Climate change impact assessment under CORDEX South-Asia RCM scenarios on water resources of the Brahmani and Baitarini River Basin, India

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Abstract This study attempts to assess the impact of climate change on Brahmani and Baitarini river basin using a GIS-based semi-distributed model Soil and Water Analysis Tool (SWAT). The SWAT model uses various physiographic features such as slope, soil and land use classes to estimate the various water balance components of the river basin for the baseline period (1980-2010) and future climate scenarios (2071-2100). Sensitivity analysis has been carried out to identify the most critical parameters of the model. The model was calibrated(1980-2000) and validated (2001-2010) using the observed average daily discharge data. The model performance was evaluated using the coefficient of determination (R^2), Nash-Sutcliffe efficiency (ENS). The data from CORDEX South Asia RCM model for RCP 4.5 and 8.5 scenarios developed by IITM was used in the SWAT model to evaluate changes in various water balance components. Overall the SWAT model performed satisfactorily having Nash-Sutcliffe efficiency value of 0.72 and 0.65 for calibration and validation respectively. Results show an increase in average annual temperature (3.1°C), average rainfall (+10.7 mm/year).This corresponds to the increase in in the annual streamflow (110%-117%%), evapotranspiration (48%%) and water yield (159%).

Keywords Climate change**,** CORDEX, RCP, SWAT, Brahmani, Baitarini.

1. Introduction

Changes in climate have caused impacts on natural and human systems on all continents and across the oceans. In recent years we have witnessed many climate extremities such as floods and droughts. Around 330 million people have been affected by droughts in India in the year 2016 only (Annual Disaster Statistical Review 2016). Earlier studies on climate change impact have revealed that the severity of droughts may increase in some part of the country whereas the intensity of floods may be higher in some other parts. However, the overall runoff available in the streams may reduce resulting in less availability of surface water for consumptive use (Gosain et al., 2006). Therefore it is essential to evaluate the impact of future climate change on water resources to develop proper water management and climate change adaptation strategies.

The impact of future climate change on a river basin may be studied by incorporating the future climate projections of General Circulation Model (GCM) into hydrological simulations of the basin. For example, Pandey et al. 2016 studied the impact of climate change on the hydrology of Armur watershed using HadRM3, a regional climate model under the A2 and B2 GHG scenarios. He found that there is a general, increasing trend in precipitation and temperature in the basin which caused an increased water yield and evapotranspiration. Many similar studies have been carried out to assess the impact of climate change on the hydrology of a river basin (Gosain et al., 2006; Ouyang et al., 2015; Tan et al., 2017;).

SWAT (Soil and Water Assessment Tool) is a conceptual continuous time model developed to assist water resource managers in assessing the impact of management and climate on the water supply, sediment and agricultural chemical yields in large ungauged basins (Arnold et al., 2005). SWAT uses topographic and weather data to simulate various water balance components of the river basin such as precipitation, evapotranspiration, water yield, surface runoff, streamflow.

SWAT was used in this study to assess the impact of climate change on the hydrology of Brahmani and Baitarini river basin. Future climate change projections have been simulated for temperature and precipitation from CORDEX South Asia RCM for RCP 4.5 and 8.5 scenarios developed by Indian Institute of Tropical Meteorology (IITM). Water balance components for RCP scenarios were simulated for the years 2071 to 2100 and were compared against baseline period 1980 to 2010 to find out the impact of climate change on the river basin.

2. Study area

In the present study, the model runs are performed on Brahmani and Baitarini river basin.The basin extends over states of Odisha, Jharkhand and

Chhattisgarh having an area of 51,822 Sq.km which is nearly 1.7% of the total geographical area of the country with a maximum length and width of 403 km and 193 km. It lies between 83°55' to 87°3' east longitudes and 20°28' to 23°38' north latitudes. The basin is bounded by the Chhotanagpur Plateau on the north, by the ridge separating it from Mahanadi basin on the west and the south and by the Bay of Bengal on the east. The topography of this region is characterised by undulations and highly dissected. It slopes down towards south-east. About 70% of the basin area has nearly level and gentle slope. The maximum elevation found in the basin is 1181 m.

The basin has a tropical climate. In the hilly parts of the basin, the variations of the temperature during the year are less marked than in the plains. Late December and early January are the coldest months. In the year, four distinct seasons occur in the basin. They are Cold weather, Hot Weather, South-west monsoon and post-monsoon. Average annual rainfall received by the basin is around 1400 to 1600 mm. December and January are the coldest months with the minimum temperature of 12° C. The average annual maximum temperature of the basin is 37.67° C. while the average annual minimum it is 20.32° C. April and May are the hottest months where maximum temperature ranges between 35° to 38° C.

