Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022), 10~12 February 2022, KUET, Khulna, Bangladesh (ISBN-978-984-35-1972-6)

SEASONAL VARIATIONS AND IMPACTS OF POLDERS ON SEDIMENTATION PROCESS AND DISTRIBUTION IN GBM DELTA

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ABSTRACT

Sedimentation in the Ganges, Brahmaputra and Meghna (GBM) delta depends on the pattern of water and sediment flows. GBM, the largest delta in the world spanning over Bangladesh and India, exhibits the Holocene deposition from the fluvial outcomes of the Ganges, Brahmaputra and Meghna river system. Though very few studies had been carried out about local sedimentation/deposition processes, no study is available that considers the whole delta in the Bangladesh part. Natural sedimentation process and dynamics are being changed due to the perpetual natural and human intervention and interruption in the fluvial regime in this agrarian delta. The main objective of the study is to apply Delft3D morphological model and analyze sediment distribution on the coastal floodplain of GBM delta due to presence of polders in different flooding scenario. Polders restricts the inundation extent but increase the flood depth on unprotected land. Without any polder, 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.The paper should be written in English using MS-Word. The header at the top of the first page should be different from other pages as shown in this templete.The authors should use this template to prepare the manuscript. Times New Roman is the accepted type face for the paper.

Keywords: *Sedimentation; Polder; Floodplain and Water-logging.*

1. INTRODUCTION

The patterns of water and sediment flows determine the nature of coastal floodplain sedimentation, and thus, affect the Ganges, Brahmaputra and Meghna (GBM) delta building processes (Elahi et al., 2015).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 tons 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). 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 al, 2018). But no study has yet to perform to study impact of polders and seasonal distribution of sediments on the coastal floodplain of GBM delta. The objective of this study is to analyze impact of costal polders on sediment distribution in the coastal floodplain in different flooding scenarios.

2. STUDY AREA

As shown in Figure-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 et al., 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.

