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Impact of Prospective Climate Change on the Discharge of the Brahmaputra River, Bangladesh using RCP Scenarios

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Abstract

This study is to evaluate the future climate change impact on the river discharge of the Brahmaputra River, a trans-boundary river entering in Bangladesh through the north from India, using SWAT (Soil and Water Assessment Tool) model. To reduce the uncertainty, the model has been calibrated and validated using the observed daily flow data at Bahadurabad from 1998 to 2007 and soil moisture data. Hydrological predicted values matched well with the observed values by showing coefficient of determination (R^2) from 0.83 to 0.85 for stream flow. Climate scenarios from the model EC-Earth under different representative concentration pathways (RCPs) of the IPCC (Intergovernmental Panel on Climate Change) AR5 (Assessment Report 5) have been fed to the SWAT model and the river discharge for the Brahmaputra River has been estimated for three time windows, i.e. 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). The future changes in the river discharge of the Brahmaputra River showed an upward tendency up to 7%, 15% and 16% increase during the monsoon seasons (June - September) and 39%, 33% and 58% increase during the pre-monsoon seasons (March - May) of the 2020s, 2050s and 2080s, respectively, under RCP 4.5 scenario. And under the RCP 8.5 scenario, it is likely to increase up to 12%, 22% and 32% during the monsoon seasons and 53%, 54% and 101% during the pre-monsoon seasons, respectively.

Keywords: *Brahmaputra, Climate Change, Future Flow, RCP, SWAT.*

1. Introduction

The Ganges-Brahmaputra-Meghna (GBM) river system plays an important role in China, Bhutan, India, Nepal and Bangladesh. The GBM basin is the third largest freshwater outlet to the world's ocean (Chowdhury et al., 2004). The Brahmaputra River contributes the 67% of the total annual water flow of Bangladesh (Immerzeel, 2008). The peak discharge of the Ganges slows down the drainage of the Brahmaputra River through the Baruria transit. This helps to increase the areal extent, depth and duration of flood in the Brahmaputra basin because the

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Brahmaputra water cannot be drained out quickly (Mirza, 2011). This river basin is the main source of water in Bangladesh. Assessment of stream flows through this river can play a vital role for the water management of the country. However, estimation of water scarcity or water availability depends on the understanding of the hydrological system that is the main governing backbone of all kinds of water movement and water pollution (Jha, 2011). Watershed analyses and hydrological modelling are important tools for management of many natural resources like land and water. Thus, for proper planning and efficient utilization of the land and water resources, it is necessary to understand the hydrological cycle and estimate the hydrological parameters (Immerzeel, 2008). However, there are insufficient studies quantifying the current basin-wide rainfall and runoff relationship. This is mainly because rainfall data from the upstream countries is either not available or, if available, not accessible to scientists in other countries (Nishat and Faisal, 2000).

SWAT (Soil and Water Assessment Tool), a modelling tool developed by the U.S. Department of Agriculture (USDA), has proven to be very successful in the watershed assessment of hydrology and water quality (Neitsch et al., 2002). It is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in un-gauged watersheds. The model is physically based, computationally efficient and capable of continuous simulation over long periods. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management. The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0 to 2 meters), shallow aquifer (typically 2 to 20 meters), and deep aquifer (more than 20 meters). Flow, sediment, nutrient, and pesticide loadings from each HRU in a sub-watershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet (Neitsch et al., 2002). The SWAT model was found very useful to study changes of flows of the semi-un-gauged Ganges due to climate change (Narsimlu et al, 2013). Hence, it is expected that SWAT will be able to generate flows for the Brahmaputra River basin which is unique in hydro-morphological nature.