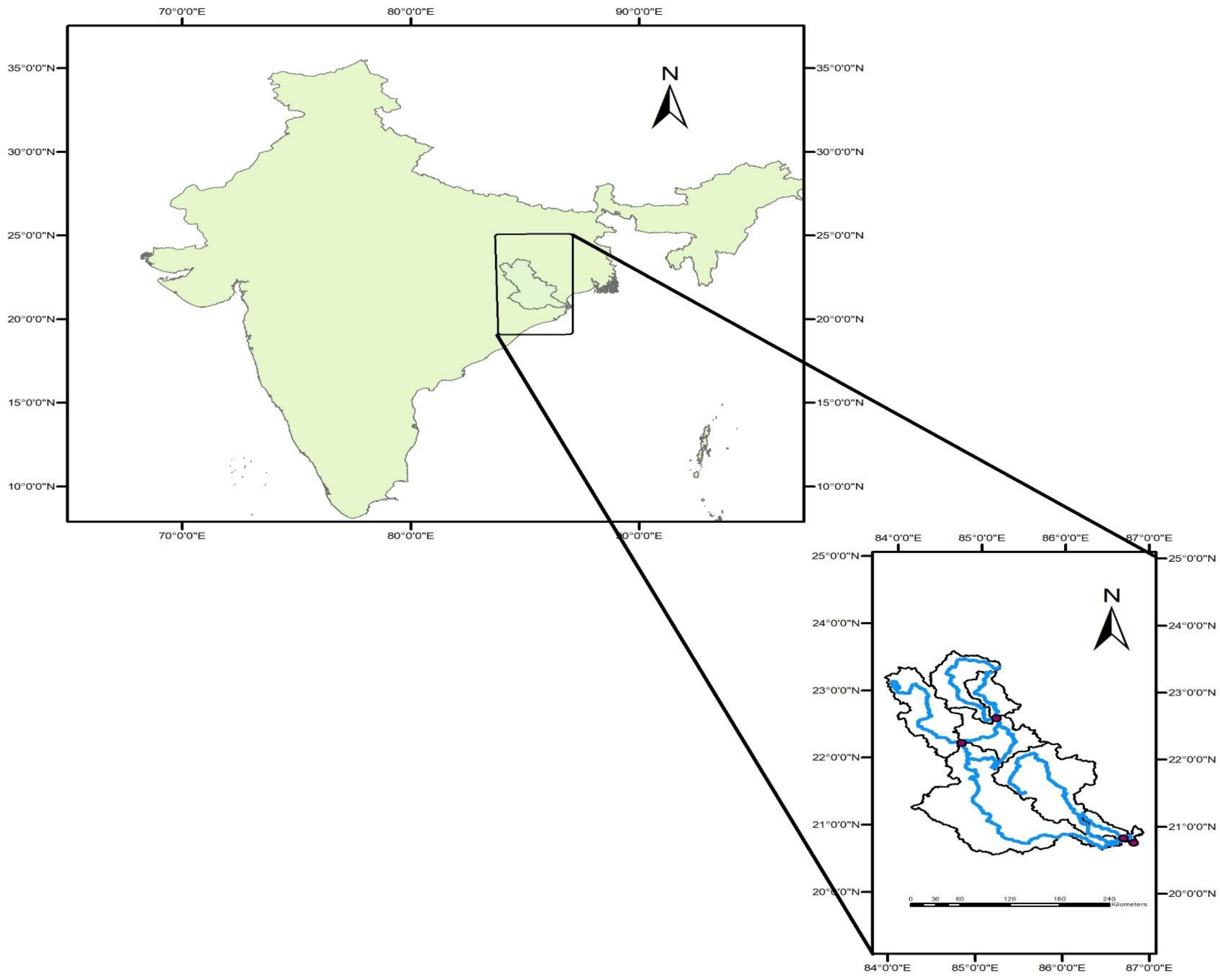

Fig 1. Location map of Brahmani and Baitarini River Basin, India

3. Materials and methodology

3.1 SWAT MODEL

SWAT, a distributed hydrologic model, can be used to predict land management practices, sediment and agricultural yield. For this purpose, the model requires specific climatic input parameters such as precipitation, temperature, solar radiation, relative humidity and wind speed. Besides these climatic parameters, the model also requires some physiographic data such as DEM, soil properties, vegetation and land use practices of the watershed. To set up the model, the digital elevation model, land use/land cover and soil map are projected into a standard projection system. The model can delineate the DEM into watershed or basin and divided into sub-basins. The layers of land use/ land cover, soil map and slopes categories were overlaid and reclassified into hydrological response unit (HRUs). Hydrological response units have been defined as the unique combination of specific land use, soil slope characteristics. The model estimates various hydrological components such as evapotranspiration, peak rate of runoff, surface runoff and other hydrological components by each HRU unit. The model calculates the hydrologic cycle at each HRU using water balance equation as follows

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \tag{1}$$

Where SW_t is the final soil water content in mm H_2O, SW_0 is the initial soil water content on day i in mm H_2O, t is the time of days, R_{day} is the amount of precipitation on day i in mm H_2O, Q_{surf} is the amount of surface runoff on day i in mm H_2O, E_a is the amount of evapotranspiration on day i in mm H_2O, w_{seep} is the amount of water entering the vadose zone from soil profile on day i in mm H_2O, Q_{gw} is the amount of return flow on the day i in mm.

