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NUMERICAL MODELLING IN ASSESSING IMPACT OF BANK PROTECTIVE WORKS AT UPSTREAM ON SILTATION IMPROVEMENT AT DOWNSTREAM

Masum Ur Rahman[1] and Sarwat Jahan[2]

[1] Junior Specialist, Institute of Water Modelling, House 496, Road 32, New DOHS, Mohakhali, Dhaka, Bangladesh,
E-mail: mur@iwmbd.org

[2] Senior Specialist, Institute of Water Modelling, House 496, Road 32, New DOHS, Mohakhali, Dhaka, Bangladesh,
E-mail: srj@iwmbd.org

ABSTRACT

Bank protective works, in general, lead depending of the river, near the structure as well as within the mid section. Such deepening is mainly due to constriction provided by the bank protective works along the bank. In response to changes in water and sediment discharges at upstream, the river morphology at downstream adjusts in order to establish dynamic equilibrium. The time scale for such adjustment varies depending on the existing hydro-morphological condition of the river. This paper is an attempt to reveal investigation of the physical process involved for such response of the Jamuna River near Hurasagar outfall. Upstream of Hurasagar is exhibiting bank erosion and on the contrary, right bank channel immediate downstream of the outfall is experiencing siltation. Relentless siltation ultimately causes hindrances to free movement of the water based transport system hampering overall navigability within this area. Applying numerical modelling technique, investigation is carried out to envisage the improvement of siltation problem at downstream adopting a bank protection works at upstream. Reflection of upstream bank protection works on river morphology are analyzed with the application of advanced two-dimensional mathematical modeling tool, MIKE21C developed by DHI Water and Environment, Denmark.

Key words: Siltation, Navigation, Numerical modelling, Two-dimensional modelling, bank erosion, bank protective works, erosion, deposition.

1. INTRODUCTION

Bangladesh is blessed with numerous rivers, which are characterized by unpredictability in their behavior. Every year many of the rivers pose different shape, follow different path showing their swinging nature. Building up of sediments, i.e. sedimentation, along the river bed may cause instability in channel morphology and this instability includes impedance of flow and increasing intensity of inundation. Additionally, reduction of conveyance area causes inadequacy of navigability hampering easy transportation through waterway. Sedimentation not only affects human life but also fish, plants, and other wildlife. Rivers provide humans with many valuable uses. They provide drinking water, water for crops, a source of power, transportation, fish and wildlife, and recreation. The disruption that sedimentation causes prevents us from utilizing these resources to their full potential. Although sedimentation is a natural occurrence, it can be exacerbated by mankind through activities such as those involved with construction.

For the last few years, sequential deposition at the bed level of the right anabranch of the Jamuna at Koitola had been observed. Such relentless deposition from year to year poses threat to navigation around this area and subsequently, the conveyance capacity of this channel is reducing which in turn increases possibility of spilling over the flood plain. On the contrary, bank erosion at upstream of the Hurasagar near Kaijuri bazaar to Binotia Bazar poses serious threat and in the last few years, the rate is several hundred meter per year. Observing the propagation rate, changing critical channel pattern and its adverse consequences, Jamuna Meghna River Erosion Mitigation Program (JMREMP) formulated a study for investigation. Necessity of the River bank protective works at upstream, its required extent, and its impact at further downstream, i.e. in improving the siltation at downstream of Hurasagar outfall, has been investigated by Institute of Water Modelling (IWM) under the study framework. The recommendation comes from the study are to protect the erosion affected area from Kaijuri Bazar to Binotia Bazar, which in addition to protecting bank, likely to improve the downstream siltation problem.

This paper is an attempt to present the role of bank protection works at upstream in improving siltation at downstream. Reflection of upstream bank protection works on river morphology has been analyzed with the application of advanced two-dimensional (2-D) mathematical modeling tool, MIKE21C, developed by DHI Water and Environment, Denmark.

