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MORPHOLOGICAL RESPONSES OF A TIDAL RIVER DUE TO CLIMATE CHANGE: A CASE STUDY FOR KARNAFULI RIVER, BANGLADESH

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ABSTRACT

Karnafuli River is an important river in Bangladesh and Chittagong seaport plays the biggest role in this country's economy. Navigability along the Seaport of Karnafuli River is dependent on the discharge and sediment transport with time. Sea Level Rise (SLR) and Temperature Rise (TMR) in the coast of Bay of Bengal are evident from different scientific reports. SLR is threatening the hydrodynamic and morphological behavior of coastal rivers including the navigability at the downstream of Karnafuli River. The backwater effects in terms of discharge and sediment transport have been carried out in this study. The future scenarios for rise in water level and temperature due to SLR and TMR have been projected for the next 25-30 years. Mathematical modeling has been carried out for 10cm, 25cm and 50cm SLR and 0.5°C, 1.5°C and 2.5°C TMR to assess the hydro-morphological responses. Morphological analysis has been carried out for three different conditions for mean sediment size d_{50}=100, 150 and 200 µm. Mathematical model study has been performed 3-Dimensionally by using Delft3D. The study reach includes from downstream of Kaptai Dam to Kafco in Karnafuli River. Results show that backwater discharge will increase 1.9% to 7.9% from the present discharge. Due to this the sediment transport will be decreased from 50 to 100 tons per second. Thus, the downstream of Karnafuli River and seaport will experience more sedimentation. The study has also focused on planform analysis, total sediment transport, settling velocity, sediment rating curves due to climate change effects on Karnafuli River.

Keywords: *Karnafuli River, Mathematical Modelling, Morphology, Climate Change, Sea Level Rise*

1. INTRODUCTION

The Karnafuli River is the principal river in Chittagong region of Bangladesh. The Karnafuli River has about a hundred numbers of tributaries and two-thirds of which lie in Bangladesh (IWM, 2013). The main rivers of that region are the river Karnaphuli, Rainkhiang, Kasalong, Halda, Ichamati, Feni, Sangu, Bakkhali, Naf and Matamuhari. Karnafuli River originates from Lusai Hills about two kilometers east of Sugarbasora in Mizoram state of India (CEGIS, 2014). It lies in the southern part of Bangladesh and finally meets the Bay of Bengal near the Chittagong seaport. The length of the river is almost one hundred and sixty kilometres (Karmakar, et al., 2011). The downstream of the River Karnafuli shows the typical estuarine features. The Karnafuli River is very important in the context of economy of Bangladesh and also for Kaptai Hydro-electric power plant.

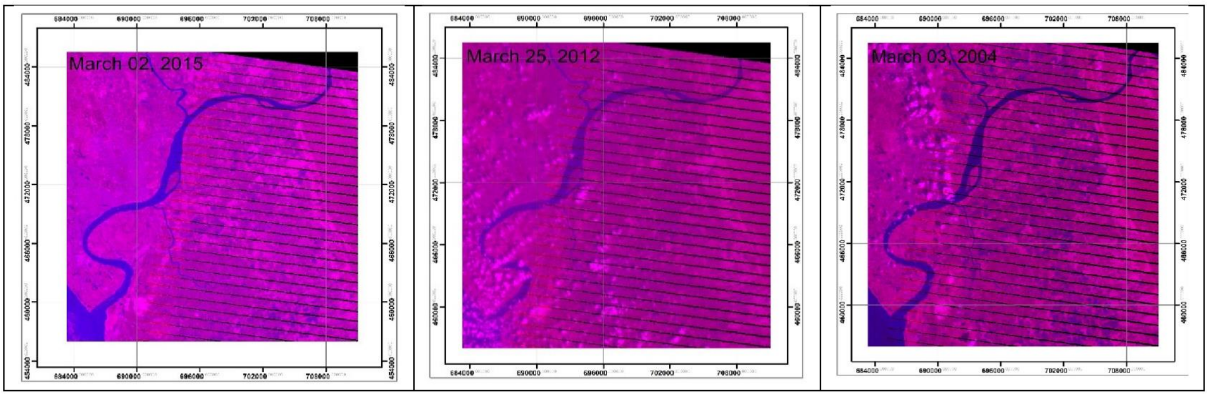

Figure 1: Satellite Images of Karnafuli River Reach

The sea port is in the south of Chittagong city, the second largest city in Bangladesh and is the nation's capital and administrative and economic center (ADB, 2011). It handles about 92% of the country's import-export trade (CPA, 2012). The most important seaport of Bangladesh is situated sixteen kilometers away from the sea mouth, Kafco (ADB, 2011). Another important part of the river is Kaptai dam which is located upstream of Karnafuli River. During monsoon period the high tidal flow and discharge is occurred in the Karnafuli River. The Chittagong Sea Port is experienced capital dredging for the succession of time. The past decade planform of the Karnafuli River shows stable bank lines (Figure 1). The river has shown same width along the reach with some bank erosion effect at certain location along the reach. The pattern of bend is observed almost same for the past decade as observed in the study.

Past literatures are the evidence of both global Sea Level Rise (SLR), Temperature Rise (TMR) warming and regional sea-level-rise including Bangladesh from the past coastal gauged water level data trends. The According to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) showed yearly Sea Level Rise (SLR) ranging 1.0 to 2.0 mm in the region1 (Unnikrishnan et al., 2015). The fourth and fifth IPCC reports show a yearly global mean SLR nearly 1.8 mm during 1961–2003 and 1.7 mm during 1901–2010 respectively (IPCC, 2007) (IPCC, 2013). The SLR is 2.15 mm per year has been found for past two decades at the location of Hiron Point gauged station (Brammer, 2013). The mean sea level is rising and sea level change was found from the gauged water level station to be 5.05 mm/year to 7.5 mm/year (CEGIS and DOE, 2011).

