
Morphological assessment of a selected reach of the Jamuna River using the Delft3D Model

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Abstract: *The River Jamuna, in Bangladesh, is one of the greatest alluvial rivers in the world. Almost every year severe erosion takes place, which renders tens of thousands of people homeless. In order to improve the livelihoods of floodplain dwellers, understanding the morpho-dynamics of the river is essential. The reach boundaries considered in this study are 30 km upstream and 20 km downstream of Bangabandhu Bridge. The main objective of this paper was to look over the sediment dynamics and the possible changes on riverbed morphology by using the open-source, Delft3D modelling software. Water level and discharge were two important hydrological*

parameters that were used as the boundary conditions to investigate the erosion and deposition process. Variation of velocity, erosion and deposition, sediment transport and bed level changes of the Jamuna River were studied using this modeling suite. The frequency of erosion/deposition and shifting of the riverbank were predicted for two consecutive years (2011-2012). Comparisons were made between the simulated results of Delft3D with the results obtained from the Mike 21. Shifting of channels were observed, as erosion and deposition took place simultaneously along the channel bed and bank line. The knowledge regarding the shifting direction and magnitude of shifting generated from the analysis developed herein could be useful in the future projection of planform changes of braided rivers around the world that are similar to the Jamuna river.

Keywords: *Morphology; Bangladesh; Jamuna River; Delft 3D; Channel shifting.*

1. Introduction

Quantification and prediction of the sediment dynamics and the possible changes on riverbed morphology is one of the most challenging tasks in river management. In alluvial channels or streams, bed aggradation evolves primarily from the passage of flood events. It creates a variety of problems such as the rising of riverbeds and increasing flood heights, meandering and overflows along the banks, choking chocking up of navigation and irrigation canals and depletion of the capacity of storage reservoir (Hossain, 1997). A stream channel at grade provides the impulsion to carry the supplied sediment load to maintain a stable bed elevation (Mackin, 1948). Aggradation occurs in a river if the amount of sediment coming into a given reach of a stream is greater than the amount of sediment going out of the reach. Part of the sediment load must be deposited and hence, the bed level must rise (Ranga Raju, 1980). Alves and Cardoso (1999) investigated the effect of overloading on bed forms, resistance to flow, sediment transport rate and average bed profile of aggrading by overload. Aggradation and degradation phenomenon of alluvial channels beds are also reported by several researchers. (Jain, 1981; Jaramillo, 1983).

Bangladesh is a riverine country with hundreds of rivers overlaying its landscape. Major portion of Bangladesh is formed with heavily charged sediment from the river Ganges, the Jamuna and the Meghna and their distributaries and tributaries. These rivers experience complicated variations of erosion and deposition over time and space due to instantaneous changes of flow and sedimentation. The Jamuna river originates from Himalayas as the Brahmaputra, consisting a network of interlacing channels, with numerous sandbars or chars. Some of these chars are often deposited and destroyed continually, depending upon the sediment-carrying capacity of the flow (Baki et al., 2012). Many poor people reside in char areas where agriculture is the mainstay of their livelihood. Bank erosion of the river strongly depends on monsoonal peak discharge, leads bank retreat to hundreds of meters annually causing destruction of the river

and to public infrastructure (Mosselman, 2006; Mount et al., 2013). Therefore, it is crucial to understand the river's dynamic behaviour to mitigate such sufferings.

The Bangabandhu Bridge is a very important hydraulic structure to connect the east and west parts of Bangladesh over the Jamuna River. Apart from movement of cargo and passenger streams, it promotes conveyance of electricity and natural gas, and telecommunication links (Jenkins & Shukla, 1997). However, due to construction of the bridge, the hydraulic environment of the nearby area of the bridge has undergone a severe change (Mohammad et al., 2010). Hence, the existing hydraulic conditions in the vicinity of the bridge, as well as hydro-morphological forecasts of the river at the critical locations within the bridge surrounding area are essential.

Several modelling studies have been conducted to understand the different behaviours of the various types of rivers in Bangladesh, as well as over the world (Jagers, 2003; Kuehl et al., 1989; Goodbred and Kuehl, 2000b). In Bangladesh, Institute of Water Modelling (IWM) created a mathematical model using Mike 21C to evaluate the hydrodynamics and sediment transport to 20 km upstream and 10 km downstream from Bangabandhu Bridge (IWM, 2011). Most of these models, including Mike 21C, are very expensive and some are very time consuming. On the other hand, Delft3D flow (FLOW), morphology (MOR) and wave (WAVE) modules are available as an open source and has proven its capabilities on many places around the world (Wang et al., 2014). It is a powerful tool for understanding and forecasting river morpho-dynamic behaviour as it takes into account the most relevant factors involved in this process and gives a broad range of results, presented in an accessible manner. Though many studies have been conducted on sediment dynamics and morphology, very little studies have been carried out to investigate the planform change of the rivers of Bangladesh by using the Delft3D model. Delft 3D has been widely applied in coastal, river and estuarine areas for simulation (Van der Wegen, & Roelvink, 2008; Crosato et al., 2011; Crosato et al., 2012). Jagers (2003) carried out two-dimensional depth-averaged morphological simulation of sharp bends to improve the understanding of the physical process of a river. In order to understand the trends and migration patterns, a 3D model Delft3D was used for simulating the hydrodynamic and morphological processes in this study.

