ANALYSIS OF MODELING RESULTS FOR RIVER BANK PROTECTION OF THE MOST VULNERABLE PART OF TAZUMUDDIN UPAZILA UNDER BHOLA DISTRICT

Md. Abdul Aziz [(1)], Rubayat Alam [(2)], Upal Mahamud [(3)], Zahirul Haque Khan [(4)]

Military Institute of Science and Technology [(1)]
Institute of Water Modeling [(2,3,4)]

ABSTRUCT :

Bhola is the largest Island of Bangladesh situated in the south central region (latitude approximately from 430000N to 525000N and longitude 555000E to 590000E) of Bangladesh in the highly dynamic Meghna Estuary. In recent years the erosion along eastern shoreline of Bhola Island has become a serious issue. Attempts are taken to establish the base line condition to simulate the natural phenomena. Baseline condition for Tazumuddin Upazilla (under Bhola district) has been developed based on hydrodynamic and morphological modelling and historical data of bank line shifting, thalweg line shifting, bathymetric data, char movement etc. To calibrate and validate the model water levels and discharge are successfully calibrated. From modeling result, erosion/deposition pattern at and outside the protective works, new vulnerable areas due to revetment have been identified. Hydrodynamic (HD) simulations during ebb tide the maximum depth integrated near bank velocity is found within the range of 1.5-3.0 m/s along the riverbank of Tazumuddin and 1.0-1.5 m/s along the riverbank of Lalmohan. Morphological simulation shows the channel is further extended towards the south-east part. Further computational simulation showed that channel in front of Tazumuddin become deeper and it is extended more towards the south-east direction. From bathymetry survey data in May, 05 it is found that there is a tendency to deepen the channel in front of Tazumuddin where protective work was suggested and the deep channel is further extended towards south-east direction like simulation result. So it can be concluded that simulation result and real condition near Tazumuddin follows the same trend of channel development.

Keywords: Embankment, bank line shifting, erosion deposition process, char movement

1. INTRODUCTION

Tazumuddin Upazilla is located on the eastern shoreline of Bhola island beside Shahbazpur Channel. Bhola island which is situated in the morphologically dynamic Meghna Estuary. The physical setting of the area has been changed remarkably over the last 200 years. Riverbank erosion and related sedimentation and land loss hazards are a resource management problem of global significance (Darby et al. 2000). Eventually the water related environment in the estuarine network is in the process of continuous changes. Currently the erosion along eastern shoreline of Bhola Island has become a serious issue in the recent years. In the year 2000 about 600 m land was eroded by the Shahbazpur channel during July to November within km 36 to km 71.425 of embankment and in 2001 about 400m of land was eroded at the same location during June to November. During the monsoon 2003, severe erosion occurred at Tazumuddin upazilla and several hundred meters of land were devoured in the river within a month.

Both bank erosion and morphological processes lie at the center of understanding fluvial geomorphological processes (Lawler 2005). To explain river channel processes with bank erosion, several fundamental studies have been conducted over the past several decades including the bend theory proposed by Ikeda et al. (1981) and Parker et al. (1982) that gives useful criteria for bend development and a method to predict temporal changes in the plan form of meandering channels. Blondeaux and Seminara (1985) modified the bend theory and derived a solution for the bed configuration of a bend in an equilibrium state. Their solution corresponds to the approximate solution proposed by Hsegawa and Yamaoka (1980), and re calculated by Parker and Johannessor (1989). However, these theories assumed constant width and a simple bank erosion model they cannot be applied to process in channels with various plan forms.

Bank erosion is the most significant and fundamental processes involved in channel migration and formation of flood plains (Hooke 1979). Most important mechanism is the hydraulic forces exerted by the flow (Hardy 2006). The erosion processes in the Meghna Estuary is mostly related to bank failure. Crosta and di Prisco (1999) found seepage erosion causing liquefaction and rapid slope failures by analyzing field failure process and the evolution of the saturated domain using a numerical model. In the present study two types of bank failure generally observed: liquefaction and flowage of material, shearing away of bank materials. The former type of bank failure occurs below the low water level or in the zone of low and high water level. Generally, they occur during the

recession of flood hydrograph. Recession rates of water level directly influence the rate of failure. The most common processes of bank failure along the Lower Meghna Estuary is due to shearing, caused by flow attacking the bank or over-steepening of the bank by a thalweg approaching the bank. In that case the flow in a river bend attacks the toe of the riverbank, removing the sediment from the toe, resulting in an over-steepening of the riverbank and causing the bank failure by slumping. Seepage effects are usually considered limited in the existing literature (Burgi and Kraki 1971). The impact of seepage erosion has not been widely reported or understood despite occurrence of seepage erosion in numerous geographical locations (Hagerty 1991; Wilson et al. 2007; Fox et al. 2007). An important factor of erosion is the near bank flow pattern, which is determined by the flow and the channel geometry. Rockwell (2002) found the greatest weakness to understand of bank failure mechanism both seepage and soil water pressure studies has been the lack of direct, local, and precise instrumentation. Quantitative data are not available at the point of erosion. This limitation could basically conduct field studies during wet periods when seepage is active (Huang and Laften 1996; Wilson et al. 2007). Figure 1 shows the studied area where data are collected for water level and discharge measurement.