Due to SLR back water effect will generally take place thus will aggravate the retardation of a river outflow at the river mouth. The past studies have focused on the water level and salinity intrusion due to climate change. The author has carried out a set of mathematical model studies to show the hydro-morphological behavior due to backwater effect for SLR. The author has also found the siltation effect at d/s of Karnafuli River reach indicating threatening to the Chittagong Seaport. The Fourth Assessment Report of IPCC has depicted that the 100-year linear trend (1906-2005) of global average surface temperature is 0.74°C (Basak, et al., 2013). The change in temperature may affect the hydro-morphological behavior of the Karnafuli River for the future scenarios.

The present study will focus on the hydro-morphological analysis using mathematical modelling tool Delft3D for the future scenarios of Karnafuli River reach due to SLR and TMR as an impact on climate change. The study has included the development of 3D hydro-morphological and Heat flux models introducing 5 number of layers for the river Karnafuli River reach from downstream (d/s) of Kaptai Dam to estuary near Kafco. The mathematical model study has covered the hydro-morphological condition of base condition or 0 cm, 10 cm, 25 cm and 50 cm SLR conditions. Another set of Heatflux Models for base condition or

0.0°C, 0.50°C, 1.50°C and 2.50°C TMR conditions have conceded for the analysis of hydro-morphological assessment of Karnafuli River reach 3-Dimensionally. The morphological analysis has also been carried out by the author through another set of models for mean sediment size d_{50}=100, 150 and 200μm as river morphology largely depends on the sediment size. The outputs results obtained from the simulated conditions have focused on the total velocity distribution, sediment transport, suspended sediment transport, longitudinal or cross-sectional profile, erosion and deposition pattern of sediment sand.

2. METHODOLOGY

This study will be based on the effect of SLR and TMR due to climate change to Karnafuli River due to its' importance for having Chittagong Sea Port and Kaptai Dam and situated in the vulnerable area to SLR and TMR. The study will analyze the hydro-morphological assessment through selection of study area, data collection and data arrange, mathematical model setup, model calibration and validation, results analysis. The methodology of the study is presented in the following article.

2.1 Selection of Study Area

The Karnafuli River from d/s of Kaptai Dam to the the estuary at Kafco has been selected to assess the hydro-morphological change due to SLR and TMR. The main tributaries as Halda, Ichamati and Shikalbaha Canal (Khal) of almost 10 km from the confluence point of Karnafuli have also been considered in the study (Figure 2). Analysis of Karnafuli River has been made 3-Dimensionally including 5 number of vertical layers. The discharge from Kaptai Dam and the water level at Kafco have been the boundary condition of the simulated models. The location of calibration and validation location have been set to Kalurghat.

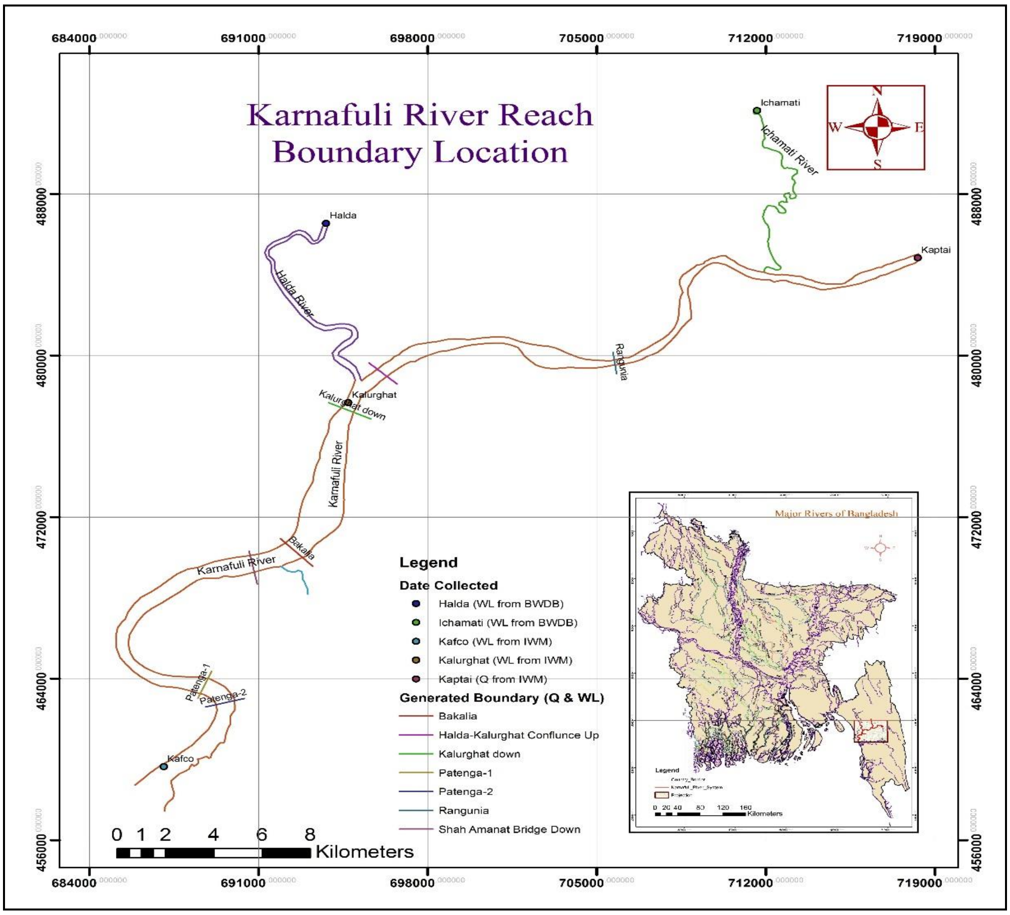

Figure 2: Study Reach with Boundary Locations

2.2 Data Collection and Data Arrange

The time series water level data at Kafco, Kalurghat and at Rangunia, Halda, Ichamati, the discharge data at d/s of Kaptai Dam, the cross sections data of the Karnafuli, Ichamati, Halda River and Shikalbaha Khal collected from both Bangladesh Water Development Board (BWDB) and Institute of Water Modelling (IWM) for the year of 2010 and 2011. Digital Elevation Model (DEM) of two major islands named Quapara and Bakalia Char has been collected from the electronic source as SRTM (30m×30m) from earth explorer. The size of the bed materials at Rangunia, Kalurghat and Kafco denoted as d_{50} and d_{75} and sediment concentration data for different locations have been collected from IWM. The satellite images of Karnafuli River reach from year 2004 to year 2015 has been collected.