2. Methodology

2.1 Water level and bed level calculation

The water level data were recorded at 3 hour intervals using the water level gauges by Institute of Water Modeling (IWM), in 2010 and 2011. These gauges have been fixed to the PWD datum from the benchmark (BM) by direct fly levelling. A Digital echo sounder, fitted with a DGPS, Laptop computer and HydroPro survey software was used to survey the water part of the river.

2.1 Numerical Model Description

Hydrodynamic and Morpho-dynamics modules are considered to be coupled in Delft3D model, in which the flow field adjusts in real time as the bed topography changes (Edmonds & Slingerland, 2007). Conservations of momentum is followed in Delft3D model by applying equations 1 and 2 in the x and y directions, respectively.

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} + \frac{\omega}{H} \frac{\partial U}{\partial \sigma} - fV = -\frac{1}{\rho_0} P_x + F_x + M_x + \frac{1}{H^2} \frac{\partial}{\partial \sigma} (v_V \frac{\partial u}{\partial \sigma}) \quad (1)$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + \frac{\omega}{H} \frac{\partial V}{\partial \sigma} - fU = -\frac{1}{\rho_0} P_y + F_y + M_y + \frac{1}{H^2} \frac{\partial}{\partial \sigma} (v_V \frac{\partial v}{\partial \sigma}) \quad (2)$$

Here, U and V defines the velocity components in the x and y directions, respectively, v_V is the vertical velocity, ω is the settling velocity, f is the Coriolis force, P is the barotropic pressure gradients for water of specific density, ρ_0 is the atmospheric pressure, F denotes the horizontal friction (Reynold's stress). Lastly, M represents the discharge or withdrawal of momentum due to the external sources like discharge of water and wave stresses.

The depth-average continuity equation is maintained in the model by Equation 3 (Lesser et al., 2004). The model in this study is calibrated for a single layer.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial [HU]}{\partial x} + \frac{\partial [HV]}{\partial y} = S \quad (3)$$

where, contribution of the discharge of water, evaporation and precipitation per unit area is expressed by S and ζ and H represent water level and depth, respectively.

2.2 Suspended Transport

Advection-diffusion equation (Equation 4) calculates the transport of suspended particles (Deltare, 2011).

$$\frac{\partial c}{\partial t} + \frac{\partial U_c}{\partial x} + \frac{\partial V_c}{\partial y} + \frac{\partial(w-w_s)c}{\partial \sigma} - \frac{\partial}{\partial x} \left(\varepsilon_{s,x} \frac{\partial c}{\partial x} \right) - \frac{\partial}{\partial y} \left(\varepsilon_{s,y} \frac{\partial c}{\partial y} \right) - \frac{\partial}{\partial \sigma} \left(\varepsilon_{s,z} \frac{\partial c}{\partial \sigma} \right) = 0 \quad (4)$$

Where, c is indicating depth averaged mass concentration, w_s is the hindered sediment settling velocity, $\varepsilon_{s,x}$, $\varepsilon_{s,y}$, and $\varepsilon_{s,z}$ are the sediment eddy diffusivities.

2.3 Bed load Transport

In this model, the Van Rijn (1984) equation was used to compute the bed load as stated in equation 5. The wave effects were not considered in the model used in this study.

$$S_b = \begin{cases} 0.053 \sqrt{(s-1)} \cdot g \cdot D_{50}^3 D_*^{-0.3} T^{2.1}; & \text{for } T < 3.0 \\ 0.1 \sqrt{(s-1)} \cdot g \cdot D_{50}^3 D_*^{-0.3} T^{1.5}; & \text{for } T \geq 3.0 \end{cases} \quad (5)$$

where, S_b is bedload transport rate ($\text{kg m}^{-1} \text{s}^{-1}$), S is specific density (ρ_s/ρ), D_{50} is the median particle diameter (m), D_* is dimensionless particle parameter and T is dimensionless transport parameter.

2.4 Profile of the study area

The study reach was selected within two districts of Bangladesh, namely Sirajganj and Tangail, from E463400 m to E486500 m and N680000 m to N730000 m (BTM coordinate) which approximately covers a 50 km reach of the Jamuna River, as shown in Figure 1. The reach considered in this study consisted of an upstream boundary at 30 km upstream of Bangabandhu Bridge and downstream boundary at 20 km downstream of the bridge.

