IMPACT OF CLIMATE CHANGE IN WATER AVAILABILITY OF THE BRAHMAPUTRA RIVER BASIN: BASED ON DIFFERENT GCM PREDICTION

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ABSTRACT

Around 800 million people are contingent on water from the Brahmaputra basin. Hydrology of Brahmaputra Basin is one of the most vulnerable in the world which is subject to combined effect of snow melting and extreme monsoon rainfall. Climate change has the potential to intensify the hydrological cycle, leading to more intense precipitation with associated changes in the temporal and spatial distribution of water availability in the Brahmaputra basin. To what extent climate change will impact on river flow of Brahmaputra Basin is not clear yet. Many researches have been done, however, the assessment of climate change impacts on the basin-scale hydrology by using well calibrated hydrologic modeling has seldom been conducted in the Brahmaputra basin due to the lack of observed data for calibration and validation. Most of the model study has been calibrated only at Bahadurbad point on Brahmaputra (Jamuna) river in Bangladesh. As a result, the uncertainty of impact of climate change effect on upper and middle part of Brahmaputra basin is inevitable. This study efforts to assess impact of change on water availability of Brahmaputra river basin using MIKE HYDRO Basin, it is a multi-purpose, conceptual lumped type decision support tool for integrated river basin analysis, planning and management. In this study, we have calibrated Brahmaputra Basin (BRB) Model at 5 different locations in different sub-catchments in the whole basin and well agreement between observed and simulated river flow is found. The calibrated model is applied 10 GCM output under two representative concentration pathway (RCP). It is observed that out of ten analyzed scenarios almost nine cases show a similar trend i.e. increase of flow due to climate change. Most of climate scenario show significant change of flow in basin in April, May and June. However, a very strong change in peak flow is projected, which may lead to a devastating flood in future.

Introduction

The Brahmaputra is the 4th largest river in the world by annual flow, and it is one of the major rivers of the Ganges-Brahmaputra-Meghna (GBM) system carries more flow and sediment to the Bay of Bengal through China, India, Bhutan, and Bangladesh than other rivers of this system (Ray et al., 2015). It is the main source of water for 130 million people and socioeconomic condition (e.g., poverty, regional development, crop production, etc.) of this region depend on Brahmaputra river basin (BRB) (Alam et al., 2016; Ray et al., 2015). Moreover, this basin is the most vulnerable area under the impact of climate change (Gain et al., 2011). Since 1920, the temperature of the planet is increasing; the number of warm years is exceeded than expected range of variability (Ghosh & Dutta, 2012). The mean surface temperature of the planet is increasing 0.65 to 1.06°C over the period 1880 to 2012 (IPCC, 2015). Change in temperature is one of the driving forces to alter the hydrological process in water cycle (Milly et al., 2008). Among the river system of the BRB, the impact of climate change on river hydrology is expected to be particularly strong. Flow of upstream part of the BRB is strongly influenced by the melt of snow and ice. Cryospheric processes are deemed to be important when topographic elevation higher than 2000m, as 60% area of BRB is elevated more than 2000m (Gain et al., 2011). Projected rise in temperature will lead to increase summer flow for few decades by increasing snow and glacial melt; therefore, after few decades snow and ice will be disappeared and lead to accelerate the scarcity of upstream flow (Immerzeel, 2008). This scenario is particularly true when water availability is crucial for irrigation system and threatening the food scarcity of an estimated 26 million people in BRB (Immerzeel et al., 2010). On the other hand, BRB is highly influenced by the extreme monsoon and flooding (Mirza, 2002). If the intensity and variability of monsoon change due to climate change, it will affect both high and low flows leading to increase flood intensity but also flow variability is increased both space and time (Postel et al., 1996). The important fact that discharge during flood and wet season cannot be used during lean period unless large reservoir system in there (Oki & Kanae, 2006). Lastly, climate change leads sea level

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rise and riverine flooding by causing back-water effect of the GBM basin along the delta (Agrawala et al., 2003).

