ESTEEM Academic Journal
Vol. 11, Special Issue 1, March 2015, 165-172

APPLICATION OF MATHEMATICAL MODEL FOR ASSESSMENT OF RIVER MORPHOLOGY: A CASE STUDY OF TITAS RIVER

Muhammad Anowar Saadat[1], Mir Abdus Subhan[2] and Imran Khan[3]

[1, 2, 3]*Institute of Water Modelling, House#496, Road#32, New DOHS, Mahakhali, Dhaka-1206*
[1]*ans@iwmbd.org;* [2]*mbs@iwmbd.org;* [3]*imk@iwmbd.org*

ABSTRACT

Titas is one of the rivers of Bangladesh which has the complex Ganges-Brahmaputra-Meghna river system. 80% terrain of the country has been formed with massive sediment carried by these rivers. Titas River originates from the Meghna River and falls again in the same at downstream. The river has become silted up over the years creating water logging in wet season and scarce water during dry season. Gradually, the river became ineffective from all aspects such as irrigation, navigation, ecological demand, etc. Government of Bangladesh has taken up a project for re-excavation of Titas River to reduce these problems and to restore the previous condition of the river by attracting more flow from the Meghna River. The re-excavation work has to be sustainable with reasonable maintenance dredging and also should not pose threat for the river banks. Mathematical modelling of Titas River using MIKE software has been carried out to simulate the morphological development under different hydro-morphological scenario. Two separate models were developed to simulate the river hydraulics in fixed bed and morphology in movable bed condition for base and re-excavated condition. Simulated base condition has been calibrated with observed data but the predicted excavated condition was not possible to check with field condition as the envisaged excavation work has not been implemented yet. Consecutive three average year flood simulation showed that the re-excavated section would be filled up to 21% of the capital dredging volume which indicates the required yearly maintenance dredging volume. The stability condition of the river banks in re-excavated condition was also checked so that the excavation work can be performed without damaging public property from excavation induced bank erosion. The purpose of the study was to assist the implementing agency with suggestions required for intelligent dredging to make the project economic, feasible and acceptable to all.

Keywords: Titas; morphology; mathematical model; siltation.

1. INTRODUCTION

Bangladesh is a very densely populated country of Asia located at the foothills of great Himalayan Range within the Indian subcontinent. The Meghna river, which carries a significant flow from the Barak river of North-Eastern India, joined with two mighty rivers,

p-ISSN 1675-7939; e-ISSN 2289-4934

the Brahmaputra and the Ganges, and finally falls into the Bay of Bengal. The Ganges-Brahmaputra-Meghna river system annually carries 1110.6 billion cubic meter water (Aquastat, 2011). The Ganges and the Brahmaputra rivers annually carry 1037 million tons sediment (Islam et al, 1999). The Meghna river has comparatively low flow but carries high sediment which is in the order of 200000 tons per day during flood (Coleman, 1969). 80% of the territory of the country is formed with sediment carried by the river system and most of the rivers are morphologically dynamic for which the river course and condition changes significantly. Many of these rivers have lost the conveyance capacity and thus water logging, drainage congestion in monsoon and water scarcity in winter season are frequently observed in these rivers. So, water resource management has been an acute issue affecting the socio-economical activities of the local people.

In this study, an attempt has been made to simulate the morphological activities of Titas river, a meandering river of the Meghna river system. The aim of the model is to simulate the morphological activities of the Titas river in its different reaches with recent survey data. The model has been calibrated hydro-dynamically and morphologically with the observed water level and sediment transport, respectively and later it has been applied to simulate the Titas river hydrology and sediment transport in re-excavated condition.

2. TITAS RIVER

Titas river originates from the Upper Meghna river at Ajobpur under Sarail upazilla of Brahmanbaria district. It takes off the Upper Meghna river with an obtuse angle of around 110°. It flows through some low lying areas of Brahmanbaria district and after travelling around 120km, it falls into the Meghna river again in the downstream near Nabinagar upazilla along with a 10km long channel named Pagla river. Titas river receives tidal discharge coming from the Upper Meghna river during winter season. It has an average width varying from about 100m to 180m (IWM, 2014) as at Ajobpur, the river has less width and conveyance and at Nabinagar it is more wider. Near Brahmanbaria city, there is an artificial link canal named Anderson Khal which diverts water from Titas river to the city area and also delivers tidal flow to upstream from Upper Meghna river (Figure 1).

