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ANALYSIS ON HYDRODYNAMIC AND MORPHOLOGICAL CHARACTERISTICS OF UPPER GORAI RIVER USING DELFT3D

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Abstract

Owing to the reduction of upstream water flow after construction of Farakka Barrage on the Ganges River, huge amount of sediment loads are settling down on Gorai river bed, hindering the safe passage of flow which contributes to the change in hydrodynamic and morphological characteristics of the Gorai River. Therefore the objective of this study is to investigate the hydrodynamic and morphological behavior of the river Gorai by Delft3D. Salinity parameter is also included in this study. A 25 km reach of the Gorai River, subdivided into 5 monitoring points for the year 2010 was selected for the model simulation. For the analysis, simulation period was divided into two seasons; dry period and flood period. Results reveal that during dry period, simulated velocity, discharge and sediment flow had been 0.1 m/s - 0.25 m/s, 200 m^3/s - 400 m^3/s, 0.07 kg/s - 0.125 kg/s respectively. The water level showed decreasing trend towards downstream and found to be 2 m-3.5m. Modeling results also reveal that in the flood period, velocity ranged from 0.7 m/s-0.9 m/s, discharge from 2800 m^3/s to 4200 m^3/s and water level from 8 m to 9.5 m PWD. It was found that during flood period sediment transport rate increased almost 50% than that of dry period. On an average cumulative erosion of the deep channel within the study area ranges from 0.05 m - 0.10 m and the sedimentation of the sides of the channel ranges from 0.20 m-0.25 m. Chloride concentration showed seasonal decreasing trend from 0.22 ppt during dry period to 0.07 ppt during flood period. It is hoped that this study will help in understanding the hydro-morpho dynamic nature of the river and will help the river regulation authority to undertake appropriate future developments projects.

Introduction

The Gorai River catchment area is 15160 km^2 and is located between 21° 30′ N to 24° 0′ N latitude and 89° 0′ E to 90° 0′ E longitude, covering partly or fully areas of Pabna, Chuadanga, Kushtia, Rajbari, Faridpur, Gopalgonj, Jessore, Jhenaidah, Magura, Norail, Pirogpur, Borguna, Bagerhat, Khulna and Sathkhira districts of South-Western region of Bangladesh. The river takes off from the Ganges at Talbaria, north of Kushtia town and 19km downstream from the Hardinge bridge and discharges into the Bay of Bengal through the Madhumati and Baleswar Rivers (Islam and Gnauck 2011). The river course is wide, long, meandering and is known to adjust its slope, width, depth and velocity to achieve stable conditions at a specified supply of water and sediment (BWDB 2011).

Being a riverine country, Bangladesh is bestowed upon by the innumerable resources from the rivers. From the time immemorial, rivers have played their part in forming the lifeline for the country, which only recently is facing problems due to natural and anthropogenic reasons. In general diversion of river flow in the upstream, salinity intrusion, excessive sedimentation causing navigability

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disturbance and consequent flooding are the major problems relating to rivers in our country (Shamsad et al. 2014). Most rivers in South-Western region (SWR) of Bangladesh depend on water flow from Ganges River. Many of the branches of Ganges River are blocked off from Ganges River due to the water intake at the upstream Indian Farakka Barrage that was built in 1975. Thus the flow volume declines during the dry-season and it impacts the region including coastal areas and Sundarbands (Banglapedia 2015).

Gorai River, a branch of Ganges River, is one of the major sources of freshwater supply to SWR and is the only one remaining branch river. However, in at least these twenty years, its flow volume in the dry-season (December – April) has been declining considerably (Islam 2005). It has a serious environmental impact: especially along the coastal areas around the sanctuary forests where the salty water has increasingly been intruding. This study has been conducted being motivated by the fact that the Gorai river is immensely important for water supply in the south-western region of Bangladesh and the brewing problems of low flow and increased sediment deposition.

Being an important watercourse for Bangladesh, Gorai River has drawn attention of different national and international researchers and organizations. Islam and Karim (2001); Clijncke (2001) and Sarker (2002) tried to predict the downstream hydraulic geometry of the Gorai river, morphological changes due to dredging and morphological changes in response to the declining flow. Islam and Gnauck (2012) studied on water shortage in the Gorai river basin and damage of mangrove wetland ecosystem in sundarbans. Horeet (2013) under Centre for Environmental and Geographic Information services (CEGIS) focused in his study on the morphological development of Gorai river off-take for the restoration of the river flow. Several modelling studies have been conducted to understand the river behaviour. Kader (2000) studied on effectiveness of pilot dredging in the Gorai River in which effectiveness of the pilot dredging has been studied on the basis of pre dredging and post dredging bathymetry using MIKE 21C. Biswas and Ahammed studied on hydrodynamic characteristics of the river Gorai using CCHE 2D.

Delft3D is a powerful tool for understanding and predicting the river hydro-morpho dynamic behaviour. It is a fully integrated modelling framework that can be used for the computation of flow, sediment transport, waves, water quality including particle tracking such as oil spill and dredging plume modelling. Delft3D solves the two-dimensional depth-averaged flow equations. As Delft3D is essentially comparable to many other hydrodynamic models, these analyses can be used to understand the capabilities of numerical models to simulate river hydrodynamics.

In this study, understanding the predicament of river Gorai in particular, efforts have been ensued to address the hydrodynamic, sediment and salinity analysis of the river with the specific objectives of

- Development of a hydrodynamic, morphological and salinity model of a 25 km reach of the River Gorai.
- To assess the Hydrodynamic parameters namely velocity, discharge and water level
- To assess morphological parameters including the total sediment load and the cumulative erosion-deposition and
- To assess the salinity parameters including only the chloride concentration for the study reach.