In the past, several studies have been done to focus on the rainfall and discharge relationship in BRB and GBM basin by identifying the correlation among the discharge, sea surface temperature and El-Nino (Chowdhury & Ward, 2004; Mirza et al., 1998; Nishat & Faisal, 2000), analyzing observed data compare to the reanalysis data (Kamal-Heikman et al., 2007), and verifying the historical flood events (Islam et al., 2010; Mirza et al., 2003). Different type of statistical methods was used in the aforementioned studies instead of hydrological modeling. In recent year, a number of global-scale hydrological model (including Brahmaputra Basin in this domain) result have been published (Haddeland et al., 2011; Haddeland et al., 2012; Pokhrel et al., 2012) but these global-scale models are not fully reliable to water management sector or other future studies due to the lack of calibration on basin scale. On the other hand, there are several studies conducted on the impacts of climate change on water availability in BRB and GBM basin (Gain et al., 2011; Ghosh & Dutta, 2012; Immerzeel, 2008; Kamal et al., 2013; Mirza & Dixit, 1997; Seidel et al., 2000). In most of the aforesaid studies, future streamflow is predicted using linear regression between precipitation and stream flow based on historical data. Immerzeel (2008) used multi-regression model in his study to predict future stream flow at Bahadurabad under the climate forcing parameter (precipitation and temperature) using statistically downscaled GCM output. Nevertheless, since most hydrological events are not linear, they cannot predict hydrological process accurately using extrapolating regression model (Masood et al., 2015). Alam et al., (2016) applied a physically based semi-distributed hydrological model, namely, soil and water assessment tool (SWAT) at the BRB, but their study is only focused on the Bahadurabad station. The alternatively for the assessment of future streamflow on basin-scale hydrology is via well-calibrated hydrological model, but it rarely been conducted for the BRB.

In the present study, an attempt has been made to develop a hydrological model for long simulation in which the calibration and validation is based on a rarely obtained long term (climate normal period 1981-2010 (Arguez et al., 2012)) observed data in BRB collected from different sources and to investigate the present condition of water availability and trend in both high low flow for BRB under climate change. Compare to the previous BRB studies, it is believed that the available quality observed data lead to better estimation of model parameters, near to earth observed hydrological simulation and predict reliable future projection.

**Study Area**

The Brahmaputra is a major transboundary river which originates from the great glacier mass of Chema-Yung-Dung in the Kailas range of southern Tibetan (China) at an elevation of 5,300 m above the sea level (m.a.s.l). The river traverses 3410 km, flowing through China (1995 km), India (983 km) and Bangladesh (432 km) before emptying into the Bay of Bengal. The Brahmaputra river drains an area of around 530,000 km² through the four different countries: China, India, Bhutan, and Bangladesh (Biswa et al., 2017; Immerzeel, 2008). The basin comprises quite diverse environments as the cold dry plateau of Tibet, the rain-drenched Himalayan slopes, the landlocked alluvial plains of Assam and the vast deltaic lowlands of Bangladesh (IWM, 2013). As categorized by (Immerzeel, 2008), the Brahmaputra basin into three different physiographic zones: Tibetan Plateau (TP), Himalayan belt (HB), and the floodplain (FP). TP (with elevation is greater than 3500 m a.s.l) covers 44.4%, HB (elevation between 100 and 3500 m a.s.l) covers 28.6% whereas an elevation of less than 100 m a.s.l is considered as FP and comprise about 27% of the entire basin. The climate of the basin is mainly driven by the monsoon (June to September), which accounts 60-70% of the annual rainfall in the basin, while the pre-monsoon season from March through May produces 20-25% of the annual rainfall (Immerzeel, 2008; IWM, 2013). And total rainfall in the lower part of the basin is 2354 mm (Gain et al., 2011; IWM, 2013).

Total water use estimated in the BRB is around 27457 Mm³/year, out of which about 90% is used in India and Bangladesh. Sector-wise water uses in the basin are: 89 % in agriculture, 9 % in domestic, and 2 % in industrial sector (IWM, 2013). Actually, BRB is the main source of water, energy and food for an estimated 130 million people living within the basin, and where the river flows through the most highly disputed areas in South Asia. As a result, BRB’s water resources that have been largely undeveloped by the conflict of interest of the downstream states (Yang et al., 2016). Now that upstream countries are enacting water development plans, these plans have a potential to increase the conflict between counties. Except Zangmu dam, there is no significant intervention in the main course of BRB. Most of the dam is built on the tributaries through the Bhutan, Assam, Nagaland, Sikkim, Tibet, and Lasha (Alam et al., 2016; Rahaman, 2012). Other than hydropower, river water is diverted for irrigation purposes. India, China and Bangladesh have been operating more than 20 barrages on several tributaries (Yang et al., 2016).

