ASSESSMENT OF CHANGE IN FUTURE WATER RESOURCES OF BRAHMAPUTRA BASIN APPLYING SWAT MODEL USING MULTI-MEMBER ENSEMBLE CLIMATE DATA

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ABSTRACT

Bangladesh is a delta formed by sedimentation from the Ganges, the Brahmaputra and the Meghna rivers and its distributaries and tributaries. Among these three major rivers, the Brahmaputra carries the highest (about 67%)annual flow to Bangladesh from China, India and Bhutan. In order to assess the water availability and predict floods in Bangladesh, it is necessary to establish a hydrologic model over the Brahmaputra basin. In this study, a physical based model SWAT has been set up over the Brahmaputra basin. The model has been calibrated and validated using the observed daily flow data at Bahadurabad from 1998 to 2007. Rainfall data from three gridded global standard data products, namely, TRMM, APHRDOTIE and GPCP, have been used to simulate the model.It has been found that TRMM data are more accurate than APHRODITE and GPCP. After calibrationg the model,SWAT has been simulated for dry,wet and extreme ensembles of PRECIS model for 2020s,2050s and 2080s. It has been found that the percentange of monsoon flow will increase to4-15% and the pre-monsoon flow will increase to25-92% at the end century.

Keywords:*Brahmaputra, Climate model, flow, GBM basin, Satellites data, 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 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, 2010). 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, is not accessible to scientists in other countries (Nishat and Faisal, 2000).For this reasons, this paper has setup an appropriate hydrological model for the large Brahmaputra river basin using three different satellite datasets.

A relatively recent modelling tool developed by the U.S. Department of Agriculture (USDA) called SWAT (Soil and Water Assessment Tool) has proven very successful in the watershed assessment of hydrology and water quality(Neitsch et al., 2002). SWAT 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 to2 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.

There are several GCMs around the world that give a range of projections to capture future uncertainties. However, none of the studies over the Brahmaputra basin used all set of the global climate model(GCM) to predict future probable flow using hydrologic models. In this context, a multi-ensemble approach will be an option to capture all the future uncertainties of model projections. On the other hand, to generate more accurate climatic information, regional climate model (RCM) like, PRECIS (Providing Regional Climates for Impacts Studies) should be simulated for a high resolution domain (25x25 km). PRECIS developed by the Hadley Centre of the UK Meteorological Office. The PRECIS RCM is based on the atmospheric component of the HadCM3 climate model. Hence, this study have used SWAT derived from a multi ensemble for a high resolution (25km) domain over the Brahmaputra basin to capture the wide range of uncertainty in climate change projections. For basin wise management, it is necessary to assess future annual flow, surface runoff and base flow. For this purpose, this study will be very helpful for decision makers and policy makers.

2. DATA

When simulating the SWAT model, several types of data are required as input. First A 90 m resolution digital elevation model (DEM) derived from the Shuttle Rader Topography Mission (SRTM) has been used in the study. A 300 m resolution of land use data of 2009-2010 has been used Europe Space Agency GLOBCOVER. This data have been reclassified to match the SWAT land classes. The soil map of the study catchment has been clipped from the FAO digital soil map of the world. Weather data (rainfall and temperature) have been obtained from TRMM (Tropical Rainfall Measuring Mission), GPCP (Global Precipitation climatology Project) and APRHODITE (Asian Precipitation - Highly- Resolved Observational Data Integration towards Evaluation) and Era-interim. Discharge data of Bahadurabad gage station of the Brahmaputra River has been used for model evaluation as flow data in the upper part of the catchment inside India are not available. For simulating climate scenarios, the output of a 25km resolution of PRECIS regional climate model has been used in this model.

2.1 Weather data preparation

One of the main sets of input for simulating the hydrological processes in SWAT is climate data. Climate data input consists of precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity and the weather generator file. The climate data for study periods were prepared in .dbf format and then imported in the SWAT model.

The meteorological data were analyzed to determine the various statistical parameters like mean monthly maximum and minimum temperature, number of rainy days, standard deviation for air temperature, precipitation, skewness for daily precipitation, and probabilities of wet day following a dry day or a wet day required as input by the weather generator file in SWAT.