3.2 SWAT MODEL INPUT DATA

Fig. 3 shows the schematic diagram of the research framework. The primary inputs for the SWAT model required for simulation are digital elevation model, land use map, soil cover map, rainfall and temperature data. Shuttle radar topographic mission (SRTM) provides the digital elevation model data (DEMs) having a 90m resolution. The DEM downloaded from SRTM website has projection system of WGS 1984 UTM, zone 45N at 90 m resolution. Land use/land cover map was prepared using supervised classification of the Landsat-8 satellite images obtained from earthexplorer. Fig 2(a) shows, the land use map, used in SWAT simulation. Soil map was prepared using FAO digital soil map of the world having a scale of 1:5,000,000. High resolution (0.5°×0.5°) gridded daily rainfall data for the period 1980-2010 over the basin area from Indian Meteorological Department (IMD) Pune, India

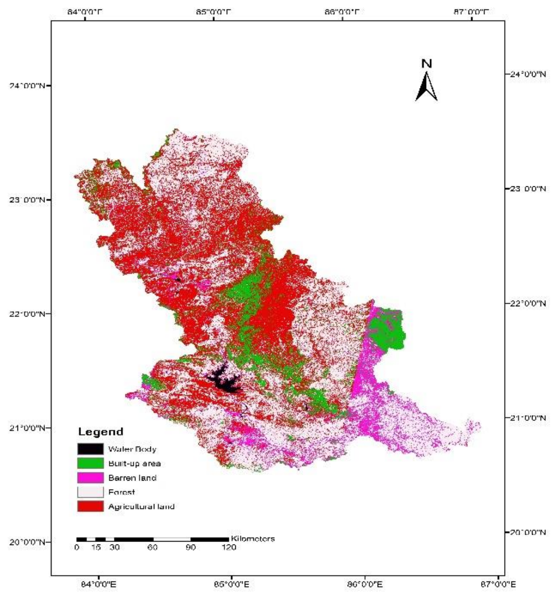

Fig. 2(a) Land Use map of the basin

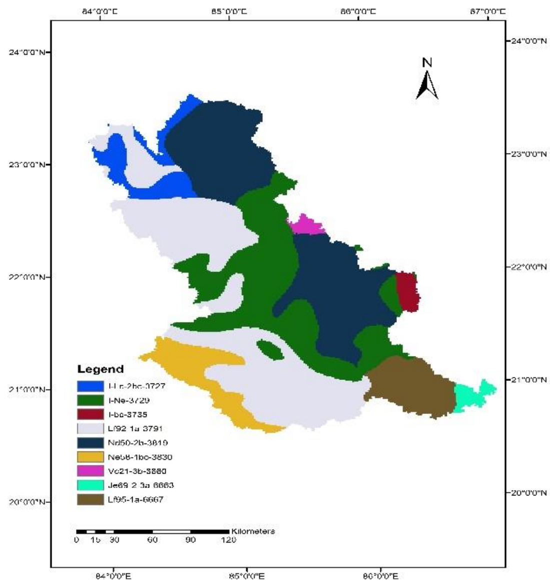

Fig. 2(b) Soil map of the basin

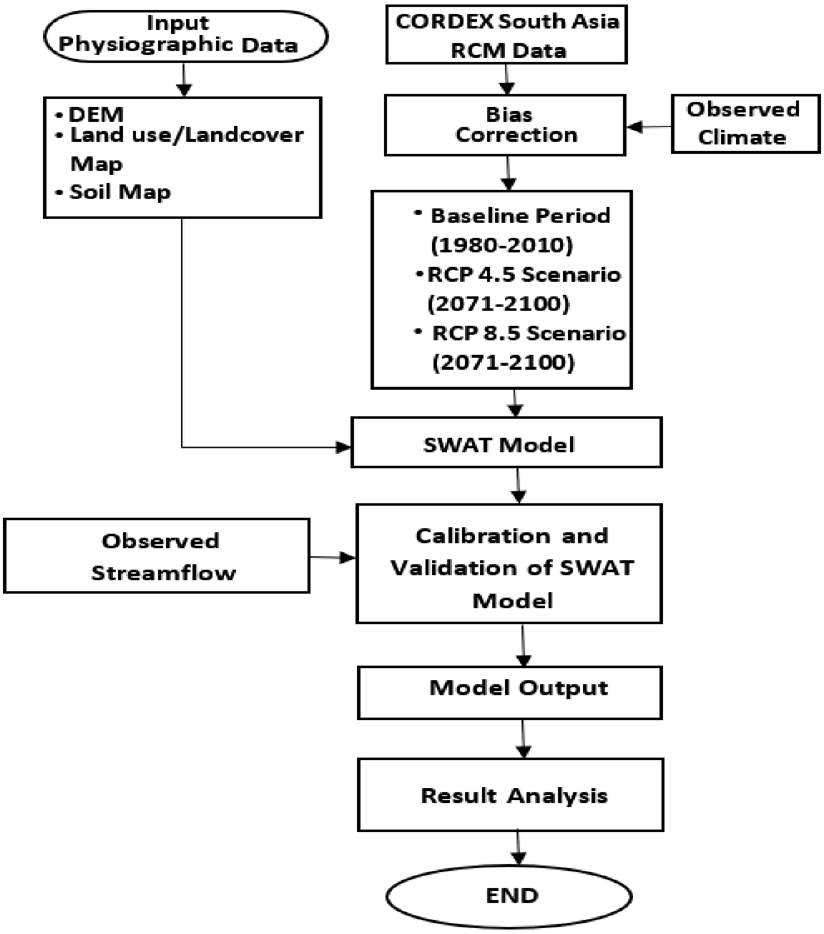

Fig 3. Schematic diagram of research framework

3.3 CORDEX RCM SIMULATED WEATHER DATA

Coordinated Regional Climate Downscaling Experiment (CORDEX) is a program to bring forth regional climate change scenarios globally. CORDEX South Asia domain experiment constitutes 11 different suites, with the combination of different RCMs driven by different GCMs' initial and boundary forcing. The CORDEX South Asia data was available at a horizontal resolution of 0.44° (~50 km) spatial resolution and monthly temporal resolution as well as daily for some experiments. The data of different experiments have been generated by different modeling groups across the world. The data for CORDEX South Asia domain was acquired from Centre for Climate Change Research (CCCR), Indian Institute of Tropical Meteorology, Pune, India.

3.4 BIAS CORRECTION OF CORDEX RCM DATA

The CF method (Hay et al. 2000; Diaz-Nieto and Wilby 2005) is an ordinary bias correction method, which is often used to reduce the bias between the GCMs outputs and observations (Chen et al. 2011; Ouyang et al. 2014). The main goal of this method is to modify the daily time series of the variables (i.e. precipitation, tasmax and tasmin) in the future years by adding monthly mean changes of GCM outputs. The adjusted formula for modified daily temperature is expressed in Eq. (2), and the modified daily precipitation is expressed in Eq. (3)

