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A CASE STUDY OF MANAGING THE BRAHMAPUTRA-JAMUNA RIVER: A PHYSICAL MODEL BASED APPROACH

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Abstract

Rowmari and Rajibpur are two upazilas under Kurigram district located near the left bank of the Brahmaputra-Jamuna River. These upazilas are suffering from severe flood of this river every year. Therefore, a study was undertaken by River Research Institute (RRI) to manage the Brahmaputra-Jamuna River in terms of bank protection works and dredging using physical modelling. The study provides support to the design of protective work and dredging required for the erosion prone areas. A stretch of about 26 km of the Brahmaputra-Jamuna River and part width of around 6 km have been reproduced in the model study. The model is distorted having horizontal scale 1:600 and vertical scale 1:80. The study was conducted with 2.33 and 100 year return period using three different options for the protection of erosion prone areas. In Option-1, a total of 11.59 km protective work is required to protect the erosion prone areas. In this case, maximum velocity and scour around the proposed protective work are found as 1.75 ms^{-1} and 6.88 m (18.32 mPWD) respectively. In Option-2, the proposed dredging through the Brahmaputra-Jamuna River would ensure the stability of the bank protection work by reducing the flow attack near the left bank and thereby, reducing the near bank flow velocity. But the dredged channel is found to be mostly silted up. The model results indicate that the average percentage of filling up of the dredged channel is about 46.72% in one year. For Dighla Para Char stabilization (Option-3), the length of the proposed bank protective work surrounding the char is 21.654 km which may not be economically feasible as it involves huge cost and environmental & other issues. But under this option a huge area of land (around 33 sq.km) will be reclaimed due to char stabilization.

Keywords: *Bank protective work, Brahmaputra-Jamuna River, Discharge, Dredging, Reclamation, Scour, Stabilization, and Velocity.*

Introduction

Originating from the Manas Sarovar Lake region of the Himalayas in Tibet, the river enters into Bangladesh at Rowmari upazila. Rowmari and Rajibpur upazilas are situated adjacent to the left bank of the Brahmaputra-Jamuna River and these upazilas are suffering from devastating flood of this river every year. Therefore, a study is required along the left bank of the Brahmaputra-Jamuna River at Rowmari and Rajibpur upazila for the protection of these areas. The satellite image at and around the study area is shown in **Fig. 1.** The objectives of the study are to identify the erosion prone areas within the study reach; to develop options of erosion management measures; to assess the efficacy of the developed options in arresting erosion; to assess the effects of the developed options on river hydraulics and morphology in the upstream and downstream of the same and to determine the hydraulic design parameters of the suitable bank protection works. Bank failure, characterized by erosion and collapse of riverbanks, is a prevalent issue along the Brahmaputra River in Bangladesh. It can be attributed to a combination of natural and human factors. Researchers have identified several causes of bank erosion, including high water velocity, sediment transport, riverbed changes, rainfall patterns, and human interventions. Rahman *et al.* (2009) conducted a study on the causes of riverbank erosion, emphasizing the role of channel migration and sediment dynamics in bank failure processes. They also highlighted the impact of climate change on the instability of riverbanks.

The consequences of bank failure along the Brahmaputra River have far-reaching effects on both human settlements and natural ecosystems. Scholars have examined the social, economic, and environmental impacts of bank erosion. They assessed the socio-economic consequences of riverbank erosion on affected communities, highlighting the loss of land, displacement, and disruptions to livelihoods. Destruction of agricultural fields, infrastructure, and housing has also been identified as significant consequence of bank failure (Hassan *et al.*, 2021). Efforts to mitigate and adapt to bank failure along the Brahmaputra River have been explored in research studies. Researchers have proposed various strategies to manage erosion and reduce its impacts. Islam *et al.* (2023) conducted a study on the effectiveness of river training works in mitigating bank erosion, analysing the roles of embankments, spurs, and groynes. They emphasized the need for integrated approaches, incorporating both structural and non-structural measures, to achieve effective erosion control.

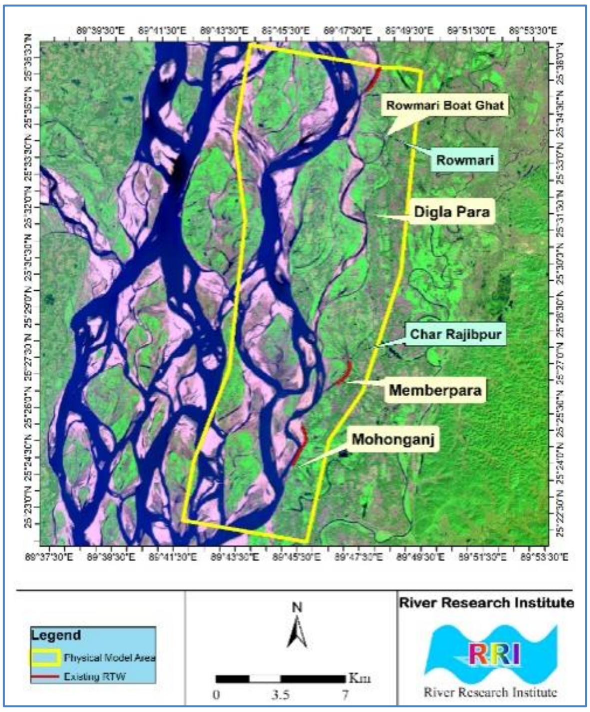

Fig. 1. Satellite image around the study area.