The Brahmaputra is a perennial river and its annual average, highest recorded and low recorded discharge are 21066 m³/s, 98300 m³/s, 1653 m³/s respectively (Immerzeel, 2008; IWM, 2013). 85% of the total annual
stream flow throw out the wet season is available and the remaining 15% is available in dry period (Alam et al., 2016). Annual water demand estimated in the Brahmaputra basin is around 36535 Mm$^3$ for four special sectors: Domestic (2373 Mm$^3$), Irrigation (31606 Mm$^3$), Industrial (2076 Mm$^3$), and Livestock (480 Mm$^3$). Monthly water demand in the basin varies ranges from a minimum of 411 Mm$^3$ (in wet months) to a maximum of 8513 Mm$^3$ (in dry months) (IWM, 2013).

Methodology

MIKE HYDRO Basin

MIKE Hydro Basin is a water management tool developed by DHI. MIKE HYDRO Basin is a multi-purpose, map-centric decision support tool for integrated river basin analysis, addressing water allocation, conjunctive water use, reservoir operation, or water quality issues. A mathematical representation of the river basin is defined including the configuration of river and reservoir systems, catchment hydrology and water user schemes with rainfall-runoff processes, river routing, surface water-groundwater interaction, and water quality processes. Rainfall-runoff model that is part of the MIKE Hydro Basin. The NAM (NedborAfstrommings Model) is deterministic, lumped and conceptual rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base flow (DHI, 2017).

Input Data

The basic data requirement for the MIKE HYDRO Basin model are digital elevation data, meteorological data and discharge data for model calibration. In this study, publicly available global datasets have been utilized to develop the MIKE HYDRO Basin model for BRB. The Shuttle Radar Topography Mission (SRTM) generated Digital Elevation Model (DEM) of 90 m resolution (Jarvis, Reuter, Nelson, & Guevara, 2008) was used to delineate the sub-basins and river network. Weather data from the National Centers for EnvironmentalPrediction (NCEP) Climate Forecast System Reanalysis (CFSR) (Stopa & Cheung, 2014) are used as climate input data, including precipitation, temperature (http://globalweather.tamu.edu/). Evaporation data are also used as climate input data it collected from ECMWF.

Streamflow data for 5 river points along the Brahmaputra river and various tributaries representing the outflow from different sub-basins are used to calibrate and validate the BRB model. Details of the various points and data sources are provided in Table 2 and the spatial positions are shown in Figure 1.

Table 1. Model input data and sources.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital elevation model (DEM)</td>
<td>SRTM</td>
<td>90m</td>
<td></td>
</tr>
<tr>
<td>Rainfall, Temperature</td>
<td>CFSR</td>
<td>0.5º</td>
<td>Daily</td>
</tr>
<tr>
<td>Evaporation</td>
<td>ECMWF</td>
<td>0.5º</td>
<td>Daily</td>
</tr>
<tr>
<td>Rainfall (Observed)</td>
<td>NMIC, BWDB</td>
<td></td>
<td>Daily</td>
</tr>
<tr>
<td>Streamflow</td>
<td>HY, ICIMOD, BWDB</td>
<td></td>
<td>Daily</td>
</tr>
</tbody>
</table>


Table 2. Model coparison point and data availability.