2.1 Problems in the Study Area

The study area is predominately low lying area. About 44% area is either very low or low and 40% area ranges from low to medium high category. Remaining 16% falls under medium to high lands (IWM, 2014). The Titas river has been silted up thorough out its length receiving sediments from neighboring Tripura hills in India and also from sediments transported by the Meghna river. The siltation condition in upstream reach, (6.06 km to 51.31 km), and in the downstream of Akhaura, (81.13 km to 107.25 km), is severe (IWM, 2014). The Anderson khal has still enough depth, but silt is deposited over the slope reducing its efficiency. 3 km of Pagla river has been silted up in downstream. The siltation has reduced the carrying capacity of these rivers causing bank overtopping in pre-monsoon resulting damages of HYV Boro and drainage congestion in the post-monsoon causing also damage of crops. Moreover, farmers has to go for costly groundwater irrigation in dry season as Titas river carries no water at that period due to being disconnected from the parent river. Akhaura, an important land port located at 80.5 km, is highly affected due to siltation as major transportation here is done through river.

p-ISSN 1675-7939; e-ISSN 2289-4934

ESTEEM Academic Journal
Vol. 11, Special Issue 1, March 2015, 165-172

3. MATHEMATICAL MODEL

Institute of Water Modelling (IWM) has carried out a mathematical modelling study for Bangladesh Water Development Board (BWDB) to simulate the hydrology and morphology of the Titas river in order to devise a sustainable re-excavation plan so that the siltation problem can be effectively solved. In this study, the modelling software MIKE, developed by Danish Hydraulic Institute (DHI) Water and Environment, has been used. Two different modules of MIKE, MIKE11 and MIKE21c simulates the hydrodynamic and morphology, respectively.

