Research on Sediment Distribution and Management in South-West Region of Bangladesh

Inception Report
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1. Introduction

Bangladesh is situated in a dynamic delta. It is a part of the Ganges-Brahmaputra-Meghna Basin systems. The rivers bring sediment from the upstream which is showing decreasing trend (Rahman et al., 2018). According to the long-term sediment budget for the delta predicted by Goodbred and Kuehl (2000), one third of the sediment carried by the rivers is deposited on the flood plain and tidal plain, and one third is trapped in the sub-aqueous delta, causing vertical accretion and lateral progression of the sub-aqueous delta. Goodbred and Kuehl (2000) were unable to assess the destination of the remaining sediment and concluded that it was probably transported to the deep ocean floor. Significant portion of the incoming sediment is carried to the Bay-of Bengal, while some portion is remaining in the tidal floodplain (WARPO and BUET, 2018). However, these sediment budgets are changing with time because of the impact of both the climatic and anthropogenic interventions which is being explored through several large-scale research projects - WARPO-BUET (WARPO and BUET, 2019), DECCMA (www.deccma.com) and ESPA Deltas (www.espadelta.net). Therefore, there need for more extensive research on sediment management in Bangladesh particularly in the south-west region.

Tidal rivers and estuaries in the south-west region are characterized by erosion and sedimentation which are ultimately discharged to the Bay of Bengal. Due to natural and anthropogenic interventions (for example climatic impacts, Farakka barrage and polderization), most of the rivers in this region are silted up. As a result, the areas have been suffering from drainage congestion and water-logging problems for quite a long time. One of the possible remedies to this problem is proper sediment management in existing physical setting which will resolve the water-logging problem and at the same time accelerate the land reclamation.

Sedimentation problem in this region is aggravated by the construction of costal polders that de-linked the floodplains from the peripheral rivers. Coastal polders were built during the 1960s. If polders were not present, sedimentation would happen inside the protected region of polders and would have increased the floodplain sedimentation area (WARPO and BUET, 2018). Polders restrict entry of sediments inside the protected region and increases sedimentation in unprotected areas and, perhaps inside rivers. Water-logging inside polders are believed to be caused by this ‘un-managed’ sediments, although there are other factors, for example inadequate drainage routes inside polders (Tahsin et al., 2019). This area has been experiencing severe drainage congestion and water-logging since the early eighties. To solve these long-standing problems, the Khulna-Jessore drainage rehabilitation project known as KJDRP was implemented during 1994-2002. Later, a popular concept based on generations of indigenous water management practices, formally known as a Tidal River Management (TRM), was adopted. TRM would allow natural movement of sediment with tidal water into a beel which is called tidal basin and allow deposition of sediment in the beel. During low tide the outgoing water would erode the river-bed and increase the conveyance capacity.

In the south-west region of Bangladesh (which is also part of the coastal zone), the main sources of sediments are mainly from Lower Meghna estuary. Due to clockwise oceanic circulation, major part of these sediments re-enter into the south-west region through the mouths of large number of estuaries (Haque et al., 2016). As mentioned before, from a gross estimate, Goodbred and Kuehl (2000) assumed that one-third of in-coming sediments might have been deposited on the floodplain. In a later study, it was found that about 23% to 47% of in-coming sediments are deposited on the floodplain (WARPO and BUET, 2019). The same study reveals the fact that sedimentation in the coastal floodplain is spatially variable. In addition, sedimentation in this region is largely impacted by anthropogenic and climatic interventions (WARPO and BUET, 2019). Due to spatial variability of sedimentation and impacts due to intervention, sediment management in the region is particularly complicated. Most of the estuaries and rivers in the western part lost their conveyance due to sedimentation causing large scale water-logging (WARPO and BUET, 2019). On the other hand, sediment is a primary ingredient for land reclamation in the off-shore region. So, there are regions which can be termed as sediment-excess region (mainly rivers and estuaries) and there are regions which can be termed as 'sediment-starve' region (mainly off-shore region). One of the widely known sediment management practice in the region is Tidal River Management (TRM). TRM is a process-based sediment management practice but its impact is dominantly local. Moreover, the implementation process of TRM creates social conflict. Other known sediment management practice in the region is dredging. Except being unusually expensive, sustainability of dredging is questionable when long-term morphological time scale is considered. Cross-dam is another well-known sediment management practice which is used for land reclamation in off-shore region. But study on system impact of cross-dam is still lacking. A process-based system approach of sediment management is a better alternative. But a detail study in this specific topic is a research gap in this region. The present study is undertaken to fill this gap.

2. Research Objectives

The overall objective of the study is to develop a sustainable sediment management strategy that will divert sediments from sediment-excess region to sediment-starve region. This will reduce water-logging problem, offset impact of sea level rise and accelerate land reclamation. The specific objectives of this research are set as:

1. To quantify the sediment loads that comes from upstream and its dispersion process in the south-west region.
2. To identify and analyze the present sediment management practices in the region.
3. To generate scenarios of sediment management strategy for uniform distribution of sediment which will divert sediments from sediment-excess region to sediment-starve region.
4. To prepare a sediment management manual that will focus sustainable sediment management practices in the region.

3. Scope of the Work

- Review of previous studies related to sediment management in the south-west region of Bangladesh.
- Collection of data (primary and secondary) related to sediment load, sedimentation thickness, velocity of the flow, land topography, river bathymetry and sediment size in some strategic locations.
- Identify the problems that the local people are facing with the present practice for sediment management.
- Scenario development considering climate change and flow from upstream of the region.
- Select option/options which will be the best solution for sediment management for this region.
- Understanding the impacts in sedimentation and morphological processes due to changes in flow and sediment load for different scenarios of upstream withdrawal and conservation of water resources.
- Assess the impacts of variety of adaptive strategies in the south-west coastal region to reduce the impact of water logging.

4. Expected Output

- Quantification of incoming sediment load and its distribution in the region
- Sediment management strategies for different scenarios
- Sediment management manual

5. Methodology

To achieve the objectives of the research, the study methodology is divided into three major parts (1) assessing incoming sediment load (2) identifying existing and possible sediment management practice in the region and (2) model study to generate scenarios of possible sediment management practices.

To assess incoming sediment load, existing and possible practices of sediment management, an extensive literature study will be made. Field visits will be made to assess people's perception on existing and local knowledge about sediment management practices in sediment excess and sediment starve areas. Range of possible incoming sediment load will be used during generation of scenarios of sediment management options.

To study impacts of different sediment management scenarios, morphology module of the Delft 3D (Deltares, 2011) will be applied. Both coastal floodplain sedimentation and sedimentation in the ocean bed will be considered to study different management intervention options. The morphology 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 transport equation. The local flow velocities in this 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 by 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 used in this study is similar to what used in previous WARPO-BUET project (WARPO and BUET, 2019). The model domain and model bathymetry are shown in Figures-1 and 2 respectively.

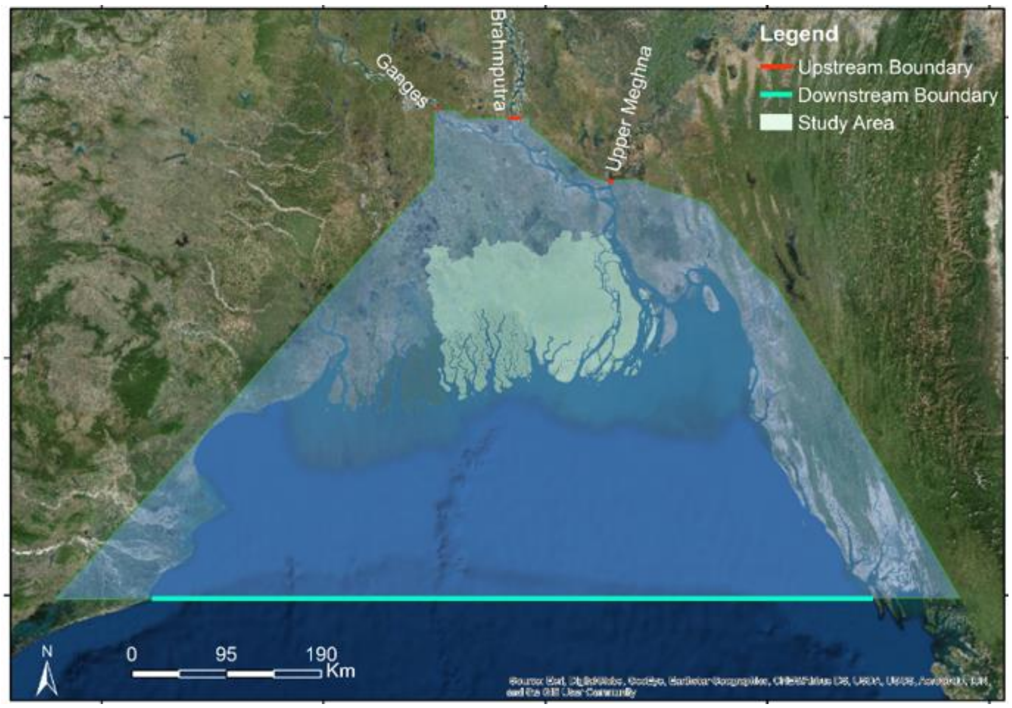


Figure-1: The model domain.