Adjusted future daily temperature $T_{adj,fur,d} = T_{obs,d} + \sum_{i=1}^{k} p_i \left(T_{GCM,fur,m} - T_{GCM,ref,m}\right)$ (2)

Adjusted future daily precipitation $P_{adj,fur,d} = P_{obs,d} \times \sum_{i=1}^{k} p_i \left(\frac{P_{GCM,fur,m}}{P_{GCM,ref,m}}\right)$ (3)

where $T_{adj,fur,d}$ is the adjusted daily temperature (tasmax and tasmin) for the future years, $T_{obs,d}$ is the observed daily temperature for the base years (2001–2010 denoted as 2000s), $T_{GCM;fur;m}$ is the monthly mean temperature of the GCM outputs for the future years, $T_{GCM;ref\ ;m}$ is the monthly mean temperature of the GCM outputs for the base years, p_i is the weight of each grid cell, and k is the number of the grid cells.

3.5 SWAT MODEL SETUP, CALIBRATION AND VALIDATION

ArcSWAT 12, an interface of SWAT model in ArcGIS 10.1 was used to develop the SWAT model of the Brahmani and Baitarini basin. There are six main steps to develop SWAT model: (1) basin delineation and river network extraction; (2) HRU definition; (3) climate station formation; (4) parameter sensitivity analysis; (5) calibration; and (6) validation.

Using the ArcGIS, digital elevation model (DEM) was used to generate the stream network of the watershed and identify the outlet points for a given threshold value. Automatic delineation delineates the main watershed into seven sub-watersheds. The subbasins were further divided into 133 HRUs (Hydrologic Response Unit). In the present study, HRUs are defined by taking all land uses and soil type occupying 10 % or more of sub-basins into account. Areas of the minor land use and soil type (10 % of a sub-basin) were re-allocated to major land uses to reflect 100 % sub-basin areas.SWAT uses two methods to estimate surface runoff namely SCS curve number (Soil Conservation Service) and Green and Ampt infiltration method. In this study, SCS curve number was used to estimate streamflow. Potential evapotranspiration was estimated using Hargreaves method.

