CLIMATE CHANGE IMPACTS ON WATER AVAILABILITY IN THE GANGES BASIN

Tanvir Ahmed [1*], Bhuiya Md. Tamim Al Hossain [2], Most. Nazneen Aktar [3], Malik Fida Abdullah Khan[4], A K M Saiful Islam[5], Munshi Md. Shafwat Yazdan[6], Farhana Noor[7], Ahmmed Zulfiqar Rahaman[8]

[1] Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail:tahmed.wre@gmail.com
[2]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail:cetamim@gmail.com
[3]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail:nazneen.aktar@yahoo.com
[4]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, email: mkhan@cegisbd.com
[5]Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh, e-mail: akmsaifulislam@iwfm.buet.ac.bd
[6]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: yazdan06buet@gmail.com
[7]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: 07farhana@gmail.com
[8]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: saikat07_wrebuet@yahoo.com

ABSTRACT

The Ganges is one of the largest river basins in the world with an area of 10,87,500 km^2. Water-related issues of the basin are due to both high and low flows and the problem will be more due to climate change. In this context, an attempted has been made in this paper to establish a basin scale hydrological model for the Ganges basin to predict the impact of climate change on water resources availability. A water balance model has been setup using physical based, semi-distributed hydrological model SWAT. Temperature and precipitation data from 9 GCMs and two SRES scenarios (A1B and A2) are used along with various input data (e.g., DEM, land use/cover, soil type, weather). Besides, assessment of statistical confidence of the results from different GCM is done utilizing the non-parametric Mann-Whitney U test. It is found that the average annual flow generated from the Ganges basin is 361,593 Mm^3. The results also indicate that the water availability will decrease during dry period and increase during monsoon. The average annual flow volume increases 22% by 2030, 26% by 2050 and 19% by 2080 for A1B scenario. A similar situation is observed for A2 also.

Keywords: *Climate change, hydrologic modelling, water availability, Ganges basin*

1. INTRODUCTION

The Ganges basin is a part of the composite Ganges-Brahmaputra-Meghna basin draining 10,87,500 km^2 in Tibet, Nepal, India and Bangladesh (JRC, Bangladesh). The origin of the Bhagirathi River is the Gangotri Glacier in the Uttaranchal Himalayas, which joins the Alakananda River at Devaprayag, also in the Uttaranchal Himalayas, to form the Ganga. The tributaries of Ganga include the Rarnganga, the Sai, the Gornati, the Sone, the Yamuna, the Mahananda, the Ghagra, the Rapti, the Gandhak, the Buri Gandhak, and the Ghugri. In Bangladesh, the Ganges is joined by the mighty Brahmaputra near Goalondo Ghat and combinedly known as the Padma. The basin has a population of more than 500 million, making it the most populated river basin in the world. Water-related issues of the basin are due to both high and low flows. Flood is the common phenomena in this area and severe flood occurs almost every year. Low flows are caused by scarcity of rainfall outside the summer Monsoon, and sometimes by failure of this monsoon to develop to its normal extent.

Due to the warming of the earth's climate system, the global hydrologic cycle is apprehended to be perturbed to alarming scales and the existing level of water resources scarcity in the South Asian region is likely to face more stress and uncertainty in the coming years. In recent years, a number of studies have assessed the impact of climate change on water resources in Bangladesh. However, none of the studies attempted to assess the national and sub-national water resources availability incorporating climate change scenarios. In this context, an approach has been developed in this paper to establish a basin scale hydrological model for the Ganges basin to predict the impact of climate change on national and sub-national water resources availability on three time slices up to 2100.

2. METHODOLOGY

The study methodology follows six sequential steps: selecting emission scenario; selecting GCMs; data collection and preparation; hydrological model setup; calibration and validation; and estimation of flows and changes in future time slices. The following sections discuss the detail of the methodology.

2.1 Selecting emission scenario

Emission scenarios are derived from population, economic and technology scenarios, which also shape vulnerability and hence impacts of climate change. Emission scenarios drive scenarios of climate change, which in turn drive impacts research. According to the IPCC AR4, there are mainly three emission scenarios such as high A2, medium A1B and low B1. These emission scenarios describe three different possibilities e.g., a global curbing of emissions over the next century (B1), a mid-21st century levelling-off of emissions (A1B), and a continual increasing rate of emissions over the 21st century (A2) (Nakicenovic 2000). Due to these patterns, during 2050 A1B shows higher temperature and precipitation estimates than A2, while during 2100 the situation is completely opposite. Based on these characteristics of different emission scenarios, A2 and A1B scenarios have been selected for the present study. A2 has been selected as an extreme scenario and A1B has been selected as a balanced scenario.