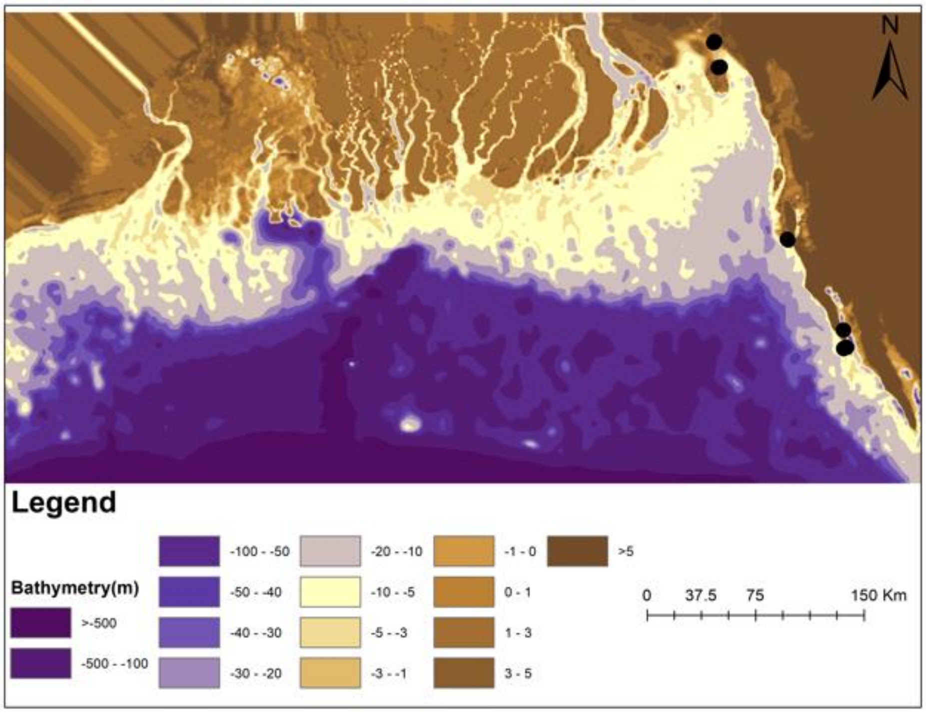


Figure-2: Model bathymetry.

6. Study Area

The entire coastal zone comprising the south-west region including part of the Bay of Bengal within the oceanic circulation zone is considered as the study area (Figure-3 and Figure-4). It is seen that most of the lands in the study area lie within 5m contour line (Figure-3). The clockwise oceanic circulation drives the sediments from Lower Meghna estuary towards the western estuarine systems (Figure-4). A total of 139 coastal polders in the region largely determine the pattern of coastal floodplain sedimentation. The lands inside these polders are considered as 'protected' and do not allow any sediments to be deposited on the floodplain (Figure-5). Depending on the estuarine characteristics, the entire study area is divided into four systems (Figure-5) – the Western Estuarine Systems (WES), the Central Estuarine Systems (CES), the Eastern Estuarine Systems (EES) and the Chattogram Region (CR).

The WES comprises the estuaries in the Sundarban region with a high salinity concentration. Sediments in this region mainly enter from the ocean due to clockwise oceanic circulation (Figure-4). Most of the coastal floodplains in this region are protected by polders (except Sundarban). Sediment-laden water can not enter inside the protected areas during regular tidal cycles. The region is known as a sediment-excess region where water-logging is a problem.

The CES is driven by the Baleshwar system where salinity is relatively low. Large areas of CES are not protected by polders. Sediments in this region enter both from upstream (Tetulia systems) and downstream (from the ocean). The region has high potential for land reclamation with a proper sediment management practice.

The EES is largely dominated by Lower Meghna estuary which is basically an ebb-dominated channel. The Lower Meghna carries the combined sediment loads of Ganges and Brahmaputra. Due to high freshwater discharge, the system remains fresh during most part of the year. The source of sediments in this region is from upstream. No sediment enters in the region from ocean.

The hydrodynamics of the estuaries of CR are different from the other three regions (WES, CES, EES). The estuarine systems in this region has no hydraulic connectivity with the rest of the systems. Sources of sediments in this region are from upstream of the local estuaries and from Lower Meghna (through a local anti-clockwise oceanic circulation). Sandwip channel in this region is a shallow-depth channel with relatively high tidal range. Natural land reclamation is a dominant phenomenon in the north of Sandwip island which can be accelerated with appropriate sediment management practice.

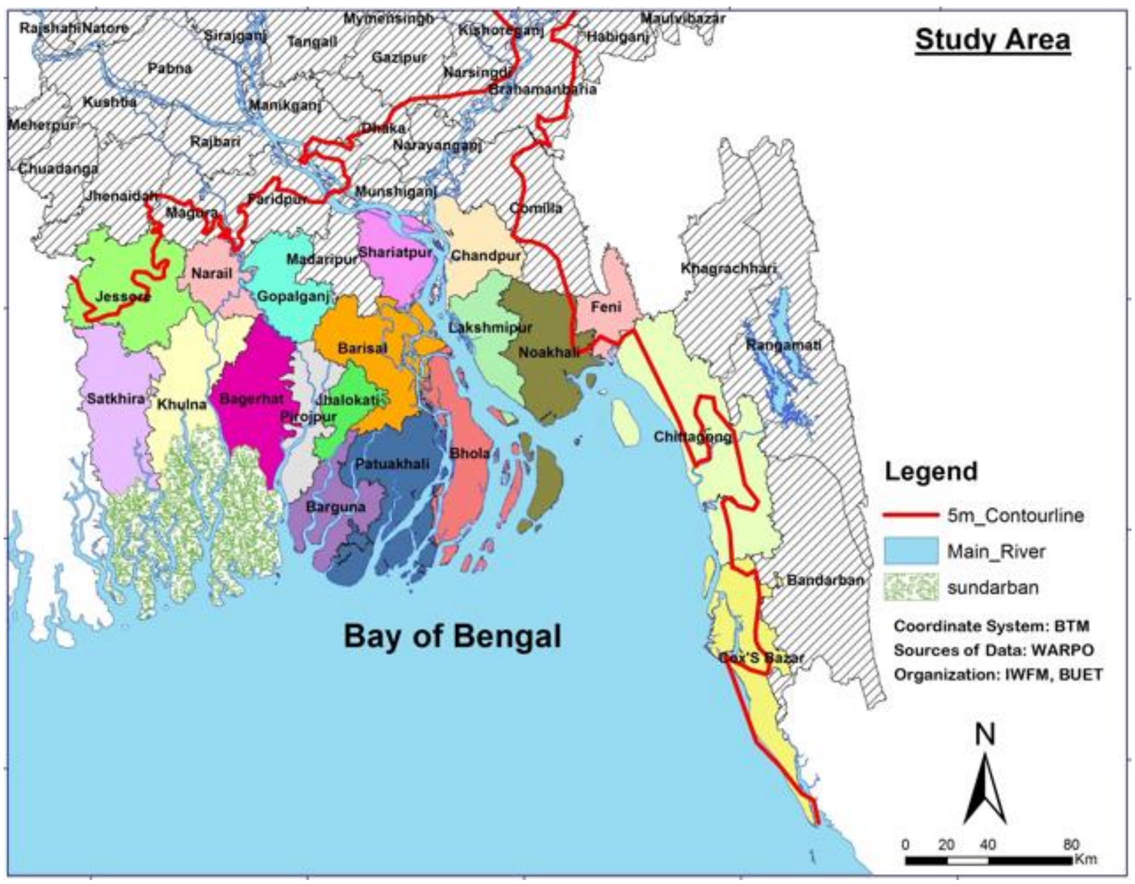


Figure-3: Study Area.