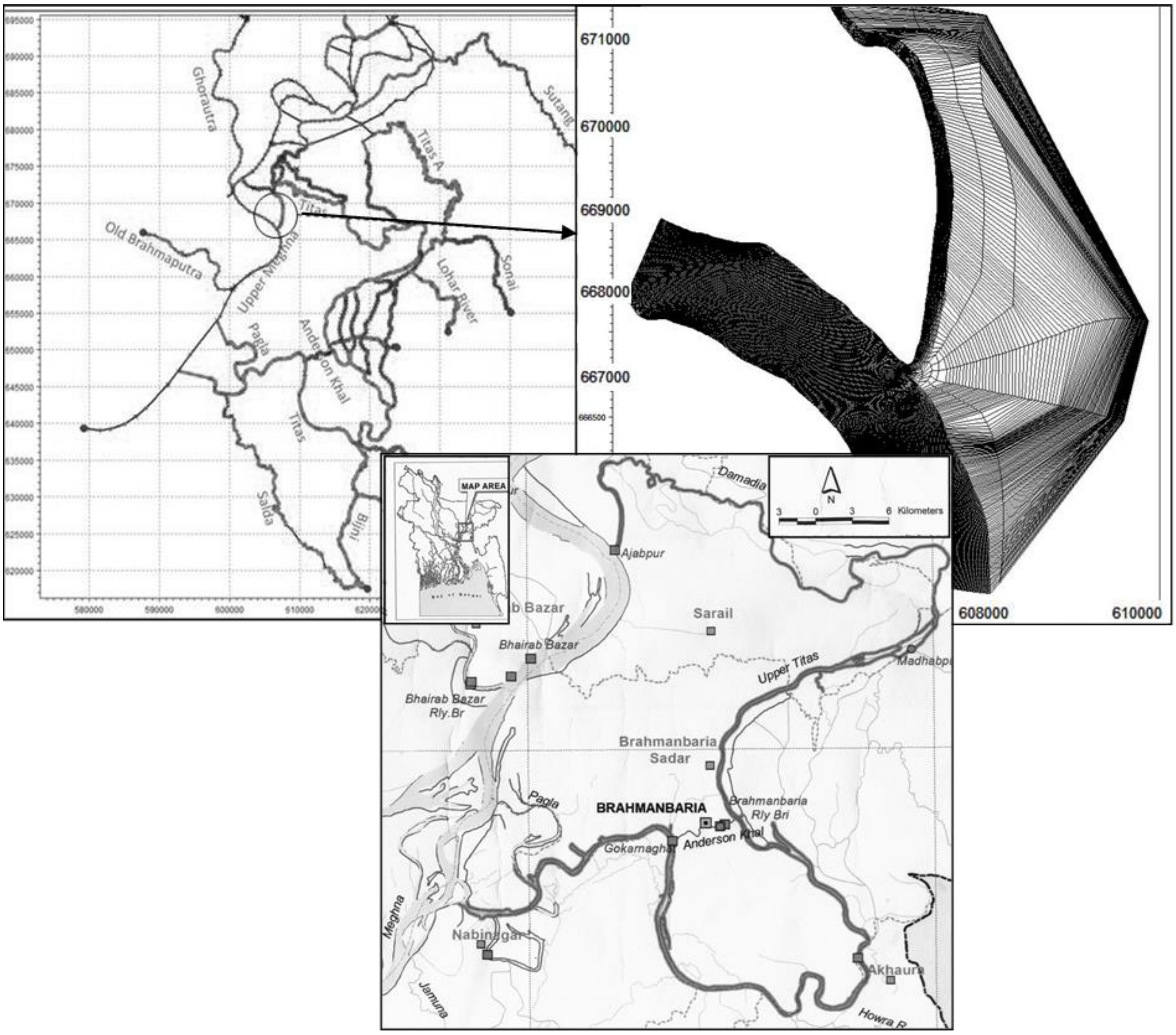

Figure 1: Planview of Meghna-Titas-Pagla river system (at bottom), schematized 1-D model river network (at left) and generated 2-D model curvilinear grid (at right).

3.1 One-Dimensional Model (MIKE11)

MIKE11 simulates the river flow dynamics with one-dimensional model and provides flow discharge, velocity, water depth and elevation, etc in fixed river bed condition in longitudinal

p-ISSN 1675-7939; e-ISSN 2289-4934

direction. A schematized river network was developed (Figure 1) for the hydrodynamic simulations supported by observed water levels and discharges at different boundary locations. It works with two equations, Equation 1 and Equation 2, for conservation of mass and momentum of open channel flow, respectively (Chow, 2010). In the equation, *Q* refers to the river discharge in m^3/s, *A* refers to the river cross-sectional area and *h* refers to the corresponding water depth. 1-D model has two independent variables such as space denoted by *x* and time denoted by *t*. The longitudinal slopes of the channel and surface water energy line have been denoted by *S* and S_f, respectively. The 1-D model has been calibrated against observed data of 2011 (Figure 2) with Manning's roughness coefficient "n", ranging from 0.02 to 0.03. It governs the river water level and computes discharge by calculating the cross-sectional conveyance. The calibration shows close match during high flood but little over estimation (0.2 to 0.5m) in low water levels. The calibrated model has been used to generate the water level and discharge boundary of extreme flood of 1998 and average flood of 2010 based upon bathymetry of Titas river on 2013.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} - gA(S - S_f) = 0 \qquad (2)$$

3.2 Two-Dimensional Model (MIKE21c)

MIKE21c combines the hydrodynamic model and morphological model in mobile bed condition. In this model, mass conservation is done in both *x* and *y* direction (longitudinal and transverse) and momentum conservation equation using Navier-Stokes formula which calculates momentum transfer in both direction. Recent surveyed bankline of Titas river has been used to generate computation curvilinear grids (Figure 1). Titas river bathymetry was obtained by superimposing and interpolating surveyed bathymetry data on the curvilinear grid. The speciality of curvilinear grid is to simulate the streamline curvature with the fluid/sediment movement in both *x* and *y* direction. To solve the mass balance accurately, the 2-D model was done in several sub-models.

3.2.1 *Sediment Continuity Equation*

Engelund-Hansen sediment transport model of total bed load transport has been taken for calculating sediment transport and sediment continuity was solved in MIKE21c, where the bed level changes over the time is calculated balancing with sediment transport variation within the model domain. Equation 3 shows the sediment balance where *z* denotes bed level and *Sx* and *Sy* are sediment transported in x and y direction, respectively in time period *t* (DHI, 2010). *Se* is lateral sediment inflow and *n* is porosity of bed material. The term *(1-n)dz/dt* is dry sediment volume generated from bed level change corresponding to the sediment balance in the channel. Sediment transport has been calibrated with observed data using 0.12mm median grain size (d_{50}) of bed material, alluvial resistance of Chezy's roughness "C" varying from 10 to 90 where $Cf(h)$, and 80% total load as suspended load. The sediment transport calibration was found within range of observed data (Figure 2).

p-ISSN 1675-7939; e-ISSN 2289-4934

ESTEEM Academic Journal
Vol. 11, Special Issue 1, March 2015, 165-172

$$(1-n)\frac{\partial z}{\partial t}+\frac{\partial Sx}{\partial x}+\frac{\partial Sy}{\partial y}=\Delta Se \tag{3}$$

