IMPACT OF CLIMATE CHANGE ON RIVER FLOWS IN THE SOUTHWEST REGION OF BANGLADESH

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ABSTRACT

Bangladesh is known as a deltaic plain at the confluence of the Ganges, Brahmaputra and Meghna rivers basins (GBM) and their tributaries.About 80 percent of the country is made up of fertile alluvial lowland that becomes part of the Greater Bengal Plain.The Fifth Assessment Report (AR5) of IPCC and other studies reported that monsoon rainfall will be increased and sea level will be raised in future under prevailing climate change. Because of increased monsoon rainfall and rising of sea level, inundation of flood will be enhanced and prolonged. In this study, a one dimensional hydrodynamic model was set up for simulationin the southwast region.This model is very helpful for knowing the unknown information about water level and discharge for unknown location and also this model can be useful to predict future flow of SW region of Bangladesh.Coefficient of determination (R^2) between observed and modelled water level has been found as 0.98, 0.97,0.99,0.85,0.84,0.61,0.92 and 0.88 at Kamarkhali, Goalunda Transit, Gorai Railway Bridge, Mawa, Bagerhat, Kabirajpur, Gournadi and Khulna respectively. But except three locations, NSE for all locations have been found greater than 0.5 which indicate the mean simulated water level are better than observed. The percentance of discharge will be increased up to 4.59-9.55% by 2030 and 5.81-15.09% in 2050for major rivers of the southwest region.The water level will be increased up to .04 to 0.32 m by 2030s and 0.17 to 0.40m by 2050for major rivers of thesouthwest region.

Keywords:*Basin, flood, forecast, HEC-RAS, southwest*

1. INTRODUCTION

Natural and man-made hazards, such as, storm surge, cyclones, floods, erosion, high arsenic content in groundwater, water logging, earthquake, water and soil salinity, various forms of pollution, risks from climate change, etc., have adversely affected lives and livelihoods of the south west region of Bangladesh, where one-fourth of the population of this country reside. Water, in this region, plays a significant role in both socio-economic and livelihood developments. The discharge measurement data is unavailable for the stations in the coastal region, although the water level data are available on those locations, which have been measured by Bangladesh Water Development Board (BWDB). It is important to conduct the river model for this area to generate discharge and water levels in various locations for the present day and also to assess the possible changes of flow in the future. This study is conducted with an objective to predict the future scenario of the river discharge and the resulting water level assuming a few scenarios of increased inflow caused by climate change. The open source software HEC-RAS has been applied for assessing flow of this region. HEC-RAS is user friendly, designed to perform one dimensional hydraulic calculation (HEC-RAS, 2010). HEC-RAS can be used for assessing the river flow of the coastal zone with a geo-referenced modelling of river channel networks.

Depending upon the variation in channel characteristic along the flow, the channel roughness shows variations along the river. HEC-RAS has been extensively used all over the world to develop hydraulic model by calibrating the channel roughness for different rivers (Patro et al., 2009; Usul and Burak, 2006; Vijay et al., 2007 andWasanthaLal,1995). Single channel roughness value, using optimization method, has been estimated for open channel flow by taking the boundary condition as constraints (Ramesh et al., 1997). Channel roughness has been calibrated for Mahanadi River, India (Parhi et al., 2012) and for Lower Tapi River, India (Timbadiya et al., 2011) using HEC-RAS model. Once calibrated, the model can be utilized for future flood of the southwest region which will enable the concerning authorities to take necessary precautions to save lives and properties therein.