2. STUDY AREA

The study area covers 45 km long reach of the Jamuna River near the outfall of the Hurasagar. The upstream boundary of the study area is at 12 km away from the Bangabandhu Bridge and the downstream boundary is at 11.8 km away from the Jamuna-Ganges-Padma confluence. Though the area of interest is around the outfall of the Hurasagar but 45 km long coverage has been considered since the morphology of any local area is governed by the upstream morphology. Study area is shown in Figure 1.

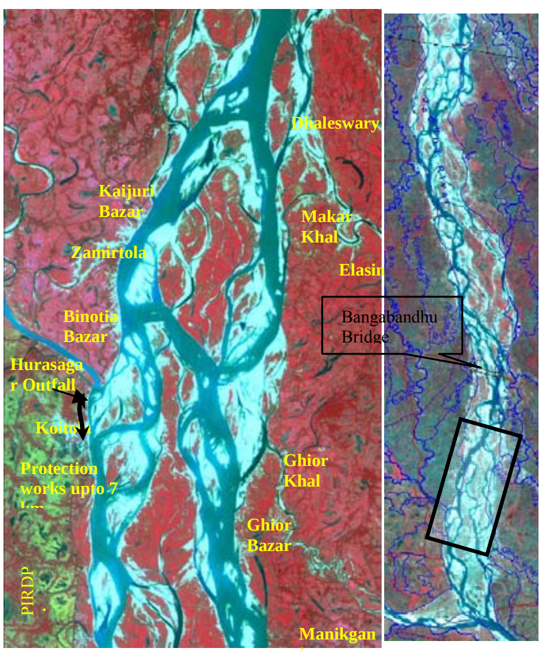

Figure 1: Study area of the Jamuna River under investigation

2.1 Characteristics of the Jamuna River

The Jamuna River is one of the world's large rivers, ranking in the top three in terms of both sediment and water discharge. The river is in fact a multi-channel one, i.e. channels of many different sizes, from hundreds of meters to kilometers wide, and of different patterns including braiding, meandering and anastomosing pattern. Numerous alluvial chars, permanent and moving, are the characteristics of the river. The formation and removal/migration of the chars during monsoon controls the erosion of bed and banks. The characteristics of the Jamuna River are summarized in Table 1 (Source: RSP FAP24, 1996).

Table 1: Summary characteristics of the Jamuna River

Description	Parameter
Length in Bangladesh	240 km
Average bankful width	11 km
Discharge	1950 ~ 102,535 m^3/s
Average discharge	20,400 m^3/s
Bankful discharge	48,000 m^3/s
Dominant discharge	38,000 m^3/s
Braiding index	4 – 6
Water surface slope	8.5 – 6.0 cm/km
Grain diameter (d_{50})	0.2 – 0.14 mm
Average yearly sediment transport	600 Million tons
Average yearly coarse suspended sediment transport	200 Million tons
Maximum erosion rate	100 to 400 m/year
Minimum erosion rate	30-40 m/year

Basic issues, which are responsible for dynamic changes of the Jamuna, are variability in hydrological factors, sediment load/morphological variability, soil characteristics of the bank and bed, and man-made structures. Past studies (BRTS, FAP, and CEGIS) indicate that the Jamuna is in the stage of dynamic equilibrium but any abrupt hydraulic condition might change the whole system even within one season. Whenever there is any abrupt change like a major flood (1998 or 1988 flood) or construction of any massive man-made structure within its regime takes place, or earthquake, the Jamuna again tries to adjust itself but changing its domain. Such adaptation for the Jamuna might take from several years to centuries and ultimately result in changing its properties like shifting of bank line, channel alignment, bed topography, etc.

3. APPROACH AND METHODOLOGY

In order to analyze the baseline hydrodynamic and morphological conditions in the vicinity of the PIRDP area and investigate the erosion deposition mechanism of the Jamuna River around PIRDP area for the proper maintenance of the navigational route, a two-dimensional (2-D) morphological model has been developed using MIKE21C modelling tool.

Prior to the mathematical modelling exercise, data analysis have been done extensively to understand the hydraulic process related to the erosion-deposition at Kaijuri bazaar and Koitola, respectively. The outputs from such analysis have not only formed the basis of understanding but also enhanced the confidence to interpret the model generated outputs.