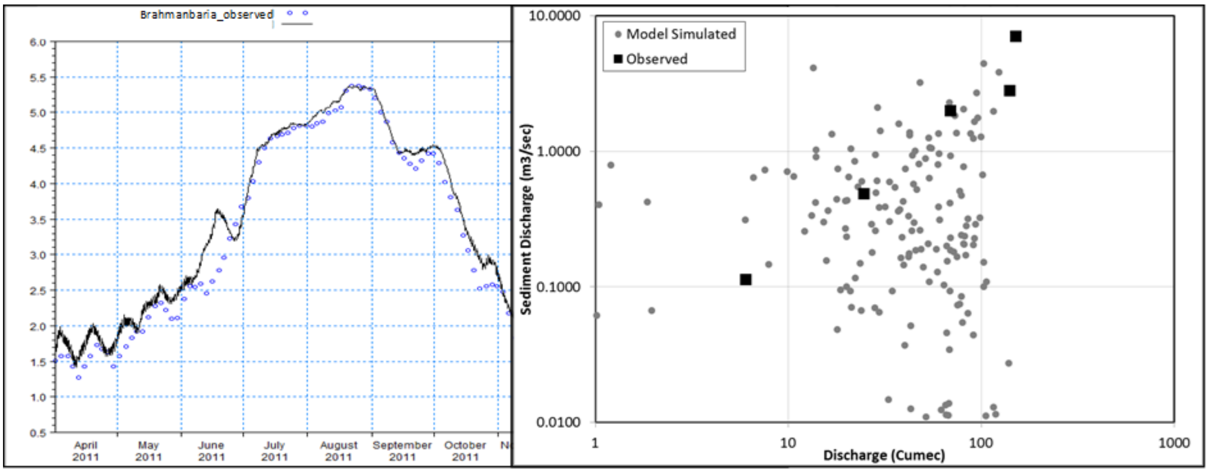

Figure 2: Calibration of 1-D model water level (left) & 2-D model sediment transport (right) (IWM, 2014).

4. RE-EXCAVATION SCENARIO

1-D and 2-D models have been simulated for both base condition and re-excavated condition. The basis of re-excavation was set considering minimum water depth for low lift pump irrigation under standard low water levels as well as minimum required navigation draft. The design dredge levels of the rivers are listed in Table 1.

Table 1: Re-excavation (dredging) design information for Titas, Pagla and Anderson khal.

Sl. No.	Water level Station	90% Dependable LWL (m PWD)	Design Depth (m)	Required Dredge Level (m PWD)	Design Dredge Level from Navigation (m PWD)	Remaks
1	Ajabpur	1.16	1.00	0.16	-2.00	For Titas river, -2.0 mPWD is set as design dredge level for 31m bed width. For Pagla river, -1.5mPWD is set as there is no navigation use and design bed width to be 20m . In Anderson khal, no dredging at bottom is required except side slopes.
3	Brahmanbaria	0.74	1.00	-0.26	-2.00	
4	Akhaura	0.88	1.00	-0.12	-2.00	
2	Gokurnaghat	0.67	1.00	-0.33	-2.00	
5	Nabinagar	0.51	1.00	-0.49	-2.00	

(IWM, 2014)

5. MODEL RESULTS

The 2-D model simulated the sustainability of the re-excavation works for both in cases of average flood and extreme flood. Initially, the extreme flood was simulated for consecutive three years which shows a lot of back fill in the rivers. In the Titas river, the back fill rates in three years vary from 30% to 80% of the capital dredging. This represents an extreme worst condition considering high flood with higher sediment transport. Figure 3 shows the location

p-ISSN 1675-7939; e-ISSN 2289-4934

of Pagla offtake and the sedimentation on the Pagla river with excavated cross-section and section after 3 years simulation. The cross-section comparison also indicates the trend of the river course shifting and tendency of bank erosion which should be accounted into during re-excavation works. Figure 4 shows the bed levels on plan view before and after the simulation which indicates the degradation/ aggradations activities.