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Longitude (deg.)</th>
<th>Latitude (deg.)</th>
<th>Sub-Basin Name</th>
<th>Data Type</th>
<th>Data Source</th>
<th>Available Data Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahadurabad</td>
<td>89.66</td>
<td>25.18</td>
<td>Whole Brahmaputra</td>
<td>Measured</td>
<td>BWDB</td>
<td>1981-2016</td>
</tr>
<tr>
<td>Kaunia</td>
<td>89.11</td>
<td>26.10</td>
<td>Teesta</td>
<td>Measured</td>
<td>BWDB</td>
<td>1988-2016</td>
</tr>
<tr>
<td>Dihang</td>
<td>91.88</td>
<td>29.28</td>
<td>All Tibetan sub-basins in the upper Brahmaputra</td>
<td>Simulated Result from HI-SPHY</td>
<td>ICIMOD</td>
<td>2002-2007</td>
</tr>
<tr>
<td>Subansiri</td>
<td>94.15</td>
<td>28.08</td>
<td>Subansiri North</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For climate change impact assessment, two RCP scenarios (i.e., RCP 4.5 and 8.5) with four GCMs of each representing four climatic conditions (i.e., total eight GCMs) were selected. RCP 4.5 considers a less extreme future climate with radioactive forcing stabilizing at an emission rate of $4.5 \text{ Wm}^{-2}$ by 2100. RCP 8.5, on the other hand, is more extreme condition with radioactive forcing stabilizing at an emission rate of $8.5 \text{ Wm}^{-2}$ (Thomson et al., 2011). One RCM is also used based one two RCP 8.5 and 4.5 (Table 3).

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Description</th>
<th>RCP</th>
<th>Selected Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dry, Cold</td>
<td>RCP45</td>
<td>GIS-E2-R-r4i1p1_rcp45</td>
</tr>
<tr>
<td>2</td>
<td>Dry, Warm</td>
<td>RCP45</td>
<td>IPSL-CM5A-LR-r4i1p1_rcp45</td>
</tr>
<tr>
<td>3</td>
<td>Wet, Cold</td>
<td>RCP45</td>
<td>CCSM4-r5i1p1_rcp45</td>
</tr>
<tr>
<td>4</td>
<td>Wet, Warm</td>
<td>RCP45</td>
<td>CanESM2-r4i1p1_rcp45</td>
</tr>
<tr>
<td>5</td>
<td>Dry, Cold</td>
<td>RCP85</td>
<td>GFDL-ESM2G-r1i1p1_rcp85</td>
</tr>
<tr>
<td>6</td>
<td>Dry, Warm</td>
<td>RCP85</td>
<td>IPSL-CM5A-LR-r4i1p1+rcp85</td>
</tr>
<tr>
<td>7</td>
<td>Wet, Cold</td>
<td>RCP85</td>
<td>CSIRO-Mk3-6-0-r3i1p1_rcp85</td>
</tr>
<tr>
<td>8</td>
<td>Wet, Warm</td>
<td>RCP85</td>
<td>CanESM2-r4i1p1_rcp85</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>RCP45</td>
<td>BCCR</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>RCP85</td>
<td>BCCR</td>
</tr>
</tbody>
</table>

### MIKE HYDRO Basin Model Setup

Development of model using MIKE HYDRO Basin includes several steps: (i) sketching of the river system, (ii) delineation of sub-catchments, (iii) computation of mean rainfall and evaporation for each sub-catchment, (iv) set up hydrological / rainfall runoff model, (v) set up of MIKE BASIN model, and (vi) simulation as well as calibration of the model. At the start of MIKE HYDRO Basin modeling, flow direction has been calculated using land terrain data of SRTM. Subsequently, main stream and tributaries of the Brahmaputra river have been sketched using the available tool. Rivers that sketched in the basin are: Brahmaputra river, Dibang, Lohit, Buri Dihing, Dhansiri, Kopili, Subansiri, Kameng, Manas, Sunkosh, Dudkumar, Dharala, and Teesta. The entire Brahmaputra river basin has been sub-divided into 52 sub-catchments which are as shown in Figure 1. The sub-catchments in the basin have been delineated using the available tool of MIKE BASIN. Total basin area under the hydrological model is 521144 sq. km. A rainfall runoff model has been developed using NAM model of DHI. The NAM model comprises 52 sub-catchments. It is to be noted that the rainfall runoff model (NAM) comprises four conceptual storages: snow storage, surface storage, sub-surface/root zone storage, and ground water storages.
Model calibration and validation