Figure-4: Oceanic circulation zone.

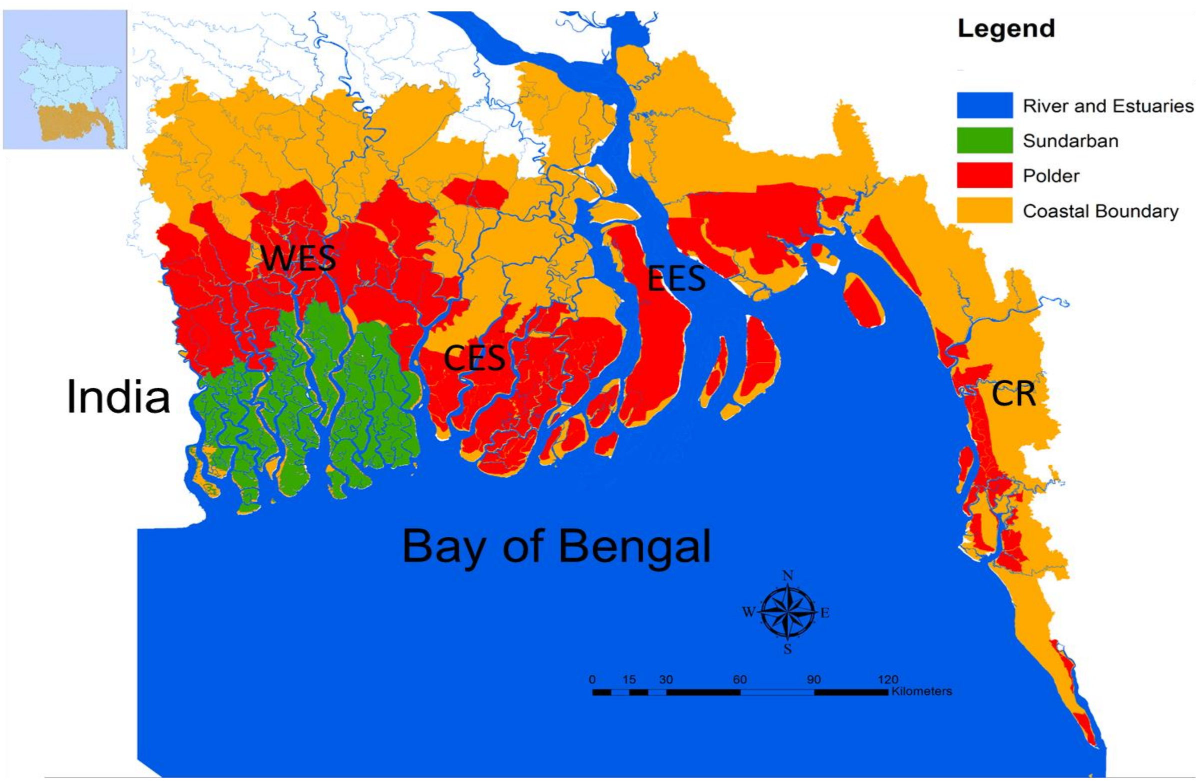


Figure-5: Protected land inside polders in the study area.

7. Incoming Sediment Load in the Region

Rahman et al. (2018) made an extensive study to determine total amount of sediment load coming into the region. The study compiled sediment load estimation from secondary literature and calculated the same data from 48 years (1960-2008) of measured sediment concentration by BWDB. Comparison of incoming sediment load in the region from three major rivers are shown in Table-1. These ranges will be used during generation of scenarios of sediment management practices.

Table-1: Incoming sediment load in the region

River	Sediment load from secondary literature Million Ton / year	Sediment load calculated by Rahman et al. (2018) Million Ton / year
Ganges	260 - 680	150 - 590
Brahmaputra	390 - 1160	135 - 615
Upper Meghna	6 - 12	N/A
Total	1000 - 2400	Average 500

8. Sedimentation in Coastal Floodplain

Secondary data related to sedimentation in the coastal floodplain is limited. Rogers et al. (2013) measured sedimentation in the Sundarbans region from March 2008 to October 2008. Later they converted these 8 months data into sedimentation/year. Measurement locations of Rogers et al. (2013) is shown in Figure-6 and sedimentation magnitude is shown in Table-2.

All the measurement locations are within the Sundarban region which is part of the western system. Sedimentation thickness in the region varies between 0.92 cm – 1.12 cm. There are no polders in Sundarban region but resistance to flow is relatively high. Considering high resistance of flow in the Sundarban region, it is likely that sedimentation in the non-protected part of the western region is of similar magnitude. In another study, it was shown that water-logging inside polders 24 and 25 in the western region is affected by sedimentation outside the poldered region which is non-protected (WARPO and BUET, 2019).

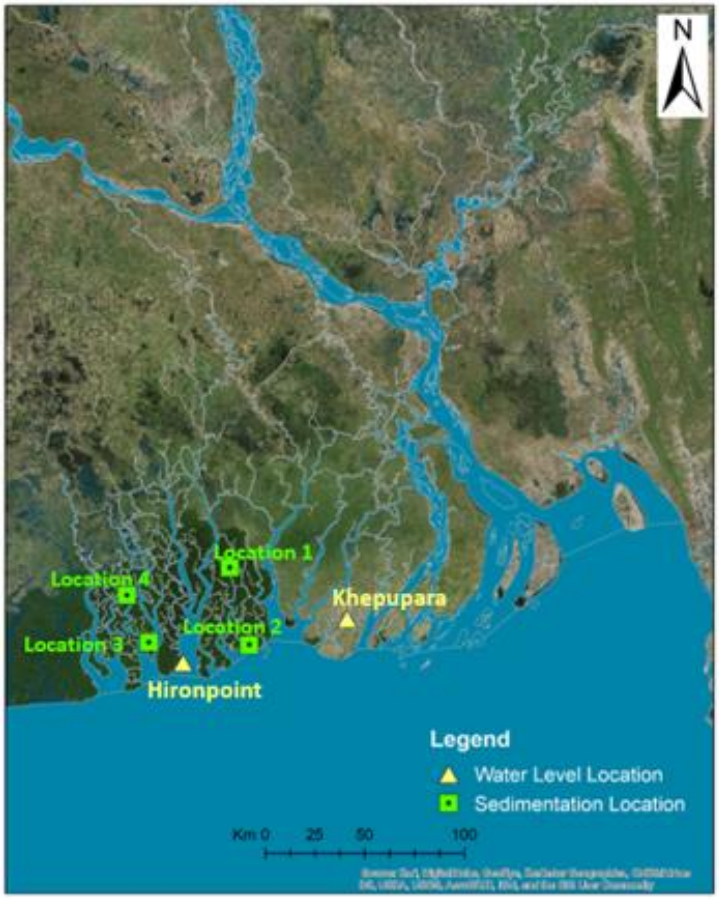


Figure-6: Measurement locations by Rogers et al. (2013).

Table-2: Measured sedimentation by Rogers et al. (2013)

Location	Location-1	Location-2	Location-3	Location-4
Sedimentation thickness (cm)	0.92	0.93	1.12	0.96

9. Spatial Distribution of Sediments in Coastal Floodplain

Goodbred and Kuehl (2000) mentioned that one third of the sediment carried by the rivers is deposited on the floodplain and tidal plain. But they were unable to assess spatial distribution of these sediments on the coastal floodplain. In a later study, WARPO and BUET (2019) simulated the spatial distribution of sediments during an extreme flood condition (Figure-7) which shows that sediment distribution in the coastal floodplain is confined within the non-poldered zone which are inundated during the flood. Pattern of sedimentation is also non-uniform. Sedimentation thickness also varies spatially.