2.2 Selecting GCMs

There are several IPCC approved GCMs for the projection of climate change scenario. For the present study, nine GCMs were selected which have better representation of climate system in areas near Bangladesh (Mukherjee et al, 2011). These GCMs are: CGCM3.1 (T47), CSIRO-Mk3.0, GFDL-CM2.0 and CM2.1, INM-CM3.0, MIROC3.2 (medres), ECHAM5, CCSM3 and UKMO-HadCM3. Temperature and precipitation data from these 9 GCMs for two emissions scenarios (A1B and A2) are used to characterize the range of potential climate changes for the Ganges basin.

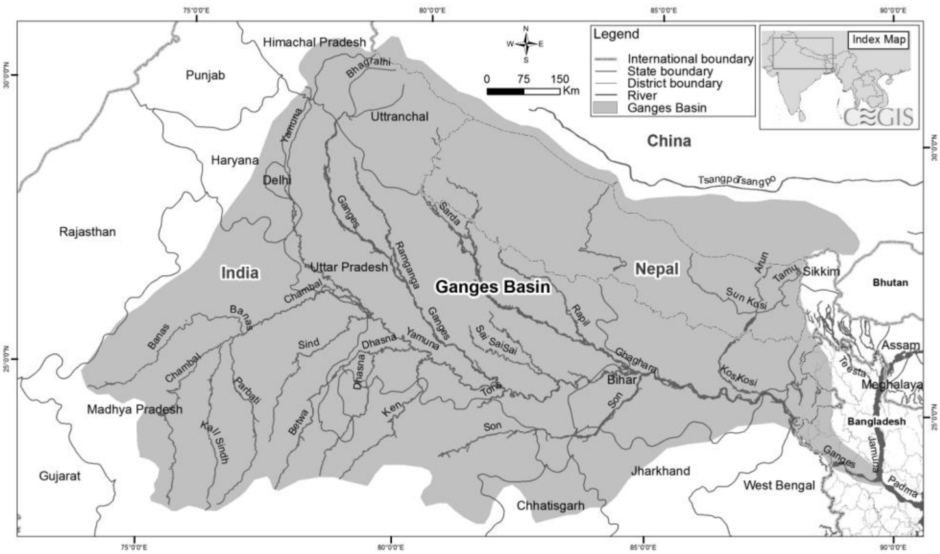

Figure 1: River system of the Ganges Basin

2.3 Data collection and preparation

For the hydrological model development several data layers are required. These are: weather/ climate data, topography data, land use and soil data and discharge data for calibration.

2.3.1 Weather/ climate data

The weather data for the Ganges basin has been collected from NASA POWER website (http://power.larc.nasa.gov). From this source daily weather data (precipitation, minimum and maximum temperature) has been collected for 1981 to 2012. The data has a spatial resolution of 1°. At the same time, weather data of BMD stations for the same period has been collected also.

The GCM data for three future time slices centering on 2030, 2050 and 2080 were collected as monthly average. The used data sets are downscaled from the CMIP3 multi-model dataset (Meehl et al., 2007) using the bias-correction/ spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003). These dataset is available at www.engr.scu.edu/~emaurer/global_data/.

2.3.2 Topography data

The topography data includes the Digital Elevation Model (DEM) data and has been collected for the Ganges basin area from the Shuttle Radar Topography Mission (SRTM). The DEM resolution is 90m.

2.3.3 Land use and soil data

Model development incorporates input data from land use/cover data and soil type data. Land use data for the Ganges basins has been collected from USGS - Global Land Cover 2000 database which has a spatial resolution of 1 km. The soil type data was collected from the Food and Agricultural Organization database. The spatial resolution is 10 km with soil properties for two layers 0-30 cm and 30-100 cm depth.

2.3.4 Discharge data

For model calibration and validation, discharge data is essential. The discharge locations for the model calibration have been selected based on the availability of data. The discharge data has been collected from NWRD database for the stations in Bangladesh and from Nepalese agencies for the stations outside Bangladesh.

