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Assessing Climate Change Impact on Water Balance Components of a River Basin Using SWAT Model

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Abstract Climate change is one of the most important global environmental challenges, which affects the entire earth system in terms of negative impacts on food production, water supply, health, livelihood, energy, etc. The intent of the present study was to assess the impact of climate change on the water balance components of a data-starved Upper Baitarani River basin of Eastern India using ArcSWAT model. The ArcSWAT model was calibrated using SUFI-2 technique. The daily observed streamflow data from 1998 to 2003 were employed for calibration and those for 2004–2005 for validation. The calibration results were found to be satisfactory with the Nash-Sutcliffe efficiency (NSE) and mean absolute error (MAE) of 0.88 and 9.70 m^3/s for the daily time step, respectively. Also, the model was validated successfully for simulating daily streamflow (NSE=0.80 and MAE=10.33 m^3/s). The calibrated and validated model was then used to evaluate basin response to the anticipated climate changes by the end of the 21st century. Twelve independent as well as twenty eight combined area-specific climatic scenarios were considered in this study to evaluate the impact of climate change on the hydrology of the basin. The analysis of model results for the 12 Independent Climatic Scenarios indicated a reduction in the surface runoff ranging from 2.5 to 11 % by changing the temperature from 1 to 5 °C, whereas the increase in rainfall by 2.5 to 15 % suggested an increase in surface runoff by 6.67 to 43.42 % from the baseline condition. In case of 28 Combined Scenarios compared to the baseline condition, the changes in surface runoff would vary from −4.55 to 37.53 %, the groundwater recharge would change from −8.7 to 23.15 % and the evapotranspiration would increase from 4.05 to 11.88 %. It is concluded that future changes in the climatic condition by the end of the 21st century are most likely to produce significant impacts on the streamflow in the study area. The findings of this study and those of follow-up studies in this direction will be useful for guiding suitable adaptation measures for sustainable water management in the basin in the face of impending climate change.

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1 Introduction

Land and water are the most vital natural resources of the earth that sustain human development, functioning of ecosystems, and economic growth of a country. However, the rapidly increasing human population and accelerating changes in lifestyle due to growing urbanization and industrialization place a tremendous pressure on these natural resources. Increasing pressure on land and water resources has resulted in their degradation with detrimental repercussions on vulnerable ecosystems and biodiversity, and thereby posing a serious global threat to sustainable development on the earth (Biswas et al. 2009; Oki and Kanae 2006). On top of it, climate change is considered as an added driver for many of the societal and environmental problems of the 21st century. Climate change may affect water systems through increased/unusual spatio-temporal variability, long-term temperature and water balance changes, and sea-level rise which in turn have implications for water security, food security, energy security, health of human and ecosystems, and human livelihoods (Vörösmarty et al. 2000; UNDP 2007; Richardson et al. 2011). Its emergence is due to the increasing concentration of greenhouse gases (GHGs) in the atmosphere since the pre-industrial times. The Intergovernmental Panel on Climate Change (IPCC) concluded that it is more than 90 % likely that accelerated warming of the past 50–60 years is caused by the anthropogenic release of GHGs such as CO_2 (IPCC 2007a). Human activities are now contributing to global environmental changes not only in temperature but also in precipitation (Zhang et al. 2007; Li et al. 2015; Mourato et al. 2015; Krysanova and Srinivasan 2014) and this development is expected to continue in the future (Bates et al. 2008). It is projected that the global mean temperature may rise between 1.4 and 5.8 °C by 2100 (IPCC 2007a). Indeed, climate change has emerged as one of the most important global environmental challenges of the 21st century and poses a threat to mankind. Nearly all regions of the world are expected to experience a net negative impact of climate change on water resources systems and ecosystems.

A recent report (WMO 2013) revealed that the past decade (2001–2010) was the warmest for both the hemispheres as well as for land and ocean surface temperatures. It further adds that high-impact climate extreme events have been witnessed globally on an unprecedented scale since the last decade. Future climatic scenarios for mid to end of the 21st century as simulated by Global Climate Models (GCMs) also show a warming trend over the entire world. However, the intensity and characteristics of impacts can vary significantly from region to region. Some regions are likely to experience water shortages, coupled with increasing water demand; this will put more and more people under water scarcity threat while rising sea levels in heavily populated coastal regions, may threaten the lives and livelihood of millions of people. The frequency of floods and droughts will increase in most parts of the world which will result in declining crop yields, thereby increasing the risk of poverty and hunger (Karim et al. 2009); the most sufferers will be developing and under-developing countries which already face serious challenges of achieving the Millennium Development Goals (MDGs) by 2015 wherein water plays a pivotal role.

For a long-term strategic planning of a country's water resources in the face of evolving climate change impacts, it is important that the effects of climate change be quantified with high spatial and temporal resolutions at a basin scale because the fifth assessment report of

IPCC warns that "the window for action is closing down very rapidly". Fontaine et al. (2001) reported significant impacts of climate change on water resources and local economies in the Black Hills of South Dakota, USA, whereas Jha et al. (2004) evaluated the impact of climate change and uncertainty in streamflow prediction by using a regional climate model (RCM) coupled with Soil and Water Assessment Tool (SWAT). Kalogerophoulous and Chalkias (2012), Wang et al. (2011) and Zang et al. (2007) estimated the potential impact of climate change on surface runoff at a basin scale. Karim et al. (2009) examined the impact of future climate on the country's (Iran) water resources. Perazzoli et al. (2013) analyzed the impacts of climate change on the flow regime and sediment production in southern Brazil. Shi et al. (2013) identified the changes in land use and climate over past half century and assessed their effects on China's water resources. Lee and Bae (2015) evaluated the impact of climate change on water availability over Asian Monsoon and quantified its impact in terms of green and blue water. Liuzzo et al. (2014) used TOPDM for simulating potential impact of climate change on surface water and groundwater availability. Ravazzani et al. (2014) quantified the impact of climate change on water resources availability using an integrated approach in Upper Po River basin, Italy. Wagner et al. (2015) assessed the impacts of climate and land use change using SWAT in a data scarce region of Western Ghats, India, while Huang et al. (2015) used the ENSEMBLE technique for projecting future droughts and floods using SWIM model in a German catchment. Ruiz-Villanueva et al. (2014) analyzed the potential impacts of climatic changes on river response in Rhone River, Lyon, France.