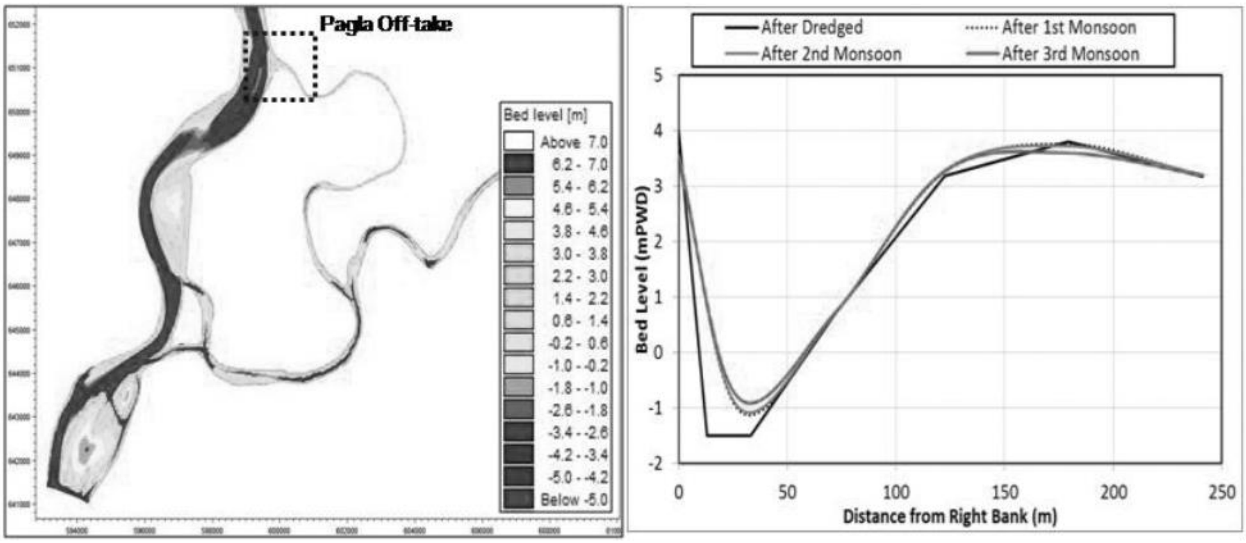

Figure 3: Location of Pagle river offtake at left and changes in Pagle river cross-section at right (IWM, 2014).

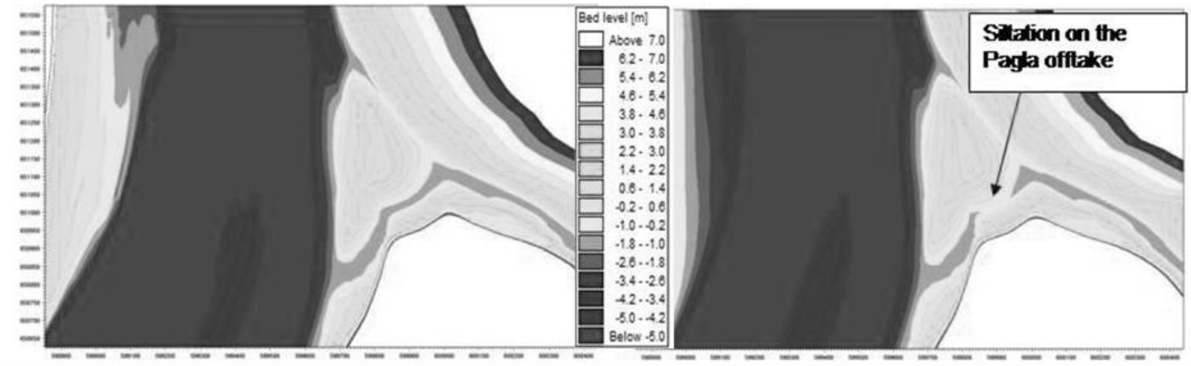

Figure 4: Bed level in re-excavated Pagla river at left and after 3 monsoon simulation at right (IWM, 2014).

To identify the yearly maintenance dredging volume, the average flood was simulated on the re-excavated rivers which show lower siltation. The back fill rate for average flood simulation was found maximum in the Titas river, around 21% of the capital dredging volume. The back fill rates in the Titas, Pagla and Anderson khal for average year flood have been listed in Table 2.

Table 2**:** Yearly back fill rates for average flood event in Titas, Pagla and Anderson khal.

p-ISSN 1675-7939; e-ISSN 2289-4934

River	Chainage in km	Re-excavation work (m^3)		Backfill rate (%)
		Capital Dredging	Maintenance Dredging	
Titas	1 - 120	7806848.92	1599000.07	20.48
Pagla	1 - 10	417639.34	32831.53	7.86
Anderson Khal	1 - 5	87011.61	647.15	0.74

(IWM, 2014)

The morphological change data in the above mentioned rivers have been plotted in GIS maps to visualize the critical locations from siltation point of view. It shows the Titas river near Akhaura is the most siltation prone location (more than 2m siltation) whereas the other reaches has moderate siltation of less than 1 m except immediate downstream are of Akhaura, ranging from 1-2m (Figure 5). Besides, the river bank stability after re-excavation was verified by observing thalweg shifting and vulnerable locations have been identified (Figure 5).