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The main causes of the Brahmaputra-Jamuna River's bank line change in Bangladesh will be examined in this study along with any ramifications. Rahman *et al.* (2022) used remote sensing and GIS tools in research to examine the Brahmaputra-Jamuna River's bank line dynamics. The river's bank lines have moved noticeably throughout this time, according to the researchers' analysis of satellite imagery from 1973 to 2019. The researchers ascribed this change to processes including sedimentation, erosion, and human activities like sand mining and embankment construction. Additionally, they looked at the effects of climate change on the Brahmaputra-Jamuna River's bank line displacement. In order to replicate future events, the researchers used hydrological modelling techniques while taking into consideration anticipated changes in temperature and precipitation. According to the findings, future bank line movements might be caused by climate change-related erosion and increasing river discharge. Concern has also been expressed about the socioeconomic effects of the Brahmaputra-Jamuna River's bank shift. In their study, Kundu *et al.* (2019) investigated the effects of bank erosion on the lives and agricultural production of farmers in riverine areas. They emphasized how regular riverbank erosion destroys fertile land, uproots communities, and has a negative impact on local businesses, especially those related to agriculture and fishing.

Several strategies have been put up to lessen the negative impacts of bank line shifts. The usefulness of bioengineering methods, such as the usage of vegetative bio-bunds, in preventing bank erosion along the Brahmaputra-Jamuna River was studied by Islam *et al.* (2003). According to their research, these methods can considerably lower erosion rates and stabilize the riverbank, providing a long-term fix. Sedimentation, erosion, climate change, and human activity are a few of the causes that affect the Brahmaputra-Jamuna River's bank line movement in Bangladesh. The socioeconomic and biological processes in the riverine zones are severely hampered by it. To solve the complex difficulties related to the bank line shift and guarantee sustainable development along the Brahmaputra-Jamuna River, further study and comprehensive management measures are needed. The vulnerable area along the left bank of Brahmaputra-Jamuna River is identified by IWM and is shown in **Fig. 2.** It is noticed from this figure that the left bank is subjected to erosion at various amount at different places. There are various places near the left bank of Brahmaputra-Jamuna River which are susceptible to river bank erosion is listed below (IWM, 2022).

- Shaheber Alga BGB Camp to Bolodmari Ghat (13 km) (starting Ch-0 KM).
- Rowmari Boat Ghat to West Baghmara (1.7 KM) (starting Ch-19.85 KM 24.94 KM).
- Dighlapara Kheyaghat to Dhonar Char (2.32 KM) (starting Ch- 24.94 KM).
- Rajibpur Boat Ghat to Hazipara (3.10 KM) (starting Ch-35 KM).
- Nayachar to Sanandabari (3.10 KM) (starting Ch- 41 KM).
- Bir Muktijoddha Ajharul Islam House to Babul Market (2.7 KM) (starting Ch- 45.63 KM).
- Algar Char to Old Brahmaputra Offtake (5.65 KM) (starting Ch- 52 KM).

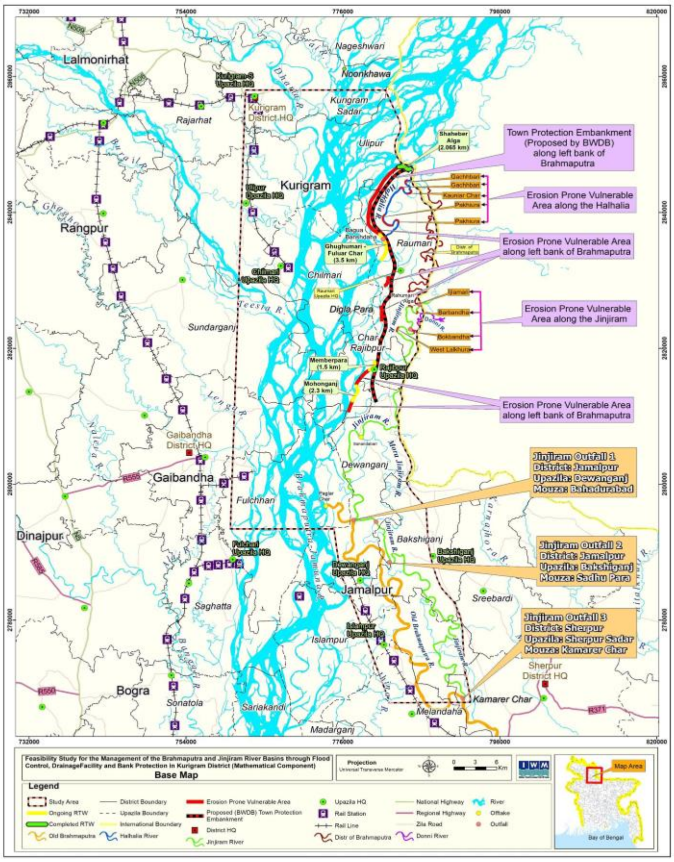

Fig. 2. Identified vulnerable area (IWM, 2022).