India is a large developing country with nearly two-thirds of its population depending directly on the climate sensitive sectors such as agriculture, fisheries and forests (Dhar and Mazumdar 2009). The NATCOM study (National Communication project undertaken by the Ministry of Environment and Forests, Government of India, New Delhi) was the first attempt to quantify the impact of climate change on the water resources of the country (Gosain et al. 2006). Spatial patterns of rainfall change over India indicated a maximum increase of rainfall in west coast and northeast India for both IPCC A2 and B2 scenarios (Gosain et al. 2006). Moreover, PRECIS estimates 20 % rise in all India summer monsoon rainfall in all future scenarios as compared to present. Rise in rainfall is seen over all states except Punjab, Rajasthan and Tamil Nadu, which show slight decrease in precipitation in the future scenarios. PRECIS simulation for 2071–2100 indicates all-round warming over Indian subcontinent associated with increasing greenhouse gas concentrations. The warming seems to be more pronounced over the northern parts of India resulting in deteriorating the severity of droughts and intensity of floods in various parts of the country under various GHG Scenarios (Kumar et al. 2006). However, there is a general overall reduction in the quantity of available runoff under the GHG scenarios. River basins of Mahi, Pennar, Sabarmati and Tapi will face water shortage conditions. River basins belonging to Cauvery, Ganga, Narmada and Krishna will experience seasonal or regular water-stressed conditions, whereas the river basins belonging to Godavari, Brahmani and Mahanadi will not have any water shortage but can face severe flood conditions (Gosain et al. 2011). In past few years (including recent years), India experienced untimely rains that resulted in flash floods in mountainous regions and the country also became a victim of cyclone's and hailstorm's fury in some parts of the country (CSE 2014).

These days, climate researchers are giving more stress on reducing the human vulnerability to natural surprises (hydrologic extremes), which can only be met by proper decision-making that in turn is fully dependent on the quality of information and the knowledge of innovative and/or advanced tools/techniques (Tyler and Moench 2012; Yang et al. 2014). In the field of climate change research, among other challenges, a grand global challenge is to provide an

adequate scientific basis for adaptation decisions which will be made under strong uncertainty and without reliance on exact projections of changes in hydrologic variables in order to ensure climate-resilient society (Kundzewicz and Gerten 2014).

Soil and Water Assessment Tool (SWAT) is a physically-based, semi-distributed hydrologic model, which has proven to be an effective tool for assessing water resource and non-point source pollution problems for a wide range of scales and environmental conditions across the globe (Neitsch et al. 2011). Over the last decade, SWAT has been extensively used worldwide to carry out hydrological modeling at a watershed/basin scale under varying agro-climatic conditions (Verma and Jha 2015). In the recent past, hydrological modeling using SWAT has emerged as a powerful tool to quantify the effects of climate change on water resources (Jha et al. 2006). The overall goal of the present study was to evaluate the impacts of climate change on the water balance components (both 'blue water' and 'green water') of Upper Baitarani River basin of Eastern India using ArcSWAT; a brief description of this basin is provided in the subsequent section. Considering the data limitation in this basin, relevant climatic scenarios as projected by IPCC (IPCC 2007a) and Indian scientists have been considered in this study to gain insights into the variation of water balance components of the basin at the end of the 21st century. To achieve this broad goal, the specific objectives of this study were: (i) to calibrate and validate ArcSWAT for simulating streamflow in the basin, and (ii) to analyze the impacts of climate change on the basin's water balance components under salient future climatic scenarios.

2 Materials and Methods

2.1 Study Area

Upper Baitarani River basin (1776.6 km^2) shown in Fig. 1 lies between 21 and 22.5° N latitude and 85 to 86° E longitude of Eastern India, Odisha. The Baitarani River originates from Guptaganga hills in Keonjhar district of Odisha which is at an elevation of 900 m above MSL (mean sea level). The study area shows a high topographical variation with the elevation ranging from 330 to 1120 m above MSL. It receives on an average 1534 mm rainfall in a year, more than 80 % of which occurs during June to October. The mean monthly maximum temperature is 34 °C in May, whereas minimum temperature is 11 °C in the month of January. The major portion of the study area is comprised of forest (about 50 % of the area) and agriculture (42.05 %) land uses, with 10.34 % of the area under waste land. Here, waste land means barren stony land, gullied/ravinous land, land with scrub and mining, and the land with industrial wastes. The soils of the study area are classified according to the USDA (United States Department of Agriculture) Soil Taxonomy classes. The total catchment is divided into 18 different soil classes, out of which dominant soil class is Loamy skeletol, Typic Haplustepts which covers 48.98 % of the study area followed by fine loamy, TypicHaplustalfs soil covering 20.83 % of the area. Other main soil classes are clayey skeletol, TypicHeplustalfs and Fine loamy, TypicHaplustepts encompassing 9.65 and 7.02 % of the study area. The dominant texture of the study watershed is 'sandy clay loam'.

The major portion of the Upper Baitarani River basin is in the northern part of Odisha encompassing north western and central plateau, and north Eastern Ghats. From agriculture point of view, the study area has soil types ranging from fertile alluvial deltaic soils in the northern part of coastal plateau, mixed red and black soils in the north central plateau, red and
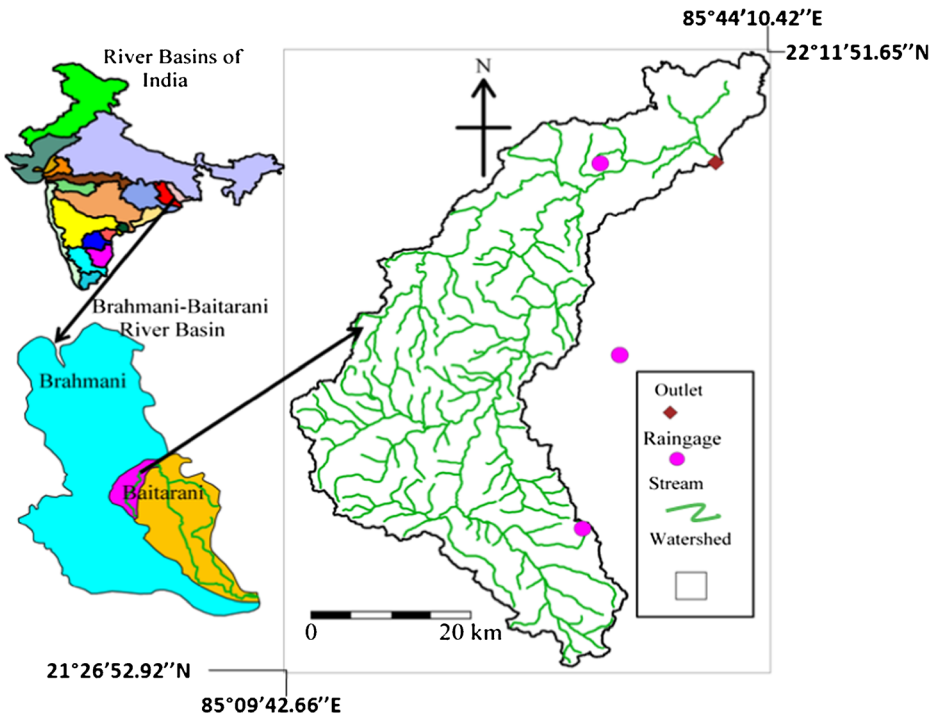
Fig. 1 Location map of the study area (Source: Verma and Jha, 2015)