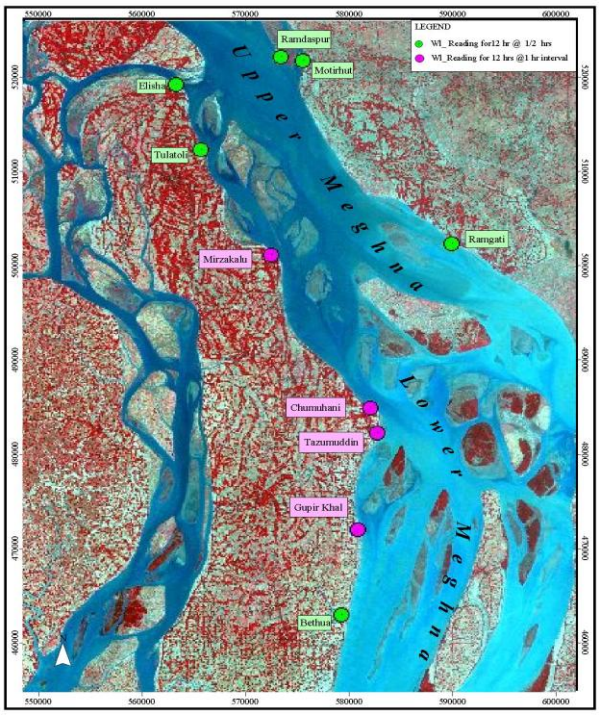

Figure 1: The project area

The objective of the study is to carry out hydraulic investigations using mathematical modelling and survey techniques in order to evaluate the performances of under constructed and completed bank protection works. This study would address the following issues:

- Understanding of the erosion/deposition processes during monsoon 2005;
- Development of baseline bathymetry;
- Identification of probable erosion prone areas from model simulation

2. BACKGROUND

Several studies had been carried out with respect to river morphology, sediment transport, river erosion carried out on Bhola and around Meghna Estuary. Problem of riverbank erosion also reported on Muramoto and Fujita (1992), Mosselman et al. (1995) and Tingsanchali and Chinnarasri (1997). Moreover existing literature on river bank erosioin in different parts of the world were also reviewed. Regarding bank movement simulation, Mosselman (1998), Nagata et al.(2000), Duan et al. (2001), and Darby et al. (2002) bank erosion models using coupled physical based with two-dimensional, depth-averaged models of flow and bed topography was considered. Due to computational complicacy imperial approach was selected in the present study.

Report of the National Committee on Erosion of Bhola (April, 1988) consider emergence of the Shabazpur channel as the main carrying channel of the fluvial flows brought by the Ganges-Brahmaputra-Meghna river system; large accretion of land in the area south of Noakhali mainland; formation and movement of chars in the river and changes in tidal characteristics of the Shabazpur channel. Regarding protective measure by constructing of spurs or groynes found in the Meghna Estuary Study (MES), (March 1999), the permeable spurs or groynes consisting of one or several rows of piles are considered perpendicular to the riverbank. Conventionally, these piles are to be driven into the riverbed with water borne equipment. To find the long term hydrodynamic and morphology of the project area it was found in Meghna Estuary Study, Technical Note MES-022, (September 1998) describe the long-term hydraulic and morphological processes in the Meghna Estuary can be stirred by gravitational circulation due to salinity gradients in the pre-and post-monsoon period. Moreover Meghna Estuary Study, Technical Note MES-001, (Tidal Volume and Sediment Transport Patterns, June 1997) explain the study determined the tidal flow characteristics and sediment transport patterns