2.3 Mathematical Model Setup

The mathematical model setup is a process that includes the selection of land boundary, generation of suitable grid spacing considering the river width, length and simulation time, making the bathymetry, preparing the roughness file for the river bed concerned, boundary condition file generation, to finally the simulation of the model including calibration and validation. The process of the model setup in this study is described in the following articles.

2.3.1 Background Governing Equations

The Delft3D-Flow-Morbasic equations of fluid flow, encode the familiar laws of mechanics as conservation of mass (the continuity equation) and conservation of momentum. The bed evolution is based on the sediment continuity where the first term expresses the changes in bed level in time and the second and third terms are the sediment fluxes (bed and suspended load) in the x and y directions, respectively. The Delft3D heat flux model includes the relative humidity, air temperature and the fraction of the sky covered by clouds is prescribed (in %). The Delft3D module is capable to compute the effective back radiation and the heat losses due to evaporation and convection.
The continuity equation in Cartesian coordinates is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

Where, *u*, *v* and *w* are the flow velocity components in the x, y and z direction.

The momentum equation used in Delft3D is

$$\rho \frac{D\mathbf{v}}{Dt} = \rho g - \nabla p + \mu \Delta \mathbf{v} \qquad (2)$$

Where Δ is the Laplacian operator, ρ is the gravitational force and g is the gravitational acceleration.

The equation states that the bed level evolution in time is depended on the suspended and bed load gradients in the x and y directions.

$$\frac{\partial z_b}{\partial t} + \frac{\partial (S_{b,x} + S_{s,x})}{\partial x} + \frac{\partial (S_{b,y} + S_{s,y})}{\partial y} = 0 \qquad (3)$$

Where, $S_{b,x,y}$ = bed-load transport in x- and y-direction (kg m^{-1} s^{-1}), $S_{s,x,y}$ = sediment-load transport in x- and y-direction (kg m^{-1} s^{-1}), z_b = bed level (m).

The Van Rijn (1984) suspended and total sediment formula has been used for the morphological analysis with Delft3D (Delft3D-Flow, 2014).

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2.3.2 3D Base Model Setup

Delft3D usually supports the use of a rectilinear, a curvilinear and a spherical grid system for setting up a model for flow of river or activities related to wave. In this study the rectangular curvilinear grid system has been used to prepare the hydro-dynamic and morpho-dynamic grid system of less than 2.0 aspect ratio. The grid generator program RGFGRID has been used in this thesis study to generate a rectangular grid system for model development. The rectangular grid system has used the land boundary and preferably the bathymetry for the preliminary set up the desired model. The land boundary is obtained from digitizing the satellite image map of resolution 30m×30m obtained from earthexplorer and the bathymetry is obtained upon using the tool QUICKIN with the help of cross section data provided by BWDB and IWM.

2.3.3 Base Model Calibration and Validation

The calibration is an iterative adjustment of the model parameters so that simulated data obtained from mathematical model represents the observed data of the river system to desired accuracy. The calibration of the model has been made for both hydrodynamic and morphological simulations. The base 3D model has been calibrated and validated against water level, discharge and erosion and deposition perspective. The hydrodynamic calibration and validation has been made at Kalurghat and at Patenga respectively for the year 2011 and 2010. The 3D validated model with the adjusted parameters as manning's roughness and morphological parameters has been used for the projected SLR and TMR scenarios. Calibration parameters has also included the model grid spacing, horizontal and vertical eddy diffusivity and the erosion factors of the Karnafuli River.

2.3.4 MOR-Model Setup for SLR Scenarios

The validated 3D base model has been used to estimate SLR scenarios for 0.0 cm (base condition), 10 cm, 25 cm and 50 cm due to climate change. The both hydrodynamic and morphological boundary conditions have been kept similar as the base condition (Table 1).

2.3.5 Heatflux-Model Setup for TMR Scenarios

The validated 3D base model has been used to estimate TMR scenarios for 0.0°C (base condition), 0.50°C, 1.50°C and 2.50°C due to climate change. The both hydrodynamic and morphological boundary conditions have been kept similar as the base condition (Table 1).

2.3.6 Mor-Model Setup for Different Sediment Size

The validated 3D base model has been used to estimate the scenarios for the different sediment size that constitute the sediment transport. The projected scenarios of morphological behaviour for d_{50}= 200µm,150µm and 100µm have been simulated in the study. This is because the sediment transport takes place with continuous sediment sorting or change to the flow direction. The both hydrodynamic and morphological boundary condition as sediment concentration have been kept similar for the four different sizes of sediments. The scenarios of the study are presented in Table 1.

Table 1: Scenarios developed in the study

Study Type	Base condition	Climate Change/ different sediment size Scenarios		
1. Hydro-morphological changes due to SLR	Post-monsoon, 2012	(+) 10 cm SLR	(+) 25 cm SLR	(+) 50 cm SLR
2. Hydro-morphological changes due to TMR	Post-monsoon, 2012	(+) 0.5°C TMR	(+) 1.5°C TMR	(+) 2.5°C TMR
3. Morphological changes with different sediment size	Post-monsoon, 2012	D_{50} =100 µm	D_{50} =150 µm	D_{50} =200 µm

3. RESULTS AND DISCUSSIONS

3.1 Hydrodynamic and Morphological Model Calibration and Validation

The hydrodynamic calibration of the model has been based on water level and discharge at Kalurghat (Figure 3 and 4). The calibration of morphological parameters has been adjusted based on simulated erosion and deposition presented in the parenthesis of Table 2 and illustrated in Figure 5. LB, MC and RB represent the Left Bank, Mid Channel and Right Bank respectively. The sediment boundary for the study of dredging has been set considering upstream and downstream at Rangunia and Kafco respectively. The 3D morphological model of 5 vertical layers has been set for the duration April, 2011 to March, 2012.