yellow soils with low fertility in the north western plateau, whereas lateritic and brown forest soils in the north Eastern Ghats region. Majority of soils in the river basin are light textured red soils, which have low water-holding capacity, low fertility and high erodibility. This condition results in high flows during monsoon season (June-September) because 80 % of the rainfall is normally concentrated in these 3 months, which renders the study area highly vulnerable to floods (OWDM 2010).

2.2 Overview of ArcSWAT Model

In this study, the ArcGIS9.3.1 interface of SWAT (ver. 2009), which is popularly known as ArcSWAT, was used. It is a physically-based, semi-distributed and continuous time step hydrologic model that is used for rainfall-runoff modeling as well as for predicting the impacts of land use and land management practices, and of climate change on the hydrology and water quality of watersheds or river basins (Neitsch et al. 2011). The water cycle simulated by ArcSWAT is based on water balance. The water balance equation used by the model is given as (Neitsch et al. 2011):

$$SW_{t_i} = SW_0 + \sum_{i=1}^{t} \left(R_{day_i} - Q_{surf_i} - E_{a_i} - W_{seep_i} - Q_{gw_i} \right) \qquad (1)$$

where, SW_{t_i} = soil water content (mm) at time t, SW_o = initial soil water content (mm), t = simulation period (days), R_{day_i} = amount of precipitation on the ith day (mm), Q_{surf_i} = amount

of surface runoff on the ith day (mm), E_{a_i} = amount of evapotranspiration on the ith day (mm), W_{seep_i} = amount of water entering the vadose zone from the soil profile on the ith day (mm), and Q_{gw_i} = amount of baseflow on the ith day (mm).

The study area is comprised of 15 sub-basins which were divided into 271 Hydrological Response Units (HRUs) that satisfactorily represent watershed's heterogeneity. HRUs are simply unique combinations of a specific soil type, land cover type and slope within a sub-basin. The SWAT model computes hydrological processes occurring in a watershed or basin such as runoff, streamflow, sediment transport and nutrients transport at the HRU level.

2.3 Data Acquisition

Digital elevation model, land use/land cover map and soil map as well as time series of rainfall, temperature and streamflow data of the study area were the main inputs to set up ArcSWAT model for the basin under study.

(1) Digital Elevation Model (DEM): It was obtained by the digitization of contour lines (contour interval=20 m) of the raster maps of study area by using ILWIS3.3 GIS software. Raster maps were created by using toposheets (1:50,000). The toposheets were obtained from Survey of India (SOI) offices at Kolkata, Bhubaneswar, Ranchi and Dehradun. The generated DEM (30 m×30 m) of the study area/basin is satisfactory for the current hydrologic analysis.

(2) Land Use\Land Cover Map: The cloud-free remote sensing image (Landsat ETM[+] imagery) of November 2, 2001 path 140 and row 45 of 30 m spatial resolution in three spectral bands for the study area were collected from the Global Land Cover Facility website. To classify land use of the basin, unsupervised classification was performed using ERDAS IMAGINE8.5 software.

(3) Soil Map: Printed soil maps of Odisha and Bihar at a scale of 1:500,000 were procured from National Bureau of Soil Science and Land Use Planning (NBSS&LUP), Nagpur, India. These maps were scanned, rectified and digitized in ILWIS GIS to prepare the grid format map as required by ArcSWAT.

Moreover, daily rainfall data were obtained from three rain gauge stations (Keonjhar, Champua and Jhumpura), whereas the daily data of temperature for Keonjhar station were obtained from the India Meteorological Centre, Bhubaneswar, Odisha for 8 years (1998–2005). Also, daily streamflow data from 1998 to 2005 of the Upper Baitarani River basin measured at the Champua gauging station were collected from Central Water Commission (CWC), Bhubaneswar, Odisha. Locations of the rain gauge stations and stream gauging station are shown in Fig. 1.

3 Calibration and Validation of Arcswat Model

Most influential parameters for streamflow simulation were estimated by sensitivity analysis before performing calibration of the model. Since the ArcSWAT contains large number of hydrological parameters and all of them may not be contributing significantly to the model output, there is a need to identify significant input parameters for streamflow simulation. This

exercise not only helps in reducing the number of parameters for calibration but also suggests us how precisely we have to handle a particular parameter. In this study, the model parameters were identified by using Latin Hypercube One-factor-At-a-Time (LH-OAT) technique (Van Griensven et al. 2006). Thereafter, the ArcSWAT model was calibrated using SUFI-2 optimization technique. The daily observed streamflow data from 1998 to 2003 were used for model calibration and those from 2004 to 2005 were used for model validation. The data of 1998 were kept as warming-up period, which allows the model to initialize and approach reasonable initial values of the state variables of the model. It has been observed from past studies that in several studies SWAT has been used to develop site-specific watershed models with no or less than 3 years as a warm-up period and their results are reported to be quite satisfactory (e.g., Stehr et al. 2008; Kalogerophoulous and Chalkias 2012; Joh et al. 2011). Thus, 1 year warm-up period used in this study could be considered reasonable under data-scarce conditions. The performance of the developed model during calibration and validation was evaluated by using selected statistical indicators (i.e., mean absolute error, coefficient of determination, and Nash-Sutcliffe efficiency) and graphical indicators. In addition, *P* and *R-factor* were also computed using SWAT-CUP to further assess the performance of the model during calibration and validation.