during spring and neap tide conditions in the Lower Meghna Estuary that prevailed during Land Reclamation Project (LRP) period. In particular a tendency of higher sediment concentration during spring tides was observed. Maximum sediment concentration of 9.74 gm/l at 0.5 m above channel bed during spring tide was recorded at the north of Urir Char. At West Shabazpur Channel the concentration is found between 1.3 gm/l and 2.2 gm/l. Furthermore Meghna Estuary Study (MES II), Hydro-Morphological Dynamics of the Meghna Estuary, (June 2001 report) analysis hydro-morphological environment of the Meghna Estuary by dividing into three zones where separate driving forces could be distinguished. Morphological processes involved in three zones were described as Marine-dominated, Mixed-dominated, or River-dominated. Energy conditions governing the erosion sedimentation processes differ significantly from those in the dry season. Compression of the Mixed-energy zone results in a situation where the energy dissipation takes place in a smaller area, resulting in higher energy conditions, which lessen the change in permanent sedimentation. In other reports observing the wave characteristics including Hydraulic Modelling Study, Second Coastal Embankment Rehabilitation Project, (SWMC May 2002) suggest to measure wave in the coastal area, especially in the eastern coast where wave height is significant. In addition to this technical feasibility Study with Hydraulic Modeling for Riverbank Protection Project at Tajumuddin of Bhola District reported to select probable area of erosion, location and alignment of the riverbank protection, evaluation of suitable options for riverbank protection, impact on erosion deposition, preliminary design and cost estimation. Some of the major technical recommendations to improve of erosion mitigation measures were considered for detail analysis and design they are bank revetment, submergible solid spur (Geo Bag), permeable spur (R.C.C Pile) and Closure at Tazumuddin. Considering cost and construction difficulties in deep channel and high flow velocities, revetment option were found suitable for erosion management. From the existing literature it was found that the huge dynamic loading in the research area require frequent analysis of the hydrodynamic and morphological characteristics. Therefore an extensive study had been carried in the project area.

3. APPROACH AND METHODOLOGY

One of the key importances to formulate the methodology in the project is to establish baseline bathymetry. In order to assess the performances of newly constructed and completed bank protection works at Tazumuddin Upazila, baseline condition is essential to compare the scenario with and without protective works. Baseline condition for Tazumuddin area has been developed based on hydrodynamic and morphological modelling and historical data of bank line shifting, thalweg line shifting, bathymetric data, char movement etc. Under the hydrodynamic and morphological modelling, the advanced two dimensional curvilinear grid models for Tazumuddin have been developed. The boundaries of this model have been generated from 2D rectangular Bay of Bengal (Bob) model. To establish hydrodynamic baseline condition simulations have been carried out for one month covering neap and spring tide during monsoon 2004 (1-15 August 2004). From hydrodynamic model result velocity field during spring and neap tide, flow pattern, maximum tidal range, tidal level variation, discharge distribution without protective works have been obtained. For morphological base line condition, morphological simulation has been carried out from April, 2004 to November 2004 in order to identify erosion/deposition pattern, maximum erosion and deposition, erosion prone area etc. Moreover bank line shifting and char movement during the period 1996-2006 has been analyzed from historical satellite images and bank line survey.

The model simulation results successfully reproduce water level and discharge at the model domain. Water level calibration of the model is done at Tazumuddin, Daulatkhan where as discharge calibration is done at Mirzakalu and Hatia (calibration of discharge at Mirzalu is shown in the figure 2).

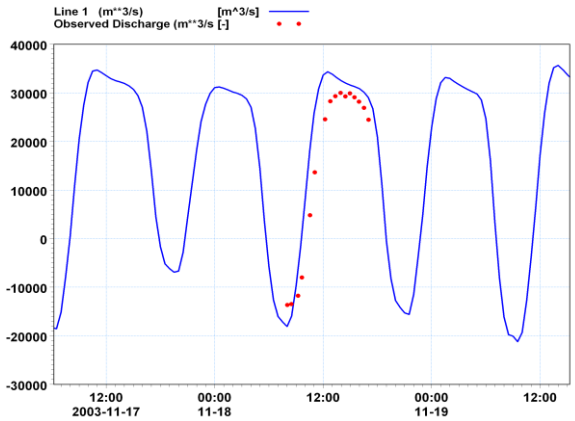

Figure 2: Observed and Simulated Discharge at Mirjakalu in November, 05

4. RESULT AND DISCUSSION

The results had been analyzed in two major catagories of hydrodynamic and morpholigical simulation. Moreover analysis from survey data and satellite image analysis has also been incorporate in the project area. Hydrodynamic (HD) simulations, water level and discharge data analysis have been carried out to determine baseline condition during monsoon 2004 (26 July-25 August). Figure 3 shows the velocity field and speed contour at Shahbazpur channel during spring ebb tide of monsoon 2004 (on 01/08/2004 13:00:00). At this time the maximum depth integrated near bank velocity is found within the range of 1.5-3.0 m/s along the riverbank of Tazumuddin and 1.0-1.5 m/s along the riverbank of Lalmohan. The figure also shows the water level near Tazumuddin varies within 0.20 m PWD to 2.95 mPWD. Maximum tidal range is found about 2.9 m during monsoon spring tide and minimum tidal range is found about 1.00 m during neap tide.

Figure 3 shows the discharge into the west Shabazpur channel (infront of Tajumuddin) and East Shabazpur channel. During the one month simulation period the model results shows that about 60% of the Lower Meghna river flow passes through the channel in front of Tajumuddin (in the West Shahbazpur channel) and a significant part of the flow hits Daulatkhan-Tajumuddin bank line at an angle about 45° during ebb tide, which is causing severe erosion at Tazumuddin.