2. METHODOLOGY

The real river networks of the southwest region of Bangladesh have been selected as a study area of this study as shown in Figure 1. The major rivers of this region are the Ganges, the Padma and the Lower Meghna and others river are the Arialkhan, the Gorai, the Kaliganga, the Chandana, the Kumar, the Sitalakhya, the Madhumati, the Bhairab, the Pussur, the Bishkhali, the Tentulia, the Baleswar and the Burishwar, etc. Firstly, the whole river networks of southwest region have been digitized in the Google Earth software. The river networks that are obtained as .kml files from the Google Earth, have been converted into shape files using the ArcGIS software. The river name, reach and junctions have been assigned along the south-west river network using HEC-GeoRAS extension. The corrected networks have been imported in HEC-RAS software. In HEC-RAS, data of all the cross sections which have been collected from BWDB (Bangladesh Water Development Board) have been set up for the whole river network of the southwest region. Boundary conditions are applied to define the inflows and outflows at the model boundary. Boundary fluxes are expressed in terms of mass and momentum exchanges. For hydrodynamic modelling, the boundary conditions are commonly specified at inflow and outflow elements of the model domain. Numerically, three types of boundary conditions are identified: Dirichlet condition (specified head boundary), Neumann condition (specified flow boundary), and Cauchy condition (head-dependent flow boundary). The Cauchy boundary condition that is also called mixed boundary condition relates heads to flows at the outflow elements. The flow is computed based on the difference between specified heads outside the model domain as supplied by the user, and the computed heads at the boundary elements (Alemseged and Rientjes, 2007). The boundary condition of the HEC-RAS model has been established from the observed upstream discharge data obtained from Hardinge Bridge station at the Ganges, the Bahadurabad station at the Jamuna and Bhairab Bazar station at the Upper Meghna have been selected as flow hydrograph data and water level data obtained from Shahabaz, Tentulia, Buriswar, Bishkhali, Baleswar and Mongla stations have been selected as stage hydrography. The data concerning the flood for years 1996 has been used for calibration of Manning's roughness coefficient, "n". Eight gauging stations, Kamarkhali, Goalunda Transit, Gorai Railway Bridge, Mawa, Bagerhat, Kabirajpur, Khulna and Gournadi have been chosen to perform the calibration of roughness coefficient (Manning's "n") of the corresponding channels. The stations have been pointed out in Figure 1.Finally, an unsteady flow simulation of the model has been performed for one-year hydrograph.

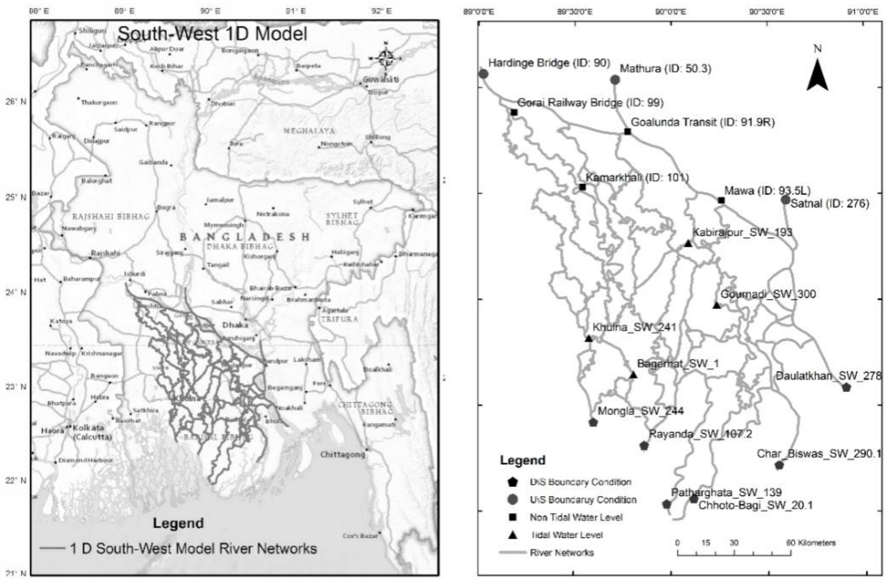


Figure 1: The southwest river network of Bangladesh (left side, highlighted with bold lines);Boundaryconditions and calibrationstations (right side)

