RESPONSE OF CLIMATE CHANGE ON THE MORPHOLOGICAL BEHAVIOR OF THE MAJOR RIVER SYSTEM OF BANGLADESH

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Abstract:

Bangladesh is blessed with numerous rivers, which are characterized by unpredictability in their behavior. Every year many of the rivers pose different shape, follow different path showing their swinging nature. Being subject to upstream condition, which is beyond control, hydrological variability and different bed and bank properties make these rivers more unpredictable. On top of these uncertainties, climate change may bring changes at the upstream by changing rainfall intensity, severity, erratic occurrence, and at downstream by raising the level at the sea. More inundation due to sedimentation, hindrance to sediment flushing and at the same time more bank erosion may take place. These impacts could be phenomenal or insignificant. Theory gives an exponential increase of morphological activity with increased river flow, implying that bank erosion might substantially increase in the future. In assessing these impacts, exact quantification might not be possible at the moment but close to precision could be achieved that would assist the planners and policy makers in the process of formulating action plans to combat the adversities, which are supposed to be caused due to climate change. With this view, assessment of morphological changes of the major rivers of Bangladesh in response to anticipated climate change has been done with the application of mathematical modelling tool MIKE 11 & MIKE 21C. This paper presents some of the key findings of some rivers, which are directly influenced by the climate change parameters.

Introduction

Bangladesh is recognized worldwide as one of the countries most vulnerable to the impacts of global warming and climate change. This is due to its unique geographic location, dominance of floodplains and low elevation from the sea, high population density, high levels of poverty, and overwhelming dependence on nature, its resources and services. Bangladesh is situated at the interface of two different environments, with the Bay of Bengal to the south and the Himalayas to the north. This peculiar geography of Bangladesh causes not only life-giving monsoons but also catastrophic ravages of natural disasters, to which now are added climate change and sea level rise (SLR). The 4th Intergovernmental Panel on Climate Change (IPCC) Report predicts for South Asia that monsoon rainfall will be higher, resulting in increased flows during the monsoon in the rivers, and sea level rise. Serious floods, tropical cyclones, storm surges and droughts are likely to become more frequent. Apart from these, climate change with higher associated rainfall and relative sea level rise will likely cause significant changes in sediment and flood regimes. The main issues of climate change that may affect morphological processes are: (i) changes in flood regime due to changes in precipitation pattern, (ii) changes in sediment load also due to changes in precipitation, and (iii) changes in base level due to sea level rise. The rivers of Bangladesh are very dynamic in nature as most part of Banaladesh has been formed by recent sediments, and rivers are loaded with huge sediment as well as partly because of the tidal and seasonal variations in river flows and run-off. Therefore, these rivers are very sensitive to changes in parameters like flood flow, sediment load and base level. The main rivers, i.e. the Jamuna, the Ganges and the Padma, may take long periods for adjustment in fluvial processes and morphological forms against the changes.

This paper aims to present an indication regarding the influence of climate change on the river morphological behavior of the major river system of Bangladesh, i.e. for the river Ganges, Jamuna and Padma, employing mathematical modelling technique. In general, river morphology refers to channel alignment, bed topography, bank erosion or deposition, etc. Attempt has been made to investigate expected river morphological changes for an average flood event applying the two-dimensional (2-D) morphological modelling system, MIKE21C. Boundary for 2-D morphological model has been generated simulating the one-dimensional (1-D) flow modelling system MIKE11. Runoff, model, has been input for river flow estimated from rainfall and evapotranspiration through applying rainfall-runoff model-NAM. The work has been done with some limited data to have an indication, and to shed light on further research and study in this area.

Study Area

Geographically, Bangladesh is a part of the Bengal Basin which has been filled by sediments washed down from the highlands on three sides of it, especially from the Himalayas. A network of rivers originated in the Himalayas flow over the country, that carries sediments-the building blocks of the landmass of the delta. The country consists of low and flat land formed mainly by the sediments carried by the Ganges and the Brahmaputra River systems except the hilly regions in the north-eastern and south-eastern parts. From physiographic point of view, about 80 percent of the land is floodplains with very low mean elevation above the sea level with the rest made up of hills and elevated lands. Topography of the country is characterized by very low differences in the elevation between adjoining ridge tops and depression centers, which range from less than 1 meter on tidal floodplains, 1 to 3 meters on the main river and estuarine floodplains, and up to 5 to 6 meters in the Sylhet basin in the north-east (Rashid 1991).