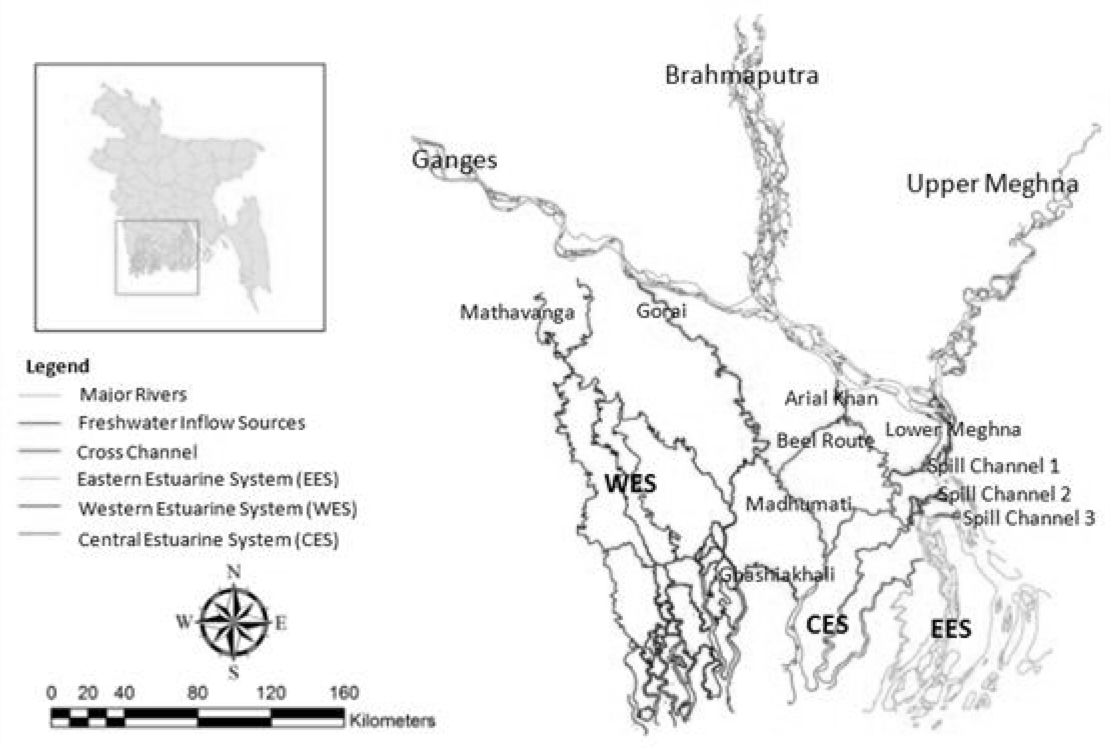

Figure 1: Estuarine systems of coastal zone

3. METHODOLOGY

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 morphology model is validated against the field measurement data collected from secondary literature.

The model domain and model bathymetry to study the coastal floodplain sedimentation in the study area is shown in Figure-2.

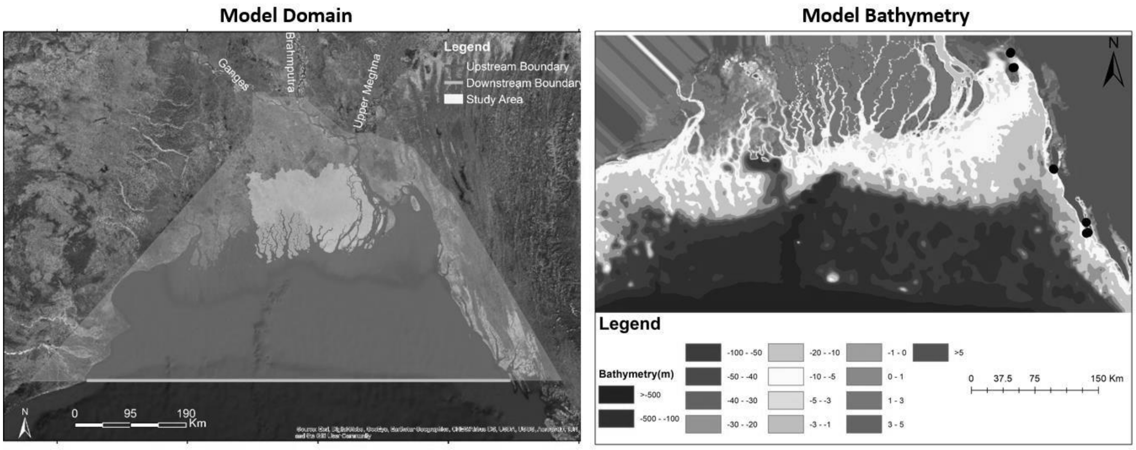

Figure 2: Model domain and model bathymetry

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.

4. RESULTS AND DISCUSSION

Calibrated and validated morphology model is applied in the study region to study patterns of flooding & sedimentation for different flooding scenarios with and without the presence of polders. An end-century future scenario is also constructed by considering 1m SLR and sediment loads generated by model simulation.

4.1 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. 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 polder area (except in the central region where there is no polder). Figure-3 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-4. This Figure shows the relation between floodplain sedimentation and monsoon flooding for the same situation presented in Figure-3, but in this case, there is no polder in the entire region. Existence of polders are not considered during simulation.