3.2 SLR Scenarios

The simulated hydro-morphological scenarios for 10cm, 25cm and 50cm SLR due to climate change has shown the increased backwater discharge ranges from 40 to 1291 m^3/hr/m near the d/s of Karnafuli River from sea mouth. Due to this backwater effect the sediment transport to the Bay of Bengal has also been decreased from for 650 kg/s/m for low tide and increased by 250 kg/s/m for high tide condition towards seaport. Thus, the siltation from mouth to seaport will experience more siltation. The backwater increased discharge from ocean and decreased sediment flow toward ocean are presented for month of August, 2012 (Figure 6). The changed in sediment rating curves for SLR scenarios are depicted in Figure 7. The mean total sediment transport along the dominating flow way (Figure 8) has shown the changed behaviour along the study reach for the backwater effect. The overall short term model analysed change in bathymetry of the Karnafuli River is presented in the Figure 9 for SLR. The backwater discharge from ocean to Karnafuli River due to SLR has been presented in Table 3. Negative sign represents the flow direction from ocean to Karnafuli River direction.

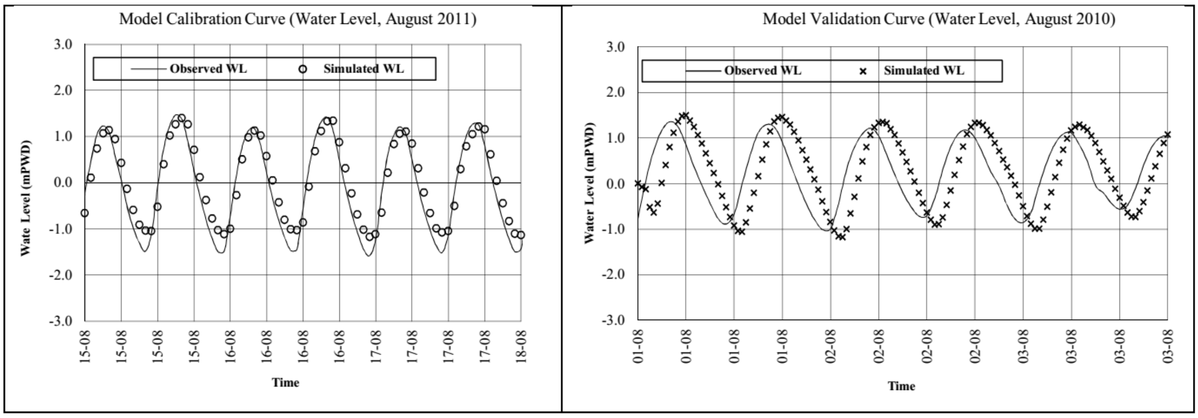

Figure 3: Model Calibration Curve with respect to Water Level at Kalurghat

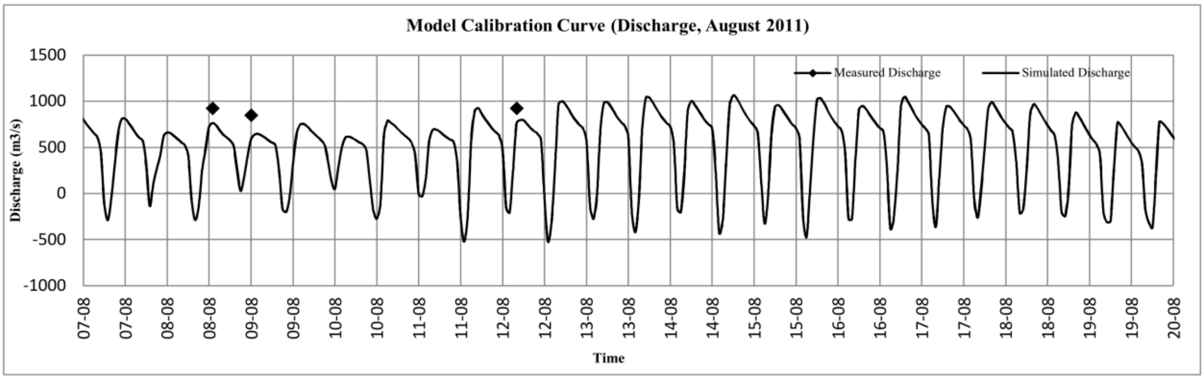

Figure 4: Model Calibration Curve with respect to Discharge at Rangunia

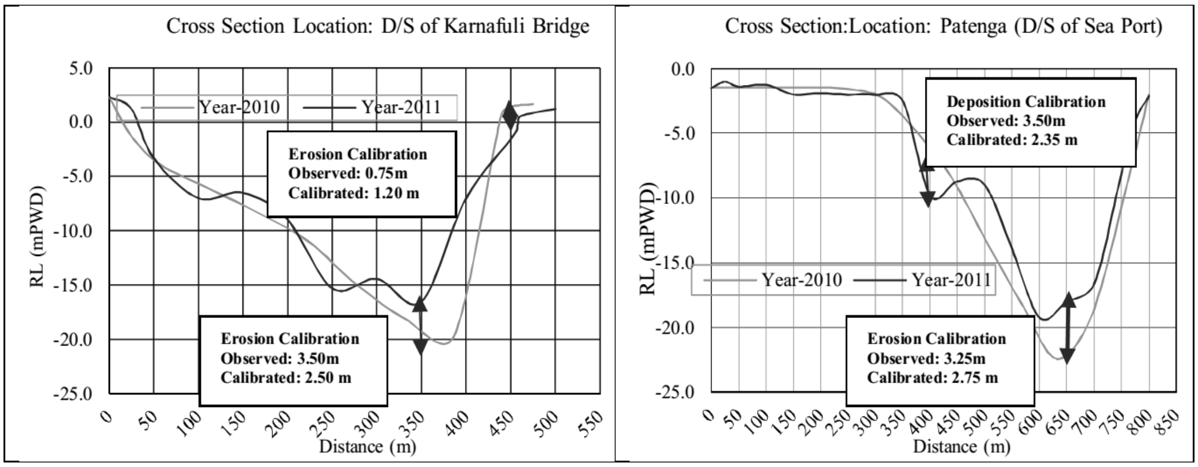

Figure 5: Morphological Model Calibration Curve with respect to Erosion/Deposition rate