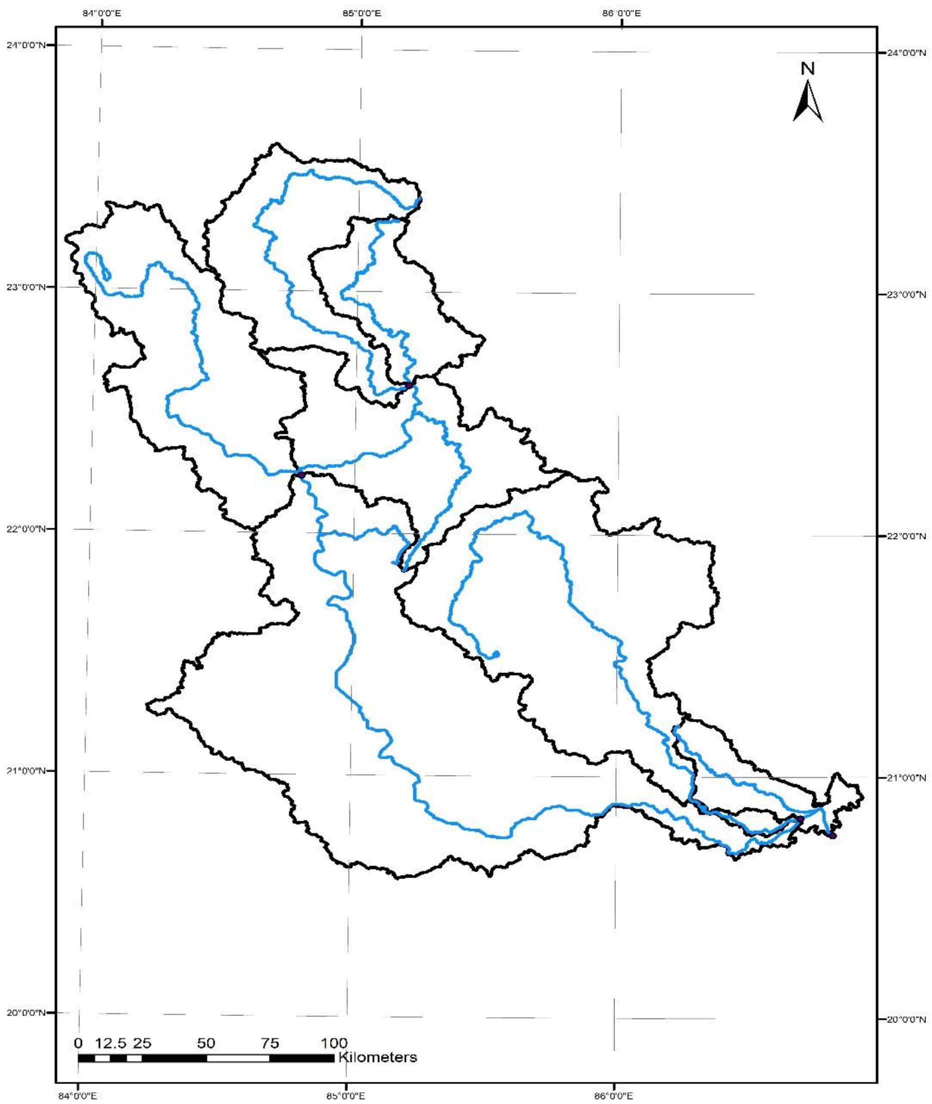

Fig. 4 Sub-basin and stream lines of delineated watershed of Brahmani and Baitrani

Model parameter sensitivity analysis, calibration and validation were performed with the SWAT-CUP tool. The global sensitivity analysis method was applied to evaluate the most critical parameters for monthly streamflow simulations in the Brahmani and Baitarini basin. Then, the SWAT model was calibrated using the sequential uncertainty fitting algorithm (SUFI-2), with 500 different parameters combinations (one iteration) for the period 1980-2000. The SUFI-2 was selected due to its capability in analyzing many parameters in the model runs. In an iteration, the SUFI-2 measures the goodness of fit and the 95% prediction uncertainty (95PPU) between simulated and observed streamflow (Abbaspour et al., 2015). Also, new parameters ranges were produced which can be used in the next iteration, to re-calibrate the model until the best parameters ranges were obtained. These best parameters ranges were then applied to validate the monthly streamflow from 1990 to 1999.

4. Results and analysis

4.1 CALIBRATION AND VALIDATION

Calibration is tuning of model parameters based on checking against observation to ensure the same response over time. In this process, model parameters varied until recorded flow patterns were accurately simulated. The model was calibrated using average monthly observed discharge data from Jenapur gauging station for the period of 1980-2000. Subsequently the calibrated parameters were used to validate the model for the period of 2001-2010.

Observed and simulated average monthly flow for calibration and validation period have been shown in Fig. 5 and 6, respectively. Coefficient of determination (R^2), Nash-Sutcliffe efficiency (ENS) have been computed to evaluate the model predictions against the observed values.

