CLIMATE CHANGE IMPACTS ON WATER AVAILABILITY IN THE BRAHMAPUTRA BASIN

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ABSTRACT

Being a riverine country, Bangladesh is highly vulnerable to climate change impacts since most of climate change related vulnerabilities are associated with water resources. The Brahmaputra, the largest river in Bangladesh has one of the large river basin and also ranked as the highest specific discharge system in the world, is expected to be impacted by climate change. In this study, water availability of the Brahmaputra Basin has been assessed for present and future using basin-scale hydrology with the help of a semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT)' for two scenarios (A2 and A1B by 2030, 2050 and 2080). To identify the range of potential range of water availability, 9 GCMs' data are used along with PRECIS RCM data. The model development has been completed in five sequential steps: watershed delineation, weather data definition, editing SWAT inputs, simulating SWAT (incorporating calibration and validation). The monthly changes in discharge for the climate change scenarios have been compared with the base condition at Bahadurabad for the Brahmaputra Basin. It has been found that there is a large variation in water availability for different GCM/RCM output data.On average, flow will be increased throughout the year by end of this century (2080) for A2 scenario. The rest time slices (2030 & 2050) will have decreased flow for both for A1B & A2 scenarios except for dry months for A1B scenario.

Keywords: *Climate change, hydrologic modelling, water availability, Brahmaputra Basin*

1. INTRODUCTION

Bangladesh is one of the most climate vulnerable countries. The hydro-geological set up (such as geographical location, topography, extreme climate variability etc.) and socio-economic factors (such as high population density, poverty incidence and dependency of agriculture on climate) make Bangladesh highly vulnerable to climate change (Ahmed, 2006). Since the hydrology is directly influenced by climatic parameters (such as temperature, rainfall etc.), the water availability in river basin is directly impacted by climate change and it will alter in future due to climate change.

Climate change might ultimately lead to more serious floods during monsoon and water scarcity during dry season in Bangladesh. The assessment of climate change impacts on basin-scale hydrology by using well-constructed hydrologic modelling has rarely been conducted for the Brahmaputra Basin due to the lack of data. In this context, an approach has been developed in this study to establish a basin scale hydrological model for the Brahmaputra Basin (Figure 1) to predict the impact of climate change on water availability on three time slices (2030, 2050 & 2080) up to 2100.

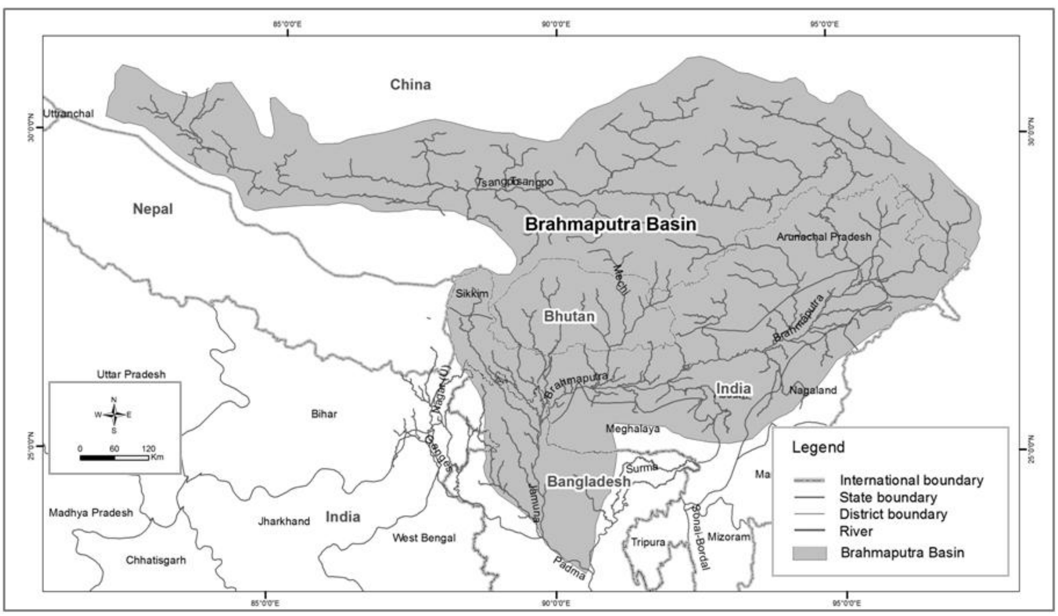

Figure 1: Geographical extent of the Brahmaputra Basin

2. METHODOLOGY

The methodologies adopted for each of the above mentioned components are briefly described in the subsequent sub-sections.

