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A STUDY ON HYDRODYNAMIC AND MORPHOLOGICAL BEHAVIOR OF GORAI RIVER USING DELFT 3D

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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 Delft 3D. 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, 200m3/s-400 m3 /s, 0.07 kg/s -0.125 kg/s respectively. 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. 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.

Keywords: *Gorai River, Delft 3D, Hydrodynamic, Morphological, Salinity*

1. INTRODUCTION

Bangladesh is a riverine country. It is bestowed upon by the innumerable resources from the rivers, being part of three major river systems of South Asia, namely, the Ganges-Padma, the Brahmaputra- Jamuna and the Meghna. From the time immemorial, rivers have played their part in forming the life line for our 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 disturbance and consequent flooding are the major problems relating to rivers in our country (Shamsad, Islam and Mahmud, 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 (FAP,1994). 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 (Tarekul and Rezaul, 2005). It has a serious environmental impact: especially along the coastal areas around the sanctuary forests where the salty water has increasingly been intruding. In December 1996, the Bangladesh government decided to implement "Gorai River Restoration Project (GRRP)" to meet the urgent need of dredging Gorai River to restore the dry-season's flow volume in SWR and the regional ecological balance. 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.

The Gorai River catchment area is 15160 km² 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). This River is an alluvial river and perennial in nature. Its 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 an important water course 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 offtake 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 MIKE21C. Biswas and Ahammed studied on hydrodynamic characteristics of the river Gorai using CCHE 2D. 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 no study on Gorai river using Delft3D has been performed yet. Delft 3D 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-RGFGRID, 2011). Delft3D solves the two-dimensional depth-averaged flow equations (Delft3D-FLOW, 2011). 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.

1.1 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 10km downstream from the Ganges-Gorai offtake within the kushtia district to the 5 km upstream of the Kamarkhali transit within the Kumarkhali upazilla.

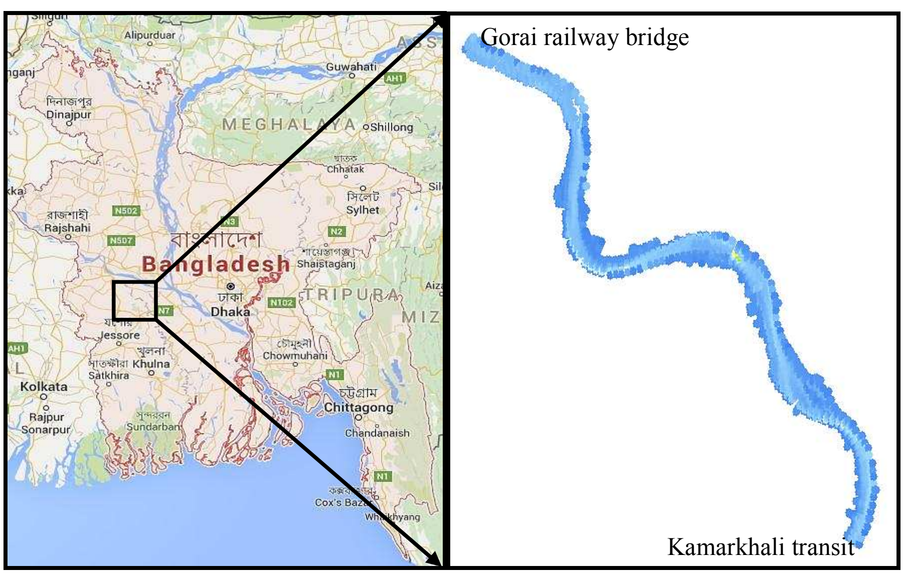


Figure1: Map of the study area(Source:Google)