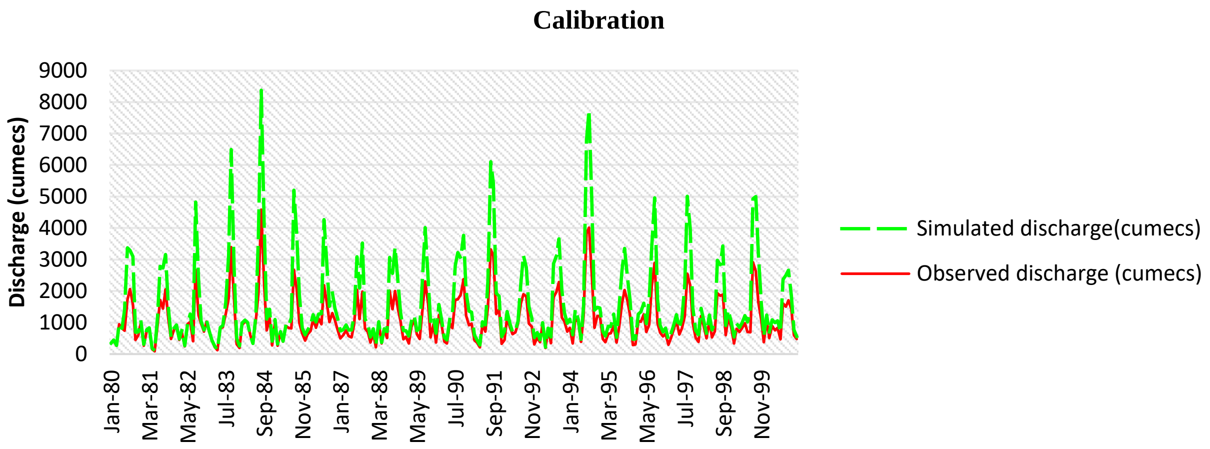

Fig. 5 Calibration results of average monthly simulated and observed flow

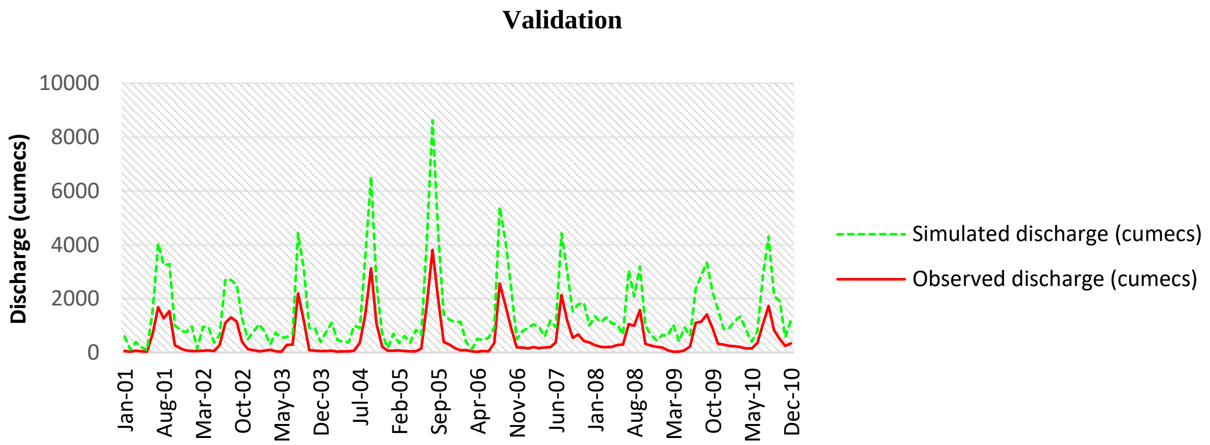

Fig. 6 Validation results of average monthly simulated and observed flow

Coefficient of determination (R^2) measures the dispersion between observed value and simulated value from model:

Coefficient of determination R^2

$$= \frac{n(\sum Q_{obs}Q_{sim})-(\sum Q_{obs})(\sum Q_{sim})}{\sqrt{\left[n(Q_{obs}^2)-(\sum Q_{obs})^2\right]\left[n(\sum Q_{sim}^2)-(\sum Q_{sim})^2\right]}} \quad (4)$$

Nash Sutcliff Efficiency (ENS)

$$=1-\frac{\sum_{i=1}^{n}(Q_{obs},i-Q_{sim},i)^2}{\sum_{i=1}^{n}(Q_{obs},i-Q_{obs\,avg},i)} \quad (5)$$

where Q_{obs} is the observed discharge (m^3/s) and Q_{sim} is the simulated discharge (m^3/s) from model. The range of R^2 lies between 0 and 1. Value of R^2, 0 and 1 indicates no correlation and perfect correlation, respectively, between observed and simulated values. Nash–Sutcliffe efficiency (ENS) values lies between -∞ and 1. ENS values, 1 indicates that the perfect match, whereas 0 value indicates that simulated values are accurate as mean of the observed values. Table (1) shows the values of R^2 and ENS for calibration and validation.

Table (1) Calibration and validation statistics

	Period	**R^2**	**ENS**
Calibration	1980-2000	0.83	0.72
Validation	2001-2010	0.76	0.65

4.2 SENSITIVITY ANALYSIS

Sensitivity analysis for the model was carried out for the period of 10 years using 26 different parameters. Out of these 26 parameters, only 8 parameters were found to have some meaningful effect on the model output. Changes in the values of other parameters showed no significant effect on the simulated flow. Table (2) describes these critical parameters.

Manipulation of sensitive parameters values were carried out within the allowable range as shown in the table (3). The parameters found to be effective for the model output were used for calibrating the model for the period of 1980-2000.