The core of the mathematical morphological modelling study is the application of the MIKE21C modelling system, which is an advanced two-dimensional mathematical modelling technology for simulation of unsteady flow, sediment transport, and morphology. A morphological model is a combined hydrodynamic and sediment transport model. The hydrodynamic flow field is updated continuously according to changes in bed bathymetry. The solution of hydrodynamics is solved at a certain time step prior to solution of the sediment transport equations. Subsequently, a new bed level is computed and the hydrodynamic model proceeds with the next time step. Other sub-models such as bank erosion, bank line update, alluvial bed resistance, bed forms, and graded sediment are also included in the simulation.

The equation solved in the curvilinear hydrodynamic model is:

$$\frac{\partial H}{\partial t}+\frac{\partial p}{\partial s}+\frac{\partial q}{\partial n}-\frac{q}{R_s}+\frac{p}{R_n}=0 \quad (1)$$

where,

s, n — Coordinates in the curvilinear coordinate system

p, q — Mass fluxes in the s- and n-direction, respectively

H — Water level

R_s, R_n — Radius of curvature of s- and n-line, respectively

The transport of bed material and the bed level change are computed from the following sediment continuity equation:

$$(1-n).\frac{\delta z}{\delta t}+\frac{\delta S_x}{\delta x}+\frac{\delta S_y}{\delta y}=\Delta S_e \quad (2)$$

where,

S_x — total sediment transport in x-direction

S_y — total sediment transport in y-direction

n — porosity

z — bed level

t — time

(x,y) — Cartesian coordinate system

ΔS_e — lateral sediment supply from bank erosion

The sediment transport model can include bank erosion in the continuity equation:

$$E_b=-\alpha.\frac{\partial z}{\partial t}+\beta.\frac{S}{h}+\gamma \quad (3)$$

where,

Eb — Bank erosion in m/s

z — local bed level

S — near bank sediment transport

h — local water depth

α,β,γ — calibration coefficients specified in the model

4. MODEL DEVELOPMENT AND SIMULATION

The 2-D mathematical morphological model has been developed and calibrated based on field survey and secondary data. The computational grid is developed with surveyed banklines as well as banklines digitized from recent satellite image of the study area. The bathymetry of the model is developed with data corresponding to September 2007 and May 2008.

Computational grid of the two-dimensional model and initial bathymetry for the study area covering 50km stretch of the Jamuna River has been shown in Figure 2. Grid of the model has 134310 computational grid cells where the grid resolution is 363 along the river length and 370 across the river width.

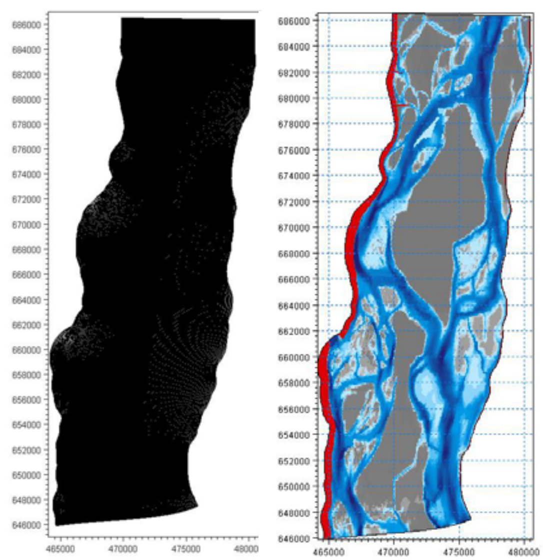

Figure 2: Curvilinear Grid and initial bathymetry

The developed model has been calibrated for 2007 monsoon. Figure 3 shows the observed and simulated water levels at Mohangonj, Bera, Pabna for 2007 hydrological year and acceptable agreement between observed and simulated water level data is revealed from the figure.