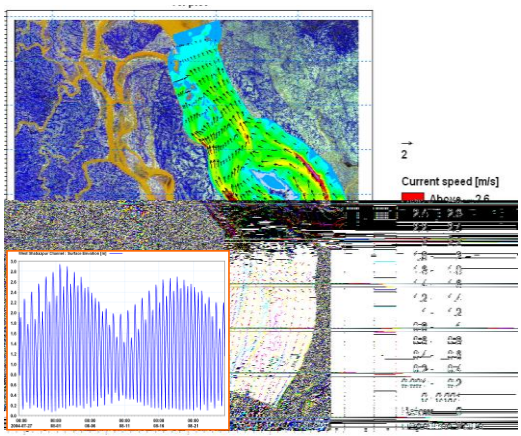

Figure 3: Velocity contour during spring tide ebb in monsoon 2004 and WL near Tajumuddin in Shabazpur channel.

The complex flow pattern during turning of spring flood tide to Ebb Tide is shown in Figure 4. At that moment in the East Shabazpur channel near Char Gazaria the flow direction is upward but in the West Shabazpur channel it is downward.

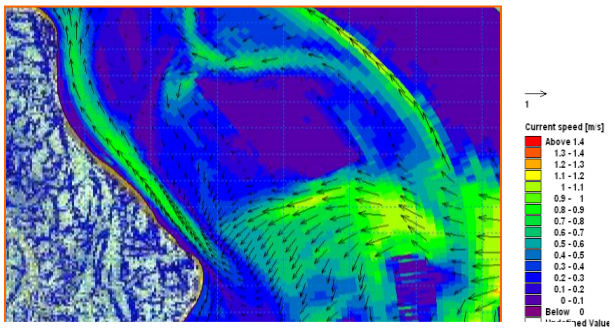

Figure 4: Flow pattern during the turning of Flood tide to Ebb tide

The baseline condition is established to have a clear idea about the erosion-deposition trend near the project area. To achieve this, the base bathymetry was developed based on cross-section data of December 2003 and Meghna Estuary study survey. The base bathymetry of the whole model domain is shown in the Figure 4 (left). Morphological simulation was done from April, 04 to Nov, 04 to find the morphological behavior of the estuary before construction of the protective work. The new bathymetry developed after 8 months simulation is presented in the middle of the Figure 4. Bathymetry survey was carried out during May, 05 near Tazumuddin adjacent to the protective work with fine resolution to increase computational accuracy and near the protective work with coarse resolution to reduce the computational time in order to monitor the critical location before and after applying the protective work. The base bathymetry was further updated with May, 05 bathymetry survey data. Bathymetry with 2005 may survey data is presented at the right side of the Figure 5.

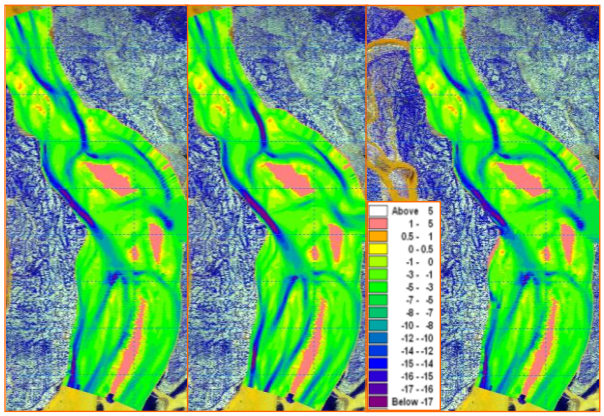

Figure 5: Shows model domain in the Figure 5 (left). The middle bathymetry is the new bathymetry Bathymetry with 2005 May survey data is presented at the right side.

From base bathymetry it is found that there is deep channel from Daulatkhan to Tazumuddin. The depth of the channel is more than 10 meter. The channel is further extended towards the south-east part. After the simulation it has been concluded that channel in front of Tazumuddin become deeper and it is extended more towards the south-east direction. From bathymetry survey data in May, 05 it is found that there is a tendency to deepen the channel in front of Tazumuddin where protective work was suggested and the deep channel is further extended towards South-East direction like that of the simulation result. So it can be concluded that simulation result and real condition near Tazumuddin follows the same trend of channel development i.e. bathymetry change.