2. Methodology and Data

Several types of data are required as input for SWAT to develop model using the ArcSWAT interference. Topographic data have been obtained from the Shuttle Radar Topographic Mission (SRTM) with a spatial resolution of 90 m. The sub-basin parameters, such as slope gradient, slope length of the terrain and the stream network characteristics (channel slope, length and width) have been derived from the analysis of Digital Terrain Model. The DEM has been masked for the Brahmaputra basin area as shown in Figure 1. Landuse maps are required for the delineation of the HRU of the model. A 300 m resolution landuse from 2009 to 2010 are collected from Europe Space Agency GLOBCOVER. This data has been reclassified to match the SWAT Land classes. Soil map of the study area was collected and extracted from the FAO digital soil map of the world. A ‘usersoil’ database table was created for the study area from the available interpretations and lookup tables. SWAT requires daily or sub-daily observed meteorological data such as rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed, etc. Climatic data has been obtained from TRMM (Tropical Rainfall Measuring Mission), GPCP (Global Precipitation climatology Project) and APRHODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation).

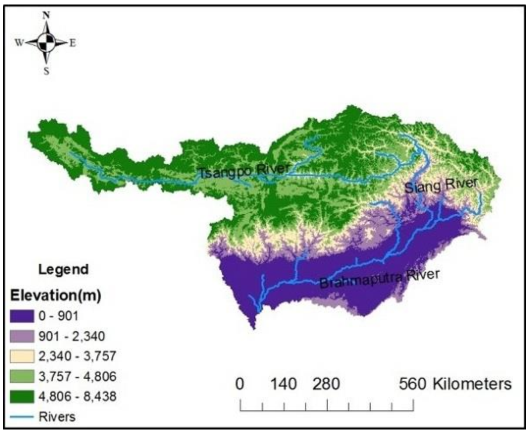

Figure 1: Digital elevation model for Ganges-Brahmaputra-Meghna Basin

River discharge data are collected from Bangladesh Water Development Board (BWDB) for Bahadurabad station (Station No. SW 46.9L) on the Brahmaputra River. Flow data of this station are used for model calibration and validation. Watersheds have been delineated through automatic watershed delineation techniques. A threshold for minimum sub-basin area has been selected for the stream network and outlet calculation. As Bahadurabad station on the downstream of the Brahmaputra basin have been selected as the watershed outlet, this delineation resulted in a watershed of area of 510452.91 km^2 and a total of 39 sub-basins. The landuse and soil maps, as derived from above mentioned methods, have been imported and linked with the respective database table to create appropriate lookup tables. ‘Multiple HRU’ option has been selected which generates 304 HRUs for the whole watershed. A period of 5 years (1998 - 2002) has been selected for calibration and 5 years (2003 - 2007) for validation based on the availability of APHRODITE and GPCP. But for TRMM datasets, a period of 5 years (2000 - 2004) has been selected for calibration and 5 years (2005 - 2009) for validation. In addition, 1 year has been kept as warm-up period for both calibration and validation. A warm-up period allows the model to get a fully operational hydrological cycle and thus helps to stabilize the model. The main methods used in modeling the hydrologic processes in SWAT were curve number method for runoff estimating, Penman-Monteith method for PET and Muskingum method for channel routing.

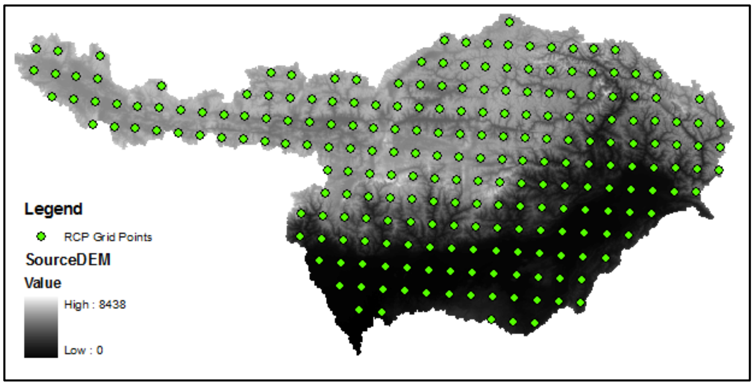

Figure 2: RCP grid points coincided with the Brahmaputra River basin area for climate data

Simulations for future prediction have been performed on the calibrated model. Climate scenarios from the model EC-Earth under RCP scenarios 4.5 and 8.5 have been used on the SWAT model and the river discharge for the Brahmaputra River has been estimated for three time windows, i.e. 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). There are 228 grid points coincided on the Brahmaputra basin area for the RCP scenarios (Figure 2). 30 years of historical data were chosen from 1976-2005.