4 Selection of Climate Change Scenarios

ArcSWAT has two ways to quantify the impact of climate change on the hydrology of a watershed. The first method of climate change impact quantification involves the calculation of change in the basin behavior towards change in the concentration of greenhouse gases (GHGs) in the atmosphere, while the second method facilitates to input specific changes in the temperature and/or rainfall. Because of the lack of necessary climatic data (RCM-predicted future climatic data) for the study area, the second method (i.e., region-specific incremental scenarios for the temperature and rainfall) has been adopted in this study to assess the probable impacts of climate change on major water balance components of the basin. This method has also been adopted in many past studies (e.g., Fontaine et al. 2001; Jha et al. 2006; Kalogerophoulous and Chalkias 2012; Jiang et al. 2014).

It is worth mentioning that although land use pattern is expected to change by the end of 21st century in conjunction with climate change, a marginal change in the land use pattern of the study area (river basin) is assumed as the basin is dominated by tribal population which mainly relies on forest and agricultural produce and these two land covers are dominant in the basin, with the settlement area limited to 1.68 % of the total basin area. Also, the study area is essentially away from industrial development until now, and hence it is assumed that the basin's hydrologic functioning in the future will be more or less the same. Thus, considering the business as usual, this study focuses on the quantification of the impacts of climatic variables on major water balance components of the river basin under study.

According to the future climate change scenarios suggested by the Intergovernmental Panel on Climate Change (IPCC 2007b), it has been found that the average surface temperature of the country could rise between 2 and 5 °C and the rainfall will increase to 15 % over the country (India) at the end of the 21st century (Kumar et al. 2006; Gosain et al. 2011). As the spatial variability of rainfall across the country is very high, based on

the literature, the variation in the rainfall specifically for the region wherein our study area falls is considered and it is reported to be less than or equal to 15 %. This is the reason of limiting the change in rainfall up to 15 % (Kumar et al. 2006; Chaturvedi et al. 2011; Gosain et al. 2011). The projected climatic scenarios possess a high level of uncertainty in predicting weather parameters because there is a non-linear relationship between them. Hence, keeping these facts in mind, this study considers both Independent and Combined climatic scenarios for analyzing the impacts of temperature and rainfall changes on the water balance components (both 'blue water' and 'green water') of the study area. The Independent climatic scenarios considered in this study are presented in Table 1. Out of 12 different climatic scenarios, the first eight scenarios include the changes in temperature from the baseline condition by a factor (numeric value), whereas the last four scenarios include the percentage change in rainfall from the baseline condition. Apart from the normal incremental scenarios in terms of temperature change, three IPCC recommended climatic scenarios (A1B, A2 and B2, which respectively correspond to Scenarios 4, 6 and 3 of this study) have also been considered in this study for analyzing the effect of climate change on the water balance components of the basin. These three scenarios represent balanced, most pessimistic and optimistic future climatic scenarios considering changes in the world's economy and environment at global and regional scales by the end of 21st century (IPCC 2007b).

The SRES scenarios A1B, A2 and B2 used in this study are based on their descriptions provided by IPCC (IPCC 2007b). In this study, the documented technical information corresponding to a given SRES scenario with regard to changes in temperature has been used. As the regional or local level downscaled projected climatic data for the study area are not available, the standard SRES climate change scenarios as suggested by IPCC have been selected. Baseline condition refers to the current condition of the study area for which the ArcSWAT model was set up. It indicates average condition of the watershed during 1999–2005. Rainfall, maximum temperature and minimum temperature on a daily time step from 1999 to 2005 were used to simulate the baseline condition. Furthermore, 28 Combined Scenarios (CS) were also considered in this study (Table 2) to analyze the combined effects of future changes in both temperature and rainfall on the water balance components of the study area.

Table 1 Climate change scenarios based on independent changes in temperature and rainfall

Scenario	Temperature increase (°C)	Rainfall increase (%)
Scenario 1	1	–
Scenario 2	2	–
Scenario 3	2.4	–
Scenario 4	2.8	–
Scenario 5	3	–
Scenario 6	3.4	–
Scenario 7	4	–
Scenario 8	5	–
Scenario 9	–	2.5
Scenario 10	–	5
Scenario 11	–	10
Scenario 12	–	15

Table 2 Climate change scenarios based on combined changes in temperature and rainfall

Scenario	Temperature increase (°C)	Rainfall increase (%)
CS1	2	2.5
CS 2	2	5
CS 3	2	10
CS 4	2	15
CS 5	2.4	2.5
CS 6	2.4	5
CS 7	2.4	10
CS 8	2.4	15
CS 9	2.8	2.5
CS 10	2.8	5
CS 11	2.8	10
CS 12	2.8	15
CS 13	3	2.5
CS 14	3	5
CS 15	3	10
CS 16	3	15
CS 17	3.4	2.5
CS 18	3.4	5
CS 19	3.4	10
CS 20	3.4	15
CS 21	4	2.5
CS 22	4	5
CS 23	4	10
CS 24	4	15
CS 25	5	2.5
CS 26	5	5
CS 27	5	10
CS 28	5	15

5 Results and Discussion

5.1 Results of Model Calibration and Validation

Figures 2a and b illustrate almost similar distribution of the observed and simulated streamflow hydrographs for both calibration and validation periods. During calibration and validation periods (Table 3), NSE (Nash-Sutcliffe efficiency) values are respectively 0.88 and 0.80, which indicate that the model performance is quite satisfactory at the daily time step. Similarly, higher values of R^2 (0.87 and 0.83 for calibration and validation, respectively) confirm good correlation between observed and simulated streamflows. In addition, graphical indicator, viz., scatter plots shown in Fig. 3a and b indicate overall under-prediction and over-prediction by the model. Low flows (<150 m^3/s) are over predicted, whereas high flows (>150 m^3/s) are more under predicted.