Yu W. H. et al. (2010) studied the future transboundary inflows of the three major rivers (Ganges, Brahmaputra and Meghna) during the monsoon period. For all three rivers, across the different global circulation models, inflows into Bangladesh are on average projected to increase over the monsoon period (driven primarily from increased basin precipitation). A total of 10 experiments were performed. Data from five Global Circulation Model (GCM) and two Regional Climate Model (RCM) have been used to generate future flows for this region. The study reveals that during the monsoon period, in 2030 the river discharges in Brahmaputra, Ganges and Meghna increase by 4.5%, 10.38% and 1.2% respectively and during 2050 the discharges increase by 9.25%, 14.05% and 6.25%, respectively. These results have been used for the study to predict the future water level and discharge of the river network of the southwest region of Bangladesh. The observed daily data of these rivers have been multiplied with these values, and therefore ,have been applied as boundary conditions while performing simulations for future prediction. Due to climate change, the sea level rise in the coastal region of Bangladesh will cause the water level to rise up to 4.5 mm/year (Ministry of Environment and Forests, 2007). This has been used to determine the boundary conditions for the southern end of the study area.

2.1 Model Description

In the present study, unsteady, gradually varied flow simulation model i.e. HEC-RAS, which is dependent on finite difference solutions of the Saint-Venant equations (Equations (1)-(2)), has been used to simulate the flood in the South West river network of Bangladesh.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA\frac{\partial H}{\partial x} + gA(S_0 - S_f) = 0 \tag{2}$$

Here, A = cross-sectional area normal to the flow; Q = discharge; g = acceleration due to gravity; H = elevation of the water surface above a specified datum, also called stage; S_0 = bed slope; S_f = energy slope; t = temporal coordinate and x = longitudinal coordinate.

Equations (1) and (2) are solved using the well-known four-point implicit box finite difference scheme (HEC-RAS, 2010). This numerical scheme has been shown to be completely non dissipative but marginally stable when run in a semi-implicit form, which corresponds to weighting factor (θ) of 0.6 for the unsteady flow simulation. In HEC-RAS, a default θ is 1, however, it allows the users to specify any value between 0.6 and 1. The box finite difference scheme is limited to its ability to handle transitions between subcritical and supercritical flow, since a different solution algorithm is required for different flow conditions. The said limitation is overcome in HEC-RAS by employing a mixed-flow routine to patch solution in sub reaches (HEC-RAS, 2010).

3. MODEL CALIBRATION

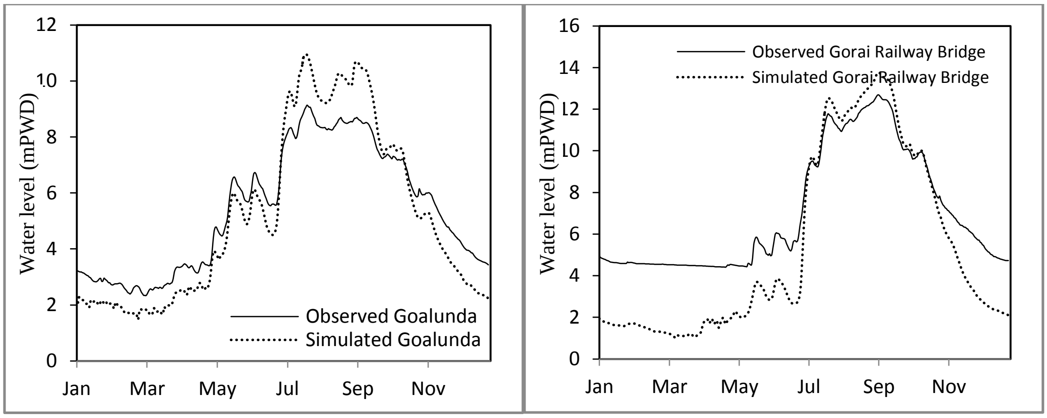
Calibration of the HEC-RAS model has been performed through setting Manning's roughness coefficient ('n') as a single value for each channel in the network using aforesaid data. Subsequently, different 'n' values have been chosen for each network to justify their adequacy for simulation of flood in the river reaches. The model has been calibrated for floods of year 1996. Nash and Sutcliffe Efficiency (NSE) test has been used for comparison of simulated flow hydrograph with the observed flow hydrograph for various Manning's 'n' as used by Moriasi et al., 2007.The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). Coefficient of determination (R^2) describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values of R^2 it indicates less error variance in the simulation, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001, Moriasi, D. N. et al 2007, Van Liew et al., 2003).