Table 2: Morphological behavior (erosion/deposition) along Karnafuli River

Location	Erosion Rate (Bed) Unit: m/yr			Deposition Rate (Bed) Unit: m/yr		
	LB	MC	RB	LB	MC	RB
D/S of Karnafuli Bridge	1.05 (1.10)	3.50 (2.50)	0.75 (1.20)	1.10 (0.90)	4.20 (3.50)	0.95 (0.65)
D/S of Chittagong Sea Port	0.80 (1.10)	3.25 (2.75)	0.75 (0.85)	0.85 (0.55)	3.50 (2.35)	0.085 (0.30)

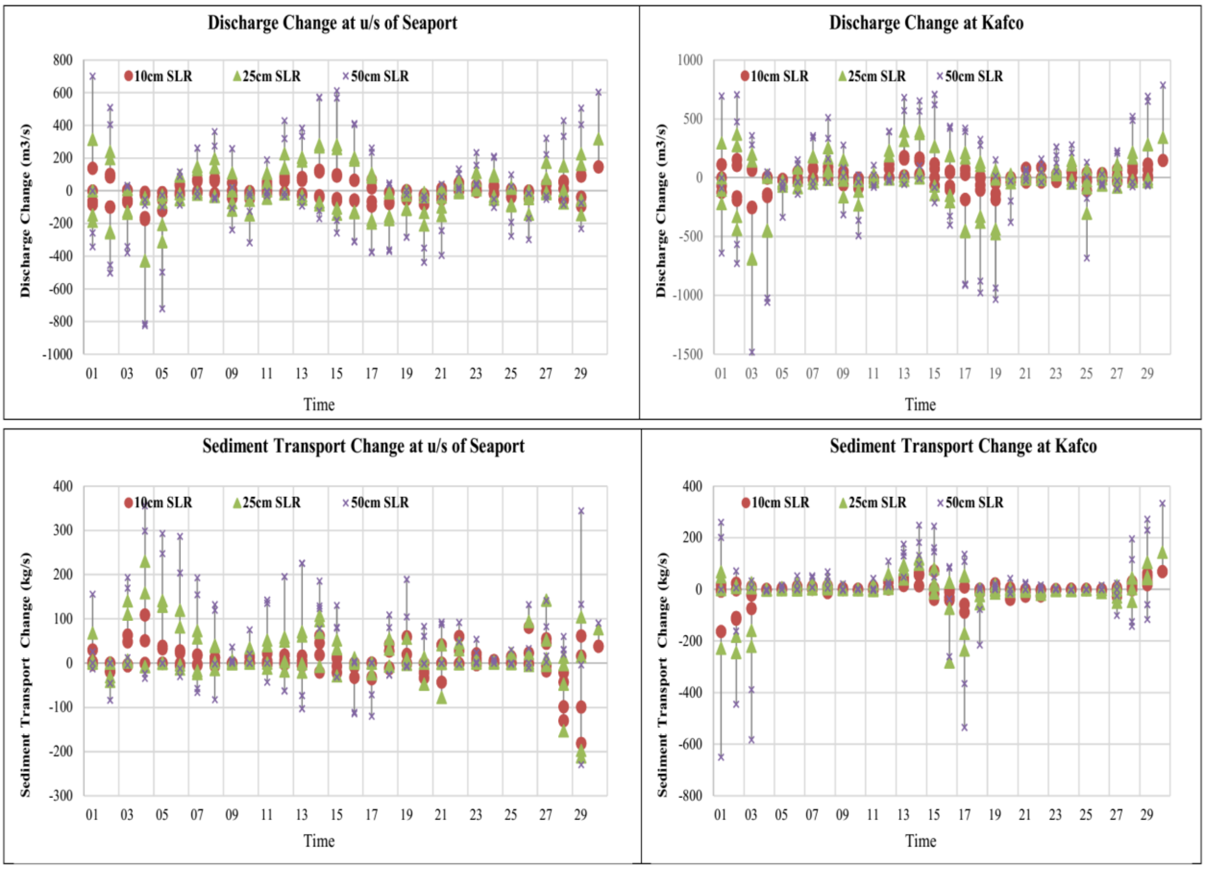

Figure 6: Change of Unit Discharge and Total Sediment Transport due to SLR scenarios