1.2 Data Collection

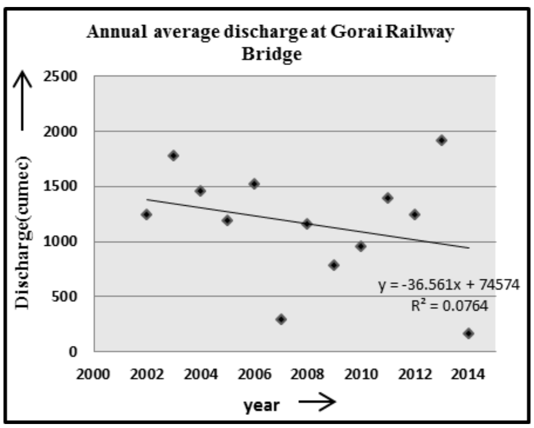
Data collected for conducting the study are summarized in Table-1.

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

1.3 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 below500 m^3/s over the last ten years. Due to reduction in flow, sediment concentration shows an increasing trend which is indicative to river bed 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.



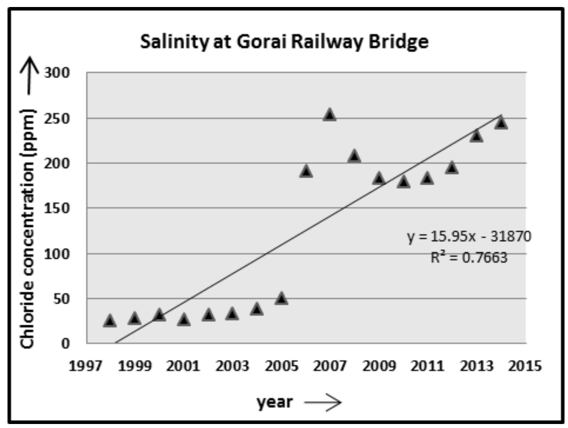
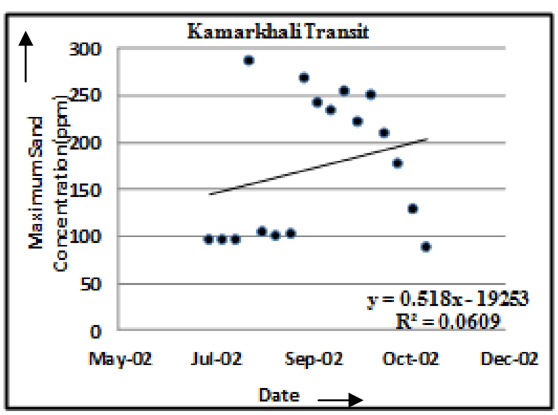


Figure 2(a): Declining trend of Mean annual discharge

Figure 2(b) Increasing trend of Gorai river salinity



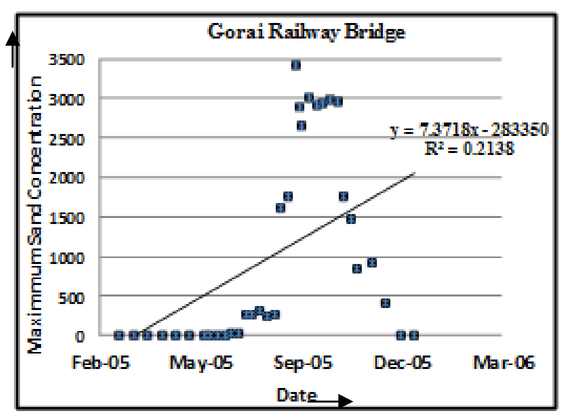


Figure 3(a): Increasing trend of Sand concentration at Kamarkhali transit

Figure 3(b): Increasing trend of Sand concentration at Gorai Railway bridge

1.4 Model Schematization

Figure 4 shows initial bathymetry 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. The reach was discretized by 720*36(m*n) grid cells. The average dimension of each grid cell was approximately 40m*40m. 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 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.