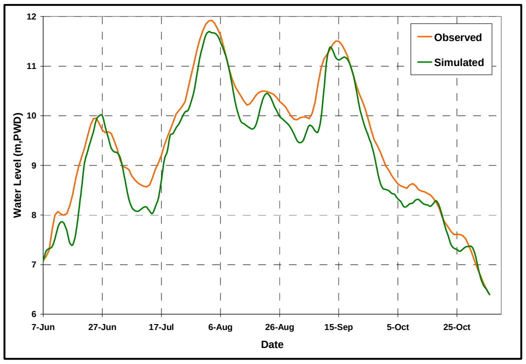

Figure 3: Comparison of observed and simulated water level at Mohangonj, Bera, Pabna

The verification of the morphological model has been done using observed sediment transport data. Figure 4 shows the simulated and observed (FAP24) sediment transport at Sirajganj. The simulated sediment transport indicates satisfactory agreement with the observed data. Since the simulated sediment transport, using Van Rijn sediment predictor, match well with the observed transport data, it can be considered that the Van Rijn sediment transport predictor generates acceptable sediment flow for the present case.

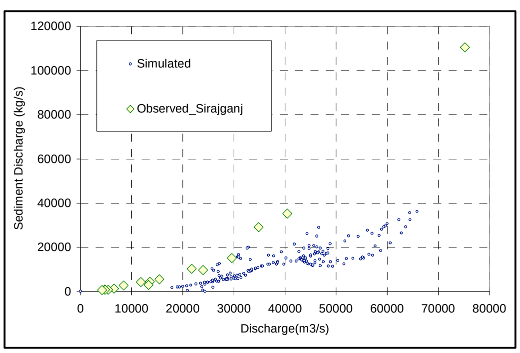

Figure 4: Comparison of observed and simulated sediment discharge of Jamuna River at downstream of Hurasagor outfall and Sirajgonj.

In order to assess the change in morphology due to implementation of the bank protection works at upstream, apart from the base model comprising the present field condition, another model with a bank protective work superimposed on the base model has been simulated thereafter for 2007 flood event.

5. RESULTS AND DISCUSSION

Siltation is directly related to the sediment load coming from upstream and intrusion of bank eroded material into the river flow. Overall siltation situation at downstream of Hurasagar may get improved if these sources of sediment can be blocked. Sediment coming from upstream cannot be obstructed, so recommendation can be made at this point to stop the bending at upstream since this bending is causing bank erosion, which is ultimately slumped and mixed with the flow.

Simulation results of the base model and the model with bank protection works have been analyzed to compare between the prevailing and with protection work for assessing the improvement. Influence of the proposed bank protection works from sediment distribution aspect has been assessed with the determination of the sediment passing through different channels. It has been observed from the model results that the model with "bank protective works" generates less amount of sediment if compared with "without bank protective works".

Base model generates 79005 million kg of total load including the sediment coming from further upstream throughout one monsoon whereas in case of revetment option, it is reduced by 546 million kg, Figure 5. Since the bank erosion could not take place due to presence of revetment, i.e. bank erosion is not allowed in the model within the protected stretch at Kaijuri, so no additional bank eroded material is added with the sediment load, i.e. the flow only carries the sediment which was coming from upstream. On the contrary, in case of base condition, sediment load coming from upstream is increased in volume with addition of bank eroded material at Kaijuri. Since less sediment is being carried, obviously less siltation is generated in the right most anabranch near the outfall of Hurasagar.

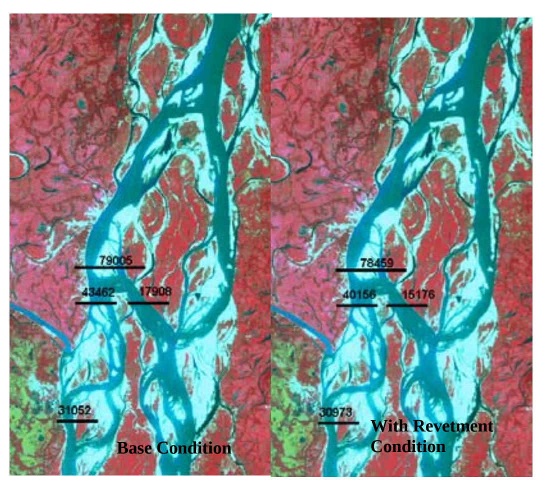

Figure 5: Simulated sediment load for base condition and with revetment scenario through different channels for 2007 flood event