Methodology

Selection of study area

Figure 1 shows the Google map of the study area. The study area covers about 25 km reach of the Gorai River flowing from 10 km downstream from the Ganges-Gorai offtake within the kushtia district to the 5 km upstream of the Kamarkhali transit within the Kumarkhali upazilla.

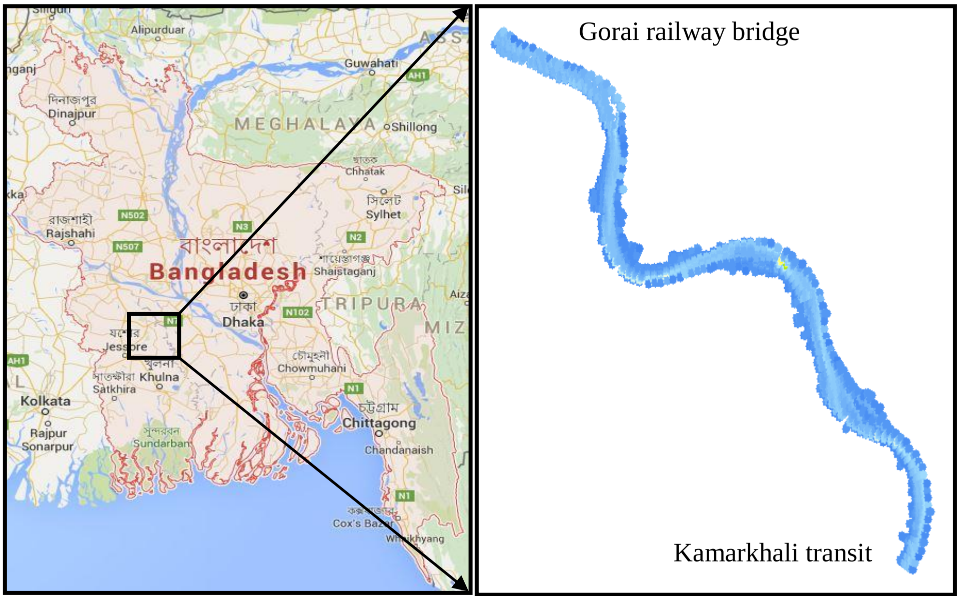

Figure1. Map of the study area (Source: Google images 2015)

Data collection

Data collected for conducting the study are summarized in Table 1.

Table 1. Types and sources of data

Data	Location/ID	Period	Source
Cross-section	25 km reach (GOR-1 to GOR-150)	2010	BWDB
Discharge	Gorai Railway Bridge (SW-99)	2000-2014	BWDB
Water Level	Kamarkhali (SW-101) and Kamarkhali transit (SW-101.5)	2010	BWDB
Sediment	Hardinge bridge (SW-91) and Kamarkhali transit (SW-101.5)	2000-2010	BWDB
Salinity	Amalsar (SW-100) and Kamarkhali transit (SW-101.5)	2000-2010	BWDB

Analysis of flow, salinity and sediment trend of the Gorai River

The average flood flow of the river is 4,500 m^3/s (monsoon period) and the annual average sediment transport is about 50 million tons in which about 40% are fine sand and the rest amount consists of silt and clay. (GRRP-Phase-II, 2014), Discharge data has been processed to obtain the mean annual discharge from 2000 to 2014. It showed that the mean annual flow volume has decreased from 2000 m^3/s to below 500 m^3/s over the last ten years. Due to reduction in flow, sediment concentration shows an increasing trend, which is indicative to riverbed siltation. Salinity data of last ten years show that the maximum Chloride concentration at Gorai Railway Bridge is 260 ppm. Though the concentration is well below the sea salinity (35000 ppm), reduced dry season flow and clogging of the River at off-take, salinity along the Nabaganga-Rupsha-Passur system has largely been influenced. Figure 2(a) shows a clear declining trend of mean annual discharge and Figure 2(b) shows an increasing trend of Gorai river salinity over time. Figure 3(a) and (b) shows increasing trend of sand concentration at two stations namely Gorai railway bridge and Kamarkhali transit for the year 2002 and 2005 respectively.

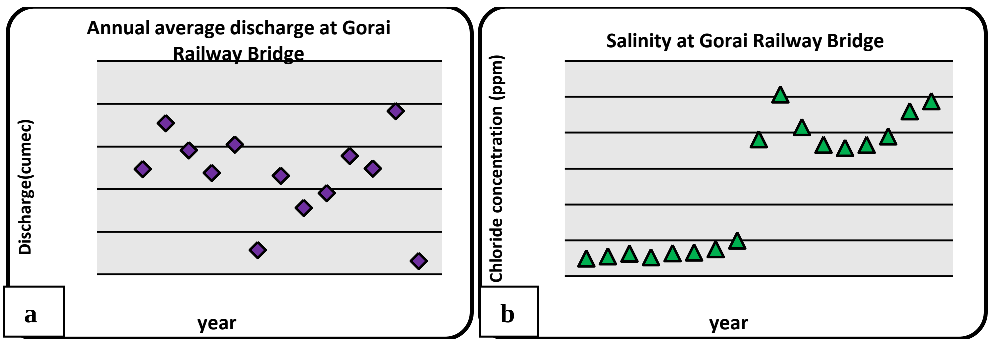

Figure 2. (a) Declining trend of mean annual discharge and (b) Increasing trend of Gorai river salinity