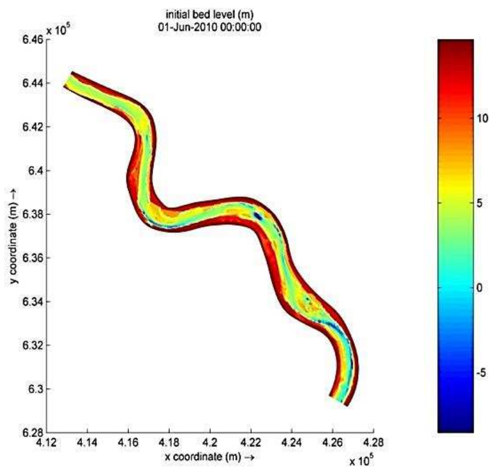


Figure 4: Initial bed level of the model

1.5 Calibration and Validation of the Hydrodynamic Model

Figure 5 and Figure 6 shows the water level calibration and validation result of the model respectively.

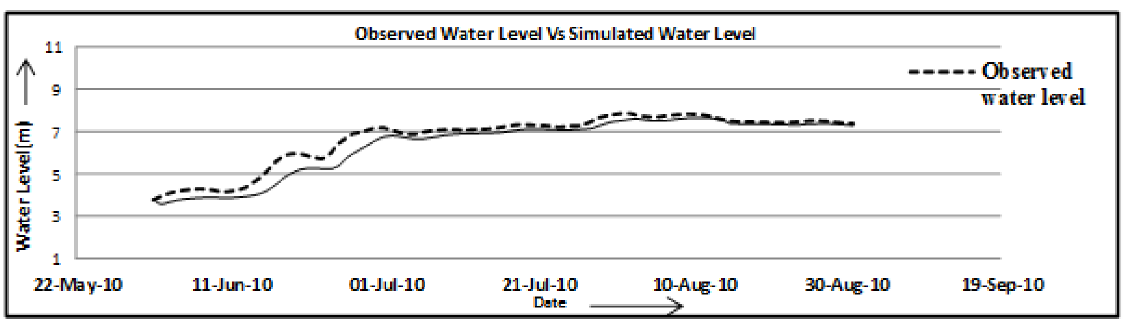


Figure 5: Calibration of the numerical model

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 as10.0 m^2/s. 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.

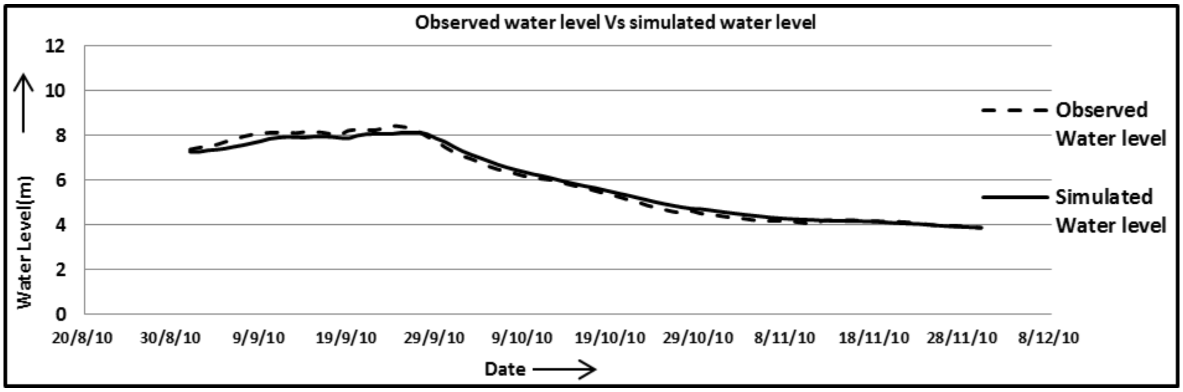


Figure 6: Validation of the numerical model

1.6 Sediment Transport Modelling

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 Boundary Sediment load

Month	Total sediment Load(kg/s)
January	29.579
February	13.606
March	17.148
April	15.105
May	22.468
June	41.512
July	69.888
August	89.815
September	67.884
October	31.009
November	17.967
December	13.474