2.3.5 Water management information

Reservoir characteristics and water withdrawal from reservoir and river reach are also major input for model setup. Reservoir and diversion locations and characteristics have been taken from the National Register of Large Dams of India. Existing major water resources infrastructures, current management/ operation practices, existing irrigation as per crop water demand and irrigation sources has also used in the model setup. The spatial distribution of the surface water and groundwater irrigation has been collected from Global Map of Irrigation Areas (GMIA, FAO)

2.4 Hydrological model setup

In order to assess the water availability for different climate change scenarios a semi-distributed hydrological model named Soil and Water Assessment Tool (SWAT) has been utilized. The SWAT model (Arnold et al., 1998, Arnold et al., 2009) is a physically-based, continuous simulation model developed for watershed assessment of short- and long-term hydrology and water quality. It is a widely used catchment-scale model that can predict the impact of land management practices and climate change over time on water, sediment and agriculture. The model development has been completed in five sequential steps, namely, watershed delineation, HRU definition, weather data definition, editing SWAT inputs and simulation. The watershed delineation is accomplished using the automatic watershed delineation tool of SWAT 2012 employing a resampled 900 m DEM. After watershed delineation, the Ganges basin has been divided into 348 watersheds. The next step of the model setup is the definition of HRU (Hydrological Response Unit). HRU is the unique combination of land use soil and slope. The overlay of 14 land uses, 63 soil unit and 3 slope classes for the Ganges basin resulted in 3,002 numbers of HRU. The daily precipitation and maximum and minimum air temperature have been used as weather input for the period of 1981 to 2012. The reservoir characteristics and water withdrawal from reservoir and river reach are also major input for SWAT model setup. For this study, 33 major reservoirs of Ganges basin have been considered. Total capacity of these reservoirs is 25,162 Mm^3 with total area of 9,021 km^2.

During the model development, the distribution of rainfall has been done by the skewed normal probability distribution function. SWAT uses Manning's equation to define the rate and velocity of flow while routing through channel network has been done using the variable storage routing method. For estimating runoff, the SCS curve number method (variable CN: Moisture condition II) has been used. The Hargreaves method has been used to calculate potential evapotranspiration (PET). The model has been simulated for the period of 1981 to 2012 based on data availability.

2.5 Calibration and validation

The model has been calibrated and validated in six locations (five in Nepal and one in Bangladesh) against monthly stream flow data. The location of the calibration points are given in table 1. The calibration and validation periods are 1981 to 1990 and 1991 to 2000 respectively. To facilitate the evaluation of model performance, visual comparison has been normally done between observed and simulated hydrographs; also, some statistical analyses have been applied, such as Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2), Mean Relative bias (PBAIS) and ratio of the root mean square error to the standard deviation of measured data (RSR) (Moriasi et al, 2007). For the model calibration, SWAT-CUP has been used.

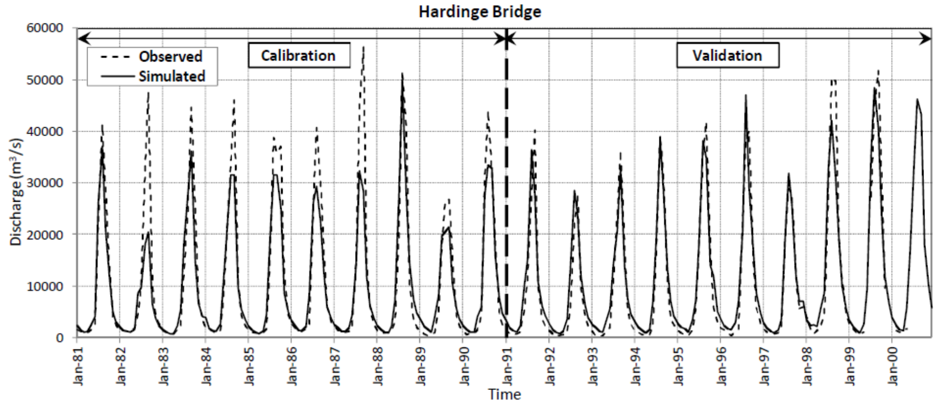

Figure 2: Calibration and Validation of SWAT model at Hardinge Bridge, Bangladesh

The visual comparison of model result for the location of Hardinge Bridge (outlet of the Ganges basin) is shown in figure 2. The model can simulate the behaviour of flow during both calibration and validation period. The model cannot capture the peak flow for several years during calibration period which is mainly due to the uncertainty of rainfall data. But it can simulate the dry season flow very well during both calibration and validation period.

The statistical measures for the stations in Ganges basin during the calibration and validation periods are presented in Table 1. During the calibration and validation periods, the NSE value for these points are in the range of 0.73 to 0.91 and 0.85 to 0.91 respectively which are in the range of "very good" and "good". The value of coefficient of determination (R^2) is in the range of 0.73 to 0.93 which is also in "satisfactory" range. The model performance is also in the ranges of "good" to "very good" for PBIAS and RSR for these locations (Moriasi et al, 2007). So, it can be said that the model shows satisfactory results in simulating the flow in the Ganges basin.