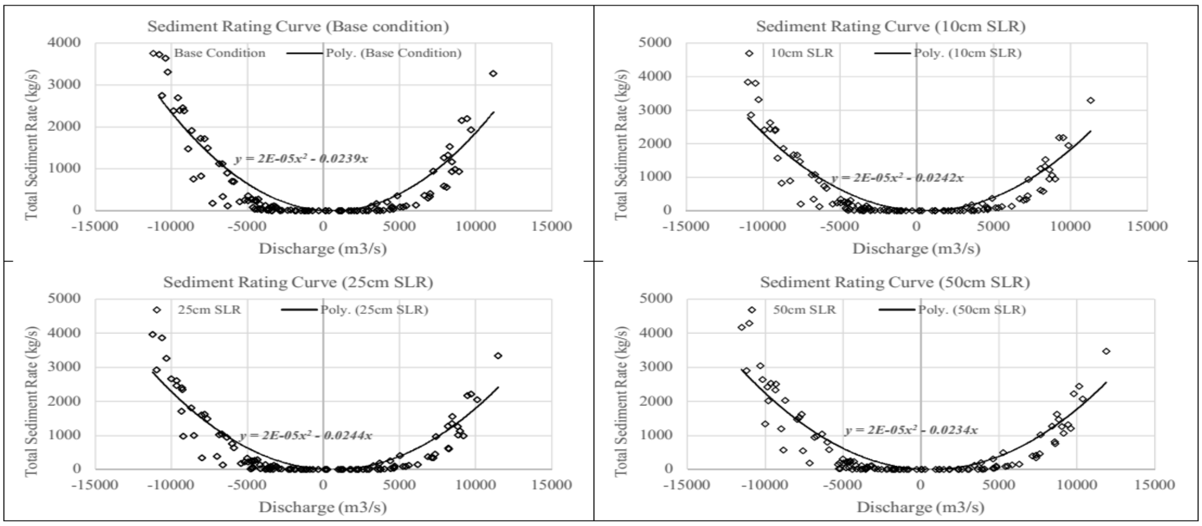

Figure 7: Sediment Rating Curve due to SLR scenarios

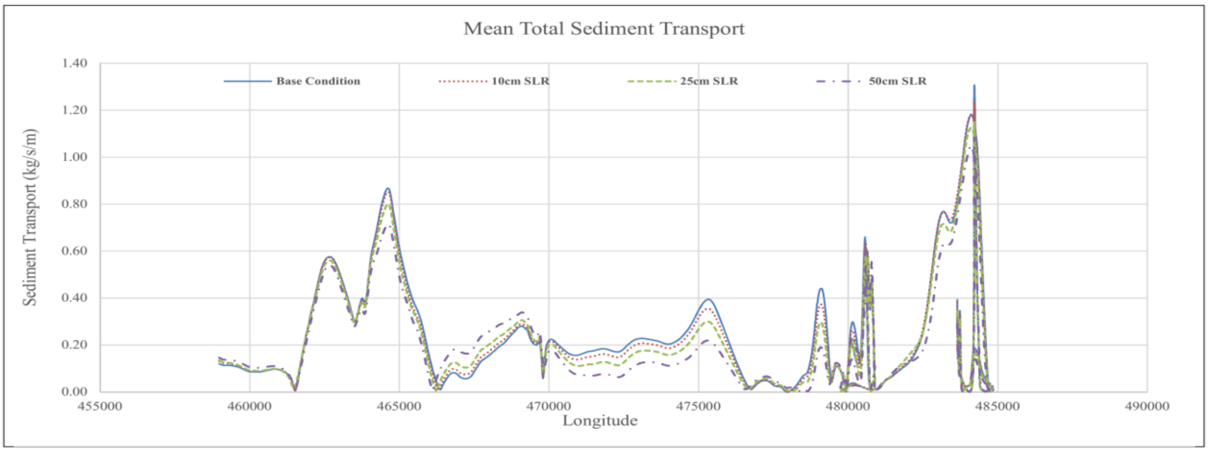

Figure 8: Change in Longitudinal Mean Total Sediment Transport due to SLR scenarios

Table 3: Backwater discharge ($m^3/s/m$) to Karnafuli River from Ocean due to SLR

Distance from Estuary (Km)	Backwater discharge from Ocean to u/s of Karnafuli River		
	10cm SLR	25cm SLR	50cm SLR
0	-202 (1.1%)	-207(1.2%)	-655(3.4%)
5	-310(1.5%)	-559(2.8%)	-1000(4.9%)
10	-192(1.0%)	-675(3.7%)	-1291(6.9%)
15	-234(1.1%)	-281(1.3%)	-565(2.6%)
20	-148(1.0%)	-311(2.0%)	-768(4.8%)
25	-40(1.0%)	-113(3.0%)	-317(8.2%)

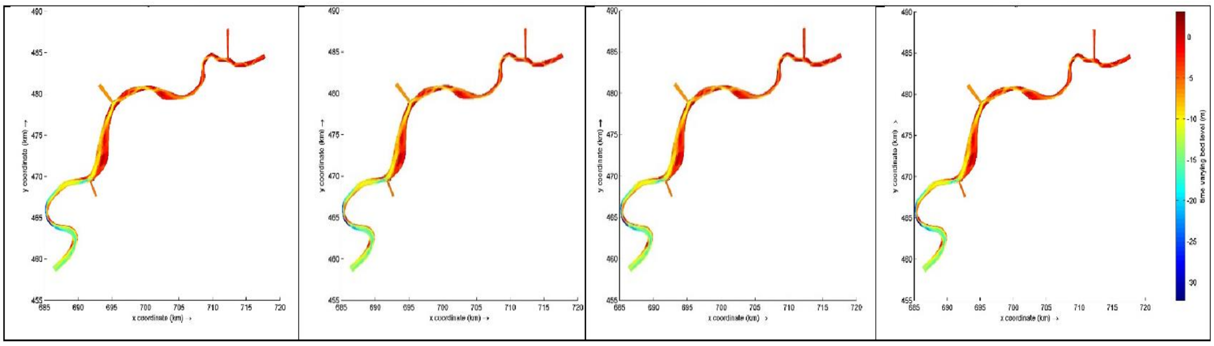

Figure 9: Simulated bathymetry for SLR scenarios

3.3 TMR Scenarios

The hydro-dynamical assessment has made for the 0.5°C, 1.5°C and 2.5°C temperature rise conditions. The hydrodynamical changes as discharge, velocity distribution, secondary has shown negligible results for the TMR as a result of climate change for the 0.5-2.5°C temperature change in the study area. The change in settling velocity is observed 1-1.5cm/s at Kafco and u/s of seaport area (Figure 10). The mathematical model simulated results have shown not significant results in morphological aspects from the average result. The noticeable results of change in sediment transport are presented during first week of August, 2012 (Figure 11).