Table 3: Downstream Boundary Sediment load

Month	Total sediment Load(kg/s)
January	1.2
February	2
March	2.05
April	2.35
May	2.4
June	5.176
July	12.325
August	48.434
September	53.824
October	40.79
November	10.73
December	1.26

1.7 Salinity modelling

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

Table 4: Upstream Boundary Sediment load

Month	Monthly average Chloride Concentration(ppt)
January	0.1792
February	0.182
March	0.2013
April	0.2205
May	0.2013
June	0.1556
July	0.08
August	0.07
September	0.065
October	0.09
November	0.177
December	0.1796

Table 5: Downstream Boundary Sediment load

Month	Monthly average Chloride Concentration(ppt)
January	0.183
February	0.161
March	0.18825
April	0.18925
May	0.187
June	0.1863
July	0.13
August	0.09
September	0.07
October	0.092
November	0.16875
December	0.1842

1.8 Defining the monitoring points for analysis

Figure 7 defines the monitoring points which have been used for observing simulated velocities, discharge, water level, total sediment transport, cumulative erosion and deposition and 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 7.

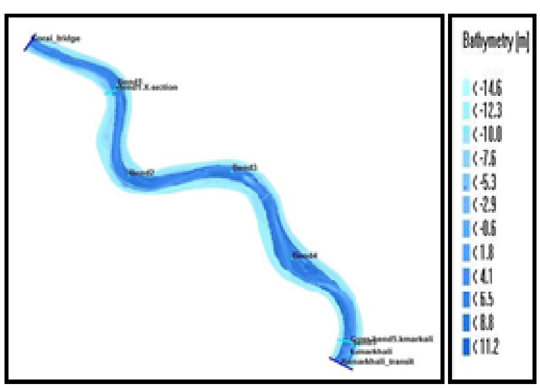


Figure 7: Monitoring points and cross sections

2. RESULTS AND DISCUSSION

2.1 Analysis of Hydrodynamic Parameters of Study Reach

2.1.1 Velocity

Figure 8 and Figure 9 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.

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 Gorai offtake 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. 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 10 shows simulated velocity profile averaged for the 25 km reach including the monitoring points for the year 2010.

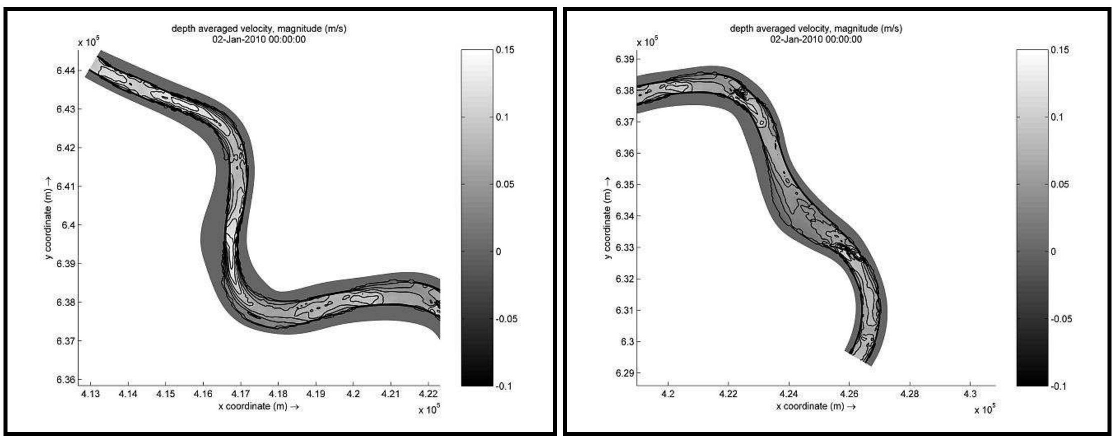


Figure 8: Simulated depth averaged velocity for dry period (January)