Table 1: Statistical parameter of the model.

Locations name and number	Statistical parameters		
	R^2	NSE	RMSE(m)
Kamarkhali (ID: 101)	0.98	0.78	1.27
Goalunda Transit (ID: 91.9R)	0.97	0.79	1.01
Gorai Railway Bridge (ID: 99)	0.99	0.37	2.24
Mawa (ID: 93.5L)	0.85	0.46	1.18
Bagerhat_SW_001	0.84	0.82	0.04
Gournadi_SW_300	0.61	0.43	0.51
Kabirajpur_SW_193	0.92	0.81	0.49
Khulna_SW_241	0.88	0.8	0.65

NSE of three of the stations, namely, Gorai Railway Bridge (ID: 99), Mawa (ID: 93.5L) and Gournadi_SW_300 show values less than 0.5. Other stations showing NSE values more than 0.5 are more likely to be accurate as the water level means of these stations are almost as same as the corresponding values of the observed means. Root mean square error or RMSE is a widely used model evalution parameter in hydrology study. The difference between the observed and the simulated water level for four of the stations are less than 1 m. Assessing the R^2, NSE and RMSE values for different stations, it can be concluded that the simulation for these stations show little variation in comparison with the observed scenarios. And the stations except the Gorai Railway Bridge (ID: 99) that are showing more than 1 m can be considered as accepted. Gorai Railway Bridge (ID: 99) station is showing this difference value as more than 2 m. The observed value should be given priority for this station.

Comparison between observed and simulated stage hydrograph at Kamarkhali, Goalunda Transit, Gorai Railway Bridge, Mawa, Bagerhat, Kabirajpur, Khulna and Gournadi gauging stations for the flood year 1996 is shown in Figure 2 illustrating the non-tidal rivers and Figure 3 illustrating the tidal rivers. Visual interpretation from all hydrographs shows that peak flow of simulated discharge are overestimated for the observed discharge for some of the stations. But the pattern of simulated hydrograph at all locations are similar to the observed pattern. Among them, Goalunda, Gorai Railway Bridge and Mawa stations have shown lower stage than observed during pre-monsoon although other stations represent quite close to the observed stage. From June to mid September, the difference of simulated stage and observed stage is maintained by 1 m at Goalunda and Kamarkhali station, 0.02 m at Gournadi Bridge station and 0.04 m at Kabirajpur station. After moonson period, the stage difference between simulated and observed at other stations are quite small.



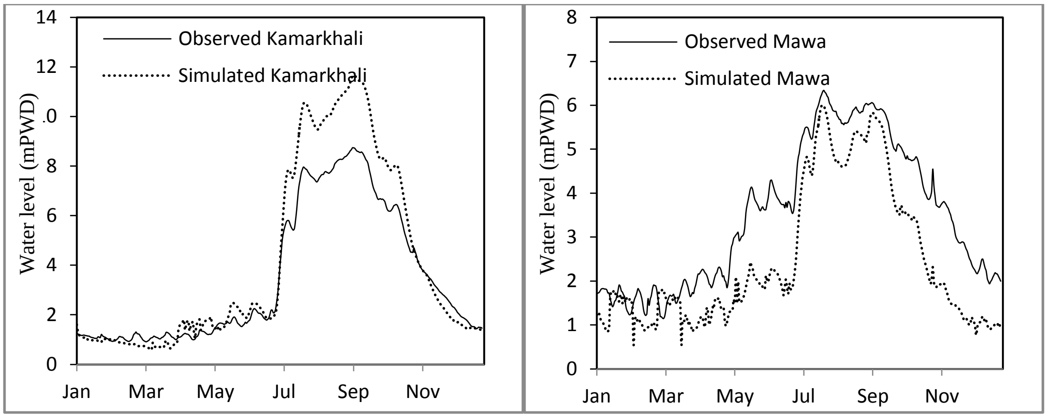


Figure 2: Observed and simulated stage hydrograph at Goalunda Transit, Gorai Railway Bridge, KamarkhaliandMawa non-tidal water level stations.