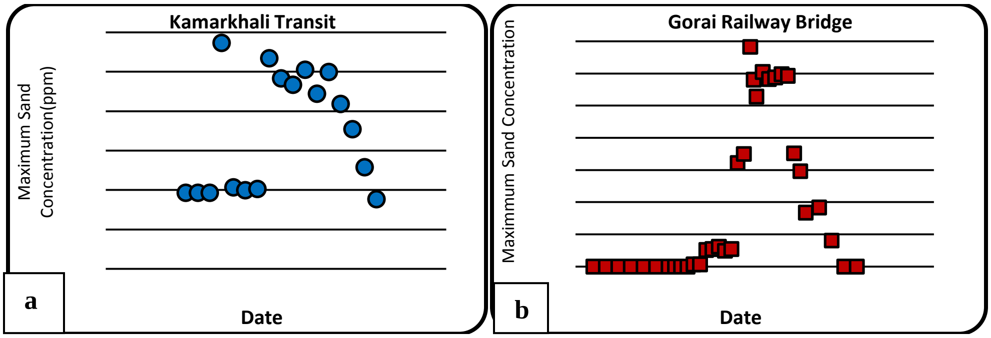

Figure 3. (a) Increasing trend of sand concentration at Kamarkhali transit and (b) Increasing trend of sand concentration at Gorai Railway Bridge

Model schematization

Grid generation

Figure 4 shows the generated grid of the model. In this study a curvilinear grid has been created by simulating a numerical model for 25 km river reach with an average width of 800 m; started from 6 km downstream from the Ganges-Gorai off-take and ended at the kamarkhali transit. The reach was discretized by 720×36 (m×n) grid cells. The average dimension of each grid cell was approximately 40m×40m.

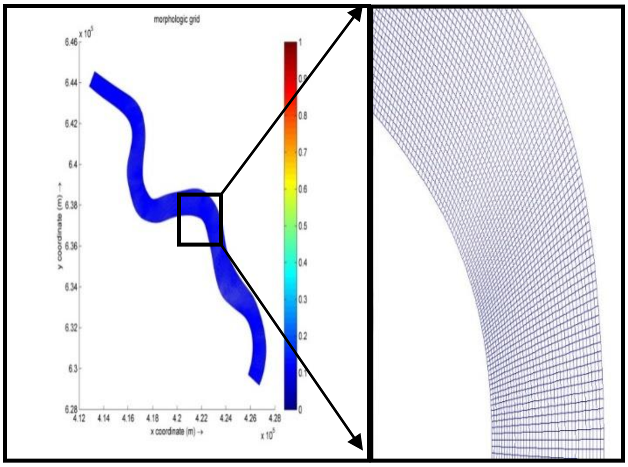

Figure 4. Hydro-morpho dynamic grid of the model

Depth generation

Figure 5 shows the depth and initial bathymetry of the model. After developing the study area with good quality grids, collected cross section data were processed to prepare sample and were imported into the mesh nodes, afterwards it has been interpolated and diffused using triangular interpolation and internal diffusion toolbars to obtain a spatially varying depth file. Bathymetry data was collected during the monsoon period of the year 2010 measured with respect to the PWD datum. 120 cross sections at approximately 200 m interval have been used for the setup of the initial bathymetry of the model.

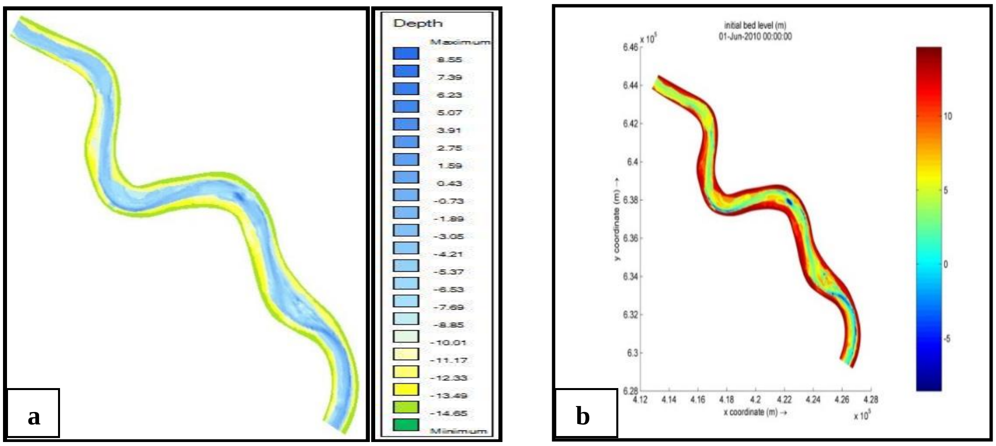

Figure 5. (a) Depth of the study area (b) Initial bed level of the model

Boundary conditions for calibration and validation

Figure 6 shows the upstream and downstream boundary conditions for the calibration and validation of the hydrodynamic model setup. Both flow peaks attained in that particular year during the month of September.

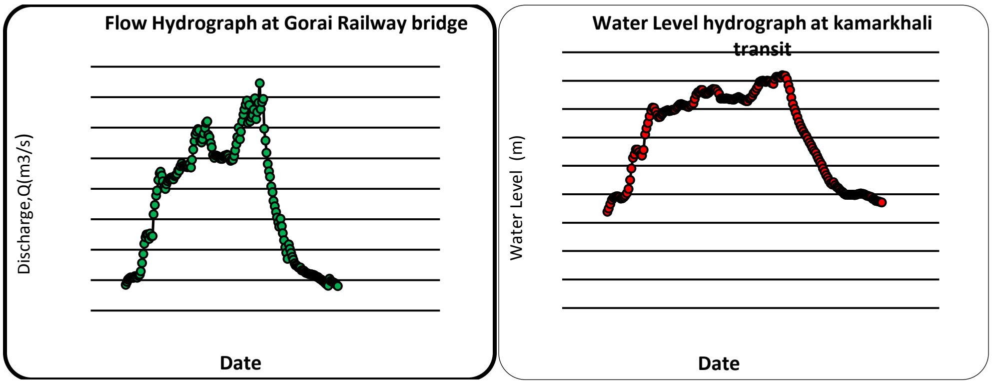

Figure 6. Boundary conditions of the model

The model was simulated for 6 months only from the 1st of June, 2010 to 30th of November, 2010. As the upstream boundary the discharge data of Gorai railway bridge (SW-99) was considered and the water level of Kamarkhali Transit (SW-101.5) was chosen as the downstream boundary.