Bank Shifting

The satellite imageries of 1984 and 2023 of the Brahmaputra-Jamuna River in the study area are superimposed as shown in **Fig. 3.** It is noticeable from the figure that the left bank of Brahmaputra-Jamuna River is susceptible to erosion. Lateral migration of the left bank varies up to 5.3 km since 1984. More than 100 sq. Km of land have eroded since 1984 in Rowmari and Char Rajibpur upazila of Kurigram District. Thousands of people losing their lands and become homeless (RRI, 2023).

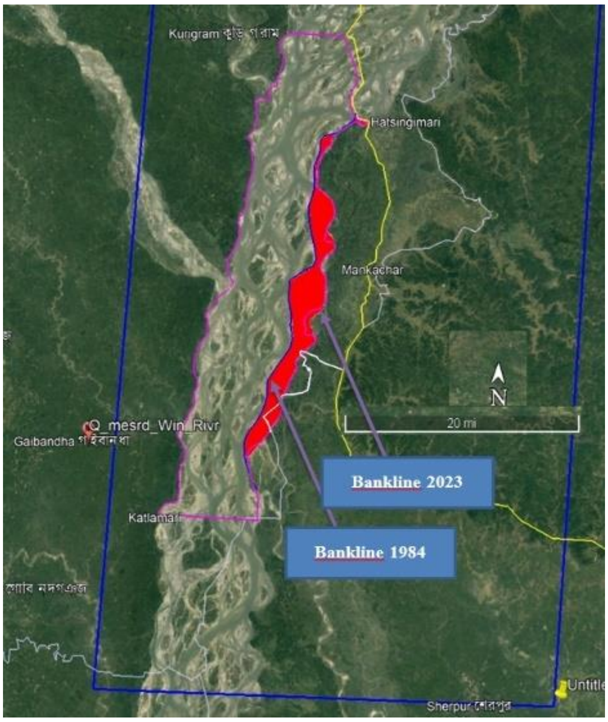

Fig. 3. Superimposed satellite imageries of 1984 and 2023 of the Brahmaputra River (RRI, 2023).

Methodology

An overall distorted morphological model was constructed which includes a river stretch covering around 26 km of Brahmaputra-Jamuna River. In order to meet the scale conditions for reproducing the flow and sediment transport processes simultaneously as well as to meet the roughness condition of the model, a distorted model with suitable geometric scales had been planned. The model was constructed having horizontal scale 1:600 and vertical scale 1:80. This model had part width of the river from the left bank so that at least 30% of the total discharge was passing within the lateral boundary. The model had been planned to come up with the hydraulic design parameters of the interventions and to assess the impacts of the same qualitatively. The main purpose of this model was to provide decision support for determining of suitable and optimal design of bank protection work as well as dredging alignment if necessary and also to investigate the efficacy of the alternative measures to ensure a stable river course.

One of the important considerations in scale modelling is the selection of bed material size to have roughly similar hydraulic and morphological condition both in model and prototype. To this end, a number of sediment samples had been collected from the river bed and bank of the Brahmaputra River. These samples were analysed to determine bed load, suspended load, wash load and soil properties in the sediment laboratory of RRI. Latest maps and satellite imageries covering the study reach had been collected from different sources including USGS. Historical satellite imageries of study area had also been collected for different periods. These satellite imageries had been super-imposed to have an understanding of the changes in the channel pattern with the passage of time due to morphological developments.

Dredging has been proven as an effective process to control the deposited sediment to prevent flooding and make a pathway for the main channel flow (Gob *et al*., 2005; Zinger *et al.*, 2011). The process also allows us to further solve engineering problems related to sedimentation and erosion in rivers, estuaries, and coastal seas (Van Rijn, 2005). A better prediction of erosion-sedimentation scenarios is inevitable to justify the long-term effectiveness of dredging, which could further promote the design strategies based on qualitative and quantitative analysis. Prediction of accurate scour depth and deposition of the braided river is methodologically very challenging because of the variation in simple path-length distribution resulting in over-scouring (Kasprak *et al.*, 2019).

Sediment was fed into the model manually. Generally, the rate of sediment feeding for a particular model discharge was determined first by using sediment transport formulae /relation proposed by different researchers. For this model the sediment transport formulae proposed by Engelund and Hansen (1967) had been used to determine the initial sediment feeding rate. The sediment feeding rate, however, had been calibrated. The calibration of sediment feeding rate had been done by taking measurements of bed levels along a few cross-sections located at different parts of the model at a regular interval of time. Calibration of sediment feeding rate involves a condition where bed level remains more or less unchanged. It means whatever sediment is fed into the model is transported out of the model.

The initial bathymetry of the model was reproduced based on the field survey data collected under the framework of this study. The model was designed as a fine sand bed morphological model. Since it was a distorted model, the model had been constructed based on selected geometric scales. The initial bathymetry of the model is shown in **Fig. 4**. The construction of model involves a series of tasks. Besides selection of geometric scale ratios, the model bed had been prepared by uprooting the grass, dismantling of the previous works in the selected model bed and disposal of debris, removing the old sand from the model bed and filling the same with new fine sand having required median size, procurement of model construction materials, collection of bathymetric and bank line data etc. The model layout is shown in **Fig. 5**.