Moreover, 95 % Prediction Uncertainty band (95PPU was calculated at the 2.5 and 97.5 % levels of the cumulative distribution of output variables) for model results is shown in Fig. 2a and b, wherein the shaded region shows uncertainty in the model which brackets all types of
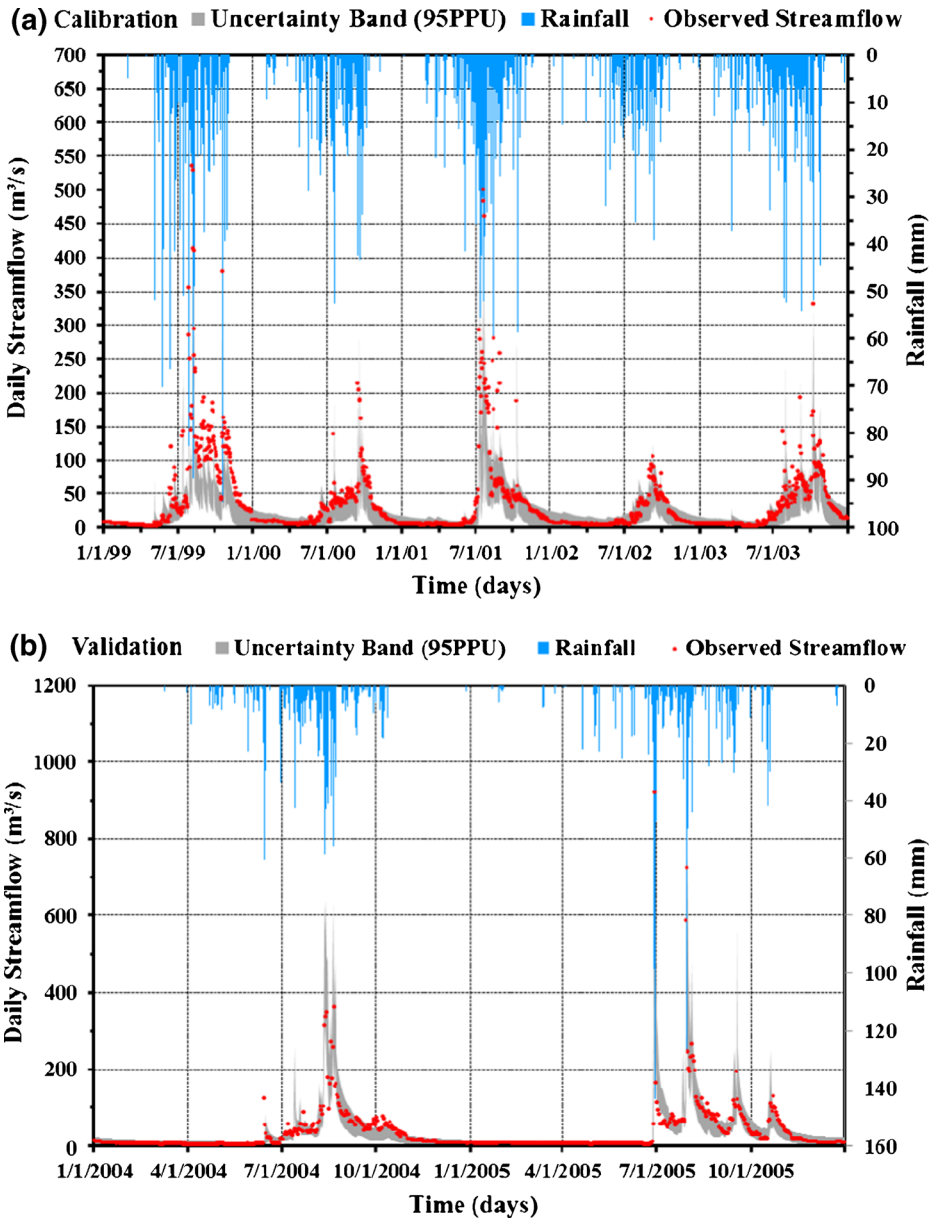
Fig. 2 Observed and simulated daily streamflow hydrographs during (**a**) calibration and (**b**) validation periods

uncertainties in the model prediction. The strength of the model for calibration was quantified by using two different statistics namely, *P-factor* and *R-factor*. *P-factor* is defined as the percentage of measured data bracketed by the 95 % prediction uncertainty (95PPU), whereas *R-factor* denotes the average thickness of the 95PPU band divided by the standard deviation of the measured data. The value of *P-factor* (Range=0–100 %) equal to 100 % or unity and that of *R-factor* (Range=0 - ∞) close to zero indicate an ideal case where observed and simulated

Table 3 ArcSWAT model performance statistics in simulating daily streamflow

Statistical indicators	Calibration period (1999–2003)		Validation period (2004–2005)	
	Observed	Simulated	Observed	Simulated
Mean (m³/s)	33.41	33.95	33.80	33.67
STDEV (m³/s)	37.90	34.15	46.34	42.98
MAE (m³/s)	9.70		10.33	
RMSE (m³/s)	19.73		28.9	
NSE	0.88		0.80	
R²	0.87		0.83	
P-factor (%)	0.87		0.99	
R-factor	0.59		0.55	

results are exactly matching (Abbaspour 2011). It is evident from Table 3 that for the daily streamflow simulation, 87 and 99 % of the observed data are bracketed by the 95PPU band, whereas the values of *R-factor* in case of calibration and validation are 0.59 and 0.55, respectively. These results suggest that the SUFI-2 technique used in this study for model calibration satisfactorily captures the observed streamflow during both calibration and validation periods, but it slightly overestimates the peak values in the years 2004 and 2005. This could be attributed to the fact that lots of uncertainties are involved in the calculation of recession by the SWAT model (Yang et al. 2008).

5.2 Results of Regional Climate Change Analysis

5.2.1 Basin Response to Independent Climatic Scenarios

The response of the study area to 12 Independent Scenarios in terms of surface runoff component is shown in Fig. 4. It is obvious from this figure that the increase of temperature by 1, 2, 2.4, 2.8, 3, 3.4, 4 and 5 °C (i.e., Scenarios 1, 2, 3, 4, 5, 6, 7 and 8) causes a decrease in the mean annual surface runoff ranging from 2.5 to 11 % at the end of 21st century compared to the baseline condition. Decrease in surface runoff is justified because the Baitarani River is not fed by glacier. On the contrary, the increase in rainfall by 2.5, 5, 10 and 15 % (Scenarios 9, 10, 11 and 12) results in a significant increase (6.7 to 43.4 %) in the surface runoff. Thus, the study area is more sensitive to future changes in rainfall than those in temperature.