Calibration and validation of the hydrodynamic model

Figure 7 shows the water level calibration result of the model. For hydrodynamic calibration, computed water surface elevations have been compared with the observed water surface elevations at Kamarkhali station (SW-101). Roughness and eddy viscosity are the parameters that have been used to play to obtain an adequate match with the observed field conditions in the present study. Manning’s roughness coefficient has been adjusted after several trial of the model during calibration to an average value of n = 0.025, the value of eddy viscosity has been considered as 10.0 m^2/s.

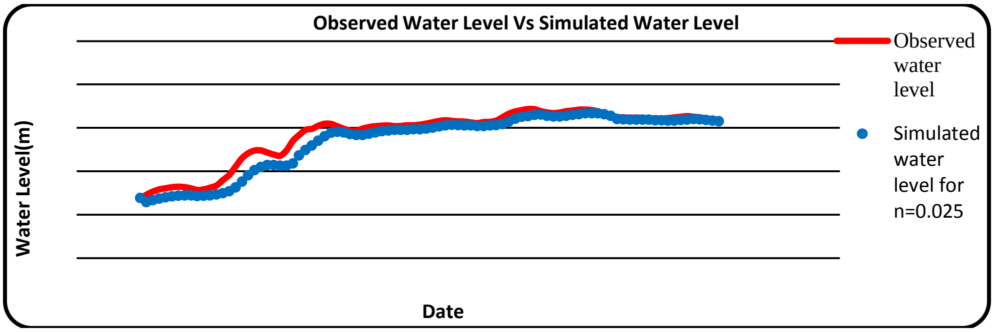

Figure 7. Calibration of the numerical model

Figure 8 shows the validation graph. The model was validated at the Kamarkhali for the period 1st of September to 30th of November that shows a good agreement with the observed data. This result indicates that the model predicted the water level well for the lower discharge condition rather than the peak of the hydrograph.

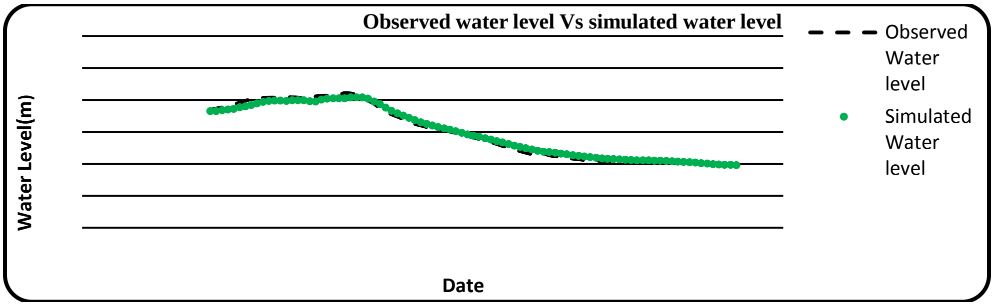

Figure 8. Validation of the numerical model

Calculation of model efficiency

In this study the Root Mean Square Error (RMSE) has been used for the calculation of error and the Nash Sutcliffe coefficient (E) formula has been utilized to calculate the model efficiency. Simulation has been performed for various values of manning's roughness, n and corresponding degree of error of the simulation to the observed data has been plotted to obtain the trial value with minimum error and maximum efficiency. Both of the graphs of Figure 9 shows that the % efficiency is maximum and the RMSE value is minimum for the trial of n = 0.025.

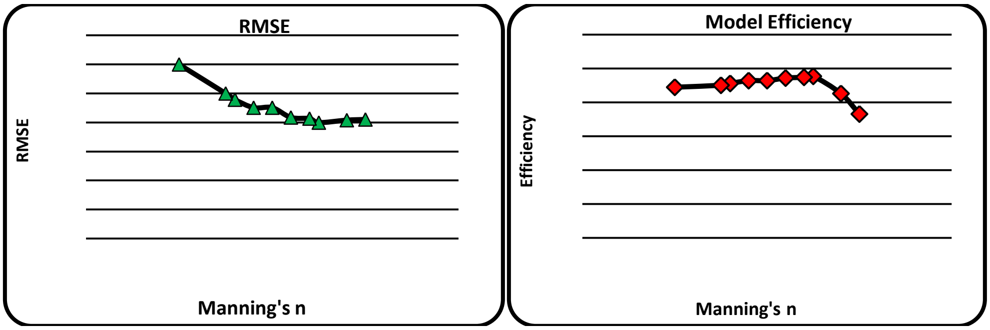

Figure 9. Model error and efficiency

Sediment transport modeling

In this section Delft3D Flow and the DELFT 2D-MOR module have been used for morphological simulation for the year 2010 (1st January to 31st December). Mean sediment diameter (D50) has been taken assumed as 0.150 mm and as the sediment boundary the monthly average sediment data for the year 2010 was given as the input which is shown in Table 2 and Table 3.

Table 2. Upstream and downstream boundary sediment load

Month	Total sediment Load(kg/s)	
	Upstream boundary	Downstream boundary
January	29.579	1.2
February	13.606	2
March	17.148	2.05
April	15.105	2.35
May	22.468	2.4
June	41.512	5.176
July	69.888	12.325
August	89.815	48.434
September	67.884	53.824
October	31.009	40.79
November	17.967	10.73
December	13.474	1.26

Salinity modeling

Delft3D Flow module with salinity process has been used for salinity modeling for the year 2010 (1st January to 31st December). Table 4 and Table 5 shows the boundary conditions for the salinity modelling

Table 3. Upstream and downstream boundary sediment load

Month	Monthly average Chloride concentration (ppt)	
	Upstream boundary	**Downstream boundary**
January	0.1792	0.183
February	0.182	0.161
March	0.2013	0.18825
April	0.2205	0.18925
May	0.2013	0.187
June	0.1556	0.1863
July	0.08	0.13
August	0.07	0.09
September	0.065	0.07
October	0.09	0.092
November	0.177	0.16875
December	0.1796	0.1842

Defining the monitoring points for analysis

Figure 10 defines the monitoring points which have been used for observing simulated velocities, discharge, water level, total sediment transport, cumulative erosion and deposition as well as the salinity concentration. The monitoring points are named as bend 1, bend 2, bend 3, bend 4, bend 5 from upstream to downstream respectively as shown in Figure 10.