2.2 Observed discharge data preparation

The outlet of Brahmaputra Basin is located at Bahadurabad station of Brahmaputra river. There are available discharge data at Bahadurabad stations which is ID SW 46.9L.This discharge are used for model calibrations and validations. A year from 1998-2009 has been used for calibrations and validations. After 2004, there are not available daily discharge data, because BWDB was measured discharge and Water level some day in each months. So, rating curve has been used for generating daily discharge data. The quality of the stage-discharge relation or rating curve determines the quality of computed stream flow data. Hydraulic theory helps in determining the general form of the rating curve. In a long straight channel friction control operates, a rating curve has the form,

$$\boldsymbol{Q} = \boldsymbol{C} * [(\boldsymbol{h} + \boldsymbol{a})^{\boldsymbol{N}}] \quad (1)$$

Where, Q=discharge, C and N =constant, a=depth at discharge zero

3. METHODOLOGY

In this study, the whole Brahmaputra basin has been set up with SWAT hydrology model. We know that Watershed analyses and hydrological modelling are important for management of many natural resources like land and water. 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. However, setup and validation of a semi un-gauged catchment is a very difficult task. Model calibration, sensitivity and uncertainty analysis can help to evaluate the ability of the model to sufficiently predict stream flow. For this purpose, SWAT model has been set up over the Brahmaputra Basin using Digital Elevation model, land use data and Soil data. Firstly, flow direction has been determined for the study area from the processed DEM. The main concept of the model is that water from cell would flow to the adjacent cell that has steepest gradient. It also assumes the catchment as depression less without any ponds or pits. A flow direction was computed by calculating the steepest slope and by encoding into each cell eight possible flow directions towards the surrounding cells. Flow direction map is used for flow accumulation map. Secondly, the flow accumulation is generated by addressing each cell of the DEM, counts how many upstream cells contribute to flow through the given cell. Flow direction and accumulation maps are then used to delineate the stream network. The stream network can be divided into segment that will determine the outlets of the basin. Watershed divide is assumed as a line whose flow accumulation value is zero and those cells, which have flow accumulation value greater than a threshold value (determined by the minimum number of pixels within each delineated sub-basin) provided by the user, is assumed as stream channel or river. A threshold value of 20% of the longest flow path was used to determine the drainage network. Based on the above threshold value, the catchment has been divided into 163 sub-catchments for Brahmaputra basin.

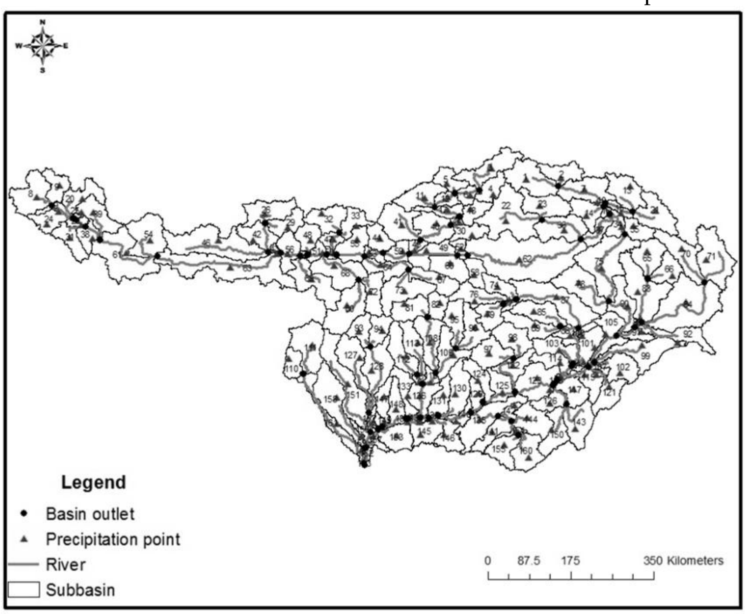

Figure 1: Location of satellites data over the Brahmaputra basin

Next the sub-catchment analysis, land use data and soil data is then incorporated with SWAT model. Then, all sub-catchment of Brahmaputra basin has been divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. Next, all weather information from different data source of satellites products have been used as input in SWAT. The model is run covering the same period at three satellite gridded products and then compared among them based on statistical parameter at Bahadurabad stations of Brahmaputra basin. The evaluation process comprises of sensitivity analysis, calibration and validation. A period of 5 years (1998–2002) has selected for calibration and 5 years (2003–2007) for validation based on the availability of Aphrodite and GPCP. But for TRMM data sets, a period of 5 years (2000-2004) has been selected for calibration and 5 years (2005-2009) for validations. In addition, one year has been kept as warm-up period for both calibration and validation. A warm-up period allows the model to get an operational hydrological cycle and thus helps to stabilize the model. The main methods used in modelling the hydrologic processes in SWAT were curve number method for runoff estimating, Hargreaves method for PET and Muskingum method for channel routing After calibrating model, the future flows of the Brahmaputra basin are generated using climate forcing by the multi-member QUMP ensembles experiments of PRECIS for the early century (2011-2040), mid-century (2041-2071) and end century (2071- 2099).