Table 1: Model performance statistics for calibration and validation period of the Ganges basin

Station	**Calibration (1981-1990)**				**Validation (1991-2000)**			
	NSE	**PBIAS**	**RSR**	**R^2**	**NSE**	**PBIAS**	**RSR**	**R^2**
Hardinge Bridge	0.86	9.80	0.38	0.90	0.91	-6.40	0.29	0.92
Banga	0.73	6.04	0.52	0.73	0.78	-0.37	0.46	0.79
Benighat	0.75	-7.69	0.50	0.79	0.85	-10.55	0.39	0.89
Jamu	0.86	11.64	0.37	0.90	0.88	5.28	0.35	0.92
Narayan Ghat	0.91	-12.26	0.29	0.93	0.88	-15.24	0.34	0.91

According to Moriasi et al, 2007:

NSE: *"very good" if NSE > 0.75 and "good" if 0.65 < NSE < 0.75;* ***PBIAS:*** *"very good" if PBIAS < ±10% and "good" if ±10 % < PBIAS <± 15%;* ***RSR:*** *"very good" if RSR < 0.50 and "good" if 0.50 < RSR < 0.60;* ***R^2:*** *Satisfactory if R^2 > 0.6*

2.6 Estimation of flows and changes in future time slices

Stream flow has been generated from the developed model (both for present condition as well as the future) at different crucial points in some major rivers which are basically the outflow of different sub-catchments. The models have been run to generate monthly results for different time slices e.g., base period, 2030, 2050 and 2080.

During SWAT modelling for the different downscaled GCMs outputs, it has been found that there is a large range of variation in model results for the same time slice. So, an attempt was made to assess the confidence of the results. In order to do this, non-parametric Mann-Whitney U test (Haan, 2002; Maurer, 2007) has been employed to assess the probability that the changes in future projections are statistically significant. The analysis has been carried out following the approach of Maurer (2007). In this method, all GCMs fed results of SWAT for the same emission scenario and time slice are assembled together in an ensemble and it was compared with base period for equality of means. These results are also presented with the results of future changes in flow patterns.

3. RESULTS AND DISCUSSIONS

The basin-wise water availability of the base scenario has been analyzed based on SWAT results. In this study, base period has been taken from 1981 to 2012. The model results show that, the average rainfall in Ganges basin is 981 mm of which 60% is evaporated, 22% is percolated, 15% is contributing to river flow as surface runoff, 2.5% is lateral flow to rivers and 3.5% is snow melt contribution to river flow. Besides, 12% is contributing to river flow as groundwater contribution which is coming from the percolated water. In total, 33% of the rainfall is going to the river.

The average annual flow generated from the Ganges basin is 361,593 Mm^3. The flows are mainly concentrated in the monsoon period (June to October) and the maximum monthly flow is 92,335 Mm^3 (Table 2). For the Ganges basin, the peak flow occurs during August.

Table 2: Monthly flow volume change of climate scenarios with respect to base scenario for the Ganges basin at Hardinge Bridge

Month	**Discharge (Mm^3)**	**Percentage change of monthly flow**					
		A1B_2030	**A2_2030**	**A1B_2050**	**A2_2050**	**A1B_2080**	**A2_2080**
January	8,047	19.56	22.53	17.22	20.50	20.20	6.13
February	4,832	10.04	20.56	7.34	19.49	17.38	18.48
March	3,960	2.42	13.06	-0.15	16.34	9.63	13.18
April	3,394	10.70	4.97	-6.95	16.27	3.04	14.04
May	8,559	-23.35	9.31	-40.68	11.26	-37.96	-15.97
June	21,019	13.79	-12.71	13.03	30.03	17.37	6.36
July	58,988	37.40	1.46	32.08	26.59	26.93	21.29
August	92,335	19.39	19.43	33.23	18.50	15.99	17.74
September	80,072	26.74	21.37	31.34	39.85	27.90	32.60
October	44,598	22.08	10.67	24.30	22.19	16.47	18.72
November	22,431	17.37	9.41	21.53	25.08	15.26	18.27
December	13,357	17.56	21.02	14.97	22.98	18.28	18.36