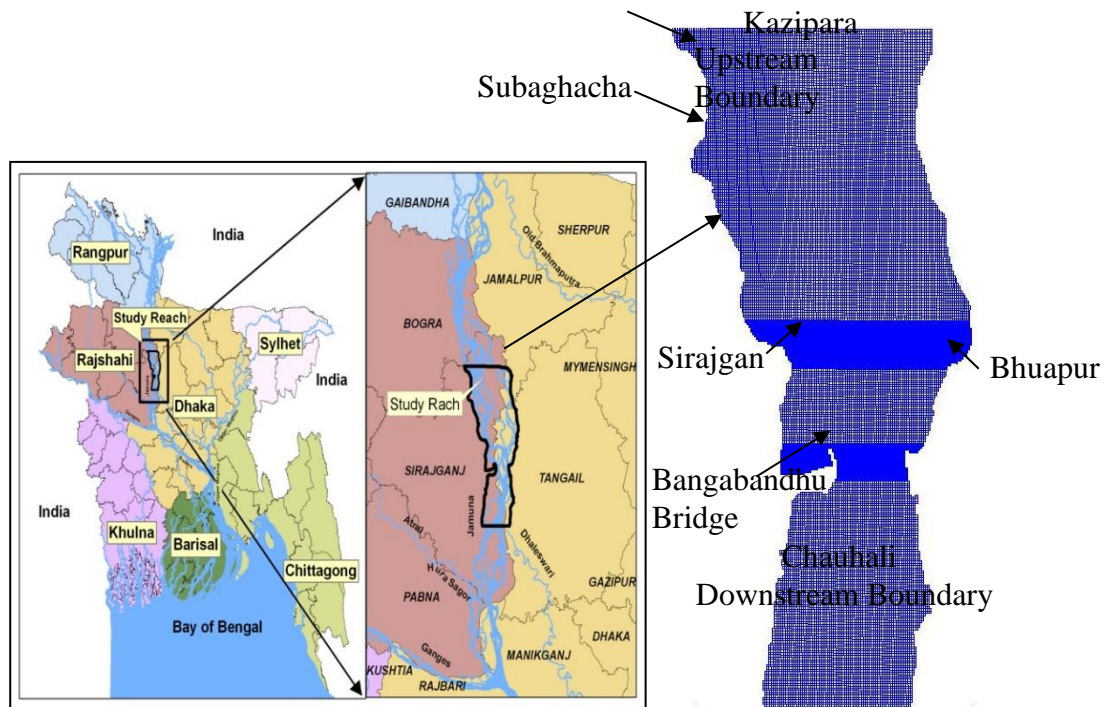


Figure 1. Study Area on the Jamuna River

The number of locations were considered to be crucial in terms of their positions and was specially monitored during the model simulation within the study reach. Sirajganj and Kazipara are located on the right side and Bhuapur is located on the left side of the river at the upstream end and Chauhali is situated at the downstream end of the study reach (Figure 1).

2.3 Model set up

Delft3D numerical model was set up utilizing reliable and sufficient data obtained from IWM to acquire accurate results. Three different basic set-ups for the Delft3D model were prepared in this study. Hydrological data of Jamuna River at April 2010, December 2010 and September 2011 were used for an initial set up to run the model, hydrodynamic calibration and validation, respectively.

2.4 Grid generation

A curvilinear grid was generated, covering the whole selected reach, extending from the upstream border near Kazipara to the downstream border close to Chauhali by Delft3D - RGFRID module to carry out continuous simulation for this study. The total number of grid cells in x and y directions were 299 and 146, respectively, with dimensions of 124 m × 171 m. Before proceeding to further development, orthogonality, aspect ratio, courant number, and grid smoothness were checked to obtain accurate solution. The grid was locally refined to develop high grid resolution in the areas of interest (i.e., near Sirajgonj Hardpoint, Bangabandhu Bridge) in order to attain results faster with accuracy. Surveyed bathymetric data was collected from the Institute of Water Modeling (IWM) and interpolated for all mesh nodes to develop bathymetry by using Delft3D – QUICKIN.

2.5 Boundary setup and Time frame

The flow grid constructed in the model area consists of two open boundaries (upstream & downstream boundaries) and two closed boundaries (east and west bank lines). Time series discharge data created from rating curve at Bahadurabad, located close to Kazipara, were used at the upstream inflow, while boundary and water level data from Sirajganj were applied as downstream boundary near Chauhali. Several simulations were performed by varying time steps and courant number spatially to check the accuracy and stability of the model. In this study, considering one-minute time step, courant numbers were found below 20, which indicates that the model was quite stable for simulation (Deltares, 2011).

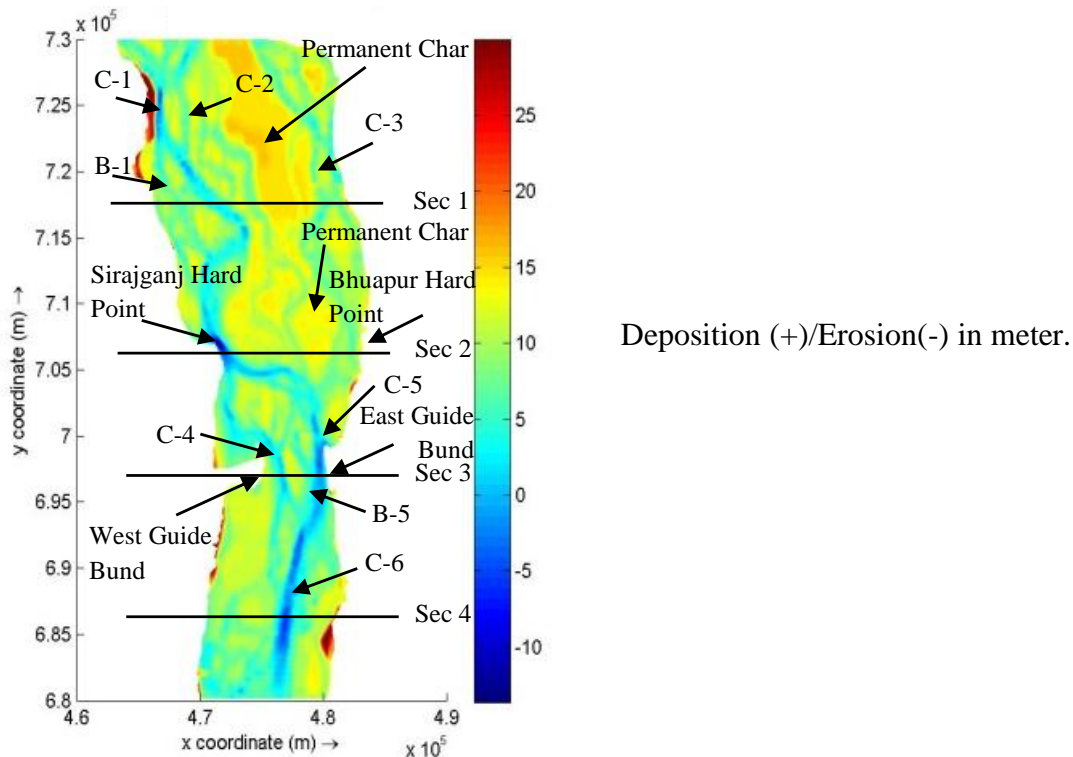


Figure 2. Selected cross section on the study area of the Jamuna River.