4. MODEL CALIBRATIONS AND VALIDATION

The 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 has been 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 Fig 2. 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.

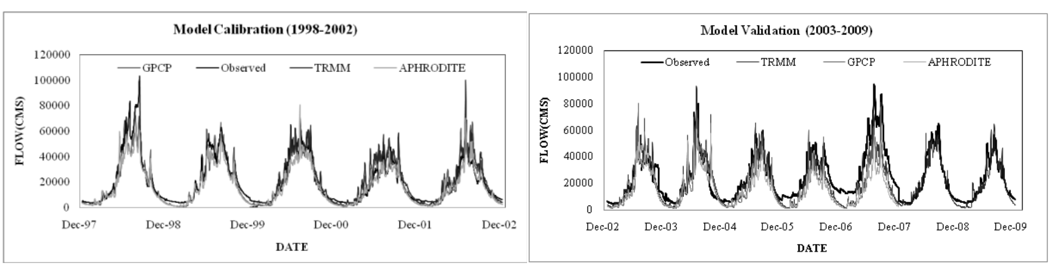

Fig 2: Model hydrographs for calibration and validation period generated by gridded rainfall data products.

However, simulated discharges from TRMM datasets are overestimated for some years of model calibration. The patterns of the simulated flow hydrographs at Bahdurabad 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 Fig. 2.A summary of the statistical analysis and comparison of model errors is given in Table 1.Nash index and correlation of determination R^2all 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 0.85 and Nash sutcliffe index are found as 0.77 and 0.62for calibration and validation of the model which close to one, 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

	Aphrodite		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

5. RESULTS AND DISCUSSION

After the calibrations and validation, The SWAT model has simulated for future scenarios. For this purpose, there have been used dry, wet and extreme UMP scenarios from PRECIS model, which are used as input climate model in SWAT.

The change of monthly flow for monsoon seasons (JJAS)is predicted to increase 7-12%, 4-13% and 4-13% for 2020s, 2050s and 2080s respectively shown in figure 3.The change of monthly flow for Pre-monsoon seasons (MAM)is predicted to increase 28-56%, 23-60% and 17-92% for 2020s, 2050s and 2080s respectively shown in figure 3.

The change of pre-monsoon flow from baseline might be high through the end century. The main cause for this higher change depends on precipitation and snowmelt on glacier. In this model, the changes of temperature from baseline in March are higher than other month. Most climate models estimate that precipitation will increase during the summer because the air over land will warm more than air over oceans in the summer, resulting in an intense monsoon (Mirza,2011).

The general circulation over the basin area undergoes abrupt seasonal changes during late spring and early summer due to tropospheric warming over the Asian landmass, and causes early summer rains over the basin (Gosh and Dutta,2012).

