image shows when there is no sedimentation in Hari river. The right image shows when Hari river is sedimented. The scenario is for end-century.

<u>Scenario-7</u>

This is the base scenario where Hari river is dredged to improve the water-logged condition. The reach of the Hari river which is dredged is shown in Figure-19.

Comparison of inundation patterns during monsoon when Hari river is not dredged and when it is dredged is shown in Figure-28. This comparison is for end-century. Figure-29 shows impact of dredging of Hari river on water-logging in end-century.

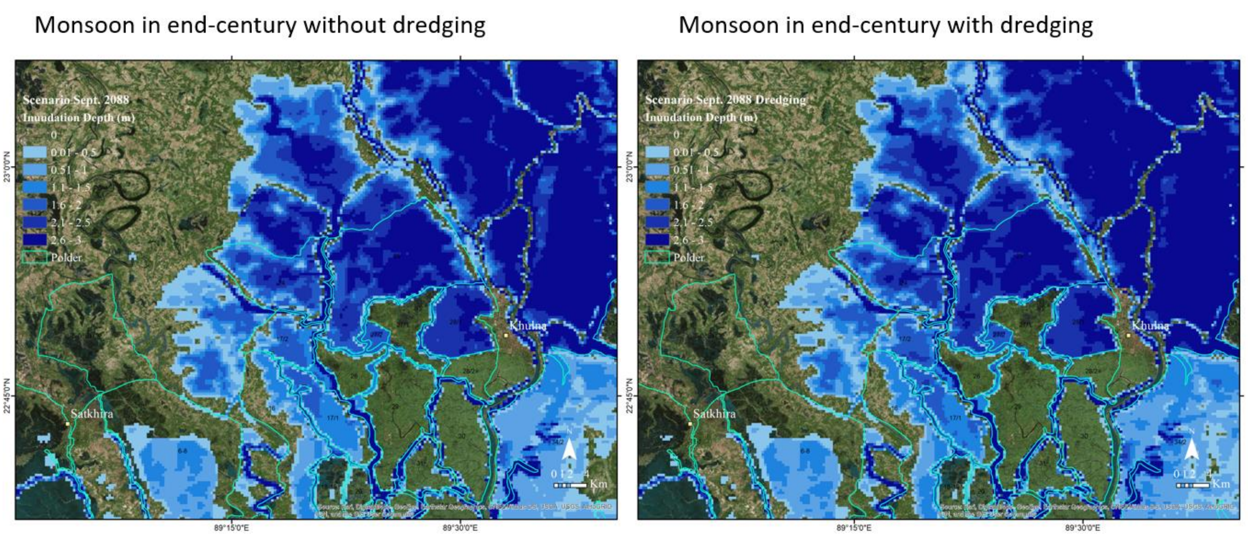

Figure-4.28: Inundation during monsoon when Hari river is not dredged (left) and when it is dredged (right). This scenario is for end-century.