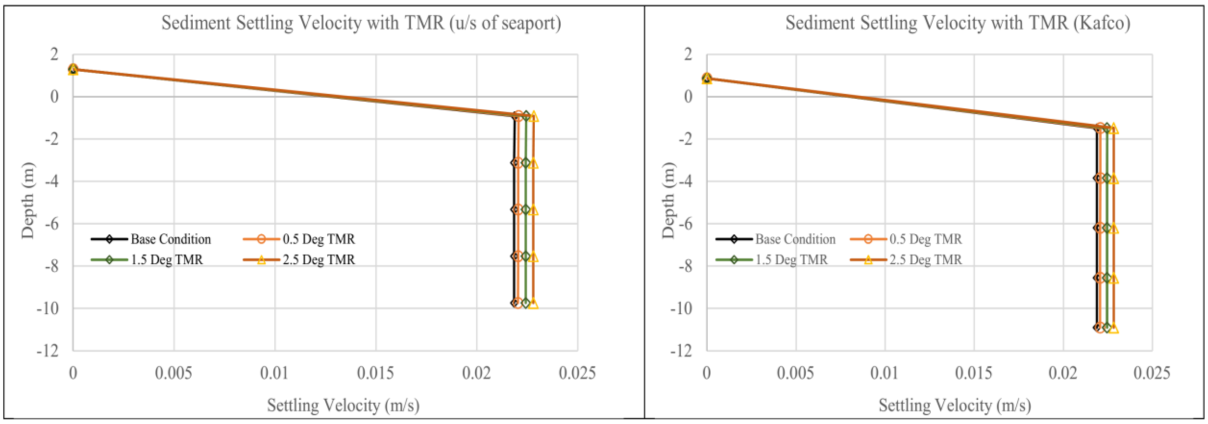

Figure 10: Change in Settling Velocity due to SLR scenarios

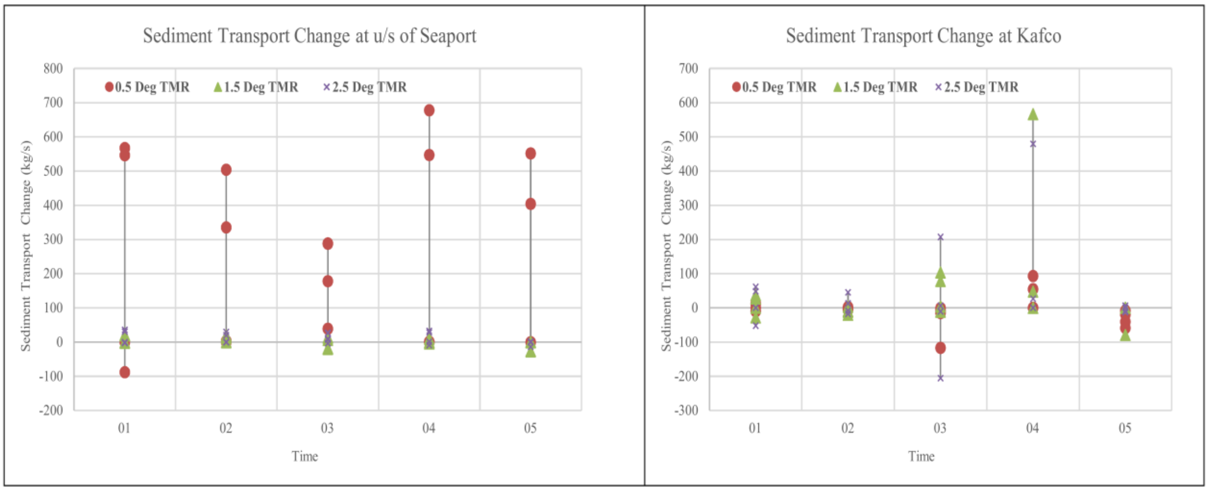

Figure 11: Change of Discharge and Total Sediment Transport due to TMR scenarios

3.4 Scenarios for different d_{50}

Sediment transport is one of the good representation of morphological characteristics of a river. The sediment transport mode largely depends the sediment characteristics as type of sediment, size of sediment etc. As the climate change is represented in terms of SLR and TMR for future scenario, the sediment size in the future condition may not be like present condition. As sediment flow changes with sediment particle size, the sediment transport rate is considered with different median size of sediment as d_{50}= 100, 150 and 200 µm. The base model of the study has considered d_{50}=180 µm based on bed material size distribution assessment of samples collected from d/s of Kaptai, Rangunia and Kalurghat. The mean total load transport along the longitudinal section of the thalweg line of Karnafuli River is depicted in the Figure 12.