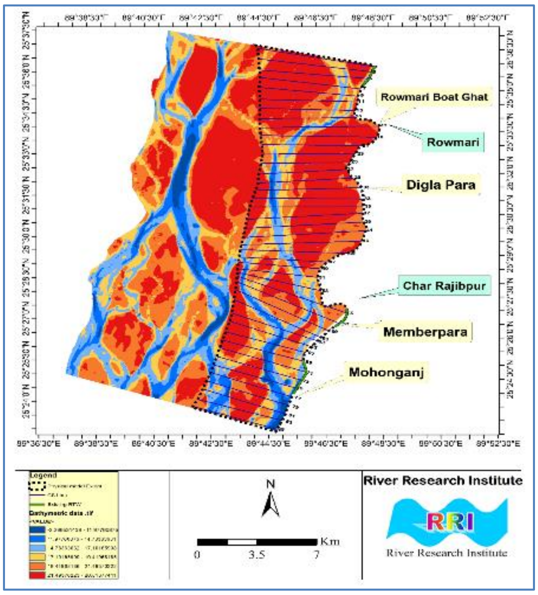

Fig. 4: Initial bathymetry of Brahmaputra River.

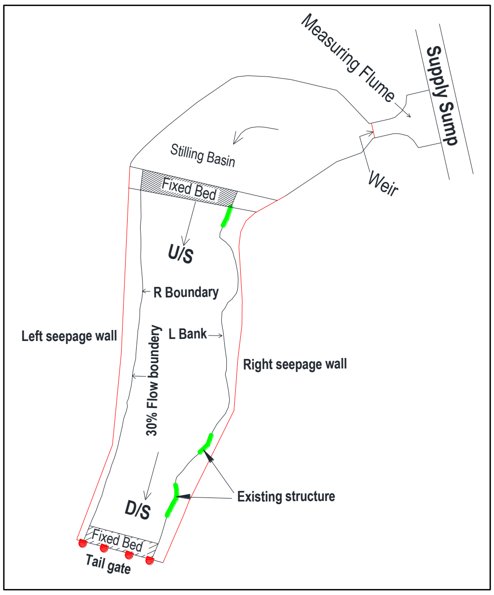

Fig. 5: Layout of the Model.

Test Scenarios

In this model, calibration test (T0) & base test (T1) in existing condition and five application test runs (T2-T4) with proposed interventions (bank protection & dredged channel) in place have been conducted. The proposed test scenarios of the model along with various test & flow conditions are mentioned in **Table 1**.

Table 1. Test Scenarios of the model.

Tests	Test Conditions	Flow Conditions
T0 (Calibration)	Existing (without project) condition and surveyed bathymetry as initial bed of the model	2.33 year return period discharge and corresponding water level at preselected location
T1 (Base run)	Existing (without project) condition and calibrated bathymetry as initial bed of the model	2.33 year return period discharge as well as 100 year return period discharge with corresponding water level
T2 (Option-1)	Existing (without project) condition + Proposed Bank Protection Works	-Do-
T3 (Option-2)	Existing (without project) condition + Proposed Bank Protection Works + Dredging at 1 location of Brahmaputra-Jamuna River (Rowmari)	-Do-
T4 (Option-3)	Existing (without project) condition + Proposed Bank Protection Works + Dighlapara Char Stabilization	-Do-

Model Calibration

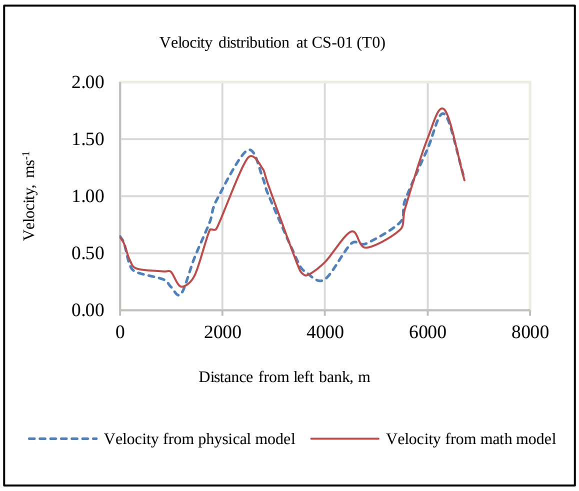

Fig. 6. Comparison of velocity distribution at CS-01 for 2.33 year return period discharge.

Model calibration is done to ensure that the model is able to reproduce the flow condition, morphological behaviour and sediment transport in the field. The calibration of the model primarily aims to see whether the model is able to reproduce a more or less similar bathymetry as is measured during field survey under imposed conditions to bring about similarity between model and prototype in terms of flow and sediment transport simultaneously. The measurements during the calibration include water levels, bed levels, point velocities, float tracks, discharge etc. The model bathymetry obtained after calibration of the model has been considered as initial bathymetry for subsequent application tests in base and intervention conditions. Calibration test was done using 2.33 year return period discharge (Q= 20,452 cumec) and corresponding water level (24.68 mPWD). This test was carried out with existing condition. The model bed was prepared according to the bathymetric survey of October, 2022**.** Flow velocity was measured in the model and is compared with the prototype measurement (mathematical model). A comparison between prototype and model velocity is made as shown in **Fig. 6.** From this figure it is evident that the velocities observed in the model are close to the prototype values.