3. Results and Discussion

3.1 Simulation of the model

Initially, a bathymetry of April 2010 was taken as the base for simulation as shown in Figure 2. Simulated bathymetries at selected cross-sections 1, 2, 3 and 4 in December 2010 have been compared to that of observed bathymetries. The model

was then simulated for predicting the hydraulic and morphologic responses of the river in the years 2011 and 2012. In the case of morphological simulation, bed levels were computed by upgrading the height of the bed at each time step. Additional features like morphological switch, morphological delay, and morphological time scale factor was included to increase the flexibility.

3.2 Model Calibration and Validation

Roughness and eddy viscosity were the parameters used as a trial to achieve a suitable match with the observed field condition. Manning's roughness coefficient was adjusted with the varying water depth, $n = 0.014$, when water depth was lower than 6 m and $n = 0.025$, when water depth was higher than 6 m. The value of eddy viscosity was considered 1.

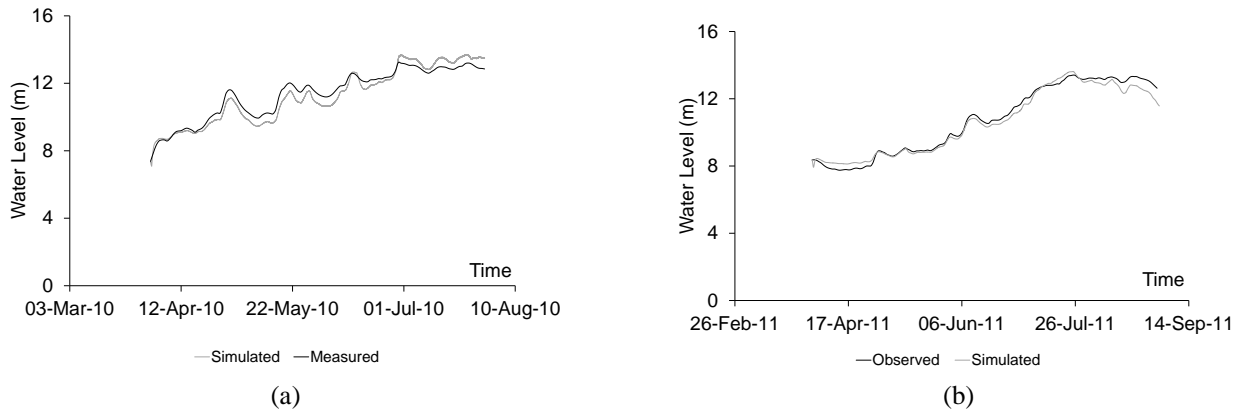


Figure 3. Simulated and measured water levels of Jamuna River for (a) calibration and (b) validation at Sirajganj.

For hydrodynamic calibration, simulated water level elevation was compared with the observed water level elevation at Shirajgonj station for the period of April to July 2010 (Figure 3a). Calibration results showed that the simulated values were within ± 0.6 m of the observed value. The model was also validated at Shirajgonj station after the calibration for the duration of April to August 2011 (Figure 3b) and showed strong agreement conforming the applicability of the model.

3.3 Sensitivity Analysis

A sensitivity analysis was performed to determine the model's performance and how the model responded to several parameter settings. Different parameters, mainly the eddy viscosity and Manning's roughness coefficient, were tested for inspecting the sensitivity of the model, which is shown in Figure 4. Different values considered for the Manning's 'n' regarding char and channel were (0.1 and 0.014), (0.1 and 0.01), (0.025 and 0.014). The value of eddy viscosity taken was 1, 3 and 10 for testing the best match.

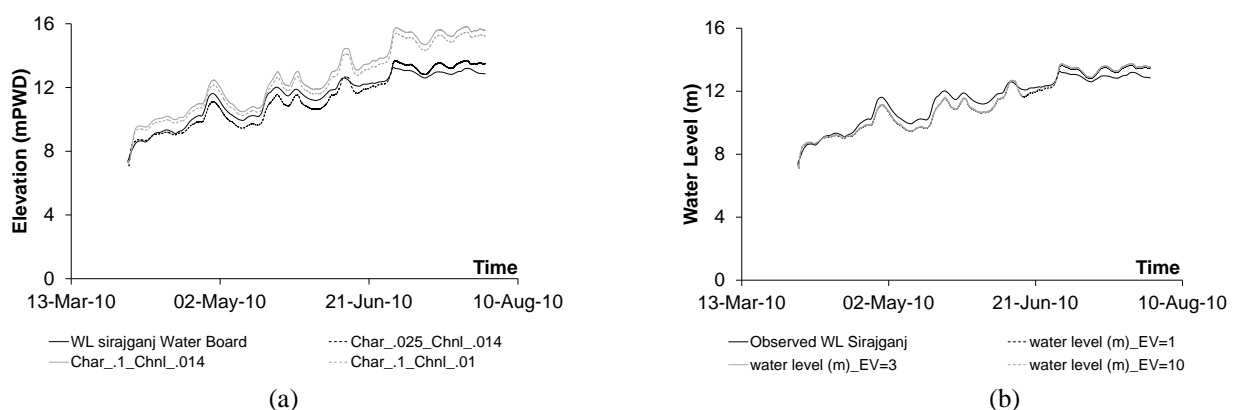
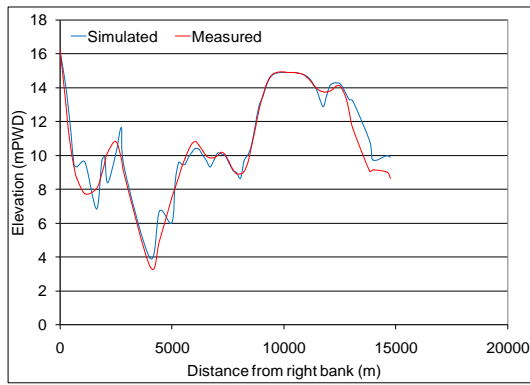