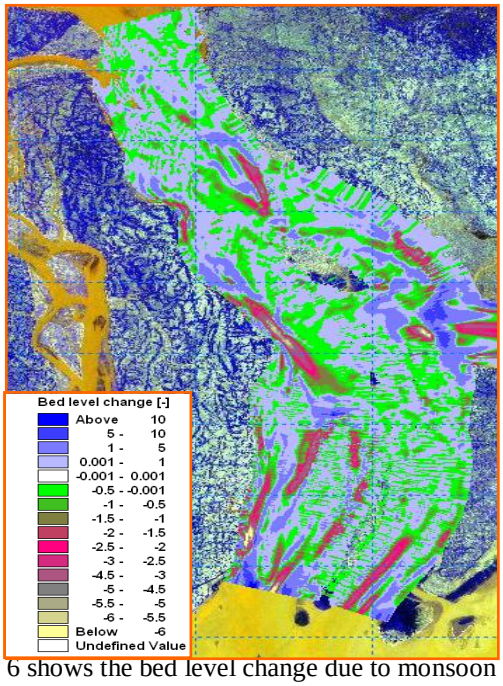

Figure 6 shows the bed level change due to monsoon 2004.

From the computation result it is found that erosion-deposition has been occurred almost every part of the estuary. Most of the part, the deposition varies from 0.001m to -1.00m and erosion (scouring) is 0.001-0.50 m. Significant scouring is found along the riverbank near Tazumuddin and Daulatkhan. Also significant scouring is found along the riverbank at Char Fasson and some portion of Lalmohon. Near Tazumoddin, scouring varies from 0.50 m -6 m and near Daulatkhan it varies from 0. 05 m -4 m. Comparing the deep channel near bank line, erosion prone area near Daulatkhan is less compare to Daulatkhan. Also high scouring is observed near Char Fassion.

Bank line shifting and char movement during the period 1996-2004 are presented in Figure 6.4. It can be visualised from the figure that the widening and the development of char in front of Tajumuddin and Lalmohan causing increase of bank erosion at these locations.

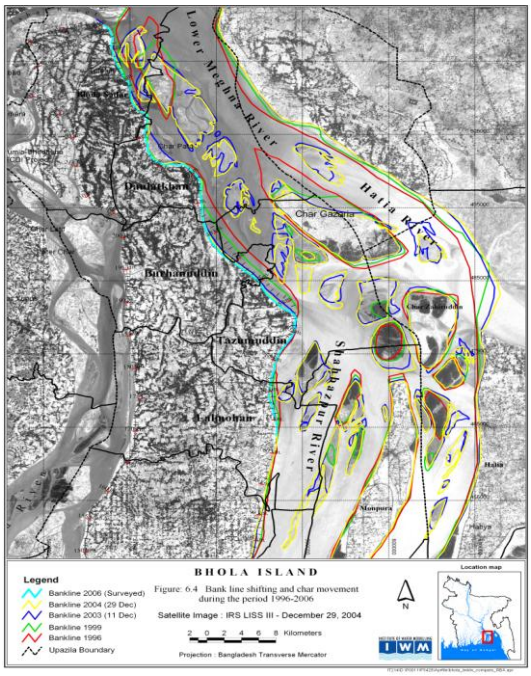

Figure 7 shows the location of thalweg line in May, July and December 2005 and the bankline of January 2006. This Figure also shows the location and amount of completed and proposed protective work.

Thalweg line is the movement of the deepest point on the project area. Figure 7 shows the movement of the thalweg line during May (pre-monsoon), June (monsoon) and December (post monsoon) 05. Also bathymetry survey was carried out along 30 km river surrounding the protective work to have a clear idea about the scour development and thalweg shifting with and without protective work. From the survey data, thalweg line movement in different period in front of the revetment and other location was identified. Figure 8 shows the thalweg line movement in front of the protective work. From the Figure it can be concluded that generally thalweg line is far in May and is closer in December from the bankline 2006. Although some different trend observe at some location where thalweg line is not shifted significantly or behave opposite.

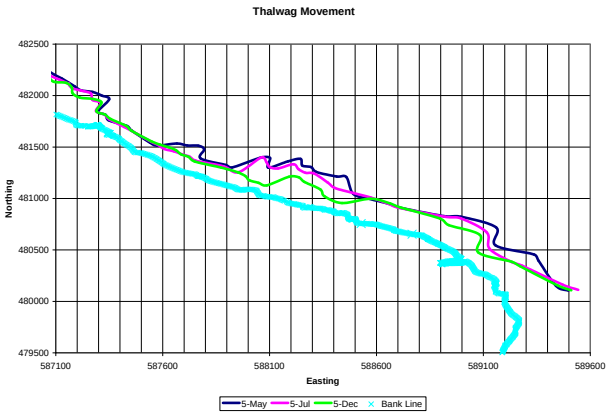

Figure 8: Movement of the thalweg line before, during and after monsoon 2005.

From the cross-section data it has been found that there is no significant change of the river bank slope here during this period (May, 05 to December05). But scour depth is changed significantly. In May average scour depth is 18 m and maximum scour depth is 19.45m. In July these are 18.8 m and 20.18m. In December, the scour depth is maximum. The average scour depth is about 26 m and maximum scour depth is 30.69 m.