Results and Discussion

In test results, the findings of base run (T1) and 3 (three) application tests (T2, T3 & T3) have been presented. In base run, there are three existing protective structures to protect the left bank of Brahmaputra-Jamuna River within the model boundary. These places are Godabari, Char Khonjonmara (U/S of Rowmari Boat Ghat), Kodalkati Boat Ghat, Munshipara (Memberpara) and Nayar Char Launch Ghat, Mohangonj Union and the length of the existing structures is 1428m, 1498m & 2364m respectively (**Fig. 7**). Bank erosion at the left bank of Brahmaputra-Jamuna model is shown in **Fig. 8**. In test T2 (Option-2), there are three proposed structures to protect the left bank of Brahmaputra-Jamuna River in addition to the existing structures. The places of proposed structures are Baghmara /Rowmari Boat Ghat, Dighlapara/Dhonar Char under Jadurchar Union and Rajibpur Boat Ghat. The length of the proposed structures is 1766m, 2338m & 3063m respectively. In the design of protective structures, the length of launching apron is 45 m, assorted CC blocks to be dumped below LWL (Low Water Level) @ 35 $m^3.m^{-1}$ (500X500X500 - 60%, 400X400X400 - 40%, 250 kg geobag to be dumped below LWL @ 33.75 $m^3.m^{-1}$. The proposed protective work is constructed in the model as per design. There are three places where bank erosion is observed at left bank during test T2 in addition to the proposed bank protection work. These places are downstream of existing protective work (Faluar Char Nouka Ghat), downstream of proposed protective work at Rowmari Boat Ghat (Chaktabari, Jadurchar Union) and Char Rajibpur (Char Velamari). These areas require bank protection work. The location of existing, proposed & erosion prone areas are shown in **Fig. 9**. Proposed and existing protective work around Char Rajibpur is shown in **Fig. 10**. Erosion prone area upstream of Rowmari Boat Ghat is shown in **Fig. 11**.

Fig. 7. Placement of existing bank protection works at Memberpara and Mohonganj ($T1_{2.33yr}$).

Fig. 8. Bank erosion occurred at the left bank of Brahmaputra model under base condition ($T1_{100yr}$).

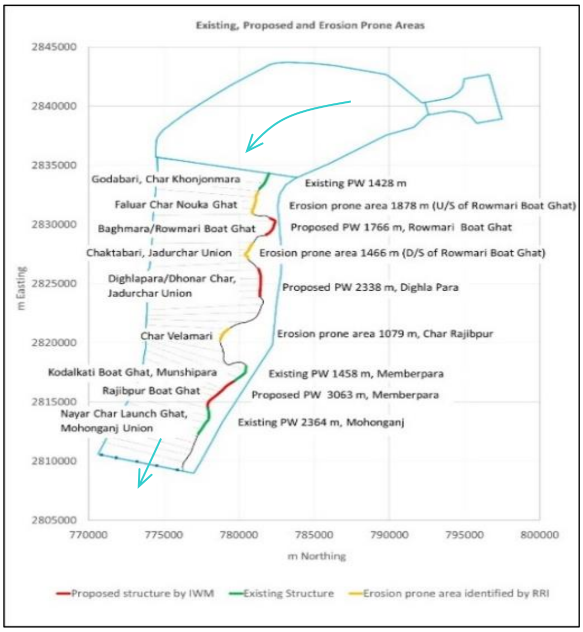

Fig. 9. Layout of model for test T2 including location of existing, proposed & erosion prone areas (T2).

Fig. 10. Proposed and existing protective work around Char Rajibpur.

Fig. 11. Erosion prone area upstream of Rowmari Boat Ghat ($T2_{100yr}$).

In test T3 (Option-2), a proposed dredged channel is reproduced **(Fig. 12 & 13)** in the model at Rowmari in addition to the existing & proposed protective works. The length of the dredged channel **(Fig. 14)** is 13.2 km. The bottom level of dredged channel is 11 mPWD, side slope 1:3, average top level 17 mPWD, longitudinal slope 5cm.km^{-1}, average height of the dredged channel is 6m. **Fig. 15** shows the longitudinal section through the proposed dredged channel. The amount of dredged volume, which is measured around 2,72,17,863 m^3 in the model. The average thickness of dredging is about 5.55m.

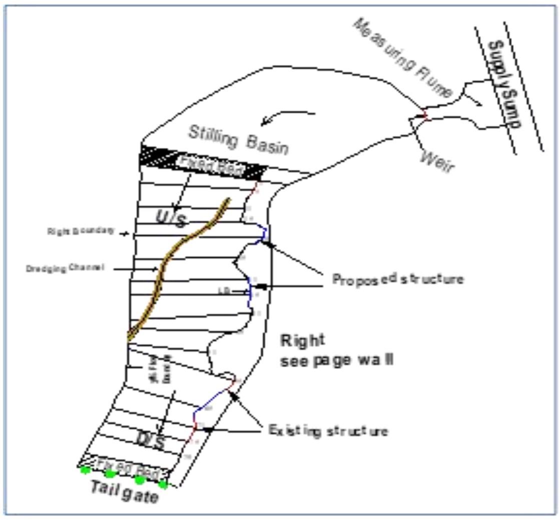

Fig.12: Layout of model for test

Fig.13: Initial alignment of dredged channel in the model (T3)