2.1 Selecting Climate Change Scenarios

Climate data for the future is an important part for water availability assessment for future. For this purpose, projected data set on climate change from different IPCC approved GCMs are required. According to the Fourth Assessment Report of IPCC, there are mainly three emission scenarios which are A2 (as high), A1B (as medium) and B1 (as low) (IPCC, 2007). The emission scenarios analyzed here describe three different possibilities for the future, e.g., a global curbing of emissions over the next century (B1), a mid-21st century leveling-off of emissions (A1B), and a continual increasing rate of emissions over the 21st century (A2 (Nakicenovic, 2000). The deviation between A2 and A1B is due to the basic assumptions made in the respective scenarios. A1B scenario has a peak emission around 2050 while A2 has a continuously increasing emission until 2100. For the present study, A2 and A1B scenarios have been used. A2 has been selected as an extreme scenario and A1B has been selected as an average scenario.

2.2 Selecting GCMs and RCM

In this study, water availability has been assessed by SWAT model for future time slices centring in 2030, 2050 and 2080. Nine best suitable GCMs' data suggested by Mukherjee et.al. (2011) is used for Brahmaputra Basin SWAT model. The selected GCMs are: CGCM3.1 (T47), CSIRO-Mk3.0, GFDL-CM2.0, GFDL-CM2.1, INM-CM3.0, MIROC3.2 (medres), ECHAM5/MPI-OM, CCSM3 and UKMO-HadCM3. In addition, PRECIS (run by IWFM) is used here.

2.3 Data Collection and Preparation

Various types of data required for a SWAT model are collected from different sources. Pre-processing of the collected data is sometimes necessary for use as input for the model development. Input data such as Digital Elevation Model (DEM), land use/cover, soil type and weather data (maximum and minimum temperature, rainfall, relative humidity, evapotranspiration, wind speed, solar radiation) have been used in SWAT model. Furthermore, discharge data has been used for model calibration and validation. SWAT supports the input of daily meteorological data either from a measured data set or generated by a weather generator model using monthly values. There are many parameters for calibrating the model such as discharge, evapotranspiration, soil moisture condition, leaf area index etc. It should be noted that for all types of input parameters, finer resolution data have been used for Bangladesh part since they are available from different national sources. The input data and their sources required for the SWAT model are described in the following paragraphs.

The national level DEM for Bangladesh is available from the NWRD is used in fine scale SWAT model (North-west regional model). On the other hand, the Shuttle Radar Topography Mission (SRTM) 90 m DEM has been used as topographic data of the rest part of the basin. In case of land use, soil texture classified by Soil Resource Development Institute (SRDI) has been used for North West Region of Bangladesh whereas land use data for the rest part of the Brahmaputra Basin has been colledted from USGS (United State Geological Survey). Observed weather data starting from 1981 to 2012 have been used in the model. For Bangladesh part, this type of data (for same period) of BMD stations has been used whereas data for rest part of the basin has been dowloaded from NASA POWER website. For observed data, consistancy and homogenity of weather data has been checked with double mass analysis. For future weather data, the GCM data for three future time slices centering on 2030, 2050 and 2080 are collected as monthly average 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) (Maurer et al., 2009). This downscaled dataset is download from website: www.engr.scu.edu/~emaurer/global_data/. For the Bangladesh part, information on water withdrawal and irrigation is collected from the local agencies. Information on Indian reservoir and diversion locations and characteristics have been taken from the National Register of Large Dams of India. The spatial distribution of the surface water and groundwater irrigation activities has been collected from Global Map of Irrigation Areas (Siebert et al., 2013).