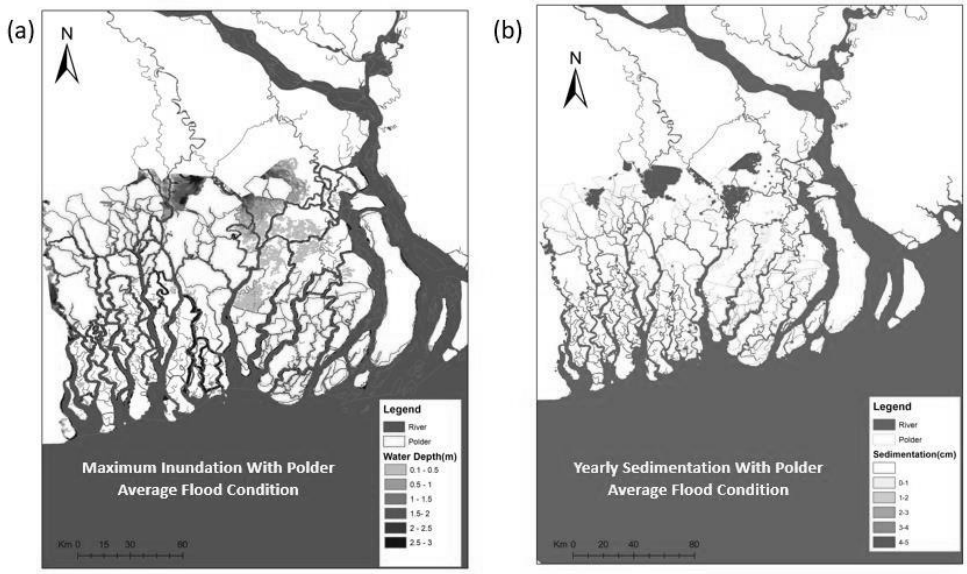

Figure 3: (a) Inundation and (b) sedimentation during an average flood condition. Existence of polders are considered during simulation

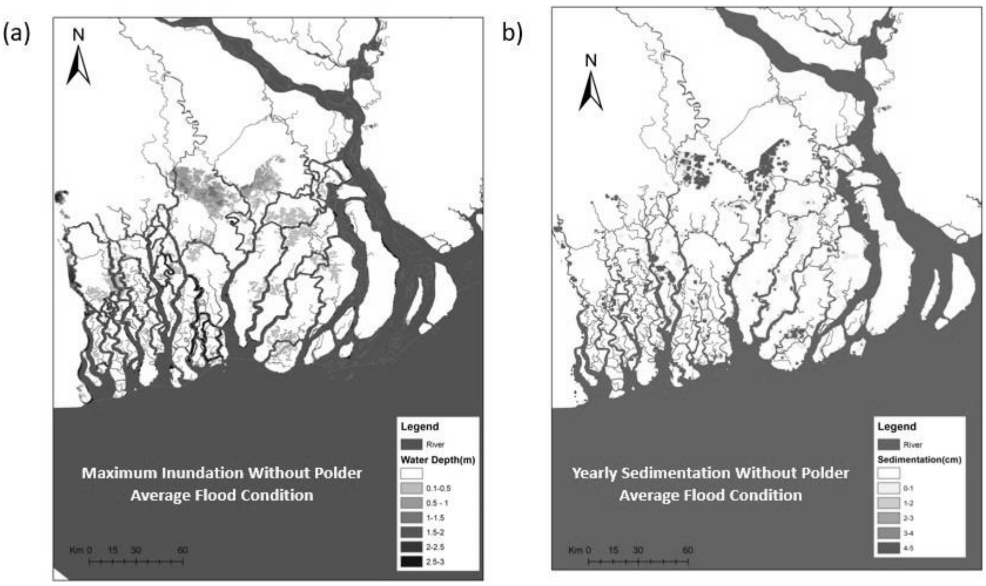

Figure 4: (a) Inundation and (b) sedimentation during an average flood condition.

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

4.2 Sedimentation during extreme flood condition

Following the BWDB definition (BWDB, 2012), the extreme flood in this case is 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-5. 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 with Figure-5 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.