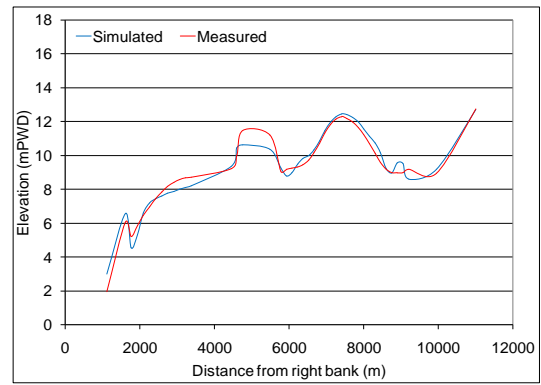
Figure 4. Influence of (a) Manning parameter and (b) Eddy viscosity on amplitudes of water level

3.4 Observed and Simulated Bed Elevations

For sediment model, a comparison was made between the simulated bathymetry of December 2010 with the observed bathymetry in December 2010. The median size of bed material was considered 0.20 mm for morphological computation. Comparison of various sections are shown in Figure 5. Simulated bed elevations adequately matched with the measured bed elevations.

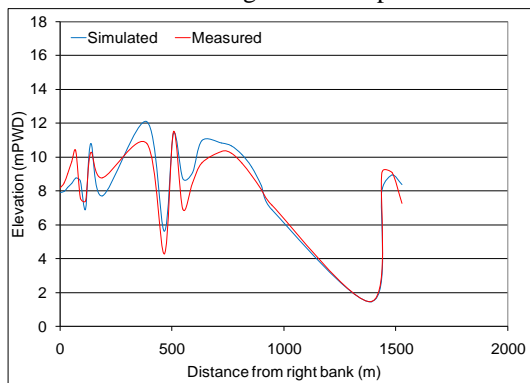


(a) Section 1

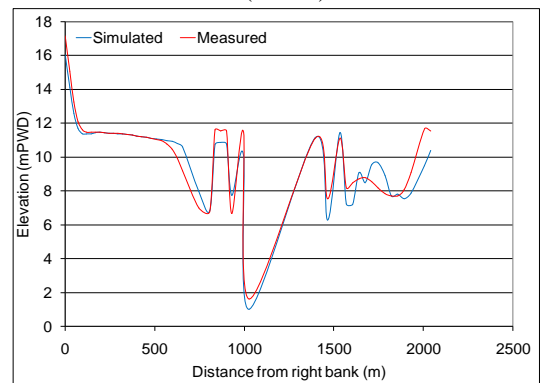


(b) Section 2

Figure 5: Comparison of simulated and observed cross-Sections (contd.)



(c) Sec 3



(d) Sec 4

Figure 5. Comparison of simulated and observed cross-Sections

3.5 Variation in Velocity and Sediment Transport

Sediment transport of the river varies spatially, influenced by the local bathymetry and associated with discharge and velocity. From Figure 6 and 7, it can be visualized that sediment transport rates for the two consecutive years (2011 and 2012) were greater during monsoon compared to the dry season, as discharge increased in wet season along with flow velocity. Velocity seemed to be high near Shuvagacha, Sirajganj hardpoint, Bhuapur hardpoint, Bangabandhu bridge area (closer to east & west guide bands) and downstream of the selected reach in both wet and dry season. These zones appeared to be eroded and carried more sediment. The flow velocity along with sediment transport increased in the successive years; except in Bhuapur hardpoint. In 2012, deposition took place in this location due to the reduction of velocity, as well as the sediment transport rate compared to 2011. Several distributary channels appeared in July 2012 due to significant erosion. The channels bifurcated from Sirajganj station, showed lower flow velocity compared to other locations and consequently possessed lower sediment transport capacity.