The BRB MIKE HYDRO Basin model was run for 1979–2010. First two years discard from calibration and validation period as a warmup period; the first 15 years (1981–1995) were taken as the calibration period and the next 15 years (1996–2010) as the validation period at five different locations of BRB. In the calibration and validation stage, model performance was evaluated by statistically and graphically (Figure. 2). It is found that the observed and simulated data is in a good agreement for dry and monsoon period based on Table 3. Statistically, the performance of the BRB model has been evaluated using Nash-Sutcliffe efficiency value (NSE), the ratio of the root-mean-square error between the simulated and observed values to the standard deviation of the observations (RSR), percent bias (PBIAS) and the coefficient of determination (proportion of the variance in the observations explained by the model, $R^2$). Figure. 3 demonstrate that model has been performed well in validation and calibration stage.

Table 4. Definitions of Goodness-of-Fit Statistics and General performance ratings for recommended statistics for a monthly time step (Moriasi et al., 2007; Rossi et al., 2008).

<table>
<thead>
<tr>
<th>Performance Rating</th>
<th>RSR</th>
<th>NSE</th>
<th>PBIAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>$0.00 \leq RSR \leq 0.50$</td>
<td>$0.75 \leq NSE \leq 1.00$</td>
<td>$PBIAS \leq \pm 10$</td>
</tr>
<tr>
<td>Good</td>
<td>$0.50 &lt; RSR \leq 0.60$</td>
<td>$0.65 &lt; NSE \leq 0.75$</td>
<td>$\pm 10 &lt; PBIAS \leq \pm 15$</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>$0.06 &lt; RSR \leq 0.70$</td>
<td>$0.50 &lt; NSE \leq 0.65$</td>
<td>$\pm 15 &lt; PBIAS \leq \pm 25$</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>$RSR &gt; 0.70$</td>
<td>$NSR &gt; 0.50$</td>
<td>$PBIAS &gt; \pm 25$</td>
</tr>
</tbody>
</table>

*NSE = Nash-Sutcliffe efficiency; PBIAS = mean relative bias; RSR = root mean square error-standard deviation ratio.
Figure 2. BRB model performance at the river points shown in Figure 1. The blue line represents the observed streamflow and the yellow represents the model simulation.

Figure 3. BRB model performance for different sub-basin with 4 metrics.
Result and Discussion

Water Availability in BRB

Water availability has been calculated in the BRB based on model simulated flow for the period of 1981 to 2010 at Bahadurabad, outlet of BRB in Bangladesh. In the BRB, the annual average water availability is around 667400 Mm³. The monthly average water availability varies ranging from around 12986 Mm³ in driest month to around 130414 Mm³ in wettest month which is as shown in Figure 4(a). At the outfall, the annual average flow rate of the Brahmaputra basin is around 21066 m³/s, whereas the monthly average flow rate varies ranging from 4848 m³/s in driest month to 48691 m³/s in wettest months in Figure 4(b). Furthermore, over the last 30 of normal climate period (1981-2010), yearly maximum stream flow is rising in Figure 4(b) and in Figure 4(d), yearly minimum flow is almost in constant although recent years trend is falling.

Effect of Climate Change on Water Availability

The effect of climate change on the water availability is determined for ten climate change scenarios and three decades: 2030, 2040 and 2050. The analysis has been carried out on the water availability at the outlet of the Brahmaputra basin.

Under this present study, raster (gridded) data files of monthly CC projected change in temperature and precipitation for the BRB region were collected from ICIMOD, Nepal and delta for each temperature and precipitation data point utilized in the BRB model development was estimated. The rainfall and temperature data for CC BRB simulations were then prepared by applying this delta (projected change in temperature and precipitation) to the base precipitation and temperature data of 1981–2010. The above-mentioned method, usually referred as delta method, is widely used in regional and local CC studies (Arnell, 1999; Lutz et al., 2016).