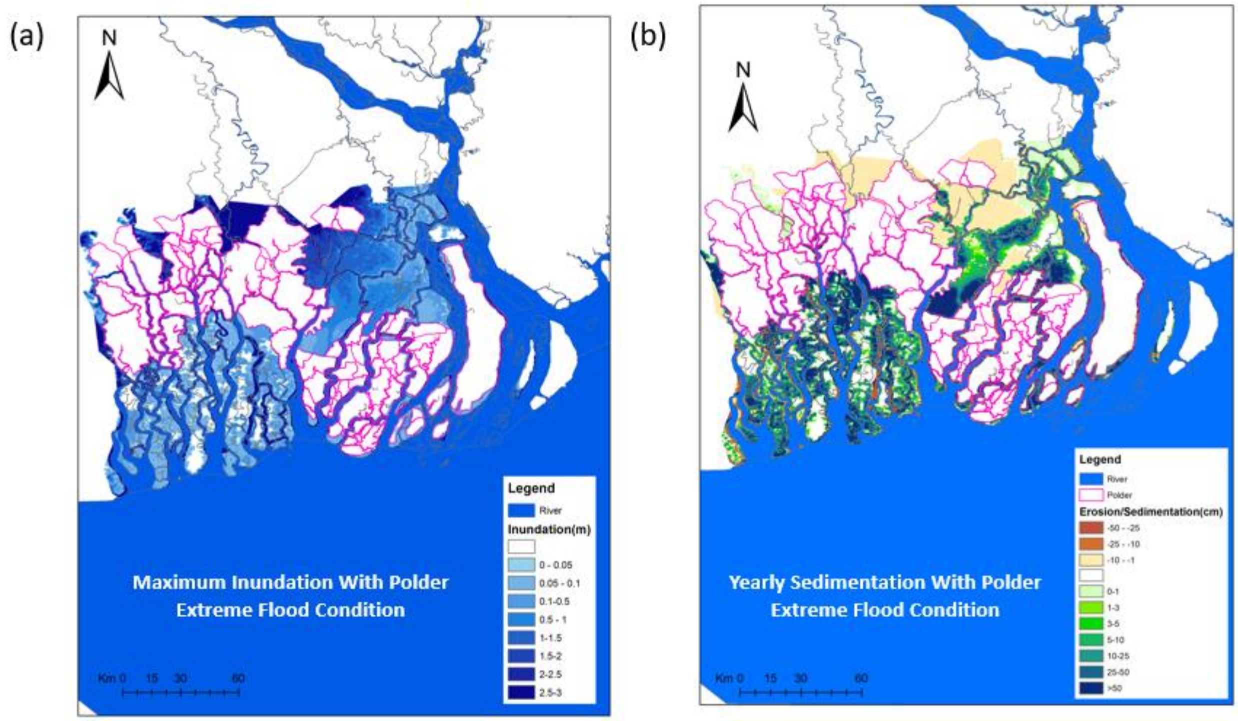


Figure-7 : (a) Inundation and (b) sedimentation during an extreme flood condition. Existence of polders are considered during simulation (source: WARPO and BUET, 2019).

10. Impact of Polders on Spatial Distribution of Sediments in Coastal Floodplain

Polders play an important role related to sediment management in the region. It is generally believed that had there been no polder, sedimentation in the unprotected floodplain will be deposited in a wider area causing less sedimentation in the river-bed. In a model simulation, WARPO and BUET (2019) shows that this belief is indeed correct in some sense (Figure-8). Sedimentation is restricted in the unprotected region only when presence of polders is considered (Figure-8a). In the same hydro-morpholgical setting, when polders are removed from the system, sedimentation is distributed in the entire floodplain but with a reduced thickness (Figure-8b). This means total sediment volume deposited on the floodplain remains the same both for ‘with’ and ‘without’ polder condition. But for ‘without polder’ condition, spatial distribution of sedimentation in the floodplain is more uniform compared to ‘with polder’ condition. So, had there been no polder, the land inside the poldered region will have the same elevation of land outside the poldered region. But this does not necessarily mean that due to polderization, the sediments which are unable to be deposited in the floodplain inside the polder will not be deposited on the river-bed had there been no polder in the region. But due to uniform sedimentation in the floodplain in ‘without polder’ condition, drainage would be better that will ultimately result less water-logging compared to ‘with polder’ condition.

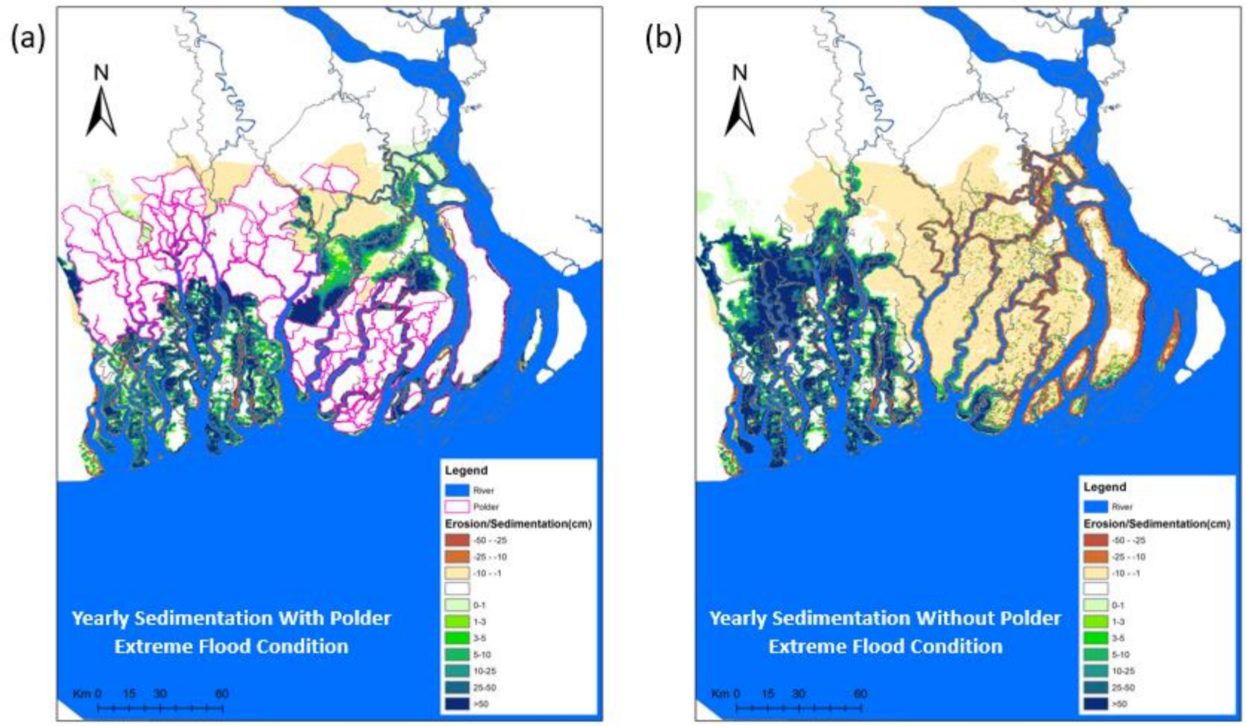


Figure-8: Yearly sedimentation during an extreme flood condition in the coastal zone for (a) with polder and (b) without polder condition (source: WARPO and BUET, 2019).

11. Present-day Sediment Management Practices

Dredging

The most popular mode of sediment management in the region is dredging. Normally dredging is done in need basis without considering the system response. Bhabodaho area within polders 24 and 25 is well known for water-logging problem. Hari river runs in between polders 24 and 25 (Figure-9). It is generally believed that sedimentation in the Hari river is the main cause of water-logging inside these two polders.