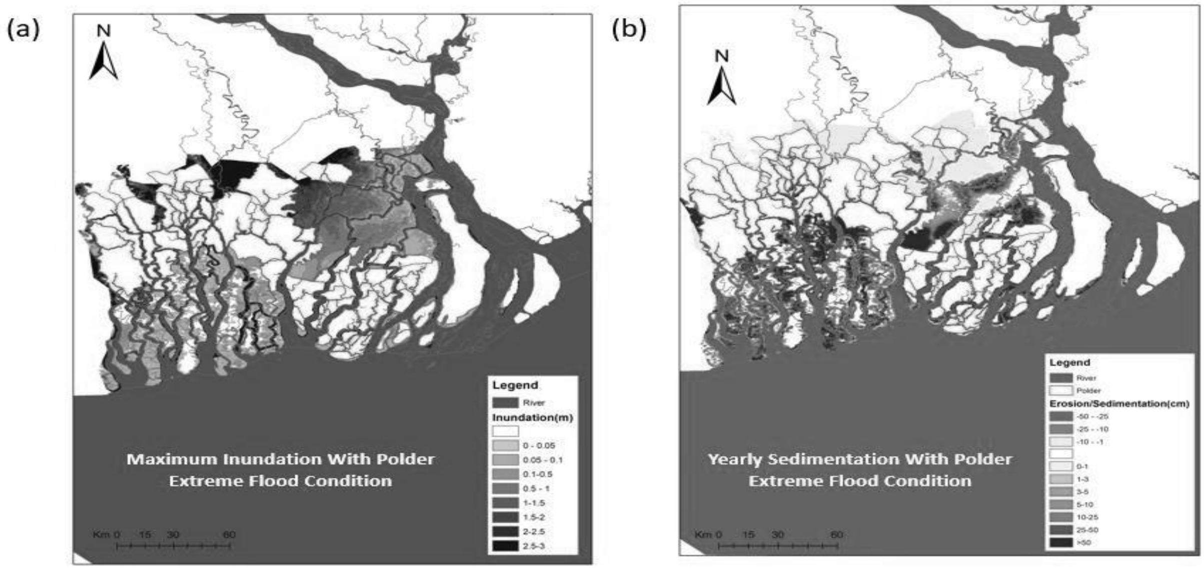

Figure 5: (a) Inundation and (b) sedimentation during an extreme flood condition. Existence of polders are considered during simulation.

When polders are removed, the entire region is flooded as shown in Figure-6. This flooding is associated with the sedimentation in the region. When compared with the average flood condition (see Figure-3), 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 and 6).

4.3 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 HydroTrend model simulation values (Darby et al., 2015). Simulated inundation and sedimentation scenarios are shown in Figure-7. Inundation scenario during the end-century looks almost similar to an extreme flood scenario (Figures-5a and 7a). But sedimentation (confined within the unprotected land) during end-century scenario is remarkably high compared to extreme flood scenario (Figures-5b and 7b). The main reason behind this is increased sediment load from upstream simulated by the HydroTrend model (Darby et al., 2015).

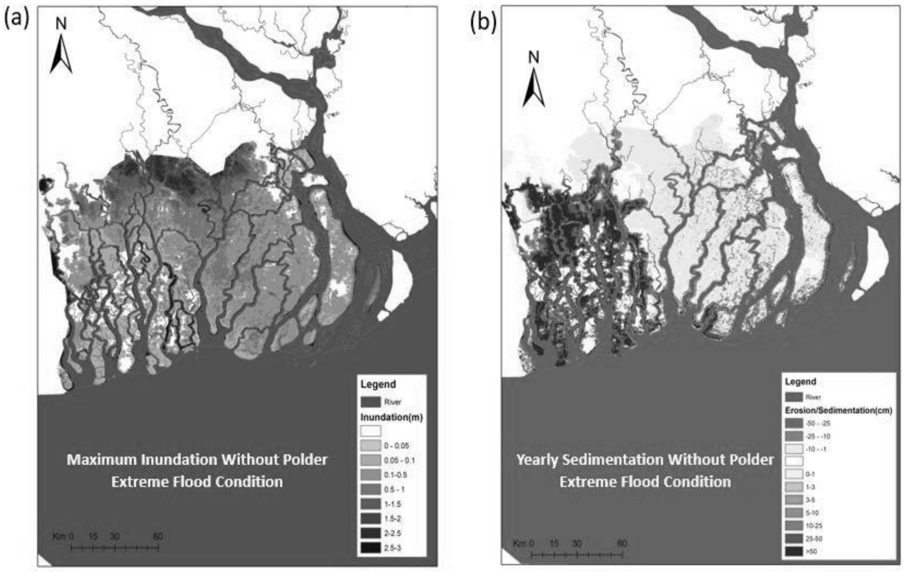

Figure 6: a) Inundation and (b) sedimentation during an extreme flood condition. Existence of polders are not considered during simulation.