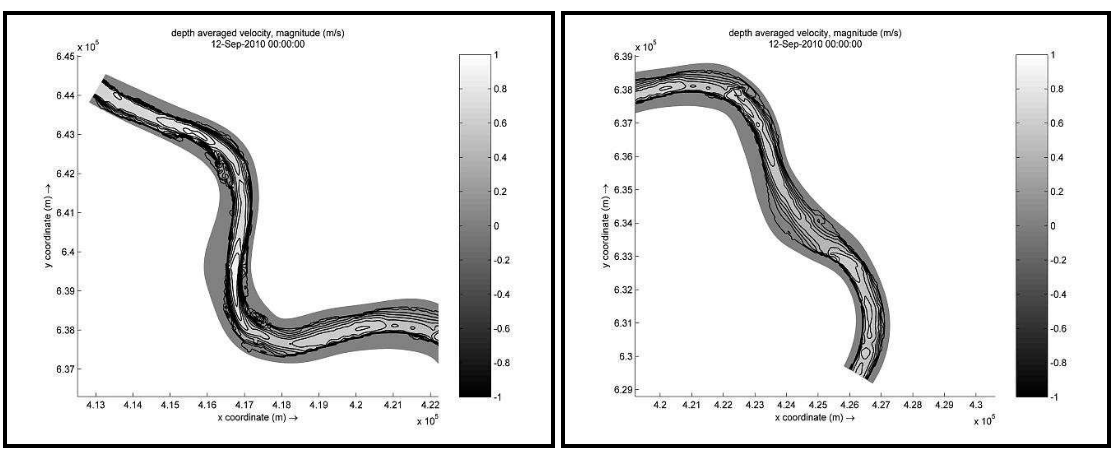


Figure 9: Simulated depth averaged velocity for flood period (September)

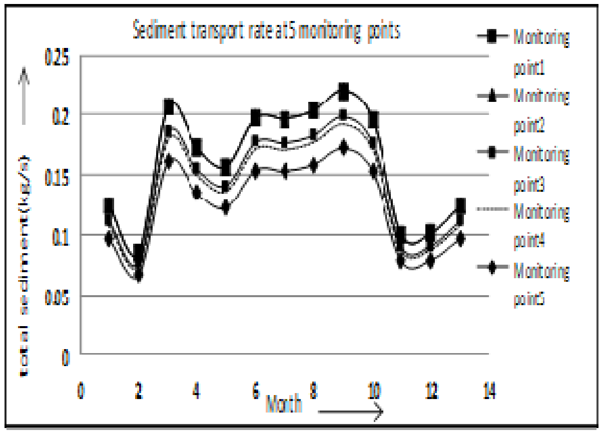
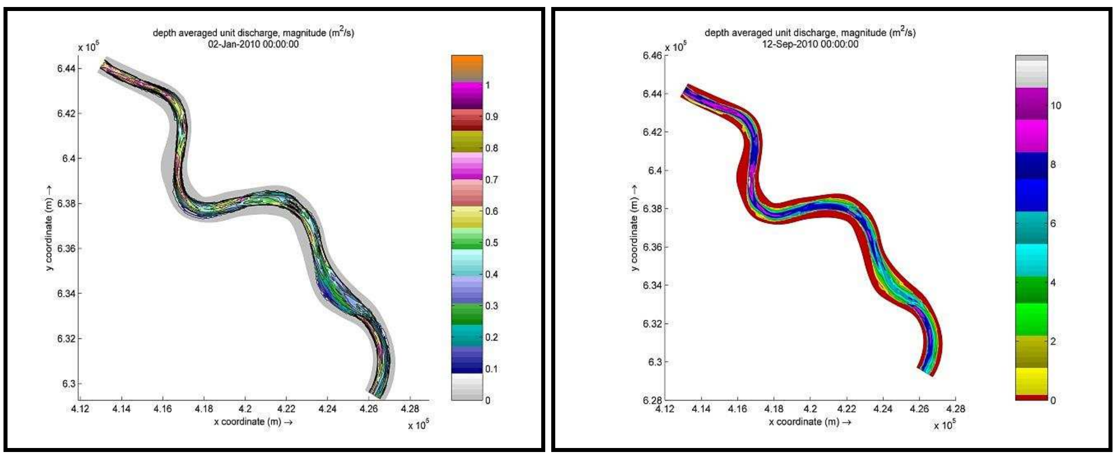