Since here SWAT is used as a water balance model, effort has been made to calibrate it using discharge. The discharge data of Bahadurabad Tr. of BWDB has been used for model calibration.

2.4 Model Development

Model development has various components such as watershed delineation, weather data definition, selecting simulation method and selecting sensitive parameters. Watershed delineation is accomplished using the automatic watershed delineation tool of SWAT 2012 employing 200 m DEM (re-sampled from 300 m DEM) for Bangladesh part and 900 m DEM (re-sampled from 90 m DEM) for rest part of the Brahmaputra Basin.

Depending on the available projected climatic data, ten sets of models are simulated for each of A1B and A2 scenarios. Among them, nine sets use earlier mentioned GCM model data for the entire basin, and the 10th set uses PRECIS' data for Bangladesh part and UKMO-HadCM3 for rest part.

To describe the distribution of rainfall, SWAT provides two options: a skewed normal distribution and a mixed exponential distribution. To simulate models for the this study, the skewed normal probability distribution function has been used. SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. In this simulation the variable storage method has been used. For estimating runoff, the SCS curve number method has been used and the variable CN: Moisture condition II is specified. The Hargreaves method has been used to calculate potential evapotranspiration (PET) as it requires less weather parameter.

2.5 Calibration and Validation of Model

In this study, base model has been simulated for the period 1981-2000 where calibration and validation periods are 1981-1990 and 1991-2000 respectively. It is well known that calibration is a process to develop correction factors for model so that the model would generate predicted values. On the other hand, validation is the process to assess the performance of the calibrated model. For calibration and sensitivity analysis, SWAT-CUP tool has been used here. Four statistical analyses applied to test model performance are: Nash–Sutcliffe efficiency (NSE), Coefficient of determination (R2), Mean relative bias (PBIAS) and Ratio of the root mean square error to the standard deviation of measured data (RSR). Validation is done by comparing model gererated discharge (of calibrated model) for validation period with observed data of that period.

2.6 Flow Assessment

Flow assessment has been made at Bahadurabad Tr. in the Brahmaputra River for model generated average monthly flow. In fact, flow assessment has been accomplished for present condition (1981 to 2012) and also for future for previously mentioned scenarios. During SWAT modeling for the different downscaled GCM and RCM outputs, it has been found that there is a large range of variation in model results for the same time slice. So, an attempt is 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 GCM/RCM fed results of SWAT for the same emission scenario and time slice are assembled together in an ensemble, and it is compared with base period for equality of means. These results are also presented with the results of future changes in flow patterns.

2.7 Changes in Flow

Percentage changes with respect to base condition (1981-2012) in monthly flow has been calculated to find out change in future (2030, 2050 and 2080).

3. RESULTS AND DISCUSSION

Before discussing flow changes in future, this paper is focusing on calibration and validation results to show model performance.

3.1 Calibration and Validation

The SWAT model has been calibrated for one discharge station (Bahadurabad Tr.) in the Brahmaputra River. The period 1981-1990 is used here as calibration period whereas 1991-2000 is validation period (Figure 2). Figure 2 shows that peak values matches well for most years and model result has similar pattern of observed data.