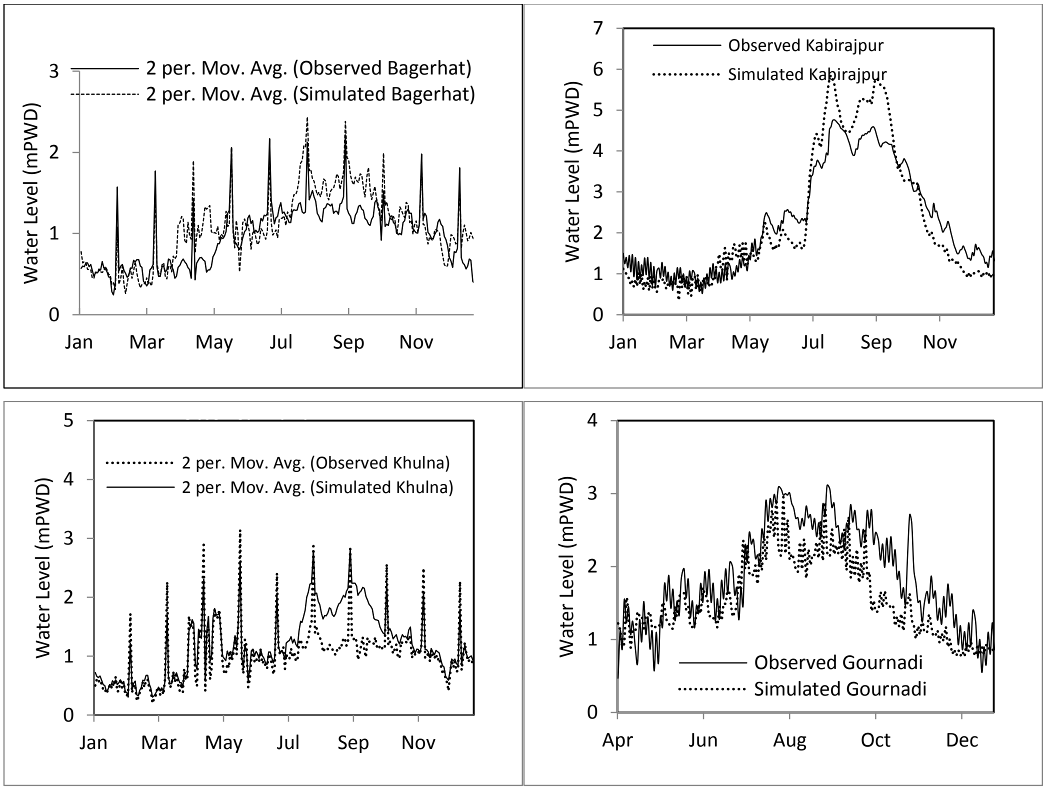


Figure 3: Observed and simulated stage hydrograph at Bagerhat, Kabirajpur, Khulna and Gournadi tidal water level stations.

4. RESULT AND DISCUSSION

From the simulations performed, it is seen that the southwest river network model of Bangladesh shows some significant changes in both discharge and water level. Notable rivers like Ganges, Padma, Lower Meghna, Gorai, Modhumati, Kumar, Pussur, Tentulia, Arial Khan, Paira and Buriswar, show significant increase in water level as well as discharge. The future changes of water level and discharge of the river network has been shown in Figure 4 and Figure 5.