3. Results and Discussions

3.1. Calibration and Validation

SWAT has been simulated using TRMM, APRHODITE and GPCP gridded rainfall data sets for the Brahmaputra river basin. Each simulation (experiment) independently was calibrated and validated against one discharge station. The calibration has been done by manually adjusting parameters until a good match have obtained between calculated and observed flows for each rainfall estimator. Then same adjusting parameters have been used for other rainfall estimators. Critical parameters have been identified during calibration were the curve number (CN2), base flow recession constant (ALPHA_BF), soil water holding capacity (AWC), Minimum threshold depth of water required in shallow aquifer for ground-water flow to occur (GWQMN), Groundwater re-evaporation coefficient that controls the upward movement of water from shallow aquifer to root zone in proportion to evaporative demand (GWREVAP). Simulated discharge from GPCP and APRHODITE satellite data are underestimating peak flow of the flood in model calibration as shown in Figure 3. It has been found that satellite based gridded rainfall data is normally not able to capture high intensity rainfall observed by the typical single point rain gauge.

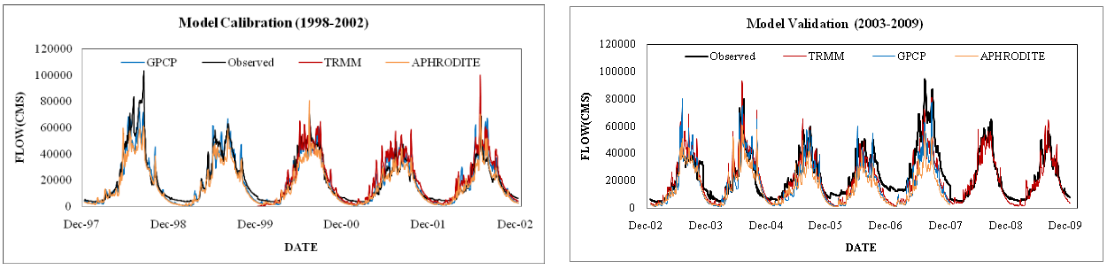

Figure 3: Model hydrographs for calibration and validation period generated by gridded rainfall data products.

However, simulated discharges from TRMM datasets are overestimated for some years of model calibration. The patterns of the simulated flow hydrographs at Bahadurabad using these three satellite datasets are similar. During the period, where model is validated, simulated peak discharge using APRHODITE data underestimated observed peak discharge more than other two datasets i.e., GPCP and TRMM datasets. However, during the 1998 and 2007 floods, peak flows from the model derived by three datasets are heavily underestimated though using TRMM rainfall provides better results as shown in Figure 3. A summary of the statistical analysis and comparison of model errors is given in Table 1. Nash index and correlation of determination R^2 all confirmed that hydrological model driven by the precipitation data from TRMM data has performed better for both calibration and validation than those from GPCP and APRHODITE. Using TRMM data, the R^2 values were found as 0.83 and 0.81 and with Nash index are found as 0.73 and 0.72 for calibration and validation of the model, respectively. Another statistical indicator, RSR (RMSE observations standard deviation ratio) is calculated as the ratio of the RMSE (root mean square error) and standard deviation of measured data. The lower RSR, the lower the RMSE, and the better are the model simulation performances. RSR for simulated discharge using TRMM data performed very well (values are less than 0.5) for both calibration and validation period. RSR from other datasets have shown values greater than 0.5 for the validation period. A RSR value less than 0.5 is reasonable accepted as per Moriasi et al. (2002). Also, the percent bias (PBIAS) has been satisfied and it has shown less than ± 25% (Moriasi et al, 2002). Here, TRMM data shows more accuracy for the both calibration and validation as PBIAS values are less than ± 25%. A positive value of PBIAS indicates underestimation whereas negative value indicates overestimation by the model. Although for the model calibration, discharge simulated by APRHODITE and GPCP data have good PBIAS values (less than ± 25%), results are not acceptable for the model validation.