The morphological pattern in the shahbazpur channel is very complicated due to char movement, very mobile river bed and tidal characteristics of the river. To analyze the morphological pattern especially after construction of the revetment, three different simulated results have been analyzed. For this simulation was carried out without revetment from April, 04 to Nov, 04, with revetment from May, 05 to October, 05 and an extreme event, 1:100 flood event, (May, 98 to Nov, 98) .

After simulation monsoon 2004 without revetment it has been observed that long deep channel has developed near Tazumuddin (middle part of the Figure 4) and the deep channel is very close to bank and from Figure 3 it has been found that high velocity attacked the river bank of Tazumuddin at an acute angle. So bank might subjected to severe erosion without revetment works. Due to revetment works in Tazumuddin thalweg line came closer to the bank adjacent to the revetment work followed by deposition but the bank line is fixed.

This model result can be successfully reproduced the morphological pattern around the revetment. From the post monsoon survey data (December 2005), it is found that immediate after the revetment work, scouring occurred near the riverbank but just after the scouring deposition is found. From the model result it is also observed the same pattern of erosion followed by deposition in the river bed.

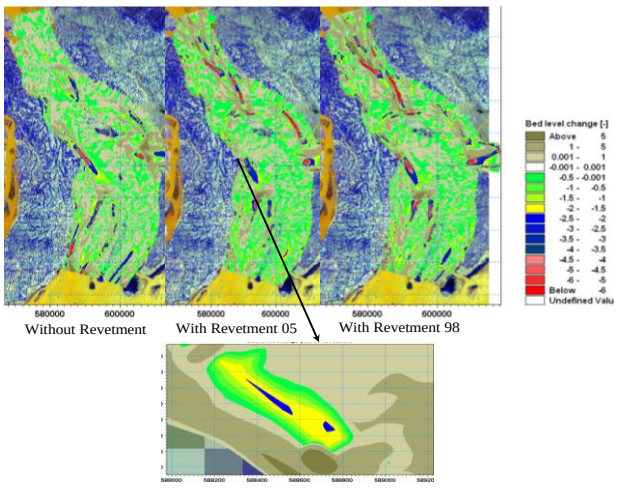

Figure 9: Model result shows the erosion deposition pattern in the project area

Survey transect just after the revetment works and simulation result followed the same trend of erosion-deposition pattern. This is shown in the Figure 10 below:

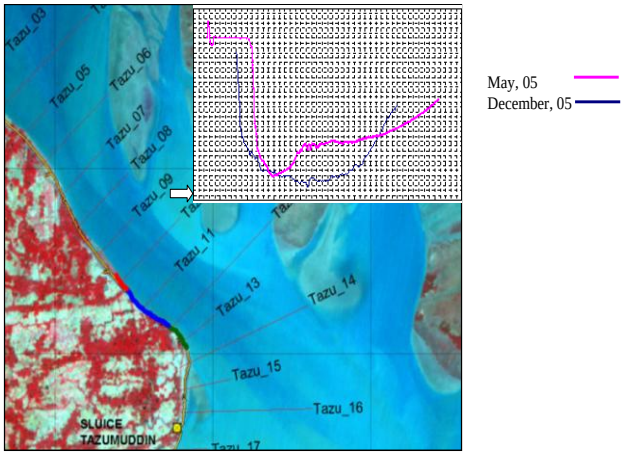

Figure 10: Shows comparison of cross section before and after monsoon.

Due to flow deflected from the revetment (predicted on the study "Technical Feasibility study with Hydraulic Modelling for Riverbank Protections Project at Tazumuddin of Bhola District") and highly mobile up stream flow deep channel is formed little downstream of the revetment work. Although erosion trend is increased on the upstream of the revetment but severe erosion is not observed near upstream of the revetment work. Furthermore severe erosion trend is observed on the upstream of Char Gazaria, which may took place due to char movement and hydro morphological changes in the river though such changes may not cause much threat to river bank erosion. In the extreme flood condition most of the morphological changing pattern matches with revetment 2005 condition but the erosion trend is prolonged due to huge upstream flow.

In the present study, direct bank line survey and satellite image analysis have been applied to identify bank line migration of Shabazpur channel. In order to find the trend of erosion, annual erosion rate and bank line shifting characteristics of the river time series satellite imageries from 1996 to 2004 and bank line survey data 2003 and 2006 were analyzed. The images were digitized to make boundary between land and water. The erosion/accretion of different years was determined at certain interval. It is mentionable that the shifting of riverbank line was measured perpendicular to the riverbank line of the reference year, the bank line of the year 1996

is considered as the reference bank line. The riverbank line shifting is shown in Figure 9. However, the erosion rate in the recent year is quite significant and a large area of land has already been eroded. From the previous study it has been observed that Shahbajpur Channel shifted about 2 km into Bhola island over the last 10 years. The erosion during the last two monsoons (2003 and 2004) is about 600m along the right bank of Shahbazpur channel at Burhanuddin Upazila.