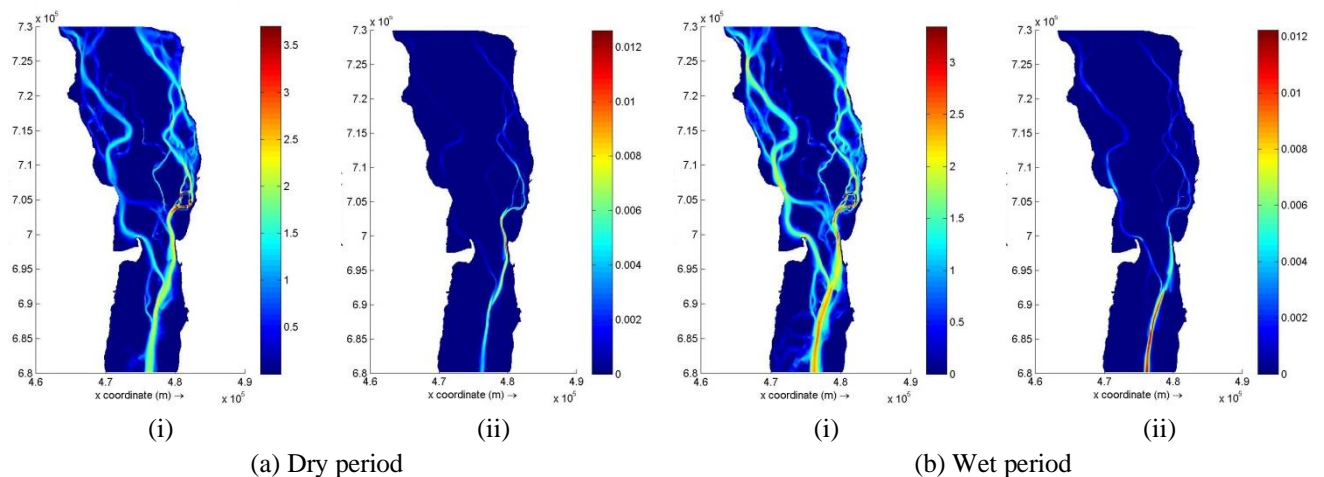


Figure 6. Plan view of Jamuna river for (i) depth averaged velocity and (ii) sediment transport in 2011

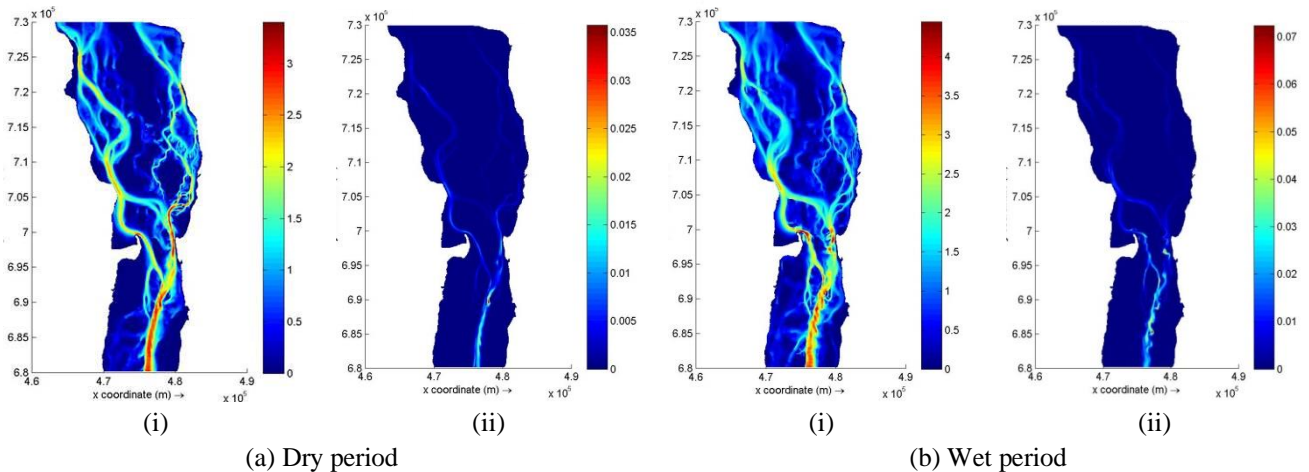


Figure 7. Plan view of Jamuna river for (i) depth averaged velocity and (ii) sediment transport in 2012

3.6 Estimation of Erosion and Deposition

Cumulative erosion or deposition all over the river reach was estimated by using the Delft3D model, for two consecutive years, i.e. 2011 and 2012. Figure 8 reveals that the three morphological years had similar types of erosion and deposition patterns. Deposition near the char areas and development of deep channels were some of the significant morphological features.

In section 1 (Figure 2), a char existed between channel C-1 and a branch channel, appeared from C-1 which is channel B-1. Maximum flow and velocity passes through C-1 due to its bending nature relative to B-1. Severe erosion took place on both of the channels. Superimposed cross-sections indicate both channels shifted westward from their bank lines and resulted in a deeper and narrower channel, due to velocity increment in C-1 & B-1, from 2.24 m/s to 2.98 m/s and 1.2 m/s to 2.3 m/s respectively, in September 2011 and 2012. The channels became narrower as some amount of deposition took place in their respective bank lines (Figure 9(i)).