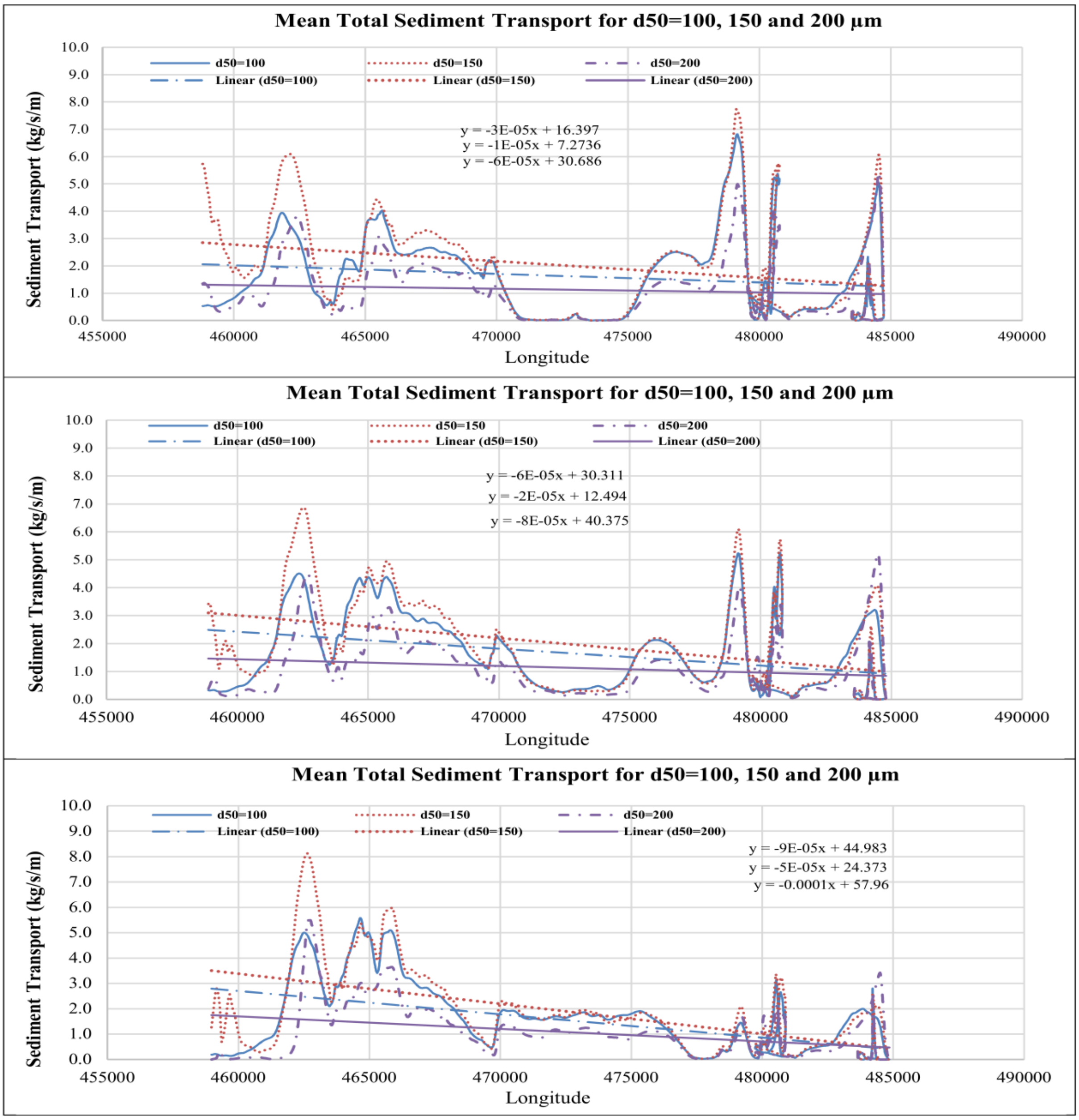

Figure 12: Longitudinal Sediment Transport with different sediment sizes along centre lines

4. CONCLUSIONS

The SLR and TMR due to climate change it is observed that the backwater effect and temperature rise may lead the hydro-morphological changes quite significantly. The very short time mathematical modelling study related to the Karnafuli River has shown that the backwater effect due to SLR has aggravated the siltation at the d/s of Karnafuli and reduced low tide flow towards Bay of Bengal. Please provide a brief conclusion on the basis of the results and discussions. On the other hand, the median sediment size variation has shown that the significant sediment transport rate along the Karnafuli River reach. The study has included the short term model analysed sediment transport analysis with median size d_{50} variation as the sediment transport is complex as it varies with time and types of sediment particles size. So, the d/s of Karnafuli River may be affected significantly in case of siltation. The more siltation will occur as a results of backwater effect about 1.9 to 7.9% of the main channel discharge at the d/s of Karnafuli river including Seaport for the long run against climate change effects.

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REFERENCES

ADB, (2011). People's Republic of Bangladesh: Strategic Master Plan for Chittagong Port. Asian Development Bank. Submitted to GoB.

Basak, J. K., Titumir, R. A. M. and Dey, N. C., (2013). Climate Change in Bangladesh: A Historical Analysis of Temperature and Rainfall Data. Journal of Environment, Vol. 02, Issue 02, pp. 41-46.

Brammer, H., (2013). Bangladesh's Dynamic Coastal Regions and Sea Level Rise. Elsevier, Climate Risk Management, Vol. 01, pp. 51–62.

CEGIS and DoE, (2011). Programs Containing Measures to Facilitate Adaptation to Climate Change of the Second National Communication Project of Bangladesh. Dhaka, Final report, submitted to Department of Environment.

CEGIS, (2014). Geo-morphological and Planform Studies with Environmental and Social Impact Assessment on Study Capital Dredging and Sustainable River Management in Bangladesh (River Karnafuli). Dhaka. Submitted to BWDB.

CPA, (2012). Chittagong Port Authority Overview. Chittagong: Chittagong Port Authority.

Delft3D-Flow, (2014). User manual: Hydro-Morphodynamics, Deltares.

Gornitz, V. M., Daniels, R. C., White, T. W. and Birdwell, K. R., (1994). The development of a Coastal Risk Assessment Database: Vulnerability to Sea Level Rise in the US Southeast." Journal of Coastal Research, Vol. ??, pp. 327-338.

Gornitz, V., (1990). Mean Sea Level Changes in the Recent Past In Climate and Sea Level Change Observations Projections and Implications, Cambridge University Press, Cambridge.

Graves, A.L. and Gooch, R.S., (1986). Central Arizona Project Start Up. Proceedings of the Water Forum '86: World Water Issues in Evolution. ASCE, New York, N.Y., Vol. 1, 546-551.

IPCC, (2007a). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, (2007b). Climate Change 2007: The Physical Science Basis, Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IWM, (2013). Prefeasibility Study to Restore the Environment of the Kaptai Lake the Rangamati Hill District, Volume I. Dhaka.

Karmakar, S., Haque, S. M., Hossain, M. M., and Shafiq, M., (2011). Water Quality of Kaptai Reservoir in Chittagong Hill Tracts of Bangladesh. Journal of Forestry Research, Vol. 22, Issue, 1, pp. 87−92. doi: 10.1007/s11676-011-0131-6.

Unnikrishnan, A. S., Nidheesh, A. G. and Lengaigne, M., (2015). Sea Level Rise Trends off the Indian Coasts During the Last Two Decades. Current Science, Vol. 108, Issue, 5, pp. 966-971.