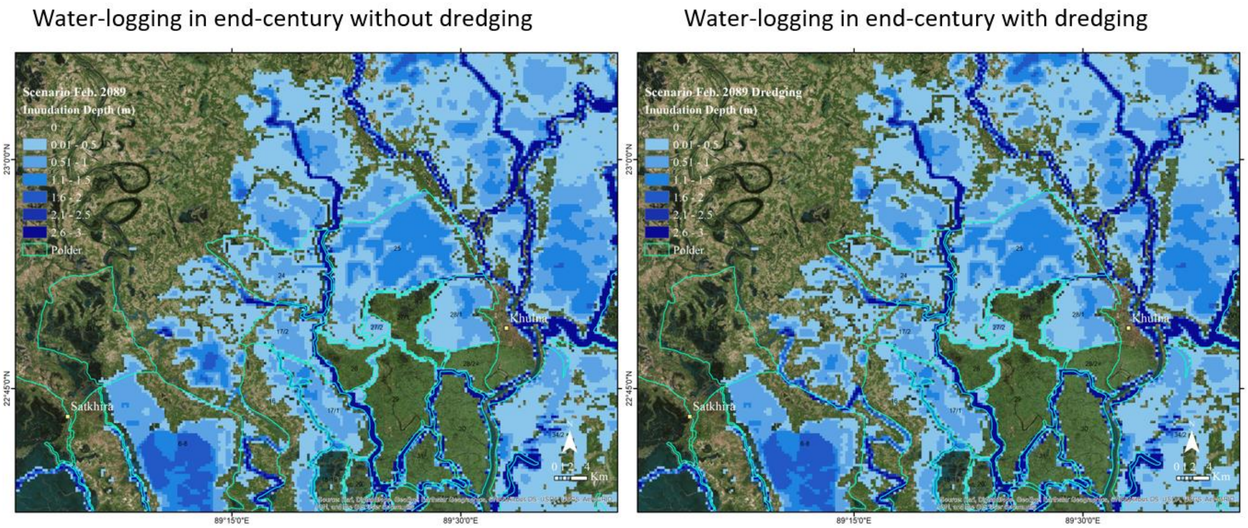

Figure-4.29: Water-logging in the study area. Water-logged condition is created during dry season of end-century. The left image shows when there is no dredging in Hari river. The right image shows when Hari river is dredged.

Results from scenario-7 shows:

- Impact of dredging is not visible in monsoon. The entire area is completely inundated.
- Water-logging remains almost same both for with and without dredging of the Hari river.

Scenario-8

In this scenario, new polders are introduced in south-central region in end-century. Location of south-central polders are shown in Figure-14. At present, there is no polder in south-central region and the region will be flooded during sea level rise (Figure-22).

Comparison of inundation patterns during monsoon when SC polders is absent and when it is present is shown in Figure-30. This comparison is for end-century. Figure-31 shows impact of SC polders on water-logging in end-century.

Results from scenario-8 shows:

- Impact of SC polders is not visible in monsoon. The entire area is completely inundated.
- Water-logging remains almost same both for with and without SC polders.

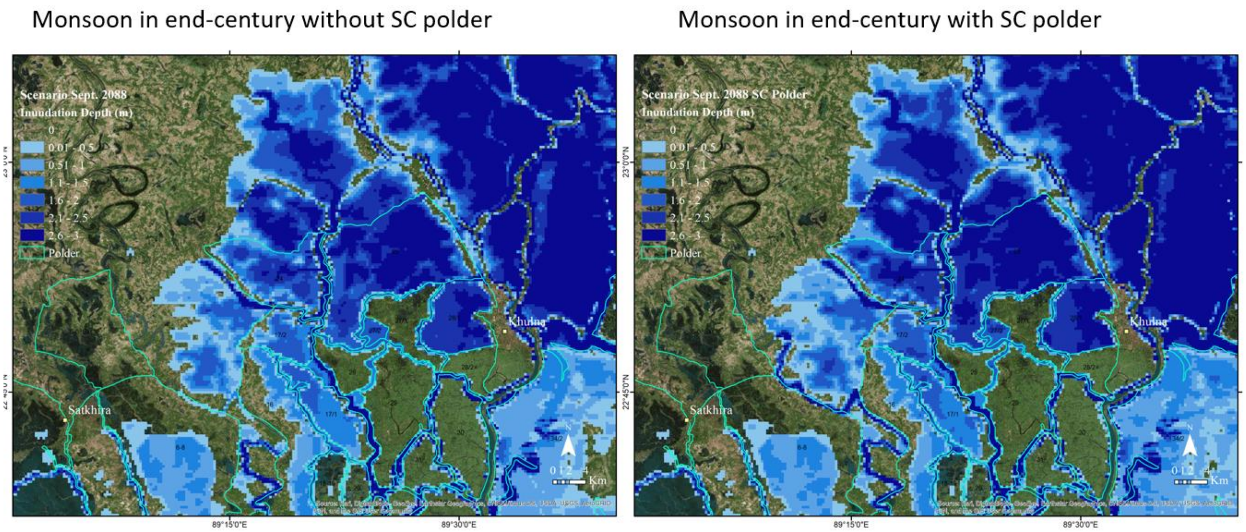

Figure-4.30 : Inundation during monsoon without SC polders (left) and with SC polders (right). This scenario is for end-century.