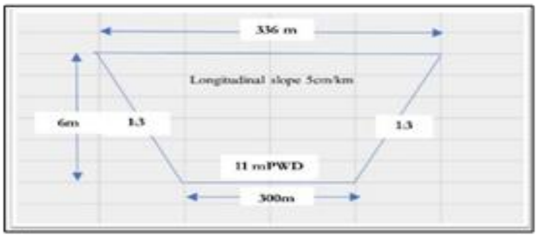

Fig.14: Section of the dredged channel

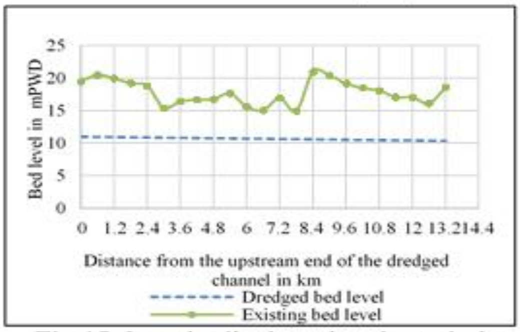

Fig.15: Longitudinal section through the proposed dredged channel ($T3_{100yr}$)

The volume of filling up of the dredged channel is found about 1,27,15,570 m^3. The average filling depth is 3.39 m. The dredged channel is mostly found to be silted up. The model results indicate that the average percentage of filling up of the dredged channel is about 46.72%. **Fig. 16-18** shows the initial & final bed level through dredged channel (T3$_{100yr}$). **Fig. 19** shows the alignment of silted dredged channel in test T3$_{100yr}$.

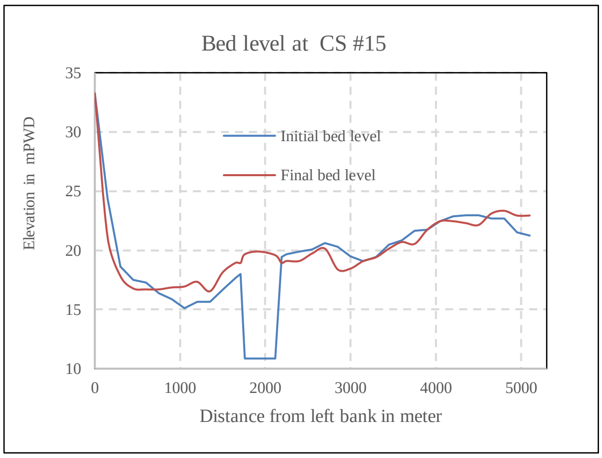

Fig. 16. Initial & final bed level through dredged channel in test T3 (U/S part).

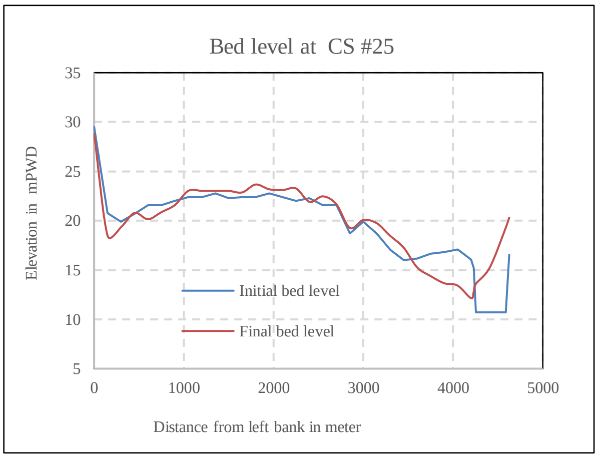

Fig. 17. Initial & final bed level through dredged channel in test T3 (middle part).

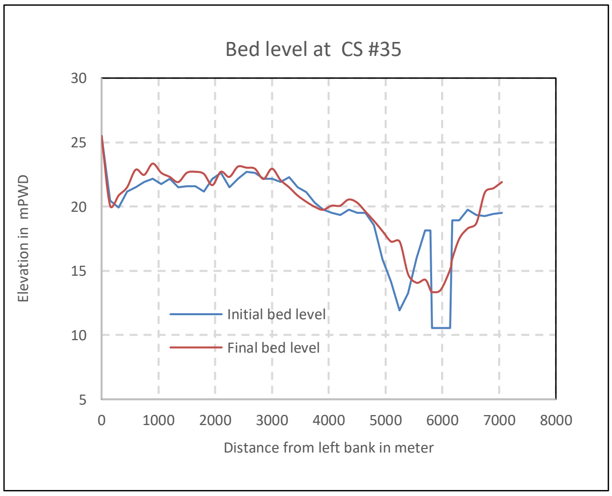

Fig. 18. Initial & final bed level through dredged channel in test T3 (D/S part).

Fig. 19. Alignment of silted dredged channel.