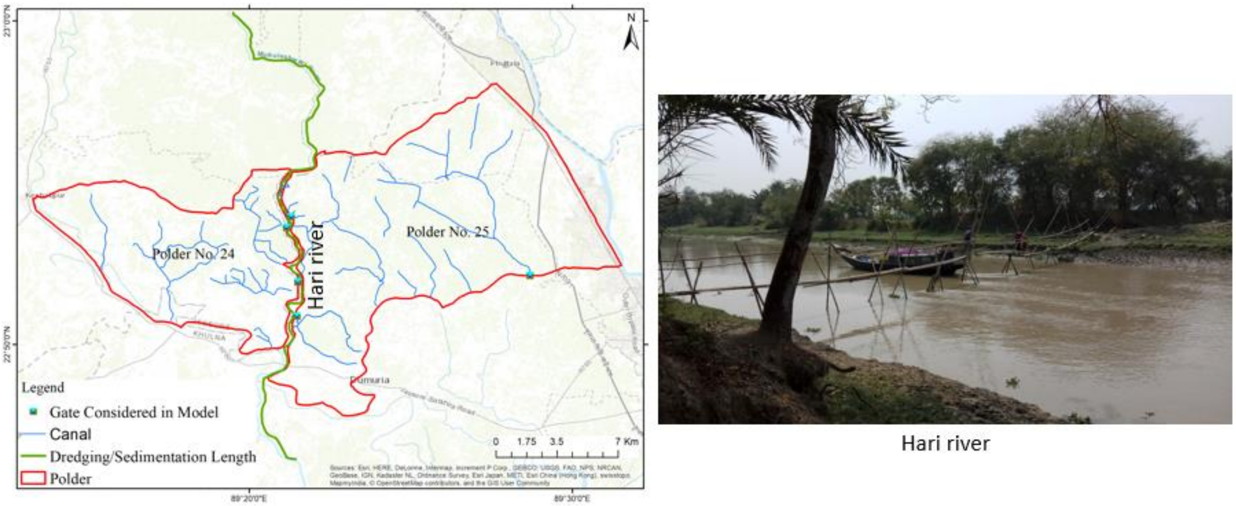


Figure-9 : Polder 24 and 25 in Bhabodaho area (left) and Hari river (right) that flows in between these two polders. The gray color of river water shows high concentration of suspended sediment.

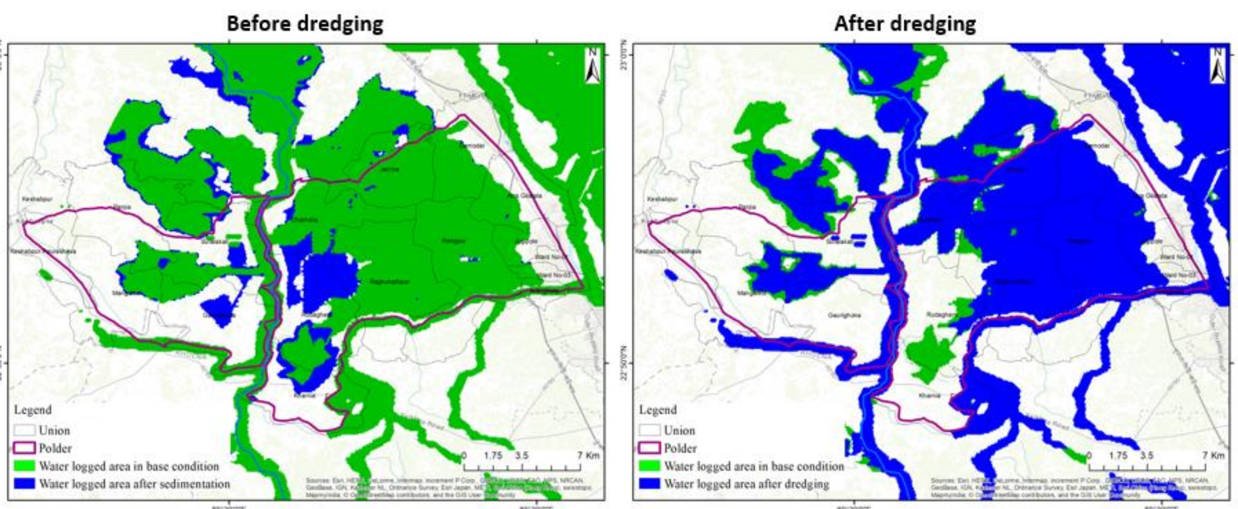


Figure-10 : Impact of dredging of Hari river on water-logging condition inside polders 24 and 25. In the left image (before dredging) the blue areas are the additional water-logged area due to sedimentation of the Hari river. In the right image (after dredging) the green areas are free from water-logging due to dredging of Hari river.

The impact of dredging of Hari river is studied by WARPO and BUET (2019) and the result is shown in Figure-10. The results show that sedimentation in the main river indeed increases the water-logging. Dredging in the main river improves the water-logging condition in the area which are within the drainage zone of the river. Outside the drainage zone, dredging impact is not visible. It is to be mentioned here that dredging is done only in the Hari river. Hari river is part of a complicated estuarine systems in the region. During dredging operation, Hari river was not considered as part of this estuarine system. This result shows that dredging as sediment management practice to remove excess sediment has limited impact to reduce water-logging when process-based system response is not considered.

Limited process-based system approach is taken to study water-logging inside polder 26 (Tahsin et al., 2019). Location of polder 26 is just downstream of polders 24 and 25 (Figure-11). The same Hari river that flows in between polders 24 and 25 also flows to the west of polder 26 with a different name, the Telegati river. Another river named Mora Bhadra comes as a distributary from Hari river, runs through north and east side of the polder and falls as a tributary to the Telegati river.

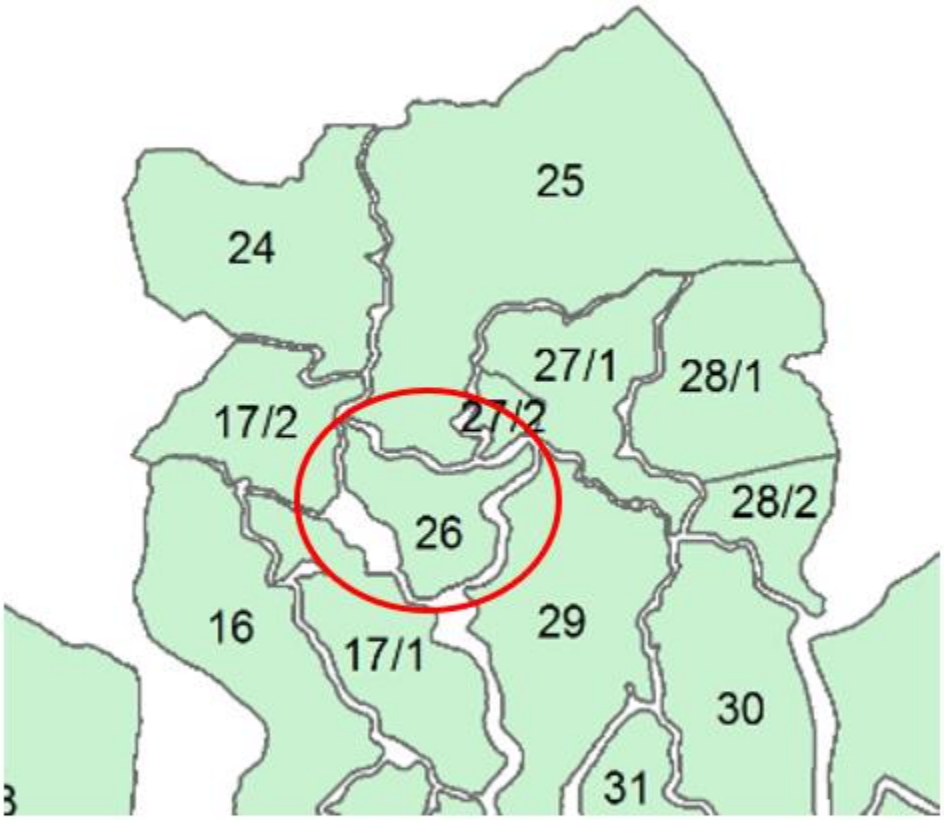


Figure-11 : Location of polder 26.

In their study, Tahsin et al. (2019) considered dredging of the Mora Bhadra river as part of the system of internal road network inside polder 26. They assumed that internal road networks play an important role in determining the drainage route which ultimately affects the water-logging (Figure-12).