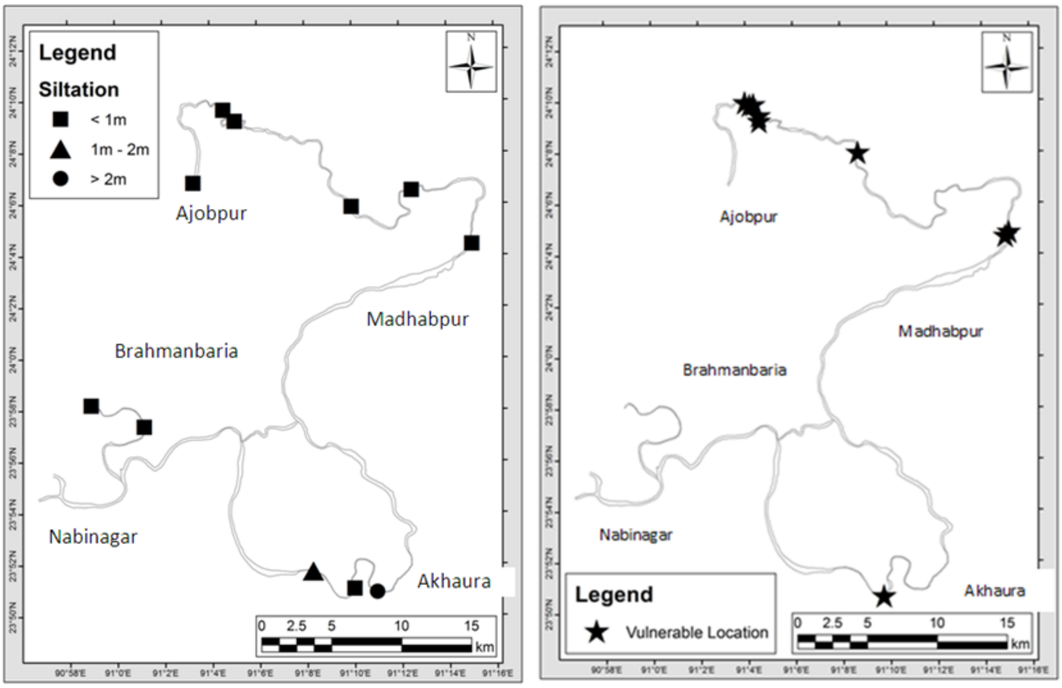

Figure 5: Siltation in Titas river in average flood at left and bank erosion prone areas at right (IWM, 2014)

6. CONCLUSION

The 2D morphological simulation shows good agreement with observed data and predicted siltation condition was similar as it was anticipated from literature and field information. The model prediction was not possible to verify as the excavation work has not been implemented yet. The study exposed the critical locations and suggested where to focus the limited resource of the implementing agency ensuring the sustainability of the re-excavation work. It also provides the annual maintenance dredging volume which will help to formulate the project planning and cost estimation in more realistic manner. Moreover, the stability condition of the river has been checked so that the project can be implemented with minimal impact to the surrounding areas. So, the use of mathematical model in such projects is very helpful in proper planning, decision making and implementation.

REFERENCES

p-ISSN 1675-7939; e-ISSN 2289-4934

Aquastat. (2011). Water Report 37. Retrieve from: http://www.fao.org/nr/water/aquastat/basins/gbm/index.stm.

Chow, V. T. (2010). *Applied Hydrology*.India: Tata McGraw Hill Edition.

Coleman, J. M. (1969). Brahmaputra River: Channel Processes and Sedimentation. *Special Issue, Sediment and Geology, 3*(2/3), 129-239.

DHI. (2010). "MIKE by DHI 2011", Curvilinear model, Scientific Document. DHI Water & Environment, P-61.

Islam, M. R., Begum, S. F., Yamaguchi, Y., & Ogawa, K. (1999). The Ganges and Brahmaputra rivers in Bangladesh: basin denudation and sedimentation. *Hydrological Processes, 13,* 2907-2923.

IWM. (June 2014). *Feasibility Study for the Re-excavation of Titas River (Upper) under Brahmanbaria District*.Institute of Water Modelling.

p-ISSN 1675-7939; e-ISSN 2289-4934