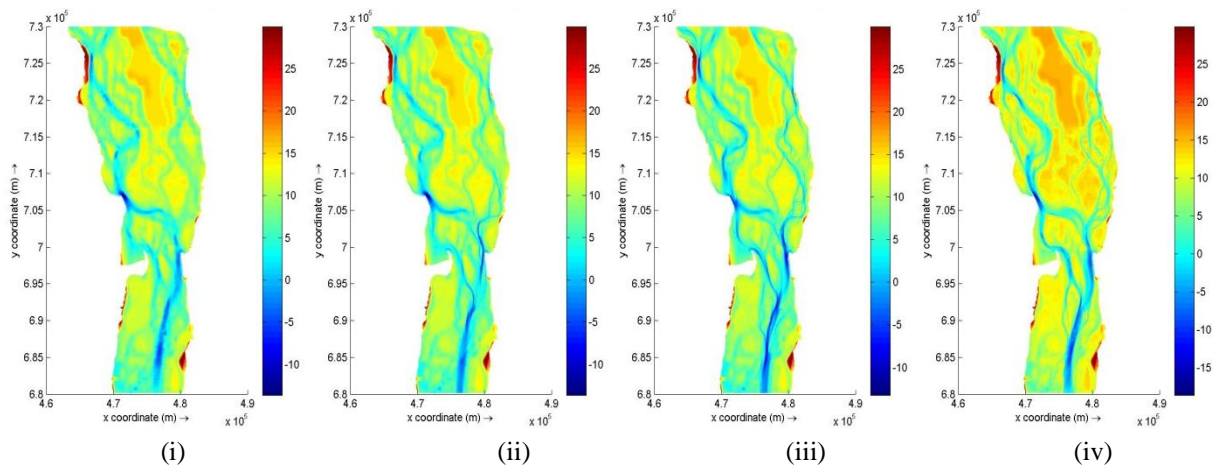


Figure 8. Plan view of Jamuna river for (i) Initial bed level in April 2010 and Simulated bed level in September (ii) 2010 (iii) 2011 (iv) 2012

Section 2 was selected near Sirajganj district, where the channel was wide and shallow in April 2010. In the subsequent years, the channel experienced severe erosions of about 5 m due to the increase of velocity from 2.38 m/s to 3.77 m/s and a shifting of erosion westwards. Also, in September 2012, erosion and deposition took place on both sides of the permanent char due to the fluctuation of velocity (Figure 9(ii)). Overall the width of the char decreased and some shallow and narrow tributary channels appeared on the erosion areas.

Section 3 lies in the portion of the Bangabandhu Bridge and the channels are indicated as C-4 and C-5. Widths of both channels reduced during the monsoon period in the year 2010 and 2011 as deposition took place on their banks due to the

reduction of water velocity. However, from the superimposed cross-sections, it is evident that both channels had undergone severe erosion in the year 2012 due to velocity increment from 2.34 m/s to 3.37 m/s and from 2.36 m/s to 3.69 m/s, respectively (Figure 9 (iii)). Hence, both of the channels changed their direction in the east and west, respectively. A small branch channel B-5 appeared which was also eroded. Besides the erosion process, deposition also took place, about 4 m on both sides of the char that existed between C-4 and C-5 (Figure 9(iii)).

Section 4 passes through the channel located in the downstream portion of the river reach, near to Chauhali. This channel C-6 underwent severe erosion in September 2012 due to increased velocity and the channel was shifted westwards, resulting in a deeper and narrower channel. A huge amount of deposition of around 7.5 m and 3 m took place on both sides of the channel in September 2010 due to the reduction of velocity (Figure 9(iv)). In September 2011, the velocity reduced to 2.05 m/s and again increased abruptly to 3.22 m/s in September 2012. Average erosion and deposition of observed and simulated bathymetries at all selected cross-sections for the year 2010 and 2011 are summarized in Table 1.

Figure 10 (middle portion of the selected reach) shows the simulated images of the bed level in September 2011 using both Delft3D and Mike 21 (IWM, 2011). It can be seen that Delft3D model predicted river bed degradation patterns near Shirajganj Hard Point and east guide bund, which are very similar with the predicted river bed degradation by Mike 21. Aggregation can be observed near the bank lines. It also can be observed that in both the pictures, the significant erosion affected zones are at the same locations of Shirajganj and near the east guide bund of the main channel. The elevations of these zones are below 0 mPWD, whereas, in case of the tributaries, the ranges are from 0 mPWD to 5 mPWD. Also, elevations at the big char areas are above 14 mPWD.