Figure 10: Simulated depth averaged velocity averaged for 5 monitoring points

2.1.2 Discharge

Figure 11(a) and (b) show 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.



(a) (b)

Figure 11: 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 12 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 offtake 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.

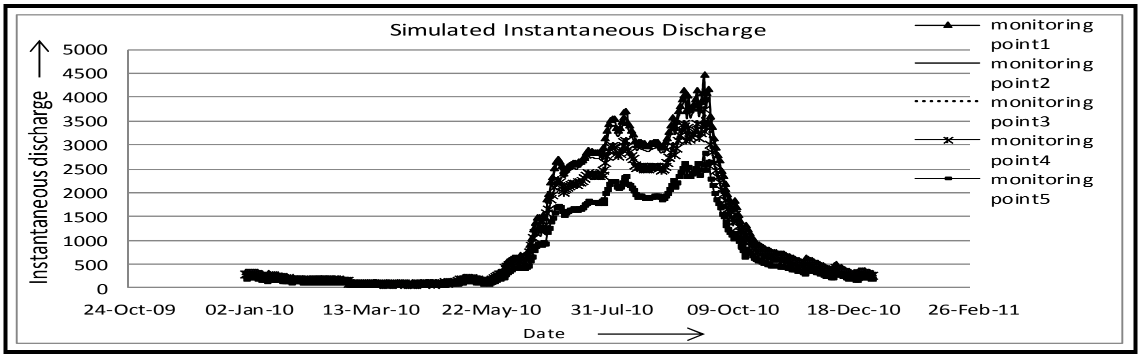


Figure 12: Simulated instantaneous discharge along the study reach at 5 monitoring points.

2.1.3 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 13 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 8m to 9.5 m during flood period.

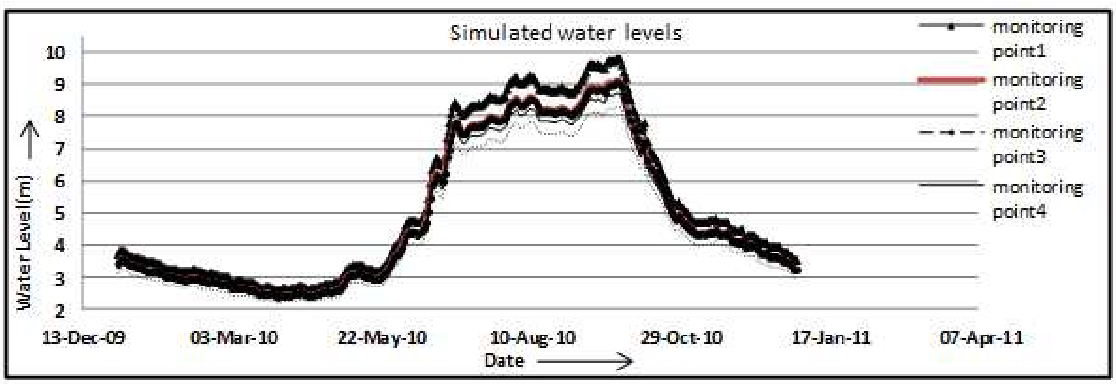


Figure 13: Simulated water levels at 5 monitoring points

2.2 Analysis of Sediment transport of Study Reach(Total Sediment Transport)

Figure 14 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 2nd edition). 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.