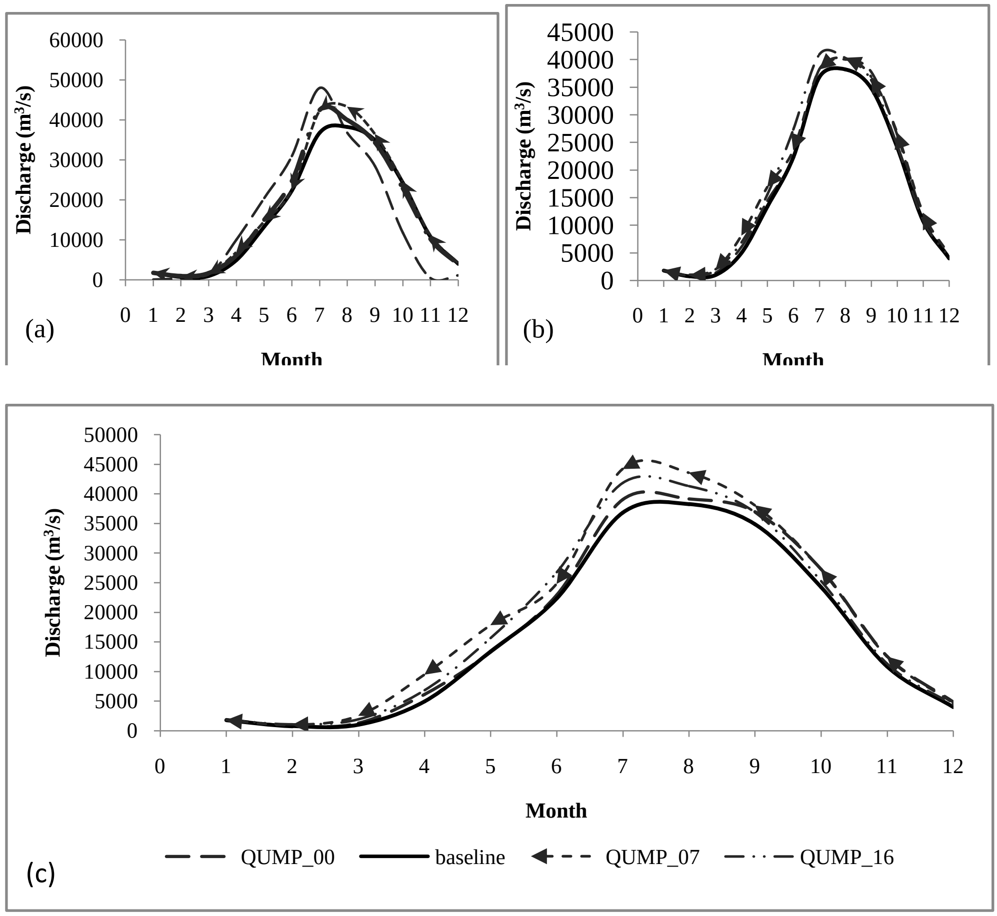

Figure 3: (a) Future Flow at Bahadurabad Stations for 2020s. (b) Future Flow at Bahadurabad Stations for 2050s. (c) Future Flow at Bahadurabad Stations for 2080s.

The left side of figure 4have shown the relationship between changes of precipitation with change of future flow. With increasing percentage of precipitation have effect on the change of future flow. Moreover, the right side of fig. 4 have shown the relationship between changes of temperature and the change of future flow. There might possible to effect of change of temperature on the future flow of Bahadurabad stations.There are very large spread shown by low R^2 but the trend shows a positive possible change in the precipitations and temperature controlling future flow.

It has also concluded that there might be possible for increases of flow at Bahadurabad stations because the regional model gives increasing precipitation over the year. With the aid of ECHAM4 and HadCM3 models, Kumar et al. (2003) constructed precipitation scenarios for 30-year time slices centered on the 2030, 2050 and 2080 s relative to the1960–1990 climatology for India. The simulations show an increase in the rainfall over a large area of land and ocean, which covers the core monsoon region.

It also decided that monsoon flow and pre-monsoon might be an increase rather than post-monsoon and winter. However, the amount of monsoon will be always more prominent than the amount of pre-monsoon flow.

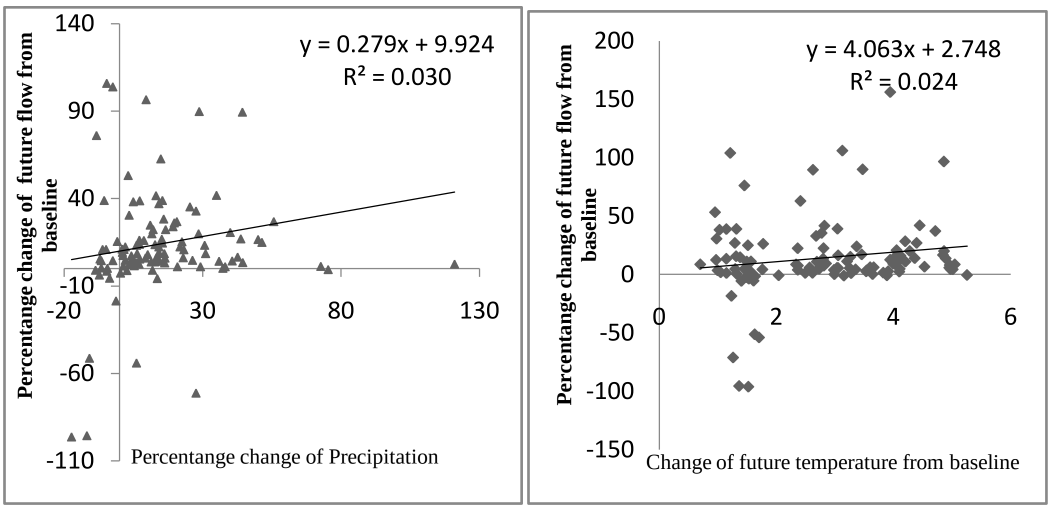

Figure 4: Relationship between precipitationwith future flow and temperature with future flow.

6. CONCLUSION

The streamflow data of upper catchment of the Brahmaputra basin, like other watersheds in many parts of the world, are not available so, 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 this 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 APRODITE 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 dry, wet and extreme ensemble of PRECIS model during the early century (2011-2040), mid-century (2041-

2071) and end century (2071- 2099).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 will be used for water sharing decision with upper catchment's country.

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