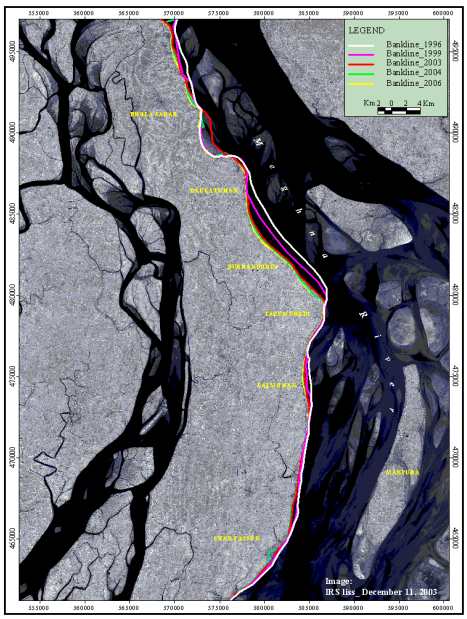

Figure 11 shows bank line shifting in the project area

From the recent Bank line survey data and Satellite images analysis it is found that from 2003 erosion tendency is observed from Tazumuddin to Daulatkhan maximum bank erosion from 2003-2006 is 370 m and from 2004-2006 is 330m near Tazumuddin. So it can be concluded that maximum recent erosion rate near Tazumiddin is about 124 m per year. No significant erosion found near Lalmohan. But erosion trend was found further downstream. From the bankline survey data January 2006 it is observed bankline adjacent to the revetment is fixed but immediate after the revetment bank line is eroded. From satellite images analysis from 1973 and from other analysis it has been found that North-Eastern shoreline of Bhola Island has been changed a lot due to the riverbank erosion since 1973. Shahbazpur Channel has 19 km bank line (Km 49 to Km 68) in Tazumuddin upazila and another 19 km bank line (Km 68 to Km 87) in Lalmohan upazila. Bank lines of 1973, 1979, 1984, 1990, 1996, 2002, 2003 and 2004 have been analyzed and found that the bank line is shifted about 5.4 km at Km 51 of BWDB embankment in Tazumuddin Upazila and retreated about 1.5 km at Km 74 in Lalmohan Upazila during the period of 1973 to 2004 i.e. within 31years. Analysis of time series satellite imageries from 1973 to 2002 shows that more than 130 km^2 land has been eroded along the north-eastern shoreline of Bhola Island (right bank of the Shahbazpur channel) from Ilisha ghat to Tazumuddin with an annual average erosion rate of 90m .

5. CONCLUSION

Hydraulic modelling study for the vulnerable location at Tozimuddin upazilla had been carried out for the assessment of impact of 1 in 100 years flood on surrounding water environment and identification of probable vulnerable location were identified. The study is based on the data and mathematical model. The model simulates the tide, current speed, and accretion/deposition. The model is calibrated and validated against measured water level and discharge both for dry and monsoon season. Both physical and environmental monitoring programme, during and after construction of embankment is suggested for the design of corrective measures through adaptive approach.

References:

1. Darby, S.E., Gessler, D., and Thorne, C.R. (2000). “Computer program for stability of steep cohesive riverbanks.” Earth Surf. Processes Landforms, 25, 175-190.

2. Lawler, D. (2005). “The importance of high-resolution monitoring in erosin and deposition dynamics studies: Examples from estuarine and fluvial systems.” Geomorphology, 64, 1-23.

3. Ikeda, S., Parker, G., and Sawai, K. (1981). “Bend theory of river meanders: Part I: Linear development.” J. Fluid Mech., 112, 363-377

4. Parker, G., Sawai, K., and Ikeda, S. (1982). “Bend theory of river meanders, Part II: Nonlinear deformation of finite-amplitude bends.” J.Fluid Mech., 115, 303-314.

5. Blondeaux, P., and Seminara, G. (1985). “A unified bar-bend theory of rivermeanders.” J. Fluid Mech., Cambridge, U.K., 157, 449-470.

6. Hasegawa, K., and Yamaoka, I. (1980). “The effect of plane and bedforms of channels upon the mender development.” Proc.JSCE, TOKYO,296, 143-152.

7. Johannesson, H., and Parker, G. (1989). “Velocity redistribution in me andering rivers.” J. Hydraul. Eng., 115(8), 1019-1039.

8. Hooke, J. M. (1979). “An analysis of the processes of river bank erosion.” J. Hydrol., 42, 39-62.

9. Hardy, R. J. (2006). “ Fluvial geomorphology.”

Prog. Phys. Geogr., 30(4), 553-567.