Table (2) SWAT parameters and their description

Parameters	Description
CN2	Initial SCS CN-2 value
SOL_AWC	Soil available water capacity
GW_DELAY	Groundwater delay time
ESCO	Soil evaporation compensation factor
ALPHA_BNK	Baseflow alpha factor for bank storage
REVAPMN	Threshold depth of water in the shallow aquifer to revap to occur
SLSUBBSN	Average slope length
GW_REVAP	Groundwater "revap" coefficient

Table (3) Initial and final adjusted parameters values of flow calibration

Sensitive Parameters	Lower and upper bound	Fitted value
CN2	-0.2 to 0.2	-0.102
SOL_AWC	-0.2 to 0.4	0.131
GW_DELAY	30 to 450	439.5
ESCO	0.80 to 1.0	0.8702
ALPHA_BNK	0 to 1.0	0.123
REVAPMN	0 to 10	1.25
SLSUBBSN	0 to 0.2	0.009
GW_REVAP	0 to 0.2	0.1926

4.3 CLIMATE CHANGE ASSESSMENT

CORDEX South Asia regional climate model (RCM) output data was analyzed to study the variation in the future climate for RCP 4.5 and RCP 8.5 scenarios. The 20 years running mean of annual precipitation and maximum and minimum near surface temperature anomaly relative to baseline period 1980-2000 mean was used to find out the trend in change in temperature and precipitation for future RCP scenarios. Fig. (7) shows the variation of temperature as well as precipitation for RCP 4.5 and 8.5 scenarios.

With reference to baseline period, the near-surface mean temperature is expected to rise by 1.5°C and 3.6°C for RCP 4.5 and 8.5 respectively by the end of this century. Similarly, precipitation is also expected to rise by 7.5 mm/year and 11mm/year for RCP 4.5 and 8.5 respectively.