From the simulation performed, as illustrated by Figure 4, it is seen that during monsoon period of the year 2030, the mean water levels of some of the important rivers like Ganges, Padma, Gorai, Modhumati and Kumar will have increased by more than 0.25 m, whereas, during 2050, the mean water levels of the same rivers (excluding Padma) will have increased by more than 0.30 m. Ganges and Gorai will have increased by 0.395 m and 0.405 m respectively during the monsoon period of 2050. Again, during 2030, the mean water levels of rivers like Lower Meghna, Pussur, Arial Khan, Buriswar, etc. will increase by more than 0.10 m in the monsoon, and the mean water levels of Paira and Tentulia will increase by less than 0.10 m. During 2050, mean water levels of all of these rivers will have increased by more than 0.15 m, whereas, Pussur, Arial Khan and Buriswar will increase by more than 0.20 m.

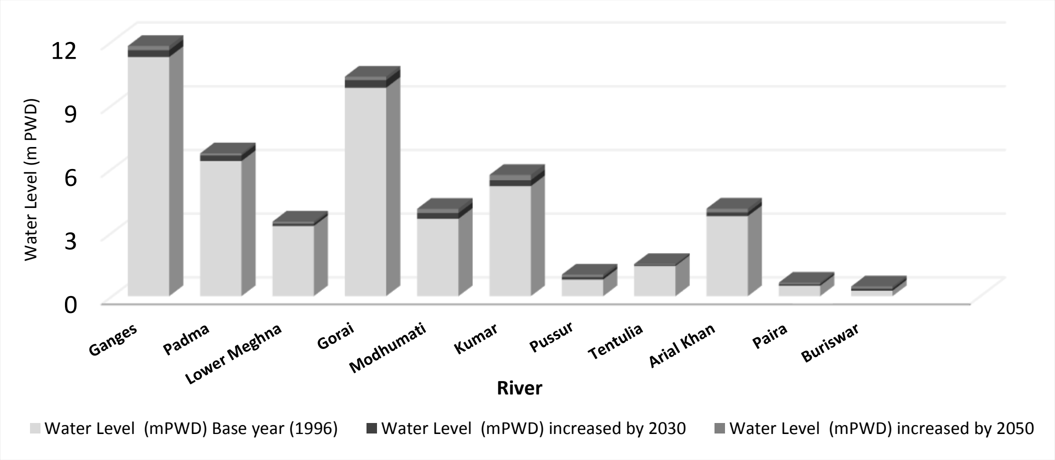


Figure 4: Increased water level of different rivers of the river network of the southwest region of Bangladesh for years 2030 and 2050.

Figure 5 illustrates the changes that are subjected to occur on the discharge of the rivers in the southwest river network of Bangladesh. Some of the rivers show significant increases of the discharges in future as a result of climate change. Mean discharges of three major rivers, i.e., Ganges, Padma and Lower Menghna is subjected to increase by more than 2000 m^3/s during the monsoon of 2030. Among them Ganges will increase by approximately 2400m^3/s whereas Padma and Lower Meghna will increase by approximately 3400 and 3700 m^3/s respectively. The mean discharge in Ganges and Lower Meghna will increase even more during the monsoon of 2050 upto approximately 3400 and 4400 m^3/s. Other rivers, having lower discharges, in comparison with these three major ones, will have less but significant changes as well. Among them, the mean discharges of Buriswar, Paira and Gorai will increase by almost 1400, 450 and 400 m^3/s during the monsoon of 2030 and Gorai will farther increase upto almost 500 m^3/s during the monsoon of 2050.