Since the model indicated less amount of sediment through the channels at mouth of Hurasagar, so it is expected that the bed would experience less siltation, i.e. bed scour would take place. Reflection of the sediment on the channel bed has been determined with extracted cross-sections for base model and model with bank protection scenario, Figure 6. Though bed scour in "with revetment condition" is not significant, it is important that scouring has initiated. At both Location A and Location B, shown in figure, bed erosion occurs at the thalweg position.

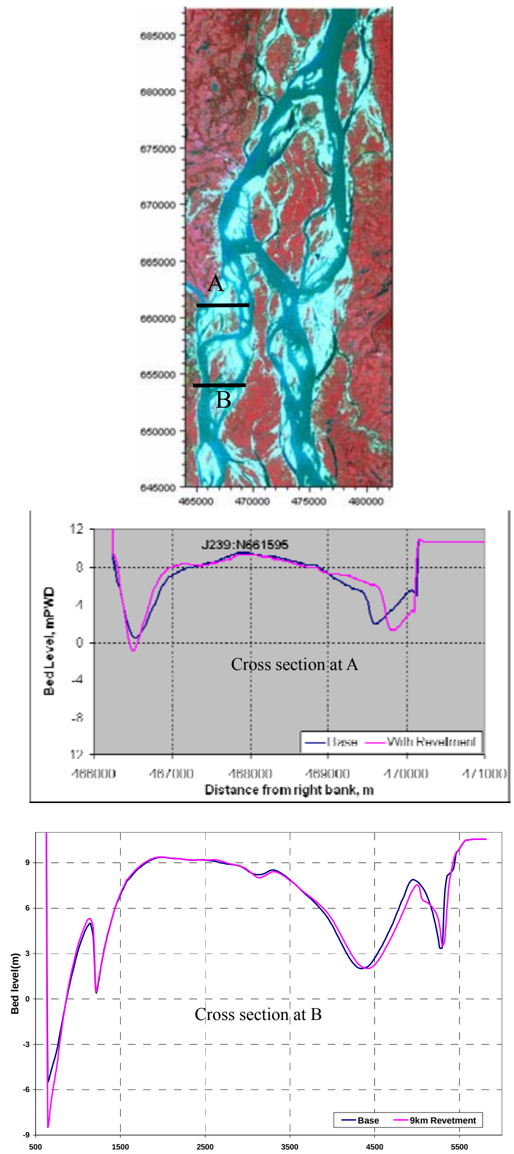

Figure 6: Bed profiles for base and with revetment condition at Koitola for 2007 flood event

6. CONCLUSION

Sediment generated due to bank erosion at Kaijuri Bazar aggravates the siltation condition at Koitola. However, this is not solely responsible for siltation at Koitola rather one of the potential causes. Morphological model has been deployed to simulate the river behaviour and thus to establish the theorem on contribution of the bank eroded sediment on the morphology at downstream. Prior to simulations, base model was calibrated and the results of the calibration were found within the acceptable range. IWM recommended bank protection works at upstream of Hurasagar outfall, i.e. from Kaijuri Bazar to Hurasagar outfall, under the JMREMP formulated study. Adopting the recommendation, both the base model and model with recommended bank protection works has been simulated for the flood event of 2007. Model result shows effectiveness of recommended upstream bank protection works at Kaijuri Bazar to improve the siltation at downstream of Hurasagar outfall near Koitola. Although the response is very minor, it shows initiation of the process and this is how a part of the sediment can be reduced that is responsible for the siltation at downstream.

With the aid of mathematical modelling, it is possible to assess the impact on river morphology for any human intervention. Modelling application for prediction of the impact in the river engineering sector can guide the planners and policy makers for planning and thus to strengthen the development works.

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