Major river system of Bangladesh

Major river system of Bangladesh, including the Jamuna, the Ganges and the Padma within the territory of Bangladesh, has been shown in Figure 1.

The Ganges enters Bangladesh from India at Nawabgani district and flows about 110 along the international km Bangladesh border of and India occupying the territory of both countries. The length of the river downstream of this reach flowina inside Bangladesh the up to confluence with the Jamuna River is 130 km. The average width of this reach of the river is 5.3 km but varies from 1.5 km to 14 km. The annual average flow as measured at Hardinge Bridge since the mid-1930s is about 11,000 m³/sec. The average median bed at material size Hardinge is 0.15 The Bridae mm. planform of the river is mainly meandering with several chute channels at some reaches. The average floodwater slope of the river is 5 cm/km. The annual average rate of



riverbank erosion is 1,000 ha/year.

The Jamuna River travels about 240 km from the international border to meet the Ganges River at Aricha. The average width of this river within Bangladesh is 12 km. The annual average flow as measured at Bahadurabad is 20,000 m³/s with a maximum estimated discharge of 100,000 m³/s. The average flood water slope of the river is 7.5 cm/km and the average median size of bed material at Bahadurabad is 0.20 mm. The river demonstrates a braided planform. The annual average rate of bank erosion is about 2,000 ha/year.

The Ganges and the Jamuna meet at Aricha forming the Padma River, which flows southeastward until it reaches the Upper Meghna River near Chandpur. The length of this reach of the river is 100 km. The annual average flow of the river is $30,000 \text{ m}^3$ /s. The reach averaged width of the river is 10.3 km but varies from 2.5 km to 20 km. The average median size of the bed material at Mawa is 0.12 mm. The planform of the river oscillates from braided to meandering and straight. The annual average rate of bank erosion is 1,500 ha/year.

Development of Climate Change Scenarios

The change in precipitation pattern of South Asia has been calculated from the A1F1 scenario predictions of the IPCC, for 2010-2039 period, popularly known as the 4th IPCC (Solomon, S.D., et al, 2007) (Table 1). The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient

technologies. Based on emission it is divided into three categories such as A1F1, A1T and A1B. Based on fossil fuel use, A1F1 represents very high emission.

Sub- regions	Season	2010 - 2039 A1F1 Emission Scenario
South Asia	DJF	-3
	MAM	7
	JJA	5
	SON	1

Table 1: Predicted Change in Precipitation in the South Asia Region (Source: IPCC, 2007)

Note: *DJF: December January February, MAM: March April May, JJA: June July August and SON: September October November.

*Values indicate percent change in precipitation

*Negative values indicate decrease in precipitation.



Figure 2: Model Projections for Mean Global Warming (Source: IPCC, 2007)



Figure 3: Prediction of Global Sea Level Rise according to IS92a Scenario (AR4,

The increase in temperature, which affects the evapotranspiration, has been taken as 0.8°C based on IPCC predictions for the year 2020 (Figure 2).

In the 4th IPCC Report, the sea level rise (SLR) for different emission scenarios has not been given but a global sea level rise pattern for the IS92a scenario has been given, which is shown in the Figure 3. From this prediction, it has been found that the sea level would rise up to 59 cm in 2100. It is to be noted that IS92a - IS92a scenario is used as a reference from which to develop other scenarios.

Sea level rise for different years according to the IS92a scenario has been calculated from the Figure 3, which has been shown in Table 2.

Year	Sea Level Rise (cm) above year 2000 level
2020	8
2030	12
2040	17
2050	23
2060	29
2070	36
2080	43
2090	51
2100	59

Table 2: Predicted Sea Level Rise for the next 100 years

Model Development

One-Dimensional Flow Model

One-dimensional (1-D) flow modelling system software, MIKE11, developed by DHI Water and Environment, Denmark, has been used for developing onedimensional flow model. MIKE11 is based an implicit finite on difference scheme solution of the Saint Venant equations and is capable of describing complicated network flow condition through a numerical scheme, which adapts according to the local flow conditions. Rainfall-runoff model MIKE11 NAM has been used to develop the rainfall runoff model, which provided precipitation input in terms of runoff to the flow model for both base and climate change scenario. The one-dimensional model afterwards provided boundaries for the two-dimensional morphological model.