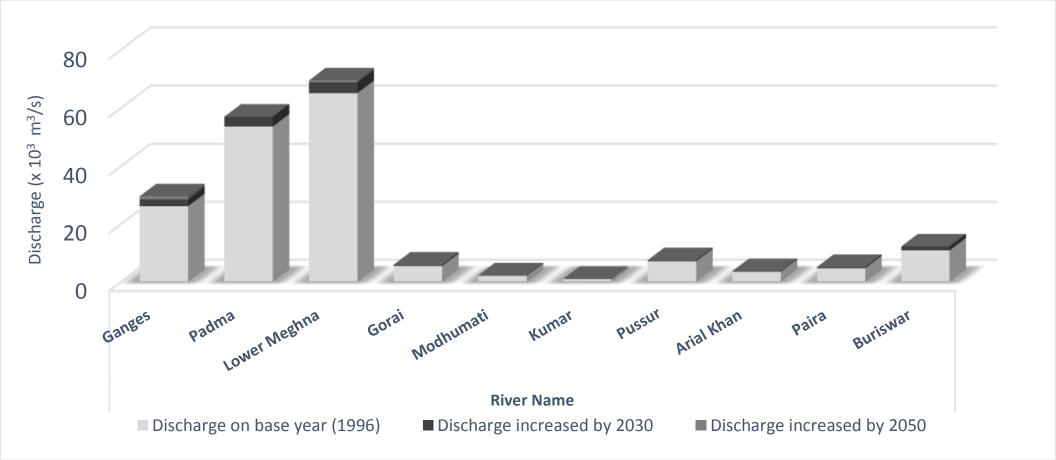


Figure 5: Increased discharge of different river of the river network of the southwest region of Bangladesh for years 2030 and 2050.

Table 2: Increased discharge (percent) of different rivers of the river network in the southwest region of Bangladesh for years 2030 and 2050.

River	Discharge		
	on base year (1996)	% increase by 2030	% increase by 2050
Ganges	26,034.08	9.28	13.23
Padma	53,487.55	6.33	4.96
Lower Meghna	64,946.98	5.75	6.76
Gorai	5,349.63	7.24	9.31
Modhumati	1,963.10	7.23	9.28
Kumar	829.65	8.51	9.52
Pussur	7,000.98	4.59	5.81
Arial Khan	3,363.06	7.14	6.64
Paira	4,602.21	7.40	9.62
Buriswar	10,748.93	7.25	12.97

Owing to climate change, the discharge of the southwest rivers in Bangladesh will have changed during the monsoon period as illustrated in Table 2. The maximum mean discharge will be increased by 9.28% in the Ganges River and the least increase of mean discharge will be 4.59% occurring in the Pussur River during the year 2030. During 2030 the mean discharges of the rivers Ganges, Padma, Modhumati, Gorai and Kumar will have raised by 9.28%, 4.96%, 9.28%, 9.31% and 9.52% respectively. For most of the rivers, the mean discharge will increase more by 2050 than it will increase in 2030, during the monsoon season. During 2050, major rivers of the southwest region of Bangladesh like Ganges, Padma, Lower Meghna, Kumar, Paira and Buriswar will be raised by 13.23%, 4.96%, 6.76%, 9.52%, 9.62% and 12.97% respectively.

5. CONCLUSIONS

One-dimensional model for the southwest region of Bangladesh is very important for flood inundation mapping and salinity intrusion study. Therefore, to set up and calibrate model is first step for the other impact studies. Output of GCM and RCM models have been used in this model for assigning future inner flow of the southwest region. Information of changes of the future flows considering climate change for various rivers of the southwest regions will useful for various purposed such as constructing any hydraulic structures (e.g. sluice gates, culverts, bridges) over the river, making embankments and roads along the banks, dredging and navigation purposes, or efficient water management etc.

Performance of themodel has been assessed through determining the coefficients of determination (R^2) between simulated and observed water levels. The differences between the simulated and observed water levels at station Kamarkhali, Goalunda Transit, Gorai Railway Bridge, Mawa, Bagerhat, Kabirajpur, Khulna and Gournadi have been considered as acceptable. Other statistical parameters have been evaluated for model performance. After calibrating, model has been used for future impact from the output of GCM model and sea level rise for downstream boundary. Major of the river in SW region has been enhanced around 4.59-9.55% from baseline in 2030s and 5.81-15.09% from baseline in 2050s.The water level will be increased from 0.04 to 0.32 m in 2030s and 0.17 to 0.40m in 2050sfor major rivers of SW region.

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