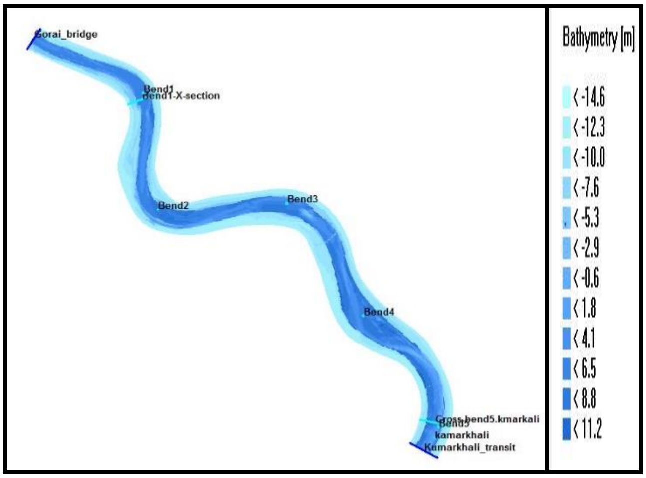

Figure 10. Monitoring points and cross sections

Results and discussion

Analyses of hydrodynamic parameters of study reach

Velocity

Figure 11 and Figure 12 shows the spatial distribution of the simulated depth averaged velocities in m/s. The Figures visualize the changing pattern along the reach during the dry and wet season respectively.The month of january represents the dry period and the month of September represents the wet period.

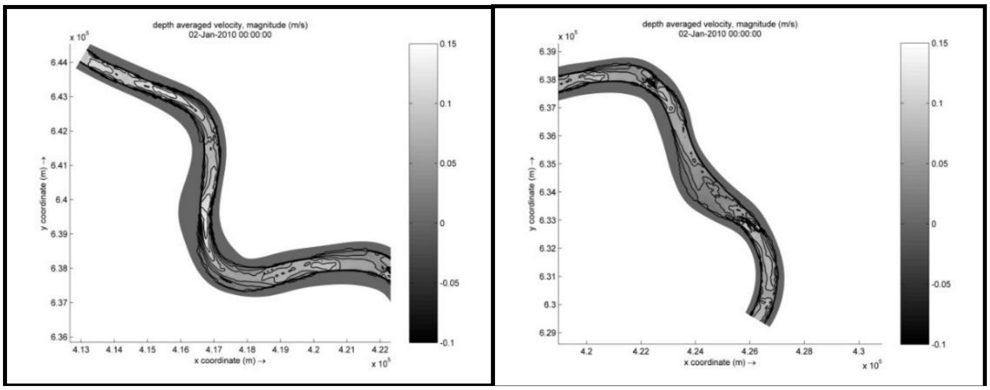

Figure 11. Simulated depth averaged velocity for dry period (January)

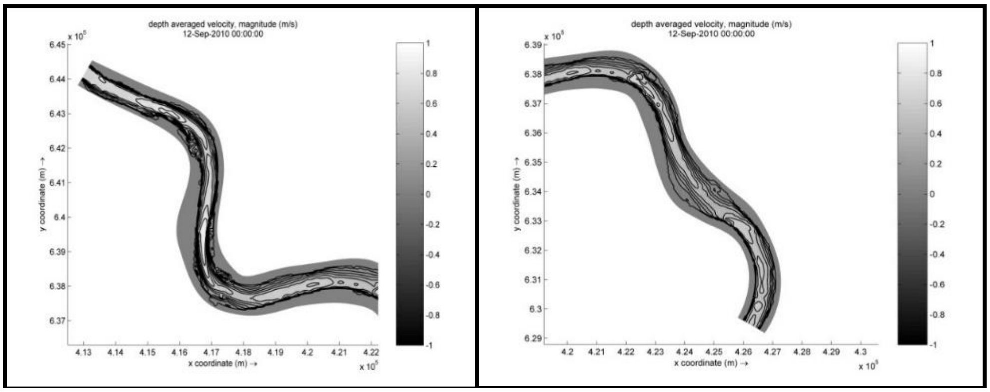

Figure 12. Simulated depth averaged velocity for flood period (September)

Simulated velocity distribution depicts that the peak velocity ranges from 0.7 m/s to 0.9 m/s during the flood period and the magnitude lies between 0.1 to 0.25 m/s during the period of lean flow. Trough and peak magnitudes of the velocities showed that change in velocity along the reach varies from 4%-7% indicating the higher velocity at the upstream areas and decreasing towards downstream. Flow velocity along the study reach decreases due to the changing fluvial processes but the percentage change is not so significant due to small length of the study area.

In progress report number-26 of the feasibility study under Gorai River Restoration Project (GRRP-II), Institute of Water Modeling through comprehensive model test in MIKE 21C found that the flow velocity in upper Gorai river ranging from Goraioff-take to Gorai Railway Bridge was 0.943 m/s for the year 2012-2013 during the month of September and the velocity falls to 0.15 m/s during the dry season for the same time consideration.