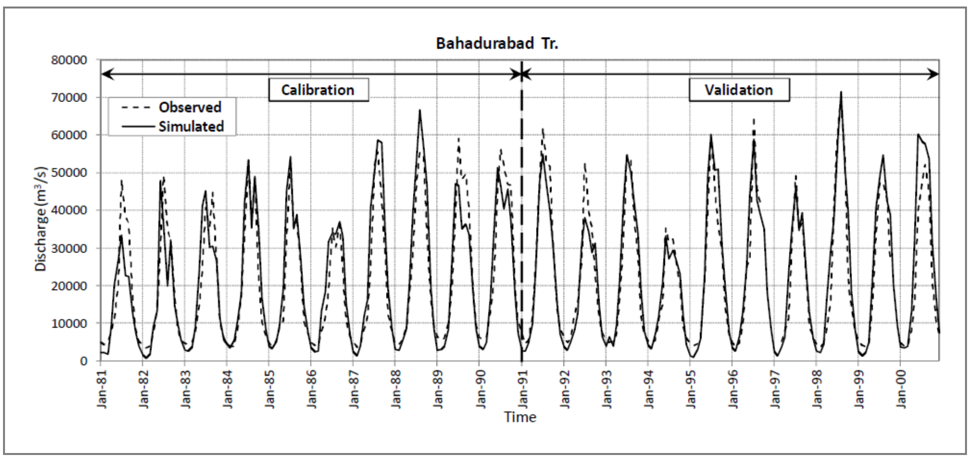

Figure 2: Calibration and Validation of SWAT model at Bahadurabad Tr.

The model performance has also been evaluated by analyzing the statistical measures after SWAT simulation. The statistical measures at Bahadurabad for calibration and validation periods are shown in Table 1.

Table 1: Model performance statistics for calibration and validation period of the Brahmaputra Basin

Station	**Calibration (1981-1990)**				**Validation (1991-2000)**			
	NSE	PBIAS	RSR	R^2	NSE	PBIAS	RSR	R^2
Bahadurabad Tr.	0.84	-3.24	0.40	0.85	0.89	-6.50	0.33	0.91

The model performance shows very good rating for both NSE and RSR. The results of R^2 is satisfactory and PBIAS has been also found to be in very good range (PBIAS<±10%) during both calibration and validation period.

3.2 Water Availability

Monthly flow of the Brahmaputra Basin has been estimated at Bahadurabad Tr. for base period (1981-2012). It has been found that it receives maximum flow in July and minimum in February (Table 2). Flow attains peak level in this basin during June-August. The total annual flow accumulation is around 661,000 Mm3.

Changes in flow for three time slices (2030, 2050 and 2080) in this basin has been estimated with respect to model generated flow (for base period) for two climate change scenarios which is presented in Figure 2. This figure shows that there are large variations among different GCM/RCM predictions. The ensemble result (median value of ensemble of downscaled GCM/RCM driver SWAT result) presented in Table 2.

Table 2: Average monthly flow generated at present and in future from the Brahmaputra Basin

Month	**Base flow (Mm^3)**	**Percentage change of monthly flow**					
		2030		**2050**		**2080**	
		A1B	**A2**	**A1B**	**A2**	**A1B**	**A2**
January	2,266	-2.58	-5.76	-5.57	2.84	0.68	8.48
February	820	1.41	-1.52	-0.68	0.41	15.74	16.14
March	946	-15.20	-21.82	-24.08	-24.06	51.41	53.49
April	3,852	17.62	-3.18	1.78	18.68	-17.26	18.44
May	11,891	34.05	-12.50	18.34	5.16	-17.54	27.99
June	30,015	-11.63	-22.33	-13.26	-3.62	-18.82	6.94
July	30,821	-4.36	-13.93	-14.61	-3.30	6.09	9.89
August	31,109	-14.32	-16.33	-8.63	-14.97	-10.67	0.69
September	23,878	-2.89	-7.34	1.93	8.00	4.85	25.68
October	20,146	-3.41	-19.13	-5.62	-15.07	-6.32	1.33
November	9,402	-1.33	-3.47	-3.10	1.92	-1.41	15.89
December	4,955	-4.26	-3.63	-5.01	1.22	-3.04	10.53

From Table 2, it is found that flow will increase during April and May months of 2030 and 2050, while for 2080, there will be increased in flow during February, March and monsoon months. Maximum reductions in flow is found for March in 2030 and 2050 while for 2080, it will attain maximum decrease in June. The statistical significance of the future changes are mostly around 50% while for some months the changes are very small (10%) or negligible (almost 0%). The average annual flow in different time slices shows that, annual flow will be decreased 4%, 6% and 6% by 2030, 2050 and 2080 respectively for A1B scenario. For A2 scenario, the changes will be 14% decrease (by 2030), 4% decrease (by 2050) and 11% increase (by 2080).