Figure 4: River Network of One-dimensional Model

One-dimensional model that is being used in the present work is taken from the existing general model available with IWM. The model covers the Jamuna, the Ganges, the Padma and the Meghna River as the main river systems along with some other minor rivers. The model has been updated and validated for the year 2005-06. The river network is shown in Figure 4.

Two-Dimensional Morphological Model

River morphological changes have been investigated employing the twodimensional (2-D) morphological modelling system, MIKE21C, developed also by the DHI Water and Environment, Denmark. MIKE21C operates on curvilinear orthogonal grid and it incorporates fully system unsteady flow, bed load as well as suspended load including dynamic bed level changes through simple sediment the continuity, updates planform through bank erosion model and includes the computation of the secondary currents, and thus provides the 3D effects for a 2D model.

developed 2-D morphological The model, shown in Figure 5, covers the entire stretch of the Jamuna, the Ganges and the Padma within the Bangladesh territory. The lateral extent of the model varies from place to place. Maximum width taken approximately 16 km at Bhuapur and the minimum is 3 km at Pakshey Bridge. Initially one model was developed comprising the three major rivers, but due to its too long



major rivers

computational time separate models for the three rivers were developed later. The initial bathymetry of the model has been prepared based on the bathymetric survey data available with IWM in connection with different previous studies on the Ganges, the Padma and the Jamuna. The bathymetric surveys have been carried out during the period 2000-2006. The initial bathymetry is, therefore, not representative of any particular time. This is accepted since the aim was to compare climate change scenario having same initial bathymetry and changed boundary conditions.

The 1-D model has twelve upstream discharge boundaries and six downstream water level boundaries. For 2-D models, besides the upstream and downstream boundaries the influence of tributaries and distributaries (Old Brahmaputra, Teesta, Dudkumar, Dharala, Hurasagar, Gorai, Arial Khan, etc.) has been included as inflow and outflow boundaries, respectively.

Existing condition and a climate change scenario has been simulated for comparison aiming at the assessment of probable impacts on river morphology due to climate change. 2000-01 flood event, representing an average flood as well as base year for predicting sea level rise, has been simulated for base condition. Increased flow (according to increase in precipitation for A1F1 emission scenario for the period 2010-2039) and SLR for 2030 have been

superimposed on base condition at the upstream and downstream boundaries of the 1-D model, respectively, for the climate change scenario simulation. Boundary conditions for 2-D models have been established from one-dimensional model simulation results.

Climate change impact on river morphological behavior

Channel Planform



Figure 6: River bed level contour at initial and end of simulations for Ganges River

In order to investigate the impact of the Climate change on channel alignment, bed level contour at initial and end of the simulation coverina period the whole monsoon have been analyzed and presented in the accompanying figures. The higher Ganges shows spatial extent of the channel widening at immediate downstream of the Hardinge Bridge, Within 240 km reach of the Jamuna, neither the alignment nor the spatial extent has differed distinctly for climate change condition. Abrupt shifting of the channels from one bank to another bank is not seen. However, there are some sporadic locations where noticeable change is seen, such as, the areas near the Jamuna Bridge, where more erosion as well as more widening of the channel has been found. In case of the Padma, more straightening at the downstream portion of the river is observed due to climate change condition. At upstream of Bridae the proposed Padma increased bed erosion has been found.



Figure 7: River bed level contour at initial and end of simulations for Jamuna River

Figure 8: River bed level contour at initial and end of simulations for Padma River

Water level

In relation to dyke heightening or spilling over the crest of the existing structure for bank protection, it is necessary to examine the probable water levels at various locations of the rivers. One of the important issues in dealing with the water level is the timing for recession of water level along the bank, especially those banks which are susceptible to bank erosion. If climate change causes rapid recession than the base condition, then more bank erosion is apprehended due to getting adequate time to release of pore water pressure. In spite of flow augmentation in climate change scenario, in case of the Ganges and Jamuna River water level at various locations has been found decreasing in comparison to existing condition. This can be due to increased bed erosion having augmented flow. In the case of Padma River, water surface elevation increases at downstream in comparison to upstream for climate change condition, as shown in Figure 9. Though there is increased flow, but this is likely to be attributed by sea level rise.