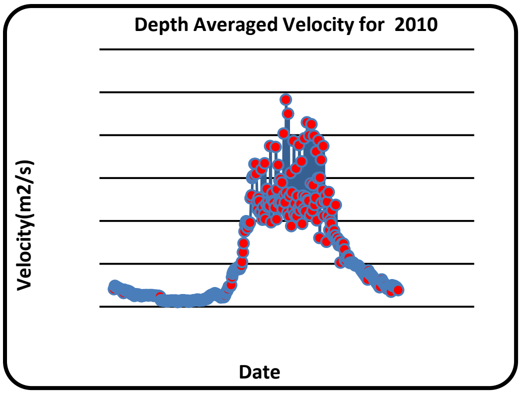

Figure 13. Simulated depth averaged velocity for 2010

From this observation it can be concluded that taking an average of the simulated velocities of the monitoring points to represent the average velocity of the reach of 25 km would not cause much deviation in accuracy. Figure 13 shows simulated velocity profile averaged for the 25 km reach including the monitoring points for the year 2010.

Discharge

Figure 14 (a) and (b) shows the spatial distribution of the depth averaged unit discharge during dry and wet season respectively. Simulated depth averaged discharge distribution depicts that the magnitude ranges from 0.5 m^2/s to 1 m^2/s during the dry period of the year 2010 and 8 m^2/s to 10 m^2/s during the flood period.

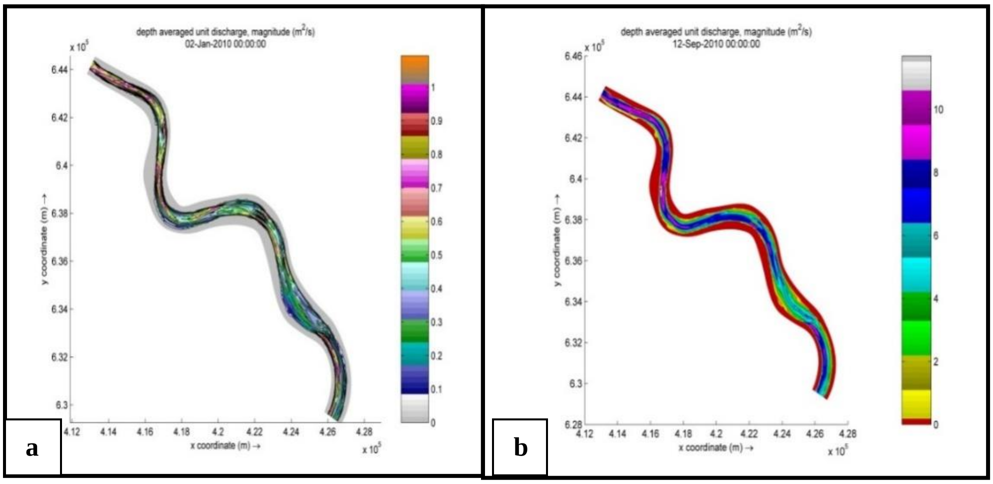

Figure 14. Depth averaged unit discharge (a) during dry period; (b) during wet period

Simulated discharges at 5 different monitoring points are plotted to visualize the changing pattern and the length-wise difference in magnitude of discharge. Figure 15 shows the simulated instantaneous discharge along the study reach at 5 monitoring points. Simulated discharge during the flood period ranges from 2800 m^3/s to 4200 m^3/s. Trough and peak magnitudes of the discharge show that change in discharge along the reach varies from 12%-17% with maximum discharge at the bend 1 (1st monitoring point) and minimum at bend 5 (5th monitoring point). In progress report number-26 of the feasibility study under Gorai River Restoration Project (GRRP-II), Institute of Water Modeling through comprehensive model test in MIKE 21C found that the flow discharge in upper Gorai river ranging from Gorai off-take to Gorai Railway Bridge was 3343 m^3/s for the year 2012-2013 during the month of September and the value falls to 250 m^3/s during the dry season for the same time consideration.

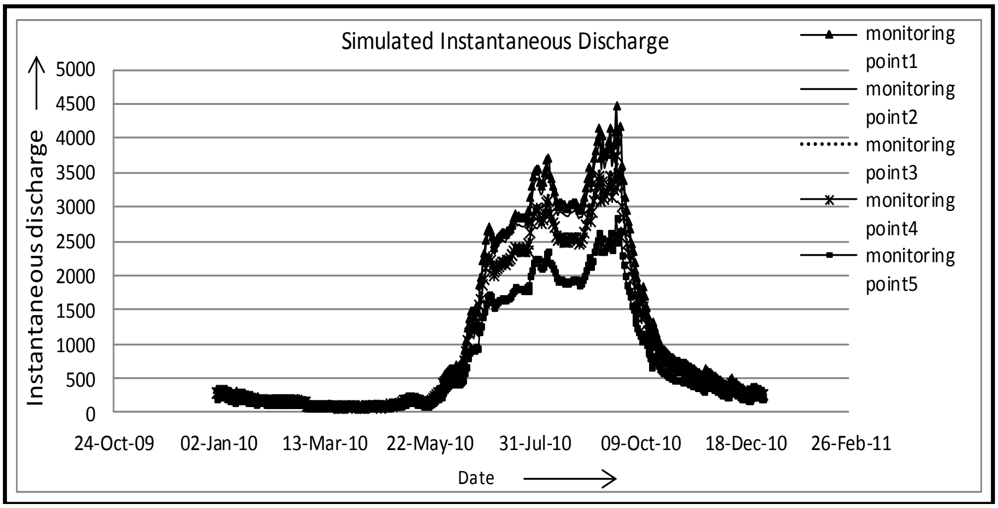

Figure 15. Simulated instantaneous discharge along the study reach at 5 monitoring points

Water level

Simulated water levels at 5 different monitoring points were plotted to visualize the changing pattern and the length-wise difference in magnitude. Figure 16 shows the simulated water levels at 5 monitoring points. Water depth increases along the reach as the flow velocity and discharge decreases along the reach. But the simulated water levels showed a decreasing pattern along the reach as the bed level lowers along the bathymetry at an average slope due to land topography. During dry period simulated water level varies from 2 m to 3.5 m and the level rises to 8 m to 9.5 m during flood period.