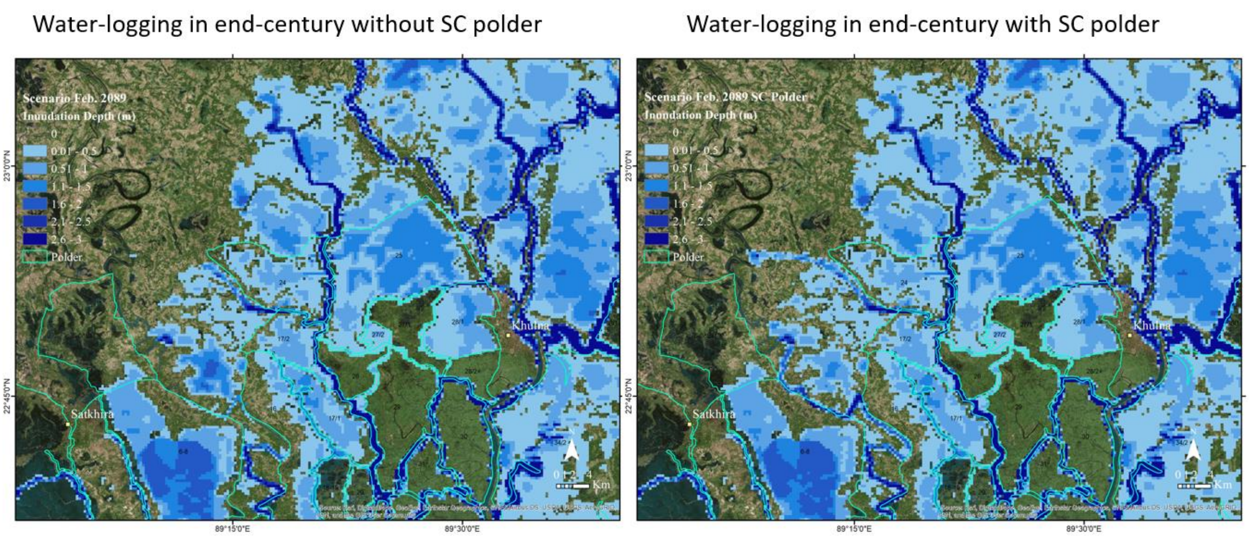

Figure-4.31: Water-logging in the study area. Water-logged condition is created during dry season in end-century. The left image shows without SC polders. The right image shows with SC polders.

The main findings from all the scenarios simulations are:

- Water-logging is more inside polder-25 compared to polder-24.
- Sedimentation in Hari river aggravates the water-logging condition.
- Sedimentation mainly affects the region which is within the floodplain of the Hari river.
- Dredging in Hari river improves the water-logging condition.

- Dredging mainly affects the region which is within the floodplain of the Hari river.
- During monsoon, impact of SC polders inside polders 24 & 25 is not visible.
- SC polders slightly aggravates water-logging condition.
- SC polders mainly affects drainage inside polders 24 & 25.
- In end-century, both the polders 24 & 25 are completely inundated.
- In end-century, impacts of sedimentation and dredging are not visible.

CHAPTER FIVE
Conclusions and Recommendations

5.1 Conclusions

This research studied the sedimentation issue in Bangladesh coastal zone from two different directions – macro-level study on floodplain sedimentation and micro-level study on water-logging inside polders due to sedimentation in peripheral river. The methodology followed in both these approaches are simulation by numerical model. The morphology module of Delft 3D is applied to simulate the floodplain sedimentation whereas, flow module of Delft 3D is applied to simulate water-logging inside polders. The morphology model is validated against the field measurement data collected from secondary literature, whereas, water-logging model is validated against the satellite image.