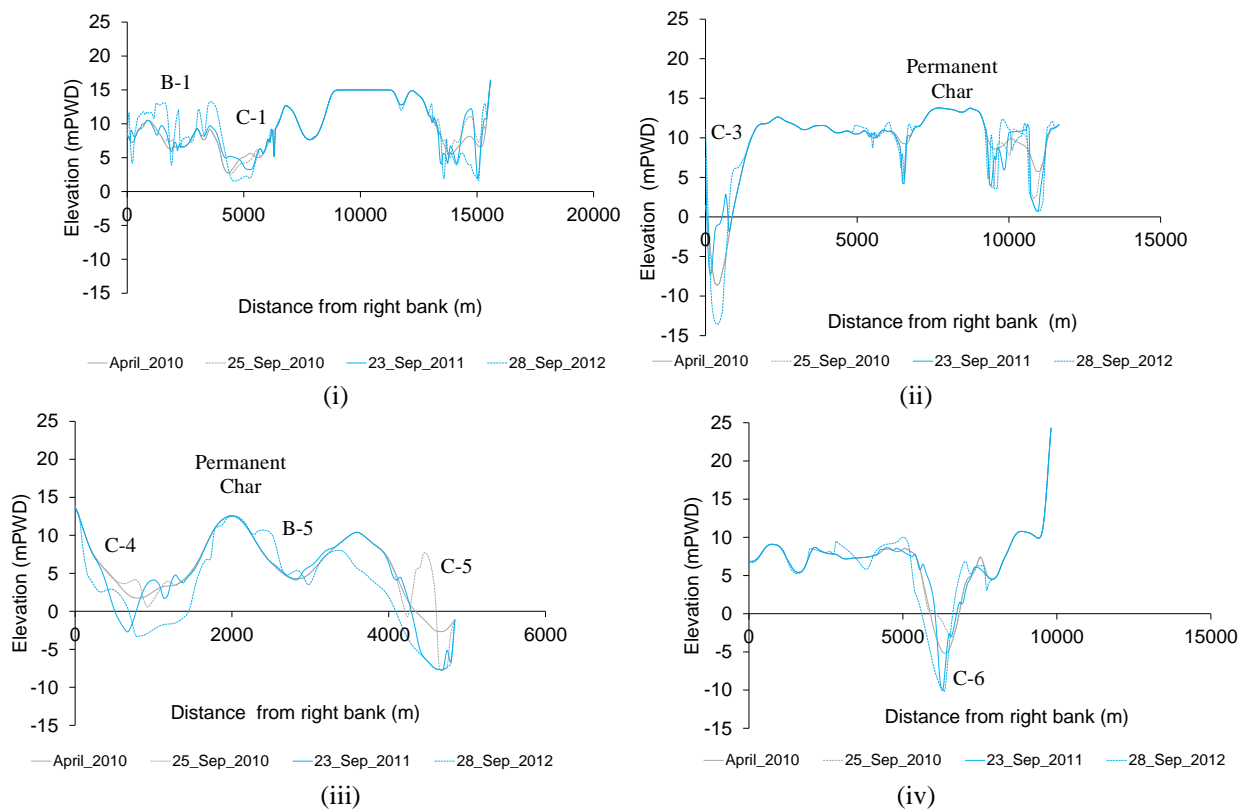


Figure 9. Elevations at cross-section (i) 1, (ii) 2, (iii) 3 and (iv) 4

Table 1 Average Erosion and Deposition of Observed and Simulated Bathymetry

Cross-section	December 10		September 11	
	Observed (m)	Simulated (m)	Observed (m)	Simulated (m)
Section 1	0.205	0.167	0.263	0.173
Section 2	0.002	0.003	-0.024	-0.039
Section 3	0.074	0.051	-0.882	-0.688
Section 4	-0.021	-0.052	-0.280	-0.354

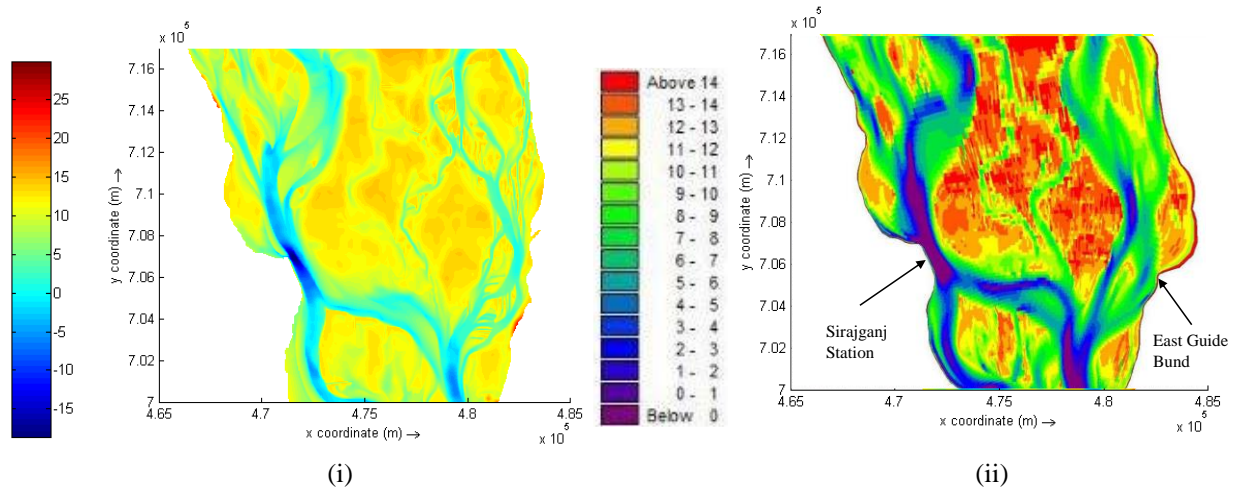


Figure 10. Comparison of the simulated bathymetry in September 2011 by (i) Delft 3D and (ii) Mike21

4. Conclusion

The aim of this research was to determine the morphological changes of the Jamuna river using a Delft3D model. Calibration and validation were carried out effectively against water surface elevations at Sirajganj. An attempt was made to calibrate only the high flow data as most of the morphological activities occur during this period, and the result obtained from the processes adequately matched with the observed values. This analysis was essential to understand the trends of river shift, as well as to identify the zone of high risks. More materials were deposited adjacent to the char areas which were surrounded by the channel branches. Considering the changes during the last two years, appreciable deposition was absent, but a large amount of erosion was observed in the west channel compared to east side of the river. Relation between the sediment transport and depth average velocity was established. A higher velocity increased the rate of sediment transport, forms erosion and the shifting of channels. Plan form analysis revealed that the river appreciably shifted towards the east and west directions in the consecutive years. The shifting activity of the river course, and its successive erosion, as well as accretion processes, caused the destruction and formation of new land continuously. Also, the simulated results by Delft3D model was compared with the results obtained from the Mike 21 model, which is a widely used commercial coastal modelling software. The results obtained from both models showed strong agreement, which demonstrated the strong acceptability of using Delft3D.

5. Acknowledgements

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