Figure 9: Water level at peak of simulations for Padma River

Bed Erosion-Deposition

Increment of flow due to climate change has been reflected in bringing changes in bed erosion and deposition. It is obvious that the higher amount of flow would cause higher bed erosion at some of the locations, and at downstream getting eroded material, deposition also is observed, which can be visualized in case of the Padma River, shown in bed level contour. Some of the important locations are illustrated in this paper. For instance, near the Jamuna Bridge, Pakshey Bridge and proposed Padma Bridge. Bed erosion at upstream of Pakshey Bridge and Jamuna Bridge area has not been found much. However, increase in bed erosion at location upstream of the proposed Padma Bridge has been found significant climate for change condition comparison to existing condition. This is likely to be attributed by combined increased flow of Jamuna, Padma, and other boundary rivers. Such unpredictable erosion may require revisiting the design for the bridge and for associated ancillary works.



Figure 10: River bed level at and end of simulations in some locations

Flow velocity

Due to enhancement of the flow under climate change scenario, velocity at certain locations has been increased. Increment of velocity during the peak of the monsoon is considered. Maximum velocity is brought into concern since it may cause threat to the existing bank protective structures. It is seen from the models that the increment of peak velocity, in general, ranges between 0.08 to 0.14 m/sec.

	Maximum Velocity (m/s)		
River	Existing Condition	Climate change condition	
Ganges	2.49	2.63	
Jamuna	2.72	2.80	
Padma	2.75	2.83	

Table 3: Maximum velocity at peak of the simulations

Bank Erosion

Like other variables, bank erosion is also increased by the climate change. On account of increment of shear stress and bed erosion, bank erosion is also increased at some of the important locations. The river Ganges and the Jamuna face increasing bank erosion but interestingly the Padma is not subject to such consequence. The reason for not having the impact is mainly the geological setting of the Padma that is different from the other two rivers. It has been shown earlier that the Padma could accommodate the increment of flow by increasing its conveyance area, where bed erosion increment of the Padma is quite higher (6 m erosion) than that of the other two rivers.

Table 4: Maximum bank erosion at peak of the simulations

	Maximum Bank Erosion (m)		
River	Existing Condition	Climate change condition	
Ganges left bank	175	210	
Ganges right bank	150	170	
Jamuna left bank	410	550	
Jamuna right bank	500	530	

Conclusions

From discussions and predictions made in different researches and seminars, climate change is now a reality with the effects already surfacing in many parts of the world. Climate change will threaten the significant achievements; Bangladesh has made in the last several decades in increasing incomes and

reducing poverty, and will threaten achievement of the MDGs. It is essential for Bangladesh to prepare now for adaptation to climate change and safeguard the future well-being of its people. Increased river bank erosion is likely to displace hundreds of thousands of people who will be forced to migrate, often to slums in cities. The sea level rise will slow down the flood recession and thus there is likeliness of large scale sedimentation. Flooding, floodplain sedimentation and bank erosion of the rivers influence life and livelihood of several millions of people. Thereby, it is now time to assess the impact of climate change on the morphology of the major rivers as well as the subsequent impacts on floodplain dwellers so that the nation can prepare itself to mitigate the effects.

With the aid of mathematical modelling, it is possible to assess the impact and to identify the location, the reaches, and affected extent. Modelling application for prediction of the impact in the river engineering sector would guide the planners and policy makers to re-think the planning and thus would strengthen the development works in this field. Main issue is not the exact quantification, but in this paper attempt has been taken to indicate the suitability of using modelling tool in this field in obtaining an indication regarding morphological changes due to anticipated climate change. The changes of the flow introduced by climate change would have impact on the morphology of the rivers of Bangladesh during monsoon. These changes, revealed by the model results correspond to one monsoon only and mostly indicative, which could not be quantified precisely due to unavailability of required data. The changes on river behavior such as impact on siltation, water level, channel alignment, etc. as indicated by the model have not been seen dramatic. However, all the responses indicate initiation of adverse situation. The model results, revealing the morphological changes in this study, can be a basis for initiating further elaborate studies.

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