The clockwise oceanic circulation in Lower Meghna estuarine systems cause re-entry of oceanic sediments into the estuarine systems. But this circulation does not necessarily drive the sediments further south in the ocean. Numerical experiment results show that ocean sediment concentration in deep ocean far from the coast (near the Sri Lanka coastline) is nearly zero. Numerical experiment results also show that sediment size distribution in the study region is composed with 30% cohesive sediments and 70% non-cohesive sediments. Numerical experiment results also show high spatial variability of sediments on the floodplain in the study region.

Model simulation shows that in an average flood year, about 21.8% of total incoming sediments are deposited on the floodplain. This value is on the lower range of what the secondary literature says (30% to 40% of total incoming sediments are deposited on the floodplain). But it should be noted here that the secondary literature did not consider the spatial variability of floodplain sedimentation and also did not consider the process of sedimentation impacted by polders.

The main cause of floodplain sedimentation is the monsoon flooding (driven by fluvial flow and tide flow) on the unprotected land. Extent of flooding on unprotected floodplain depends on the magnitude of seasonal flood. Polders play an important role both on flooding and floodplain sedimentation. Polders restricts the inundation extent but increase the flood depth on unprotected land. Without any polder, the same volume of flood water is re-distributed on the entire floodplain that increases areal extent of flood but decreases the flood depth. This causes sedimentation on a wider area but with a reduced sedimentation thickness. On the western floodplain, where water-logging is believed to be due to restricted sedimentation due to polders, shows that during an average flood year, percentage of sediment retention on the floodplain increases from 11.2% to 14.6% of the total incoming sediments when polders are removed from the system. These values are 49.8% and 59.2% for an extreme flood year. On average, on the western floodplain, polders restrict 14 Million Ton/Year of sediments in an average flood year to 108 Million Ton/Year in an extreme flood year. Without any polder, this additional amount of sediment could contribute to the delta building process and to rise the land elevation alleviating most of the present-day water-logging problems. But at the same time, absence of polders will cause large area of the region to be flooded with fluvial and tidal flows during monsoon.

Water-logging in the western floodplain of the system came into existence during mid 80's. In addition to polder effects, the reason which believed to contribute water-logging are : change at the entrance of Ganges river, death of Mathavanga river, Farakka barrage, encroachment of river banks, poorly aligned roads and unplanned aquaculture. From image analysis and data from secondary sources shows that main cause of water-logging inside Polders-24 and 25 is sedimentation of the peripheral river. Model simulation results on 8 generated scenarios for water-logging inside Polders-24 and 25 reveals that sedimentation in the Hari river (the river which flows in between Polders-24 and 25) aggravates the water-logging situation inside the polders. Effect of sedimentation of the Hari river is confined within the floodplain of the river. Dredging of the Hari river does improve the water-logging, but the impact is confined within the floodplain of the river. If new polders are constructed in the south-central coastal region (at present there is no polder in this region), it will have little impact on the water-logging condition inside Polders-24 and 25. Towards the end of century with a sea level rise of 1.48m, the system becomes insensitive to any physical change of the Hari river.

5.2 Recommendation for Further Study

Present study mainly concentrates on the sedimentation process in the study region along with the quantitative impacts of polders on floodplain sedimentation. The study also shows the impact of sedimentation of peripheral river on water-logging inside polders. This study did not consider the specific issue of sediment management in the region from a system approach. Any future study in the region should systemically analyze present sediment management practice in the region. The study should also generate scenarios of sediment management strategy for uniform distribution of sediments in the region by accepting the reality of the presence of polders. This strategy will suggest how to divert sediments from sediment-excess region to sediment-starve region. A sediment management manual will be useful for any future plan and policy related to any physical intervention in the region documented in the Deltaplan 2100.

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