10. Crosta, G., and di Prisco, C. (1999). "On slope instability induced by seepage erosion." Can. Geotech. J., 36, 1056-1073.

11. Burgi, P.H., and Karaki, S. (1971). "Seepage effect on channel bank stability." J. Irrig. and Drain. Div., 97, 59-72.

12. Hagerty, D. J. (1991a). "Piping/sapping erosion. I: Basic considerations." J. Hydraul. Eng., 117(8), 991-1008.

13. Wilson, G. V., Periketi, R. K., Fox, G. A., Cullum, R. F., and Shields, F. D. (2007). "Seepage erosion and properties contributing to streambank failure." Earth Surf. Processes Landforms, in press.

14. Fox, G. A., Wilson, G. V., Simon, A., Langendoen, E., Akay, O., and Fuchs, J.W. (2007). " Measuring streambank erosion due to ground water seepage: Correlation to bank pore water pressure, precipitation, and stream stage." Earth Surf. Processes Landforms, 32(10), 1558-1573.

15. Rockwell, D. L., (2002). "The influence of groundwater on surface flow erosion processes." Earth Surf. Processes Landforms, 27(5), 495-514.

16. Huang, C., and Laflen, J. M. (1996). "Seepage and soil erosion for a clay loam soil." Soil Sci. Soc. Am. J., 60(2), 408-416.

17. Wilson, G. V., Periketi, R. K., Fox, G. A., Dabney, S. M., Shields, F. D.,and Cullum, R. F. (2007). "Seepage erosion properties contributingto streambank failure." Earth Surf. Processes Landforms, 32(3), 447-459.

18. Muramoto, Y., and Fujita, Y. (1992). "Recent channel processes of the major rivers in Bangladesh." Annuals of the Diaster Prevention Res. Inst., Kyoto Univ., Kyoto, Japan, 35 B-2, 89-114 (in Japanese).

19. Mosselman, E., Huisink, M., Koomen, E., and Seijmonsbergen, A. C.(1995). " Morphological changes in a large braided sand-bed river." River Geomorphology, E. J. Hickin, ed., Wiley, Chichester, U.K., 235-247.

20. Tingsanchali, T., and Chinnarasri, C. (1997). "Desing of Mekong river bank protection." Proc., Conf. on Mgmt. of Landscapes Disturbed by Channel Incision, University of Mississippi, Miss., 345-348.

21. Mosselman, E. (1998). "Morphological modeling of rivers with erodible banks." Hydrolog. Process., 12, 1357-1370.

22. Nagata, N., Hosoda, T., and Muramoto, Y. (2000). "Numerical analysis of river channel processes with bank erosion." J. Hydraul. Eng., 126(4), 243-252.

23. Duan, J. G., Wang, S. S. Y., and Jia, Y. (2001). "The applications of the enhanced CCHE2D model to study the alluvial channel migration processes." J. Hydraul. Res., 39, 469-480.

24. Darby, S.E., Alabyan, A. M., and Van de Wiel, M. J. (2002). " Numerical simulation of bank erosion and channel migration in meandering rivers." Water Resour. Res., 38(9), 2-1-2-12.

25. Report of the National Committee on Erosion of Bhola, Ministry of Irrigation, Water Development and Flood Control, April 6, 1988

26. Meghna Estuary Study, Draft Development Plan, Volume 6, Reconnaissance Studies Erosion Control, March 1999, DHV Consultants BV in association with Kampsax International, Danish Hydraulic Institute, Development Design Consultants, Surface Water Modelling Centre, Aqua Consultants and Associates Ltd.

27. Meghna Estuary Study, Technical Note MES-022, Gravitational Circulation Shahbazpur Main Channel, September 1998, DHV Consultants BV in association with Kampsax International, Danish Hydraulic Institute, Development Design Consultants, Surface Water Modelling Centre, Aqua Consultants and Associates Ltd.

28. Meghna Estuary Study, Technical Note MES-001, Tidal Volume and Sediment Transport Patterns, June 1997, DHV Consultants BV in association with Kampsax International, Danish Hydraulic Institute, Development Design Consultants, Surface Water Modelling Centre, Aqua Consultants and Associates Ltd.

29. Meghna Estuary Study (MES II), Hydro-Morphological Dynamics of the Meghna Estuary, BoB-MoWR, GoN-DGIS, June 2001, DHV Consultants BV in association with Devconsultants Ltd. and Surface Water Modelling Centre.

30. Hydraulic Modelling Study, Second Coastal Embankment Rehabilitation Project, SWMC May 2002.

31. Technical Feasibility Study with Hydraulic Modeling for Riverbank Protection Project at Tajumuddin of Bhola District.

32. Technical Feasibility Study with Hydraulic Modeling for Meghna-Tentulia River Bank Protection Project