Apart from the surface runoff, some other major water balance components such as baseflow, evapotranspiration (ET) and groundwater recharge were also considered to examine the impacts of climate change. Figure 5 shows the changes in average annual values of the four major water balance components under 12 Independent Scenarios. It is obvious that the surface runoff, evapotranspiration, baseflow and groundwater recharge will be affected to a varying degree by the changes in temperature or rainfall in the future. It is discernible from Fig. 5 that as the temperature in the study area increases (Scenarios 1 to 8), it directly affects the average annual evapotranspiration, thereby reducing the average annual surface runoff, baseflow and groundwater recharge. However, under increasing rainfall scenarios (Scenarios 9 to 12), the average annual surface runoff from the river basin will increase along with the average annual baseflow and groundwater recharge.

As far as the IPCC scenarios are concerned (i.e., A2, B2 and A1B), if there is a continuous increase in population and somewhat slower and fragmented economic growth in the region
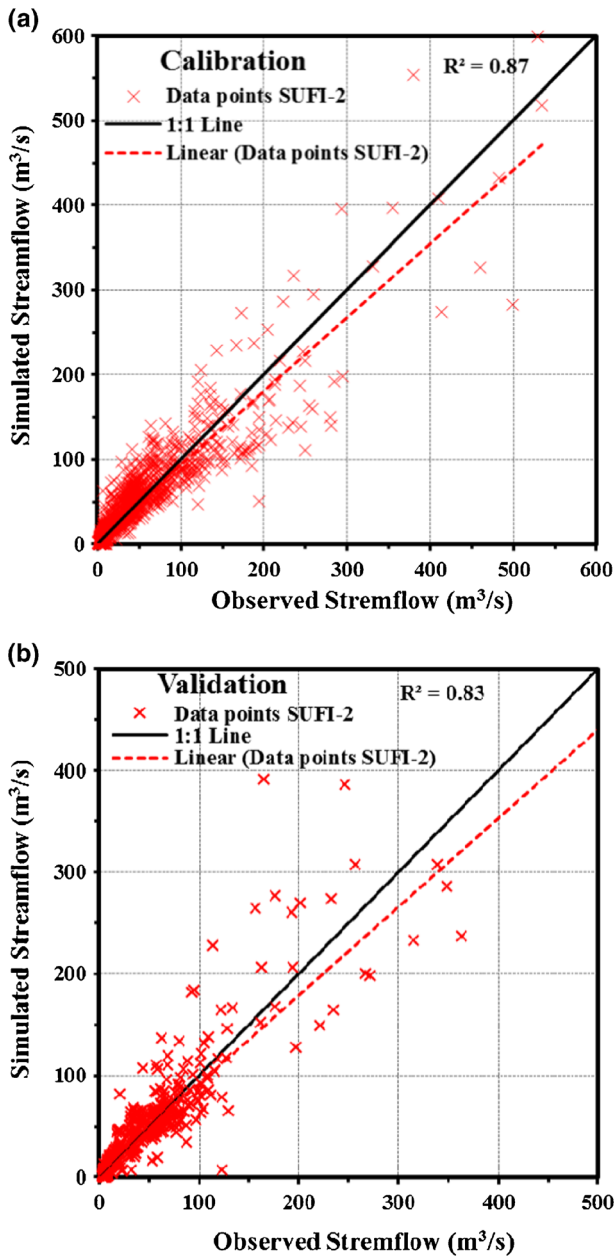
Fig. 3 Scatter plots of observed versus simulated daily streamflows during model (**a**) calibration and (**b**) validation periods

(A2 scenario), then the evapotranspiration of the river basin will increase by 5.3 % which will result in the reduction of surface runoff, baseflow and groundwater recharge by 7.2, 15.1 and 11.5 %, respectively from the baseline condition (Fig. 5). On the other hand, if the population growth is less than A2 and there is an intermediate economic development with the moderate
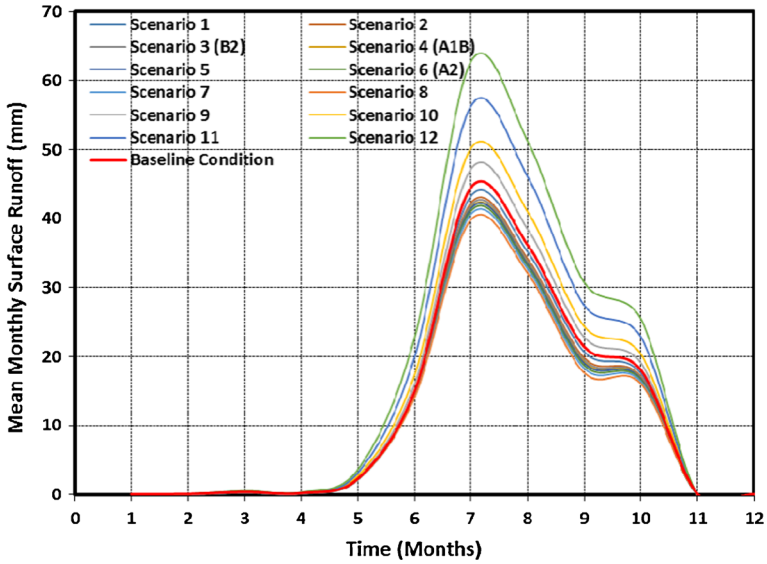
Fig. 4 Response of surface runoff under independent climatic scenarios