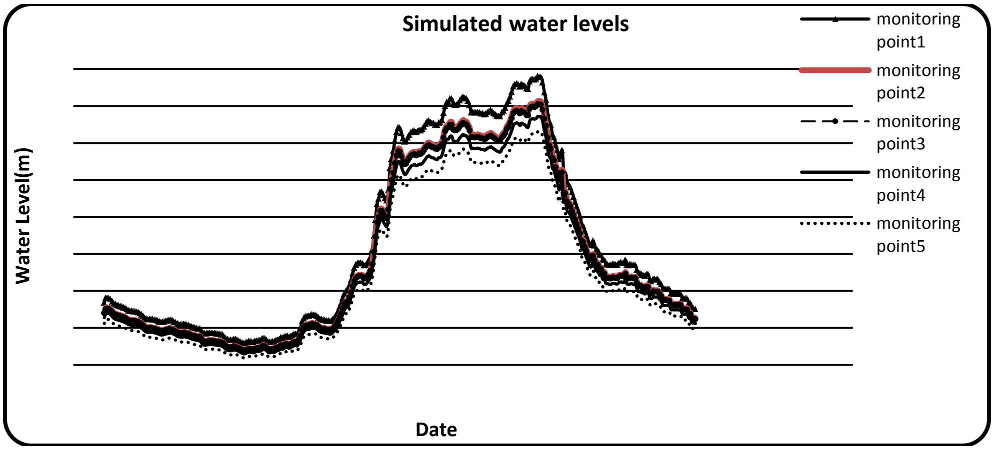

Figure 16. Simulated water levels at five monitoring points

Analyses of sediment transport of study reach

Total sediment transport

Figure 17 shows the simulated sediment transport rate along the study reach. Discharge and flow velocity are of major importance to determine whether deposition or erosion will occur. A general increase can usually be observed in suspended sediment concentration with increasing water discharge (A Guide to Use of Biota, Sediments and Water in Environmental Monitoring 2ndedition). Along downstream the channel decreases due to retarding flow velocity, which causes the decrease of total sediment transport of the channel. The simulated sediment transport rates follow the decreasing pattern along the reach. During the period of lean flow sediment transport rate varies from 0.07 kg/s to 0.125 kg/s and the transport rate rises to 0.22 kg/s during the peak flow season

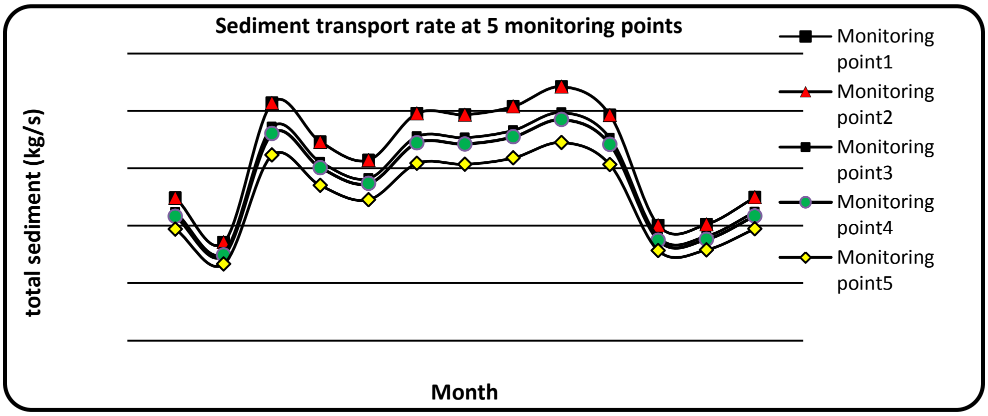

Figure 17. Simulated sediment transport rate along the study reach

It is evident from Figure 19 shown below that in case of natural bathymetry, erosion occurs along the deepest channel (thalweg) and the deposition of sediment occurs near the bank lines. On an average cumulative erosion of the deep channel within the study area ranges from 0.05 m - 0.10 m and the sedimentation of the sides of the channel ranges from 0.20 m - 0.25 m. During the dry period of the year 2010 (mostly in January) change in cumulative sediment deposition along the study reach is minor due to very less discharge. It is evident from the figures of cumulative erosion and deposition that the zones with higher velocity carry more sediment than the other zones.Table 6 shows the cumulative erosion and deposition during the wet and dry season.

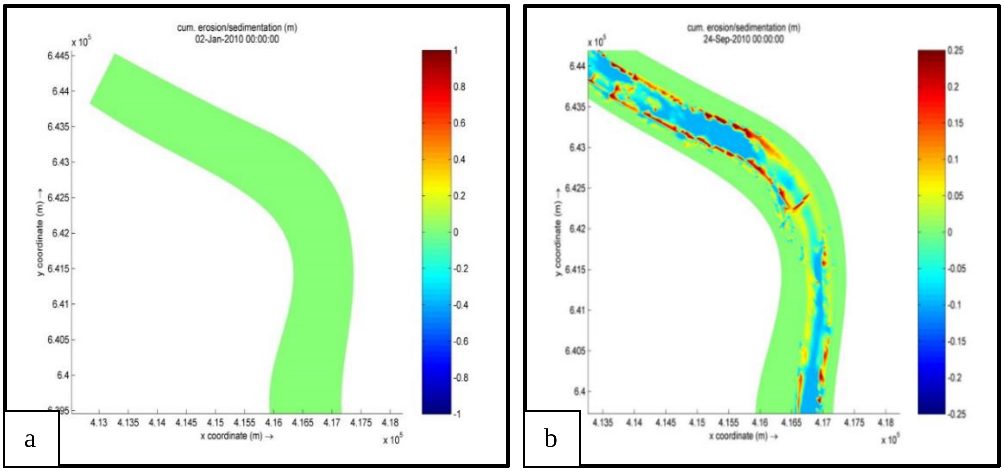

Figure 18. Cumulative erosion sedimentation (a) Dry period; (b) Wet period

Table 6. Net erosion-sedimentation

Season	Cumulative erosion (m)	Cumulative sedimentation (m)
dry	0.0	0.18
Wet	0.15	0.15