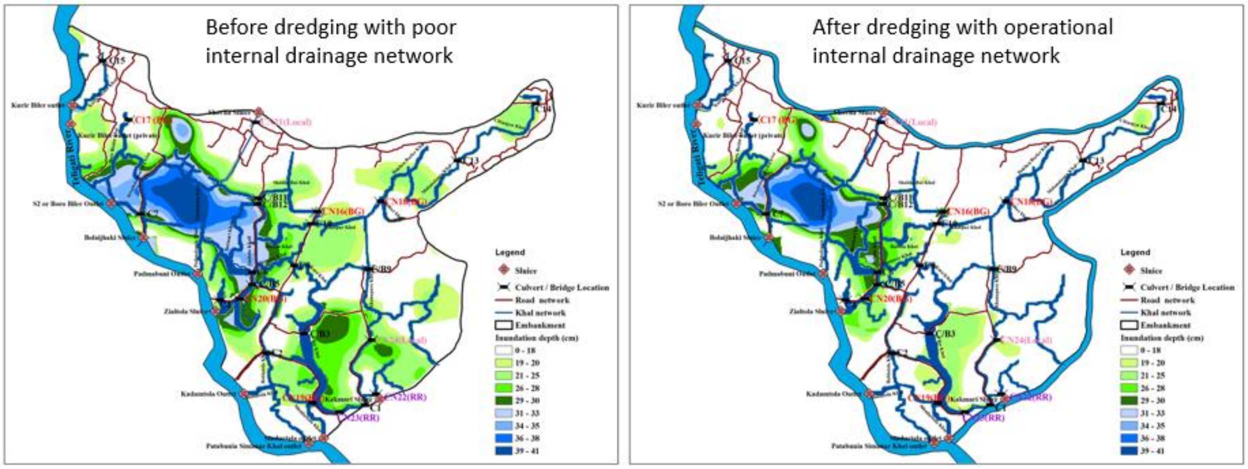


Figure-12 : Impact on water-logging of poor internal drainage route with non-dredged condition (left) and operational internal drainage route with dredged condition (right) (Tahsin et al., 2019).

They showed that water-logging inside polder 26 significantly improves when dredging of Mora Bhadra river is conducted at the same time when internal drainage route is operational (Figure-12). This result shows that dredging as a sediment management technique works better when a process-based system approach is taken. In their study, Tahsin et al. (2019) did not consider system response of the peripheral rivers which are part of a broader estuarine systems including the upstream rivers and downstream Bay of Bengal.

Tidal River Management (TRM)

The Tidal River Management or TRM is another sediment management practice applied in the same area between polders 24 and 25. The concept of TRM comes from local knowledge and later successfully applied for some years to increase conveyance of Hari river. TRM is basically a natural dredging process by utilizing tidal movement of the river and creating a tidal basin that acts as a storage for sediments (Figure-13). The basic principle of TRM is explained in Figure-13. During flood tide (shown by brown arrow), sediment laden water from the ocean enters the river and travels inland. With a connecting channel, the river is connected to a beel (a natural depression) and sediment laden water from the river enters in the beel. The beel acts as a tidal basin where due to low flow velocity, the incoming sediments from the river deposits. Due to less sediment than its carrying capacity (as sediments are deposited in the beel), the river performs the natural dredging of the river during ebb tide (shown by blue arrow). After operation of several years, the conveyance of the river increases due to natural dredging at the cost of filling the beel with sediments. To show the process, Rocky (2017) applied a numerical model in beel Khuksia which is located within the drainage zone of Hari river (Figure-14). Numerical model results (Figure-15) show progressive sedimentation in the tidal basin. These sediments are infact 'naturally dredged materials' from the Hari river.

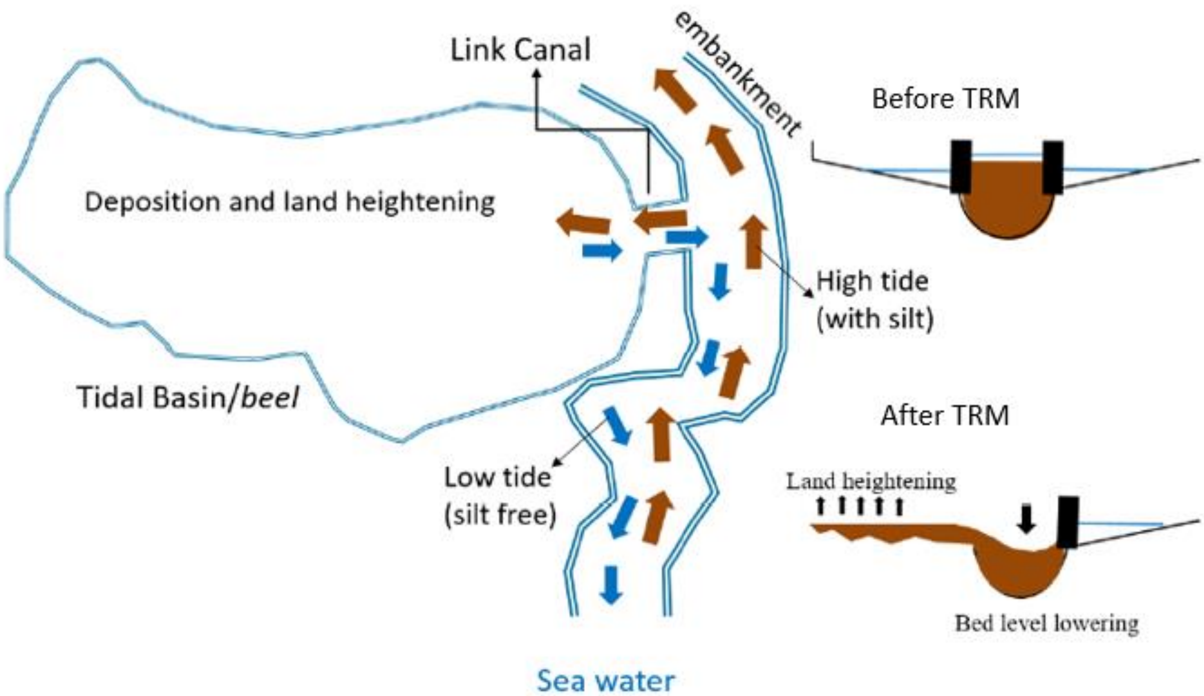


Figure-13 : Basic principle of TRM (source Rocky, 2017).

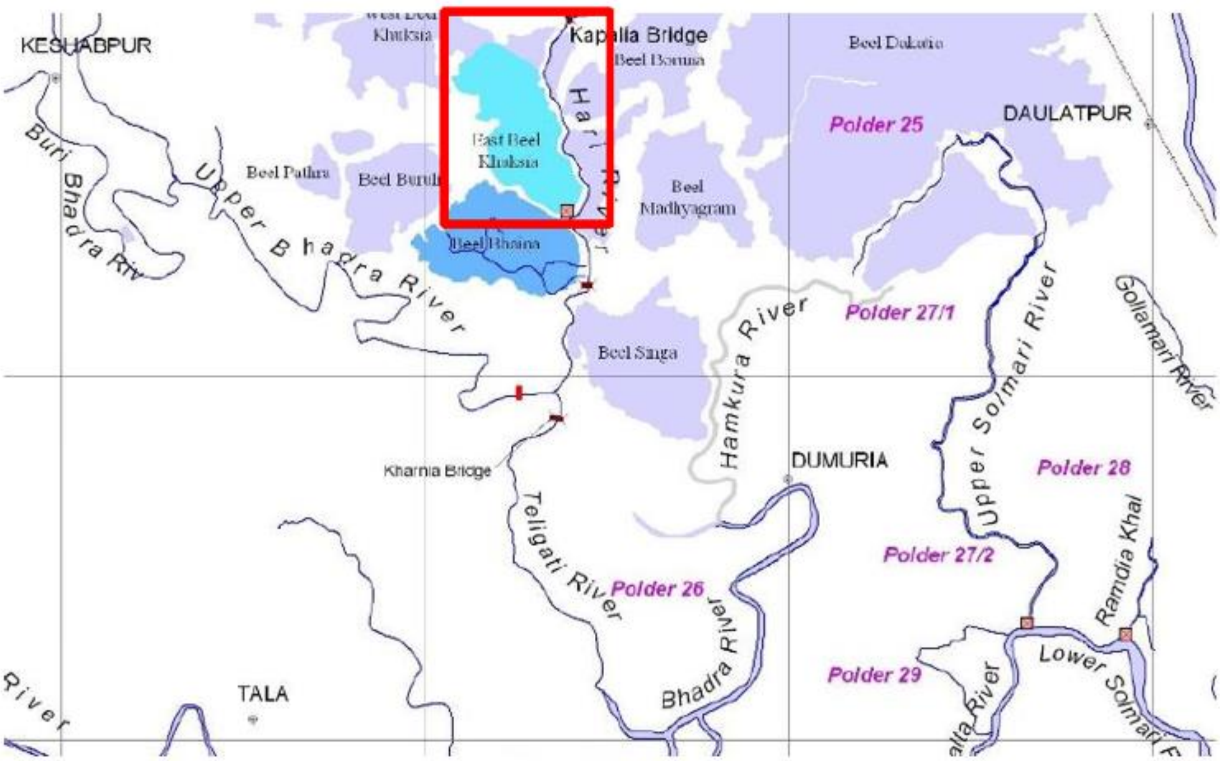


Figure-14 : Study area of model application for TRM (Rocky, 2017)