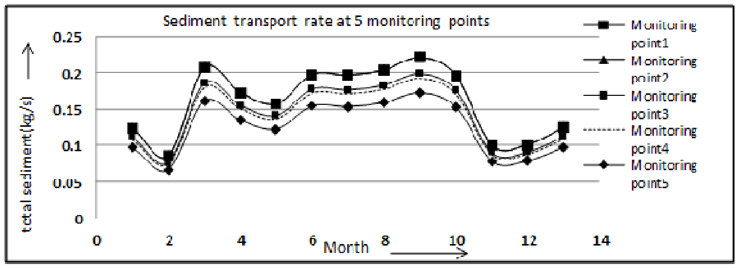
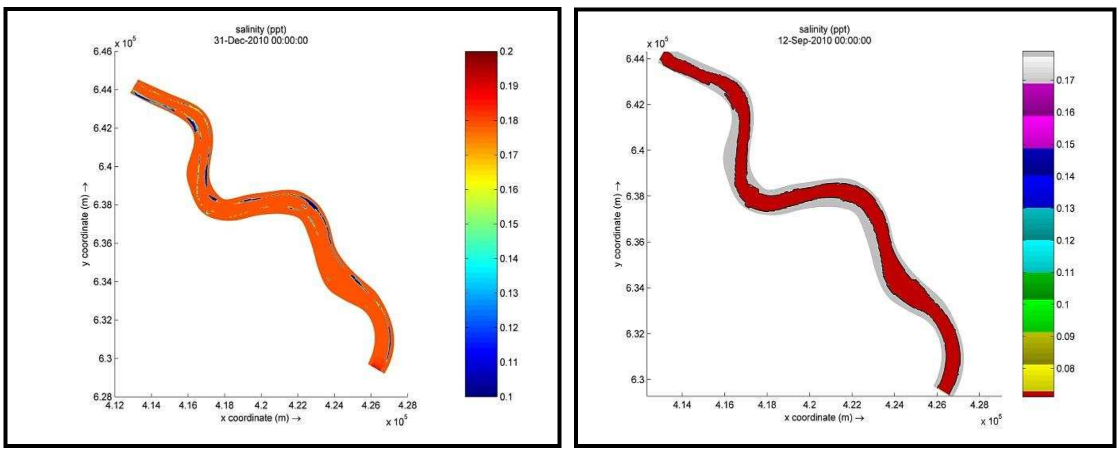


Figure 14: Simulated sediment transport rate along the study reach

2.3 Salinity Concentration(Chloride Concentration)

To represent the salinity along the study reach only the chloride concentration has been considered. Figure 15 shows that the reach wise variation in chloride concentration during the wet and dry season respectively indicating that the chloride concentration in upper reach of Girai river is 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 16 that depicts that the concentration variation is negligible at the upper Gorai reach.



(a) (b)

Figure 15: Chloride concentration (a) Dry period; (b) Wet period

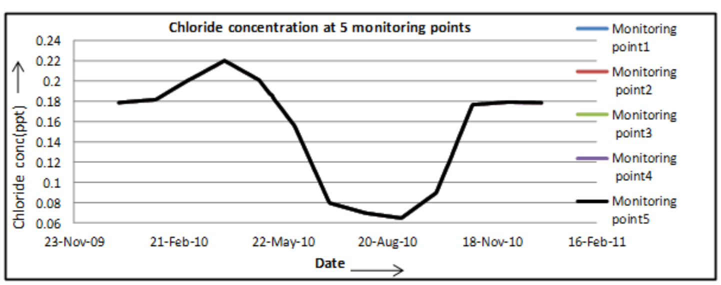


Figure 16: Simulated Chloride Concentration at 5 monitoring points

CONCLUSIONS

Numerical modeling technique of Delft 3D has been applied in this study in case of a 25 km reach of Gorai river extending from Gorai Railway Bridge to Kumarkhali. 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, 200m3/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. 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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