use of environment-friendly technologies (B2 scenario), then there will be comparatively less variation in the water balance components compared to the A2 scenario. The surface runoff will reduce by 5.8 %, resulting in the reduction of baseflow and groundwater recharge by 10.7 and 7 %, respectively, whereas the evapotranspiration will decrease by 3.9 % from the baseline condition. Furthermore, the A1B scenario refers to a balanced scenario on all energy sources with a rapid economic growth, a convergent world, growing population and quick spread of new and efficient technologies. Under this scenario, the water balance components will have intermediate impacts compared to the A2 and B2 scenarios. For instance, the increase in evapotranspiration from the river basin by 4.5 % will result in the reduction of surface runoff, baseflow and groundwater recharge by 6.7, 12.7 and 8.22 %, respectively from the baseline condition (Fig. 5).
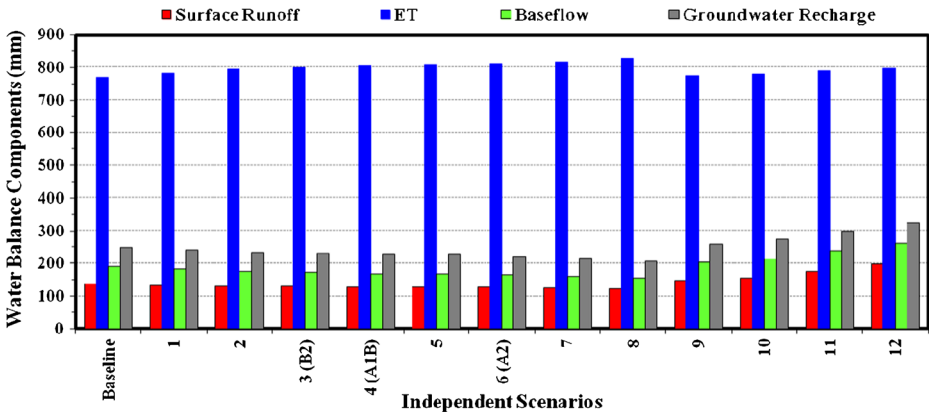

Fig 5 Water balance components values for different independent climate change scenarios

5.2.2 Basin Response to Combined Climatic Scenarios

For a better understanding of the effects of climate change on hydrology of the river basin, scenarios with simultaneous changes in temperature and rainfall were also considered. Table 4 summarizes the response of basin's water balance components (surface runoff, evapotranspiration, baseflow and groundwater recharge) under 28 Combined Scenarios (CS) in terms of percentage change from the baseline condition. It is apparent from this table that with an increase in temperature for a given rainfall increase (e.g., scenarios CS1, CS5, CS9, CS13, CS17, CS21 and CS25 with 2.5 % increase in rainfall and varying degrees of temperature increase), there is a decreasing trend in the surface runoff, baseflow and groundwater recharge among these seven scenarios, but there is an increase in

Table 4 Change in the water balance components under combined scenarios

Scenarios	Percentage increase or decrease from the baseline			
	Surface runoff	ET	Baseflow	Groundwater recharge
CS1	1.72	4.05	−2.17	−1.17
CS 2	8.48	4.73	3.93	3.74
CS 3	22.68	6.03	16.10	13.48
CS 4	37.53	7.26	28.26	23.15
CS 5	0.73	4.63	−3.60	−2.19
CS 6	7.47	5.32	2.49	2.72
CS 7	21.60	6.61	14.68	12.50
CS 8	36.43	7.82	26.88	20.71
CS 9	−0.24	5.29	−5.28	−3.39
CS 10	6.51	5.98	0.79	1.49
CS 11	20.60	7.29	12.93	11.24
CS 12	35.35	8.52	25.10	20.94
CS 13	−0.64	5.56	−5.88	−3.85
CS 14	6.12	6.25	0.17	1.02
CS 15	20.21	7.57	12.00	10.45
CS 16	35.00	8.79	24.45	20.48
CS 17	−1.46	6.10	−7.25	−4.80
CS 18	5.27	6.80	−1.20	0.07
CS 19	19.31	8.11	10.91	9.81
CS 20	34.05	9.33	23.09	19.55
CS 21	−2.67	7.00	−9.42	−6.41
CS 22	3.94	7.77	−3.65	−1.35
CS 23	17.88	9.14	8.43	8.00
CS 24	32.53	10.39	20.52	17.68
CS 25	−4.55	8.29	−12.55	−8.66
CS 26	2.03	9.07	−6.80	−3.92
CS 27	15.68	10.55	4.97	5.56
CS 28	30.13	11.88	16.87	15.12

− indicates decrease; + indicates increase; Water Yield=Surface runoff+Baseflow

evapotranspiration (ET) compared to the precedent scenarios. The same trend was found in case of other Combined Scenarios with fixed rainfall and varying temperature increases. By the end of the 21st century, the changes in surface runoff are expected to vary from −0.24 to 37.5 % from the baseline condition, whereas groundwater recharge may alter from −8.7 to 23 % along with an increase in ET from 4.05 to 11.88 % from the baseline condition. It can also be seen that the scenario CS9 has the least impact on the water balance components of the river basin because an increase in temperature by 2.8 °C along with the rainfall increase by 2.5 % from the baseline are simply nullifying the effect of each other.

Additionally, Fig. 6 shows the variation in the mean monthly surface runoff with the combined changes in temperature and rainfall. It can be seen from this figure that there are four separate bands corresponding to different rainfall increases (i.e., 2.5, 5, 10 and 15 %) from the baseline condition. These bands comprise of seven different graphs for different temperature increase scenarios. It is clear from this figure that under the scenario CS25, there is a maximum reduction in the surface runoff (4.6 % from the baseline condition), while there is a maximum increase (37.53 %) in surface runoff under the scenario CS4 (Table 4).

Moreover, Fig. 7 illustrates annual variation in the four water balance components (surface runoff, evapotranspiration, baseflow and groundwater recharge) under 28 Combined Scenarios. This figure reveals that with an increase in temperature under a given rainfall increase (CS1, CS5, CS9 and CS13), there is a decrease in the surface runoff, baseflow and groundwater recharge, but there is an increase in ET. The CS4 (2 °C temperature increase with 15 % increase in rainfall) corresponds to maximum increase in average annual surface runoff,
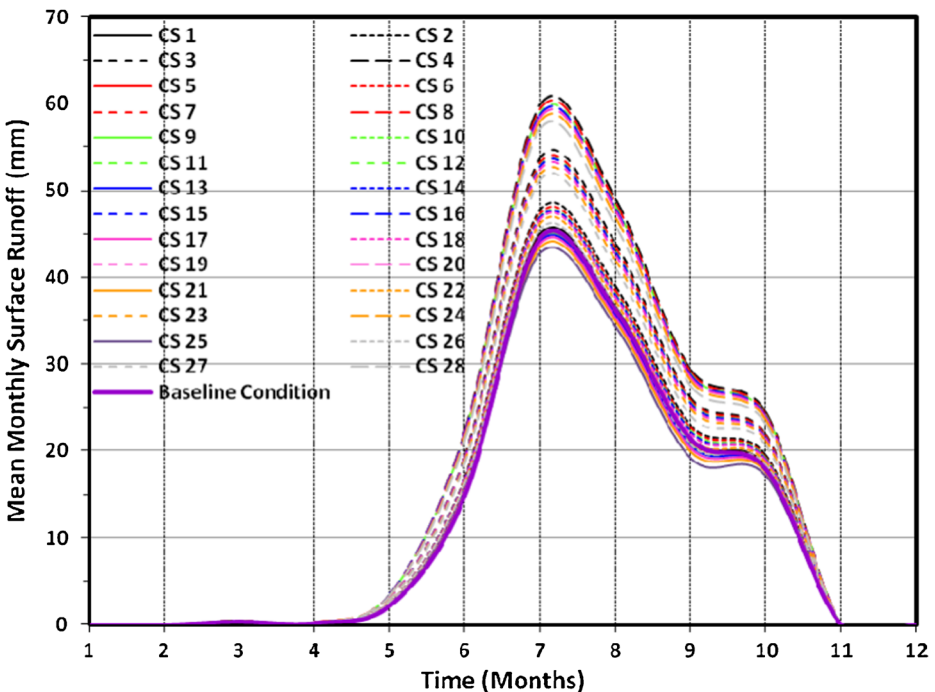