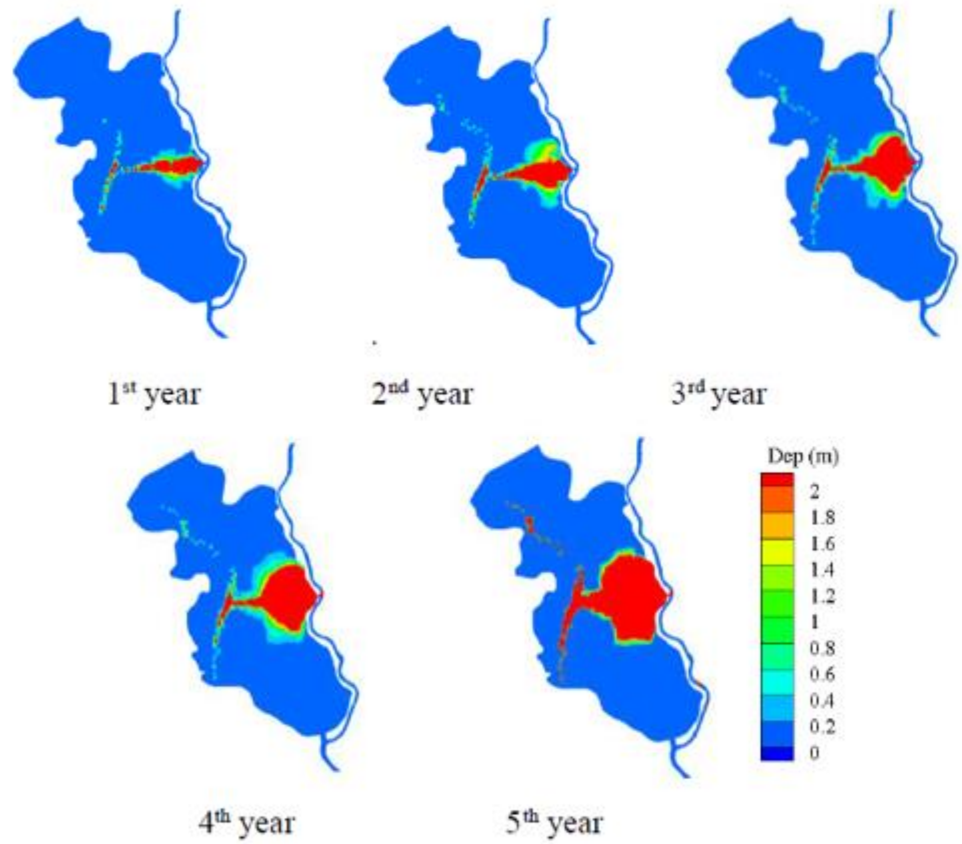


Figure-15: Numerical simulation of progressive sedimentation in tidal basin

Cross-dam

As a sediment management practice, cross-dam is used to reclaim land in the coastal area. Land reclamation in the off-shore region is largely dictated by availability of sediments. Intervention like cross-dam accelerate the process of sedimentation. Effectiveness of cross-dam depends on sediment availability. A particular example can be shown where a cross-dam is constructed by BWDB in between char Islam and char Montaz. Cross-dam in this location is built sometime in 2010. Impact of cross-dam in this region is shown in Figure-16 (in year 1984 which is almost 16 years before construction of the cross-dam) and in Figure-17 (in year 2018 which is almost 8 years after construction of the cross-dam). The reclaimed lands are shown in Figure-17 by green, red, blue and yellow circles whereas, the lost land located in the south of char Kukri Mukri is shown by white circle. This example clearly shows system response when a specific sediment management option is implemented.

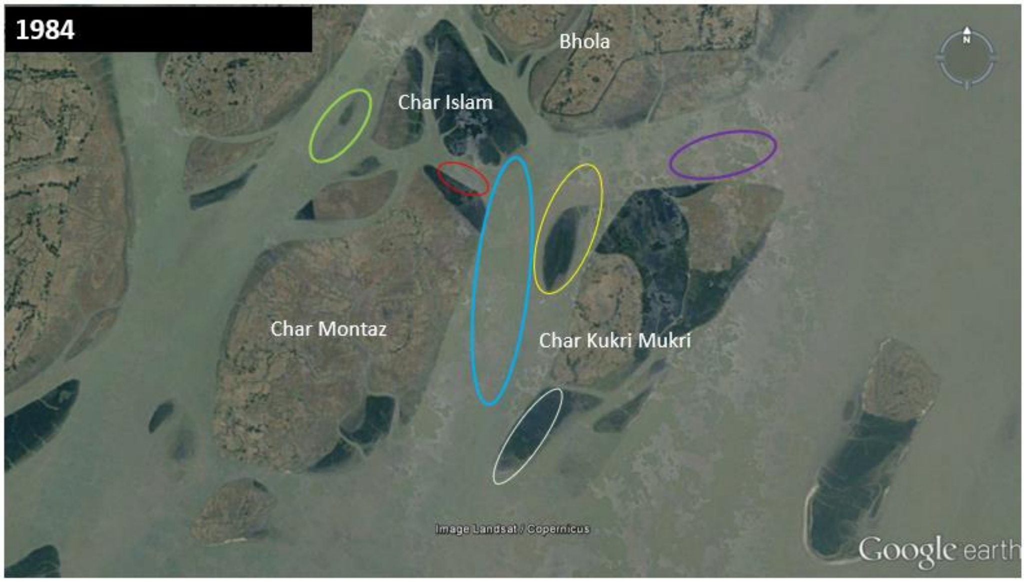


Figure-16: Land status and cross-dam location almost 16 years before the construction of the cross-dam. Cross-dam is constructed just west of red-circled zone during the year 2010.

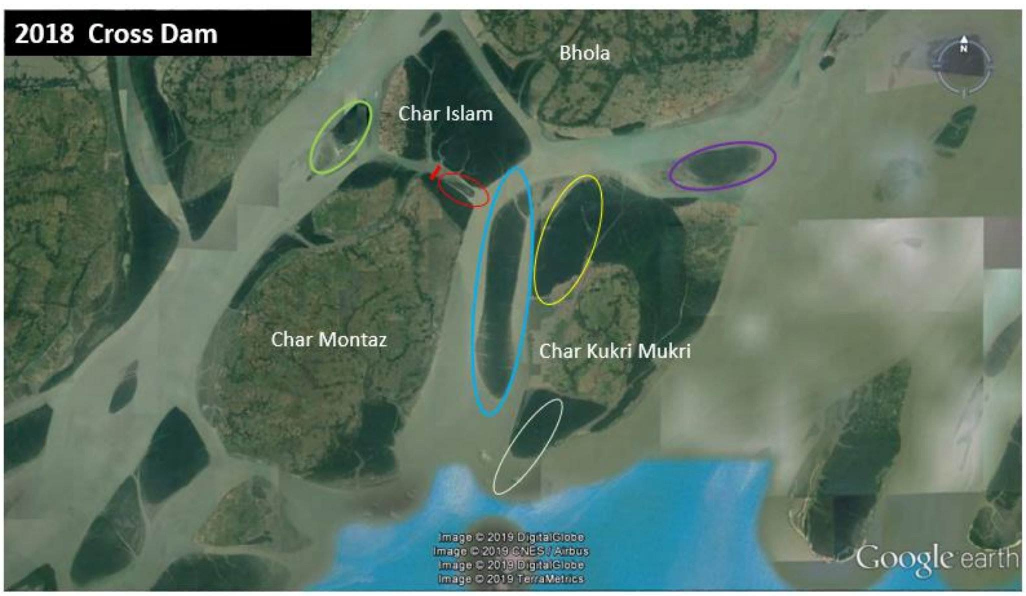


Figure-17: Reclaimed and eroded lands as a system response almost after 8 years due to construction of cross-dam. The green, red, blue and yellow circles show reclaimed land. The white circle south of char Kukri Mukri show the lost land. The cross dam is shown by red line in between char Islam and char Montaz.