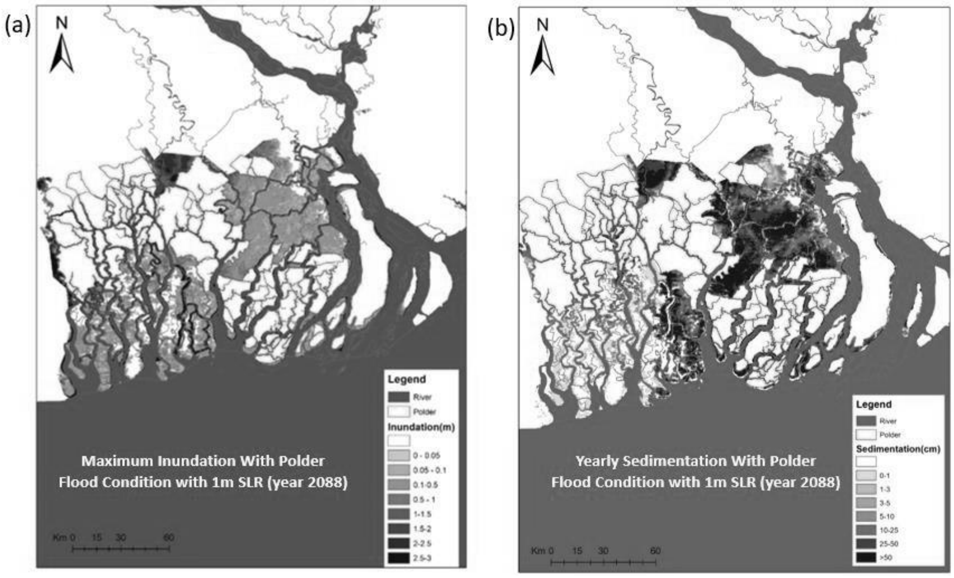

Figure 7: (a) Inundation and (b) sedimentation during an end-century (year 2088) flood condition. Existence of polders are considered during simulation.

4.4 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. 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-8 (pre-monsoon), Figure-9 (monsoon) and Figure-10 (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

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During monsoon, inundation due to fluvial and fluvio-tidal flood is observed (Figure-9). 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.

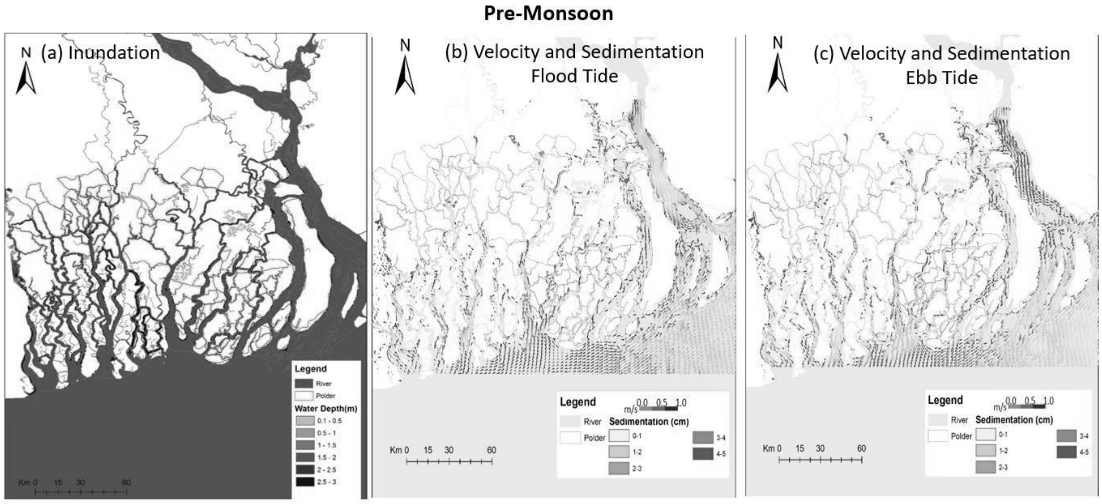

Figure 8: Distribution of (a) inundation (b) velocity & sedimentation during flood tide and (c) velocity & sedimentation during ebb tide during pre-monsoon of an average flood condition.