The calibrated and validated models has been utilised to simulate six sets of climate change scenarios (A1B and A2 scenario for 2030, 2050 and 2080). The SWAT model has been run for the future considering a monthly change in temperature and precipitation with respect to base period. Table 2 and Figure 3 shows the results of monthly average discharge during base period and also the changes in future scenarios at Hardinge Bridge. A look at the percentage change in monthly flow volume in future time slices with respect to the base condition (1981-2012) shows that there are rapid changes between consecutive months. It has been found that the flow decreases for May in A1B for 2030 while for A2, 2030 there is decrease in June flow. There is significant decrease in flow in 2050 during March, April and May months. For 2080, the monthly flow for May decreases by at least 16 percent. There are expected increases during monsoon (Jul- Sept). The statistical significance of the future changes are mostly around 50% while for some months (e.g., March, June and August of A1B 2030) the changes are very small (10%). The average annual flow volume of three time slices in two different SRES scenarios shows that annual flow volume increases 22% by 2030, 26% by 2050 and 19% by 2080 for A1B scenario. A similar situation is observed for A2 also. So, there is increasing flow which reaches the peak by 2050 and then reduces during 2080.

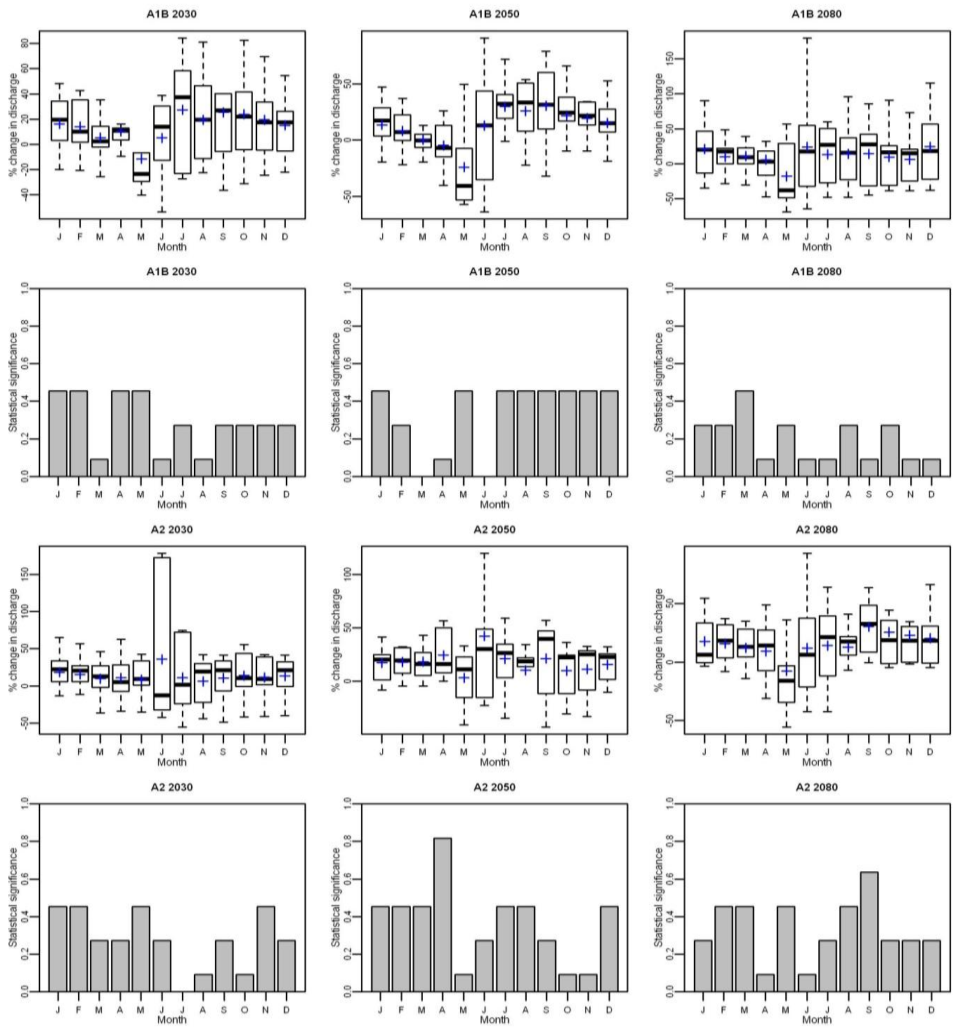

Figure 3: Change in monthly flow of the Ganges basin at Hardinge Bridge

4. CONCLUSIONS

A calibrated and validated water balance model has been setup for the Ganges basin to assess the climate change impact on water availability using SWAT. The model is simulated for base and different climate change scenarios. It has been found that the monsoon will be more wetter and dry season will be more drier due to climate change. This result will provide the inputs to the decision makers for future water management strategy.

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