Salinity concentration

Chloride concentration

To represent the salinity along the study reach only the chloride concentration has been considered. Figure 19 shows that the reach wise variation in chloride concentration indicating that the values are well below the sea salinity. Chloride concentration is the maximum (0.22 ppt) during the month of January and February and falls to the value of 0.07 ppt during the monsoon flow. Spatial variation of the concentrations at 5 monitoring points for the year 2010 is plotted in Figure 20 that depicts that the concentration variation is negligible at the upper Gorai reach.

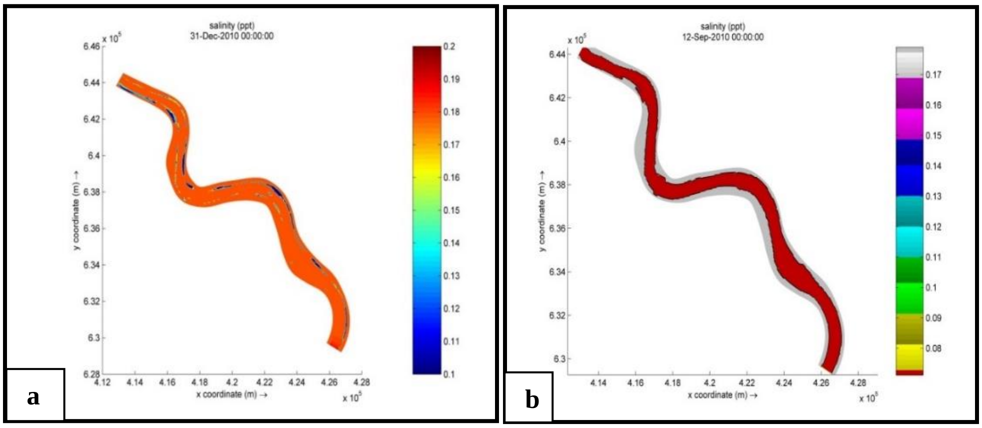

Figure 19. Chloride concentration (a) Dry period; (b) Wet period

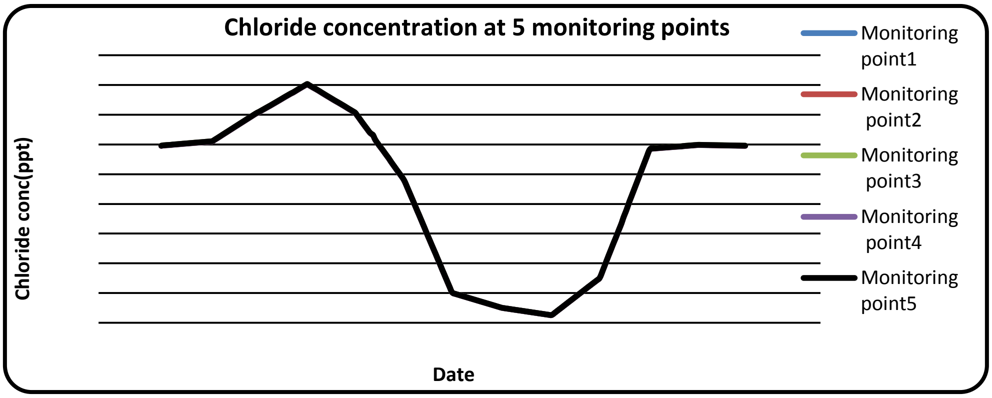

Figure 20. Simulated chloride concentration at five monitoring points

Conclusion

Numerical modeling technique of Delft3D has been applied in this study in case of a 25 km reach of Gorai river extending from Gorai Railway Bridge to Kamarkhali. April 2010 field data of bed level has been taken as reference bed level and the discharge, water level, sediment and salinity data of the corresponding year have been taken as the boundary conditions. The model has been verified by calibrating and validating with the help of iteration of the calibration parameters manning's n and morphological scale factor, Morfac. A value of n = 0.025 and Morfac = 10 was found to be most efficient while comparing the simulated and observed data set. At 5 different monitoring points, different simulated hydrodynamic parameters (Velocity, Discharge and Water level), morphological parameters (Cumulative sedimentation- erosion, total sediment load) and salinity parameter (Chloride concentration) were observed and recorded. The hydrodynamic, morphology and salinity analysis showed that simulated velocity, discharge and sediment flow had been 0.1 m/s-0.25 m/s, 200 m3/s - 400 m3 /s, 0.07 kg/s - 0.125 kg/s. The water level showed decreasing trend towards downstream and found to be 2m-3.5m. Modeling results also reveal that in the flood period, velocity ranged from 0.7 m/s-0.9 m/s, discharge from 2800 m3/s to 4200 m3/s and water level from 8m to 9.5 m. It was found that during flood period sediment transport rate increased almost 50% than that of dry period. On an average cumulative erosion of the deep channel within the study area ranges from 0.05 m - 0.10 m and the sedimentation of the sides of the channel ranges from 0.20 m - 0.25 m. Chloride concentration showed seasonal decreasing trend from 0.22 ppt during dry period to 0.07 ppt during flood period. It is hoped that this study will help in understanding the hydro-morpho dynamic nature of the river and will help the river regulation authority to undertake appropriate future developments projects.

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