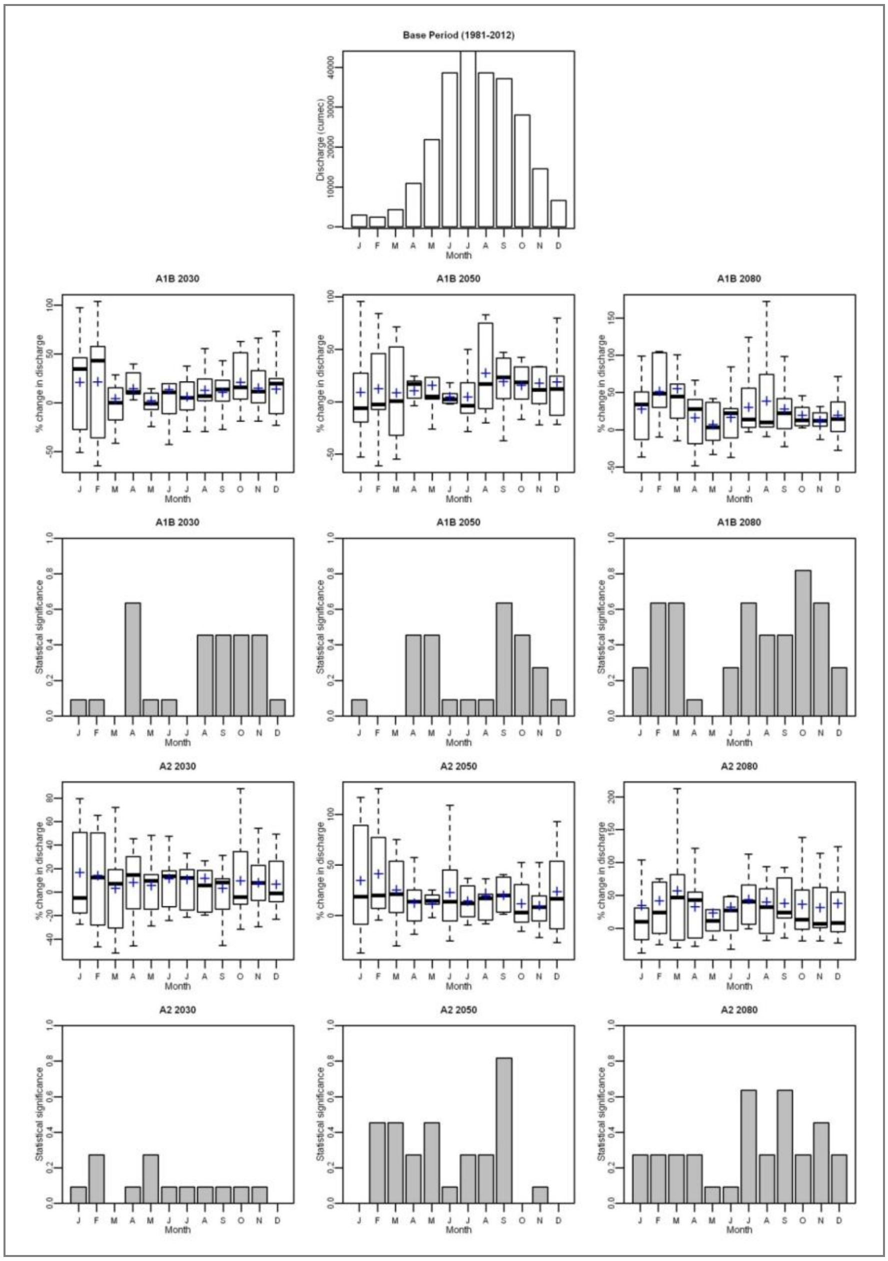

Figure 2: Monthly flow in Brahmaputra River at Bahadurabad Tr.

4. CONCLUSIONS

For 2030 and 2050, changes in monthly flow will have similar pattern for both scenarios. For A1B, it will increase during April and May for 2030 and 2050 but for 2080 it will reduce for same months. For 2080, flow will increase in all months for A2 scenario. In March and monsoon months flow will reduce in 2030 and 2050 for both scenarios. In general, for A1B scenario, the expected future flow is smaller than present. But for A2 scenario, flow pattern will be different in future. It will decrease till mid century but will increase by end of this century.

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