Table 1: Statistical parameter of calibration and validation period (daily) for different climate source

	APRHODITE		GPCP		TRMM	
Time period	1999 - 2002	2004 - 2007	1999 - 2002	2004 - 2007	2001 - 2004	2006 - 2009
R^2	0.92	0.72	0.88	0.74	0.83	0.85
NSE	0.77	0.13	0.78	0.235	0.77	0.62
RSR	0.27	0.5	0.26	0.5	0.27	0.33
PBIAS	30	52	25	50	-1	25

3.2. Change in Flow

After calibration and validation, the simulations has been performed for future scenarios. For this purpose RCP 4.5 and RCP 8.5 scenarios have been used and compared with historical simulation.

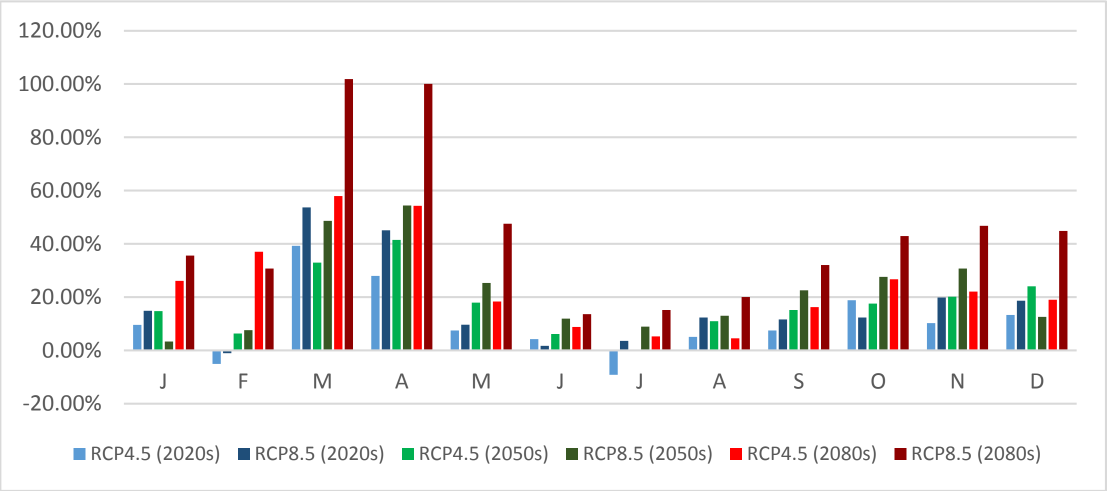

Figure 4: Future Projection of Mean Discharge in Brahmaputra River under RCP 4.5 and RCP 8.5 Scenario

The change of monthly flow for monsoon seasons (June - September) is predicted to change -9% to 7%, 0% to 15% and 8% to 16% for 2020s, 2050s and 2080s respectively under RCP 4.5 scenario shown in figure 4. The change of monthly flow for Pre-monsoon seasons (March - May) is predicted to increase 7-39%, 17-33% and 18-58% for 2020s, 2050s and 2080s respectively under RCP 4.5 scenario shown in figure 4. The change of monthly flow for monsoon seasons (June - September) is predicted to increase 1-12%, 8-22% and 13-32% for 2020s, 2050s and 2080s respectively under RCP 8.5 scenario shown in figure 4. The change of monthly flow for Pre-monsoon seasons (March - May) is predicted to increase 9-53%, 25-54% and 47-101% for 2020s, 2050s and 2080s respectively under RCP 8.5 scenario shown in figure 4.