Groyne-type structure

This kind of structure is normally used for river-bank protection and to increase of navigation depth. A variant of the groyne-type structure is the bundle which is traditionally being used in navigation channel in this region to increase the navigation depth in the mid-channel. This structure can also be used as an effective means of sediment management by trapping sediment (Teraguchi et al., 2011) that will accelerate sedimentation on the newly formed coastal chars (Figure-18). Sedimentation will occur during the flood tide when sediment-laden water flows over the newly formed chars and thus increase the char height. In this way, it will be possible to trap the sediment which will otherwise go to the sediment-excess region and result sedimentation in the channel bed.

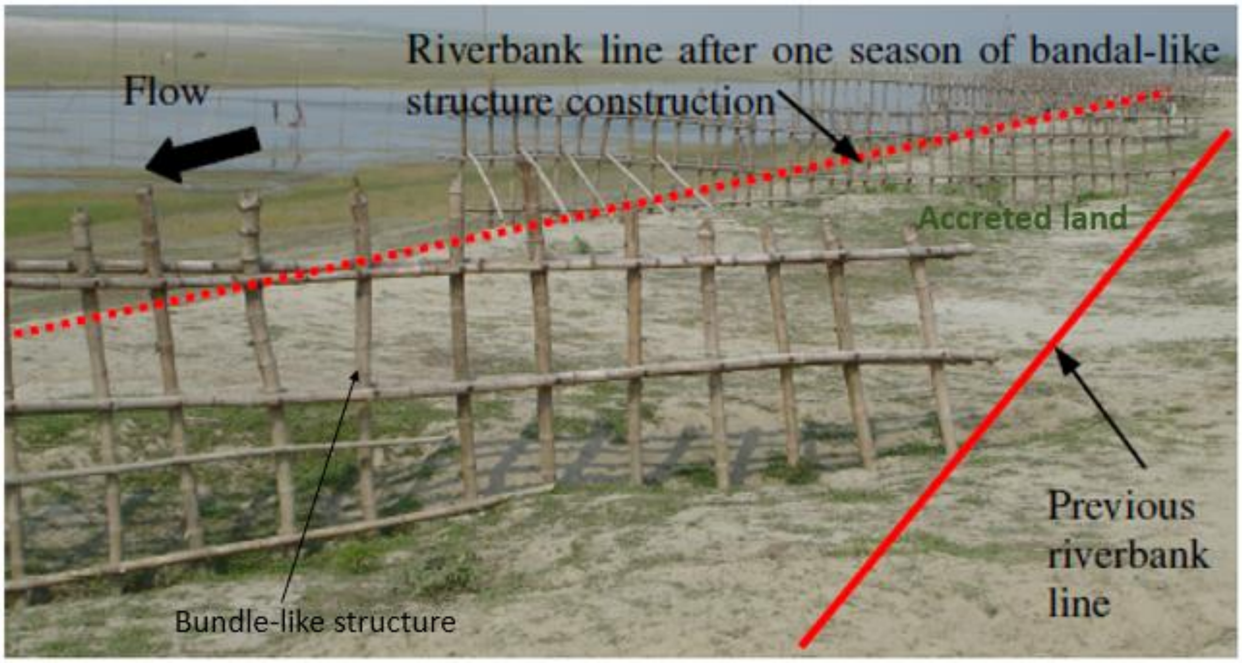
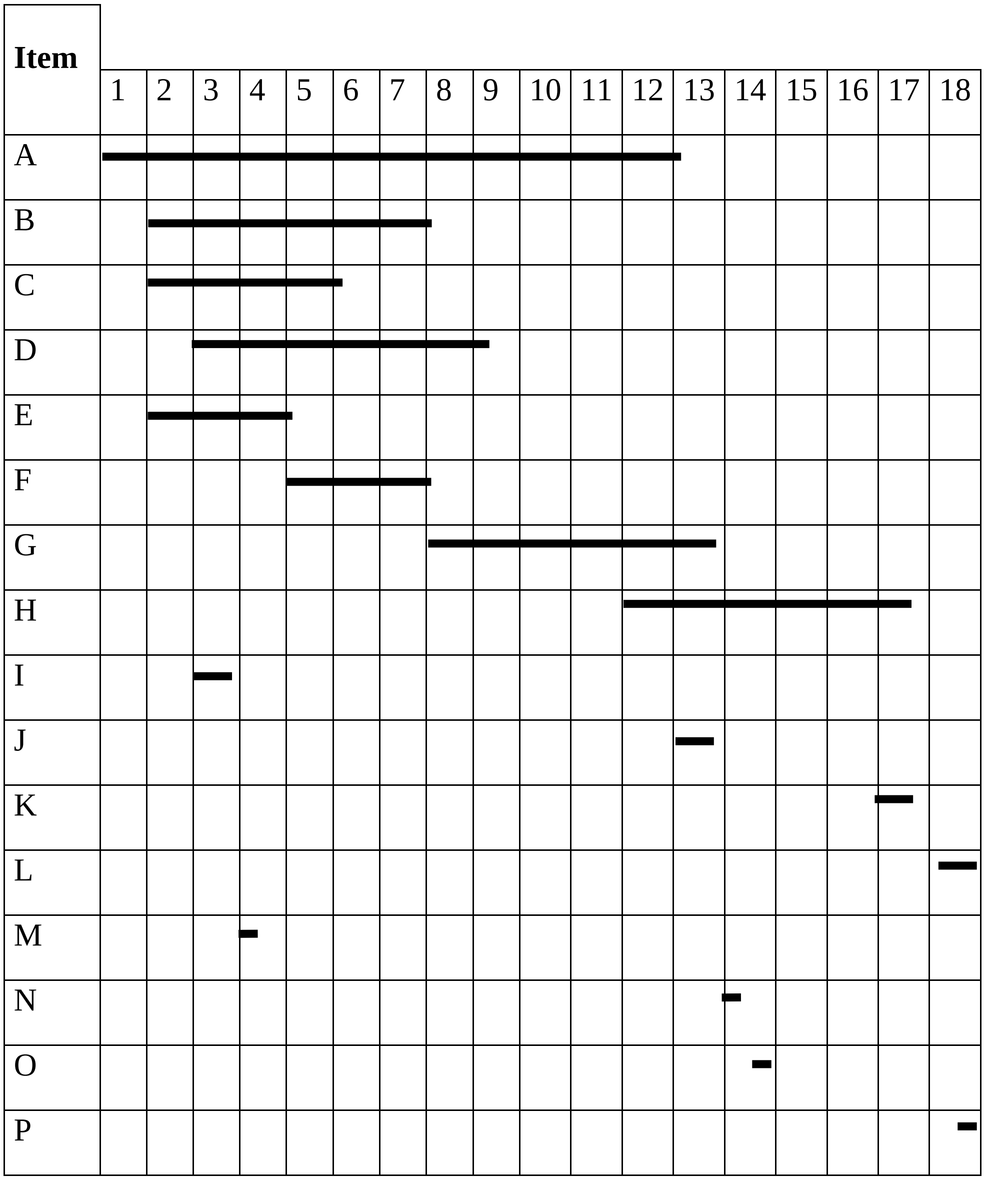


Figure-18: Bandle-like structure and accreted land (source: Teraguchi et al., 2011)

12. Concluding Remarks

This research is undertaken to assess suitable sediment management practices for the south-west region of Bangladesh which will make it possible to divert the sediment from sediment-excess region to sediment-starve region. To achieve this main objective, ranges of incoming sediment load in the region will be assessed. Study from secondary literature shows that ranges of incoming sediments in the region vary within a large range. Measured data from secondary sources shows average range of sedimentation in the coastal floodplain of Sundarban region varies between 0.92cm to 1.12cm. Results from literature shows that coastal sedimentation in the region is spatially variable. Polders do impact the spatial distribution pattern of sediments on the floodplain. Existing sediment management practices in the region are mainly dredging, tidal river management, cross-dam and groyne-type structures. Assessment of these sediment management practices show that process-based system approach is a research gap in these methods. Based on this assessment, several scenarios of sediment management practices (or a combination of these practices) will be generated by considering a process-based system approach. Numerical model will be applied to generate these scenarios. Consideration of process-based system approach will be a rational approach for any sediment management practice in this region.

13. Work Plan and Timeline



A = Literature review
B = Data collection
C = Quantify of incoming sediment loads
D = Identify present sediment management practice
E = Model setup
F = Model calibration and validation
G = Model application to generate scenarios of sediment management scenarios
H = Preparation of sediment management manual
I = Inception report
J = Interim report
K = Draft final report
L = Final report
M = Inception workshop
N = Interim workshop
O = Regional workshop
P = Final workshop

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