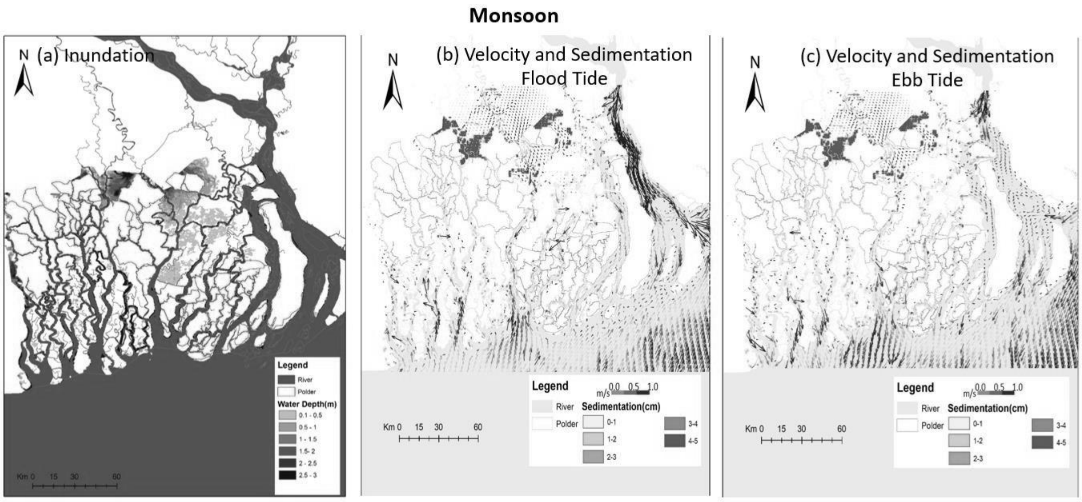

Figure 9: Distribution of (a) inundation (b) velocity & sedimentation during flood tide and (c) velocity & sedimentation during ebb tide during monsoon of an average flood condition.

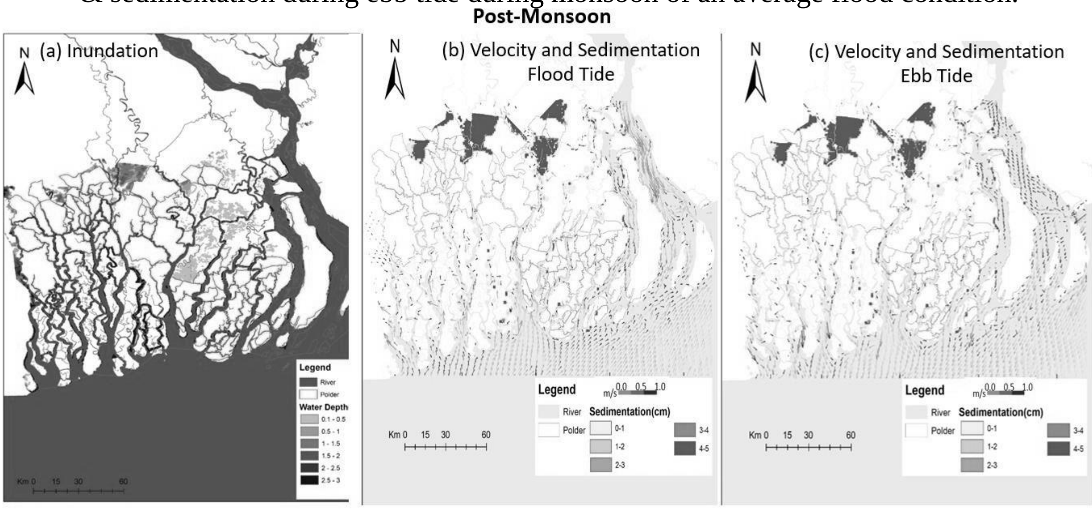

Figure 10: Distribution of (a) inundation (b) velocity & sedimentation during flood tide and (c) velocity & sedimentation during ebb tide during post-monsoon of an average flood condition.

The main sedimentation occurs during post-monsoon (Figure-10) 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.

5. CONCLUSIONS

The main cause of floodplain sedimentation in the GBM delta is the monsoon flooding (driven by fluvial flow and tidal 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. 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.

ACKNOWLEDGEMENTS

This paper is based on the collaborative research project of Water Resources Planning Organization (WARPO) and Institute of Water and Flood Management, BUET. The authors express their gratitude to Ministry of Water Resources for funding the research.

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