For both the RCP 4.5 and RCP 8.5 scenarios, the results of multi model weighted variation (i.e., uncertainty estimation) of discharge have been shown in Figure 5 that represents seasonal flows of four time windows.

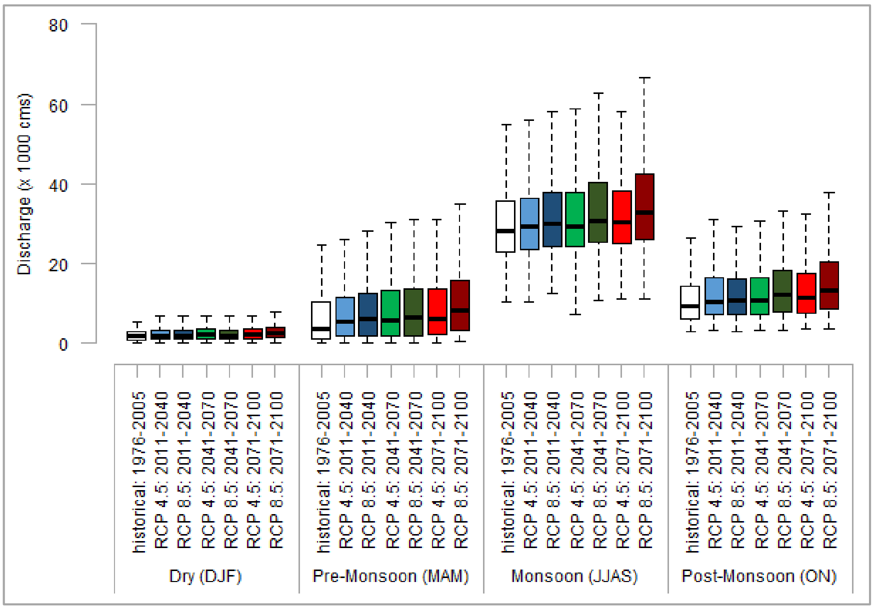

Figure 5: Simulated average seasonal discharge for the four time windows

4. Conclusion

As the streamflow data of upper catchment of the Brahmaputra basin, like other watersheds in many parts of the world are not available, this basin is called as poorly gauged or not gauged. Specific objectives of this study were to assess sensitivity of basin hydrologic response to changing satellite based gridded rainfall data products and to assess potential impact of climate on the water availability of this basin. For these reasons, different parameters of the governing equations of the model are adjusted and fine-tuned to calibrate the model. The results of the study indicated that SWAT performed watershed simulations reasonably well using different sources of precipitation with parameterizing methods. Visual inspection from hydrographs and statistical indicators all have shown that the simulation performance of SWAT is better when using TRMM data. It can be seen that the accuracy of precipitation input determines the accuracy of model results. However, there are still some difficulties to predict peak flow of the flood year.

Only coefficient co-relation as statistical parameter is not a good indicator because most hydrology models derived by different satellite based gridded rainfall data products show similar as 0.91. However, other statistical parameters have failed drastically in APHRODITE and GPCP datasets. Because TRMM datasets capture more rainfall than other datasets for NASA and JAXA use good algorithm for measuring precipitations.

After the calibration and validation, SWAT model has been simulated by forcing RCP scenarios of EC-EARTH model during the early century (2011-2040), mid-century (2041-2070) and end century (2071-2100). The amounts of monsoon flow are higher than the amounts of pre-monsoon flow in spite of the higher percentages of pre-monsoon flow. This model is very helpful for checking water availability based on the basin-wide decision. Moreover, in future, this model can be used for water sharing decision with upper catchment's country.

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6. References

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