It is observed that out of ten analyzed scenarios almost nine cases show the similar trend i.e. increase of flow due to climate change. The model: CSIRO-Mk3-6-0r3i1p1_rcp85 shows decrease in flow during July and August. Only one model: IPSL-CM5A-LR-r4i1p1+rcp85 shows decrease trend of flow during dry, pre-monsoon and monsoon months. With long future, the potential impact of climate change becomes significant i.e. change of flow in the basin increases. Most of the models scenario show significant change of flow in the basin in April, May and June. In future 2030, the change of flow obtained from the scenarios vary ranging from -2.5 to 16 % in the months of August to February; the highest change of flow is observed in April which is around -10 % to 11 %. Moreover, in future 2050, the average change of flow vary ranging from -3 to 18 % in the months of August to February, and that is about -25 % to 28 % in April. Figure 4 shows the changes of flow in the Brahmaputra basin due to climate changes in all five models with two RCPs in future 2030, 2040 and 2050.
Figure 5. Change of flow in the BRB due to CC in future 2030(a), 2040(b) and 2050(c) based on different GCM output.

Figure 6. Average change of flow in the Brahmaputra basin due to climate change obtained from five models with two RCPs

The average changes of flow of all models and RCPs vary in different months of the years, and also in different future time line. The average change in flow in the basin is minimum in post-monsoon and dry months, and that is maximum in pre-monsoon months i.e. April and May. In future 2030, the average increase in flow is as low as 2.34 % in March and that is as high as around 7.07 % in April. In future 2050, the average change in flow is as low as 4.4 % in January to as high as 9 % in April. Average changes of flow
in the basin due to climate change for four different future decades are as shown in Figure 6.

Conclusions
In this study, a well calibrated MIKE HYDRO Basin model is developed for BRB. Different calibration parameter and routing method have been found by auto calibration method and literature review. The annual average water availability in the Brahmaputra basin is around 667400 Mm$^3$ at Bahadurabad. The monthly average water availability varies ranging from around 12986 Mm$^3$ in dry months to around 130414 Mm$^3$ in wet months. The annual average flow rate of the Brahmaputra basin is around 21066 m$^3$/s whereas the monthly average flow rate in the basin varies ranging from around 4848 m$^3$/s in dry months to around 48691 m$^3$/s in wet months. The water availability mentioned above is calculated based of MIKE BASIN based model simulated discharge for the period of 1981 to 2010. It is to be mentioned that there is limitation in calibration of the model in dry months. Therefore, care should be taken before using the above specified figures of water availability in dry months.

The effect of climate change on water availability in the Brahmaputra basin has been analyzed using predicted rainfall, evaporation of five climate prediction models with two RCPs. It is observed that most of the scenarios simulated show increase trend of flow due to climate change. With long future, the change of flow in the basin increases, and becomes more significant in pre-monsoon months: April, May and June. In future 2030, the flow is likely to be changed about -2.5 to 16 % in the months of August to February; the highest change of flow is observed in April which is around -10 % to 11 %. Moreover, in future 2050, the flow is likely to change about 0 to 10 % in the months of August to February, and that is about -25 % to 28 % in April. The average change of flow is likely to be increased in future 2030 by amount of about 2.34 % in March and that is as high as around 7.07 % in April. The same is as low as 4 % in January and as high as around 9 % in April in future 2050. Although, combined effect of all scenario show average flow is increasing, some climate scenario like IPSL-CM5A-LR-r4i1p1+rcp85 and BCCR_RCP85 indicate pre-monsoon flow is decreasing as -25%, and it could be led to arise adverse impact on agriculture and river ecosystem. On the other hand, most of the climate models output show flow will be increased in monsoon period under climate change. Thus, there could be an adverse impact on flood flow leading to increase in enhanced recurrent flood in the floodplains of the Brahmaputra river mostly located in Assam of India and in Bangladesh.

The present study has used a calibrated BRB model for simulating future streamflow in a climate change using 8 GCM and 2 RCP climate model. In future extension of this study, this calibrated model will be used (1) for estimating sub-catchment wise water resources which will provide more insight detail and which sub-catchment is more vulnerable under climate change and (2) evaluating satellite predicted rainfall and other meteorological data from different sources, which are suitable for this region.

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References


IWM. (2013). Water availability, demand and adaptation option assessment of the Brahmaputra river basin under climate change. *Institute of Water Modelling.*