Test T4 (Option-3) is the third application test conducted for char stabilization (Connecting Char Dighla Para with the main-land including river bank protection) in place. The advantage of interventions considered under this option is that a huge area of land (around 33 sq.km) will be reclaimed due to char stabilization. Moreover, the reclaimed area may be developed rapidly immediately after char stabilization due to the construction of different infrastructures such as schools, colleges, offices, industries, factories etc. Due to these, the socio-economic condition of that area will be improved a lot. At present, the char land is separated from the main land by a secondary channel of the Brahmaputra-Jamuna River. The proposed design of bank protective work for Dighla Para Char Stabilisation is verified by physical modelling. The model layout for test T4 is shown in **Fig. 20.** Here the length of the proposed protective work (as shown in **Fig. 21)** surrounding the Dighla Para Char is 21.654 km. The launching of protective work is shown in **Fig. 22-23.**

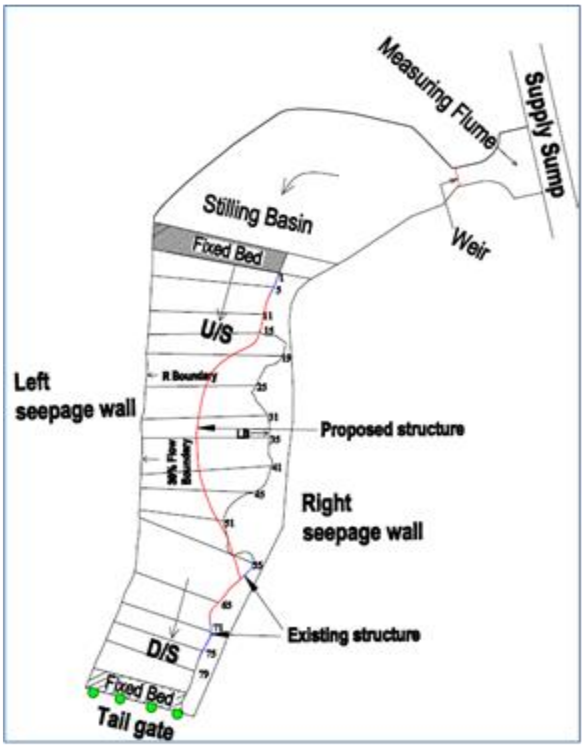

Fig.20: Layout of model for test T4

Fig.21: Proposed protective works surrounding Dighla Para Char

Fig. 22. Launching behaviour of proposed protective works (T_{100yr}).

Fig. 23. Launching pattern of proposed protective works after run (T_{100yr}).

Suitable Option

The protection measures considered under Option-1 will arrest left bank erosion of the Brahmaputra-Jamuna River at the erosion prone locations where they are implemented. Erosion may still occur at some unprotected locations. Also, this option does not facilitate reclamation of any land if it does not happen naturally by abandonment of secondary channel or retreat of the river channel. If land development/reclamation occurs naturally it may again come under erosion attack at a future time given the very dynamic nature of the Brahmaputra-Jamuna River. Therefore, with interventions considered under Option-1 in place recovery of the lands that are already engulfed by the river remains uncertain.

Option-2 also does not facilitate reclamation of any lost land unless it happens naturally. Dredging at Rowmari considered under this option appears to be not feasible as the dredged channel may get largely filled up within a year. The cost of capital and maintenance dredging may not be compatible with the likely benefit from the dredging.

Bank protection and char stabilization considered under Option-3 appear to be beneficial in terms of erosion protection and land reclamation. Char stabilization in the Brahmaputra-Jamuna River may occur naturally. However, implementation of suggested protective works (21.654km long) is likely to be a challenging task as the protective works will come under high flow attack of a major channel of the Brahmaputra-Jamuna River. In the past the river has shown a trend of increase in braiding intensity and width leading to large scale bank erosion in the project area. It is believed that this trend no more exists now. It creates an opportunity to go for narrowing the river and reclaim valuable floodplain land. However, response of the Brahmaputra-Jamuna River to human interventions still remains unpredictable.

Under this circumstance, it would be wise to implement the proposed protective works following an adaptive approach keeping scope for improving and optimizing the designs for systematic stabilization measures to be implemented. Since interventions under Option-3 provides left bank erosion protection of the Brahmaputra-Jamuna River covering a long stretch and facilitates regaining of lost land it could be a suitable option that may be considered.

Conclusion

The near left bank velocity is high enough to cause bank erosion at unprotected places when tested for flood discharge of 2.33 year and 100 years. Bank erosion may continue at these areas if appropriate bank protection measures are not taken immediately. Float tracking in the base run reveals that the left bank of the Brahmaputra-Jamuna River is under flow attack at the unprotected areas. In base condition (T1), maximum velocity around the existing protective work at the upstream of Rowmari Boat Ghat, at Memberpara and at Mohonganj is found as 1.32, 1.32 and 0.92 ms^{-1} respectively for 2.33 year discharge and as 1.34, 0.94 and 1.40 ms^{-1} respectively for 100 year discharge. In test T2 (Option-1), maximum velocity around the proposed protective work at Rowmari Boat Ghat, at Dighla Para and at Memberpara is found as 0, 1.52 and 1.17 ms^{-1} respectively for 2.33 year discharge and as 0, 1.63 and 1.75 ms^{-1} respectively for 100 year discharge. In test T3 (Option-2), maximum velocity around the proposed protective work at Rowmari Boat Ghat, at Dighla Para and at Memberpara is found as 0, 0.59 and 0.19 ms^{-1} respectively for 2.33 year discharge and as 0, 0.77 and 1.00 ms^{-1} respectively for 100 year discharge. In test T4 (Option-3), maximum velocity along the proposed protective work placed around Dighla Para Char is found as 1.78 ms^{-1} for 2.33 year discharge, 4.5 km downstream from the upstream end of the proposed protective work and as 2.81 ms^{-1} for 100 year discharge, 5.1 km downstream from the same.