Fig. 6 Response of surface runoff under combined climatic scenarios
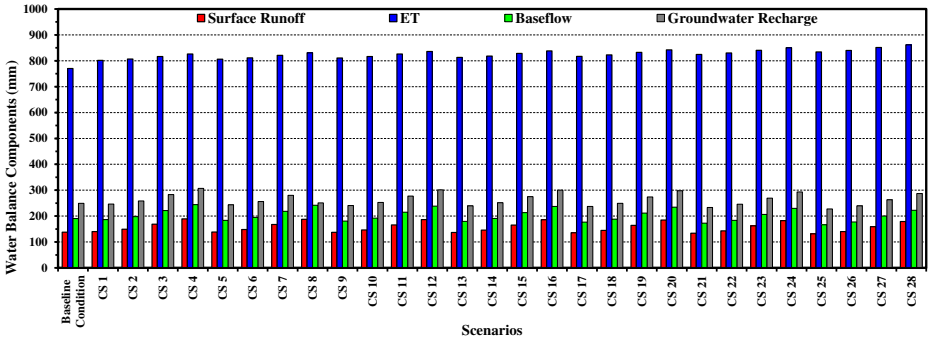
Fig. 7 Water balance components values for different combined climate change scenarios

baseflow and groundwater recharge from the baseline condition, which are 189.36, 244.5 and 306.98 mm, respectively. On the other hand, maximum decrease in average annual surface runoff, baseflow and groundwater recharge from the baseline condition corresponds to scenario CS25 (5 °C temperature increase with 2.5 % increase in rainfall), which are 131.43, 166.7 and 227.69 mm, respectively. Evapotranspiration has an increasing trend from the baseline condition in all the scenarios, with a minimum value (770.11 mm) under scenario CS1 (2 °C temperature increase with 2.5 % increase in rainfall) and a maximum value (861.62 mm) under CS 28 (5 °C temperature increase with 15 % increase in rainfall).

On the whole, it can be inferred from the above results and discussion that the variations in the water balance components of the study area are mostly due to anthropogenic factors like ever increasing urbanization, industrialization, technological advancements and rapid economic growth. The changes in the hydrology (water balance components) of the basin can be balanced by promoting the use of resource-efficient and environment-friendly technologies and the adoption of modern water management concepts and tools such as integrated land and water resources management (ILWRM), adaptive management, rainwater harvesting, artificial recharge, and other innovative resource management techniques.

6 Conclusions

This study demonstrates the application of ArcSWAT under data-sparse condition to simulate the regional impacts of salient future climatic scenarios on the major water balance components of a river basin in Eastern India. A hydrologic model of the study area was developed using ArcSWAT to simulate streamflow and its performance was found to be reasonably good with NSE and MAE values of 0.88 and 9.70 m^3/s during model calibration and those of 0.80 and 10.33 m^3/s during model validation. This calibrated and validated model was further applied for predicting the impacts of 12 independent and 28 combined climatic scenarios on the water balance components of the basin. The approaches followed in this study to deal with data scarcity are: (a) only 1 year data were used as the model warm-up period; (b) the current condition, i.e., time period from 1999 to 2005 was used as a baseline scenario in the absence of ideal time-period (1960-1990) data; and (c) to cope with the unavailability of RCM-predicted

future climatic data, region-specific incremental scenarios for temperature and rainfall and suitable SRES scenarios were considered to assess the probable impacts of climate change on the water balance components of the basin.

Comparisons of the simulated results with the current model setup revealed that the Combined Scenarios are more plausible and effective in simulating the basin's response to future climate change. Out of all the scenarios the Combined Scenario i.e., CS4 (2 °C temperature increase with 15 % increase in rainfall) shows maximum increase in average annual surface runoff, baseflow and groundwater recharge from the baseline condition, whereas CS25 (5 °C temperature increase with 2.5 % increase in rainfall) shows maximum reduction in the average annual surface runoff, baseflow and groundwater recharge from the baseline condition. The evapotranspiration is showing a continuous increasing trend (4.05–11.88 %) from the baseline in all the scenarios. The results of this study also revealed that the river basin under study is more sensitive towards the change in rainfall as compared to the change in temperature. Particularly, the results corresponding to the three IPCC scenarios (A2, B2 and A1B) revealed that surface runoff in the study area will reduce by 5–8 % at the end of 21st century, which in turn will reduce the baseflow (11–15 %) and groundwater recharge (7–11.5 %) in the river basin therefore we need to focus our attention towards different locally available climate adaptation strategies such as rainwater harvesting, afforestation, green water conservation, artificial recharge, and reuse and recycling of water, together with innovative adaptation strategies (like generation of resources from wastes) in order to ensure the climate resilient society.

The proposed analysis provides valuable information about the response of watershed towards climate change on the water balance components of the river basin irrespective of different assumptions taken and model limitations. Analysis of the different climate change scenarios provides a range of results which will help in efficient water resources planning and management in the Upper Baitarani River basin. The findings of this study and those of follow-up studies using future climatic data forecasted by regional climate models for assessing the impact of climate change on the river basin will be useful for identifying suitable adaptation measures for efficient water management in the study area under changing climatic conditions.

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