In base condition (T1), with respect to initial bed level maximum scour depth around the existing protective work at upstream of Rowmari Boat Ghat, at Memberpara and at Mohonganj is found as 3.52 m (17.84 mPWD), 2.32 m (19.84 mPWD) and 1.36 m (20.43 mPWD) respectively for 100 year flood discharge. In test T2 (Option-1), with respect to initial bed level maximum scour depth around the proposed protective work at Rowmari Boat Ghat, at Dighla Para and at Memberpara is found as 0.96 m (20.85 mPWD), 0.96 m (18.73 mPWD) and 6.88m (18.32 mPWD) respectively for 100 year flood discharge; In test T3 (Option-2), with respect to initial bed level maximum scour depth around the proposed protective work at Rowmari Boat Ghat, at Dighla Para and at Memberpara is found as 1.12 m (20.69 mPWD), 4.72 m (25.06 mPWD) and 6.88 m (11.43 mPWD) respectively for 100 year flood discharge. In test T4 (Option-3), with respect to initial bed level maximum scour depth along the proposed protective work placed around Dighla Para Char is found as 12.72 m. The corresponding minimum scour level is 8.88 mPWD. It has happened at around 5.7 km downstream from the upstream end of the proposed protective work for 100 year flood discharge. The maximum scour depths and corresponding minimum scour levels obtained from different options are qualitative due to presence of scale effects in reproduction of scour holes.

The proposed bank protection works proposed by IWM and introduced along the left bank at their appropriate positions is found to be working well as noticed from the model study. However, still there are three places along the left bank where bank erosion may occur as revealed from the physical model investigation (Test T2, Option-1) in addition to the bank protection work proposed by IWM**.** The location of these erosion prone places is in the downstream of the existing protective works (Faluar Char Nouka Ghat), in the downstream of the protective work proposed by IWM at Rowmari Boat Ghat (Chaktabari, Jadurchar Union) and at Char Rajibpur (Char Velamari). Protection against bank erosion is also needed at these places. In Option-2, the flow velocity along the dredged channel in the beginning of the test varies from 0.42 ms^{-1} to 1.63 ms^{-1} and from 0.94 ms^{-1} to 2.04 ms^{-1} for 2.33yr and 100yr discharge respectively. With the passage of time flow velocity along the dredged channel is found to have decreased due to progressive filling up of the dredged channel. The upstream portion of dredged channel gets silted up earlier than the downstream portion. For the considered dredge plan and design under Option-2, the total volume of material to be dredged is 27217863 m^3. The likely volume of material that may get deposited in the dredged channel within a year for an extreme event (100 year discharge) is 12715570 m^3. The dredged channel is found to have gotten mostly silted up in the upstream part of the channel and the average percentage of filling up of the dredged channel is about 46.72% in one year. The average dredging area and dredging depth is 49,04,119 m^2 and 5.55 m respectively. The near bank velocity along the left bank of the river within the study reach is reduced to some extent due to the introduction of dredged channel. However, this positive effect of the dredging may diminish with time due to progressive filling up of the dredged channel. It appears from the model results that maintenance dredging is needed once in a year and may be carried out for two to three years following the capital dredging. If the proposed capital and maintenance dredging is accomplished it will ensure the stability of the bank protection works by reducing the flow attack near the left bank and thereby, reducing the near bank flow velocity. However, proposed dredging involves economic, management, availability of dredger, environmental and other issues to be considered for implementation. Monitoring of the developments in the dredged channel will be needed for taking decision as to maintenance dredging. Cross-section survey along the dredged channel at some preselected locations before dredging, after dredging and during post monsoon period is needed for this purpose.

For char stabilization, the length of the protective work around Dighla Para Char proposed by IWM is 21.654 km. The proposed protective work may come under high flow attack during flood period and consequently large scour hole may develop near the protection works. Char stabilization may be implemented following an adaptive approach i.e., systematic construction of the protective works together with monitoring and assessment of morphological developments allowing for improvement and optimization in the design of protective works. Char stabilization around Dighla Para Char under Option-3 (T4) will be helpful for massive land reclamation. However, this option involves cost, environmental and other issues and in the present physical model, a 26 km stretch of the Brahmaputra-Jamuna River covering part width has been reproduced. Therefore, morphological developments beyond the study reach under different discharge conditions remain unknown. Also, the rate of bank erosion varies spatially and temporarily and depends on several factors. The model is able to reproduce bank erosion qualitatively. Therefore, it is not possible to predict the rate of bank or char erosion quantitatively.

Recommendation

It is revealed from the examination of historical satellite images that over the last four decades the Brahmaputra River has shown an overall widening trend due to increase in the braiding intensity leading to widespread bank erosion in the project area and elsewhere. Due to left bank erosion of the Brahmaputra River in the project area numerous people have lost their homesteads and valuable lands. Many infrastructures are also swallowed up by the river. At present the widening trend of the Brahmaputra River is reversing. Therefore, emphasis should be put on reclamation of lost land in all river stabilization projects concerning the Brahmaputra River.

Interventions considered under Option-3 may be implemented in the field in order to meet the project objectives despite the fact that it entails massive construction and huge cost. The implementation of the proposed protective works should be adaptive. Monitoring and assessing the river behaviour in response to phased construction should form the basis for improving and optimizing the design of proposed protective works and there should be a concrete plan for beneficial use of the reclaimed land including resettlement of displaced people.

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