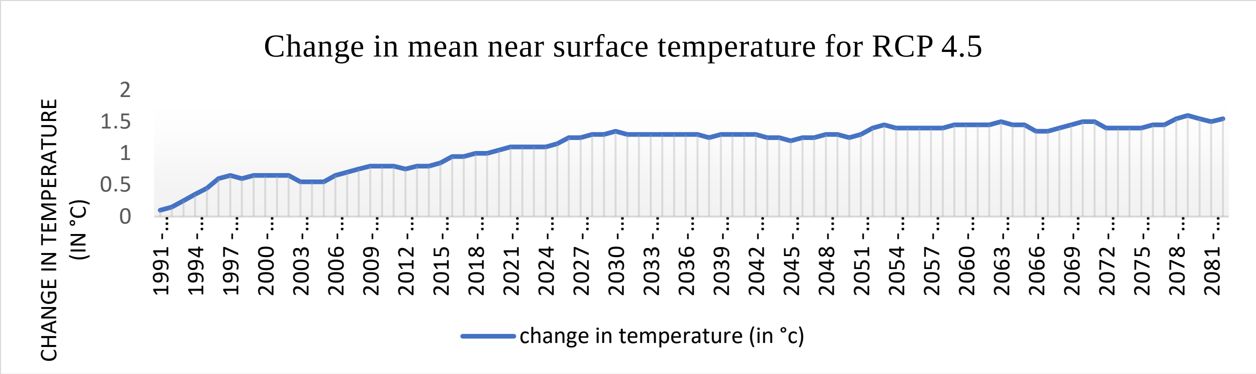

Fig 7(a) Long-term mean temperature variation trend for RCP4.5

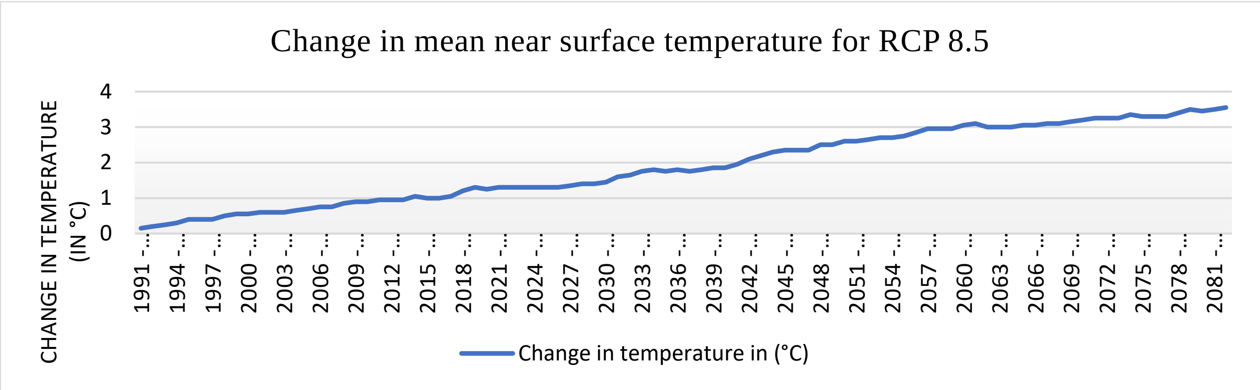

Fig 7(b) Long-term mean temperature variation trend for RCP8.5

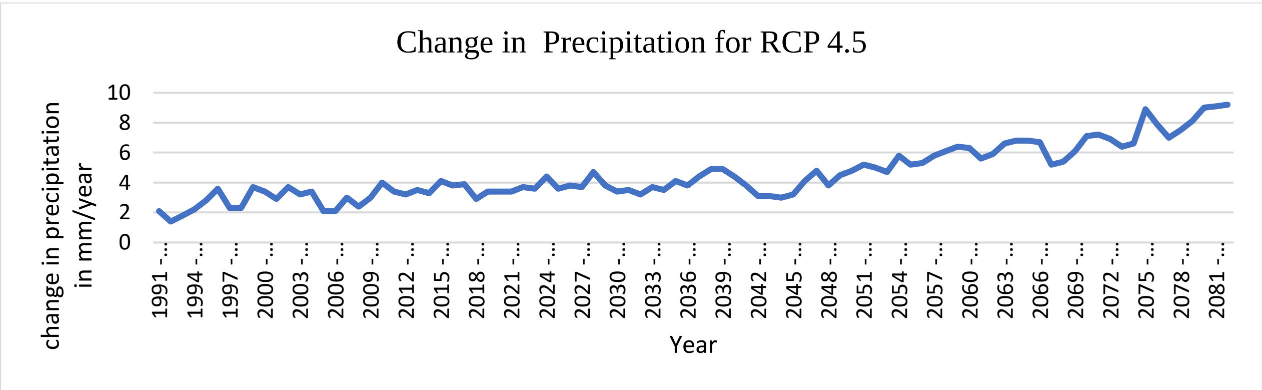

Fig 7(c) Long-term precipitation variation trend for RCP4.5

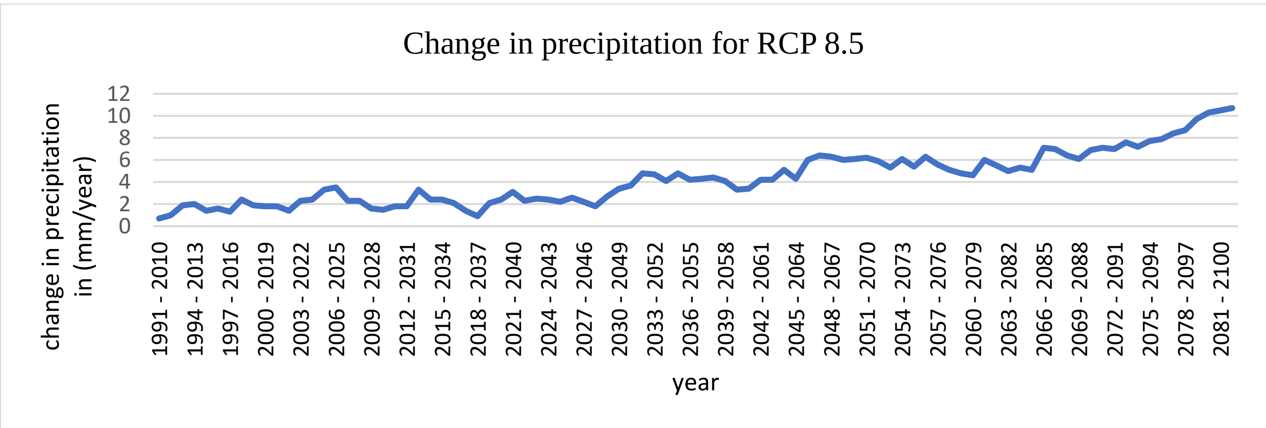

Fig 7(d) Long-term precipitation variation trend for RCP8.5

4.4 ASSESSMENT OF SWAT MODEL OUTPUT

CORDEX simulated daily weather data of baseline (1980-2010) and RCP scenarios (2071–2100) were used to run the model. Results from the model have been analyzed on annual and monthly basis. Considering the benchmark of baseline period, percentage changes in water balance components for future scenario have been shown in Fig. 8 (% change in streamflow), Fig. 9 (% change in evapotranspiration), and Fig. 10 (% change in water yield) on annual basis, whereas monthly percentage changes have been shown in Fig. 11 and Fig. 12 for RCP 4.5 and 8.5 scenario. Results based on annual studies for baseline (1980–2010) period indicate that the maximum value of streamflow, evapotranspiration and water yield are 10372.06 m^3/s (2008), 832 mm (1992) and 2315 mm (2008), respectively. The minimum values are 4.88 m^3/s (1986), 315 mm (2000) and 263 mm (1997) for streamflow, evapotranspiration and water yield, respectively.

Considering the benchmark of average streamflow (for baseline period), maximum streamflow has increased by 110 % and minimum streamflow decreased by 38 % corresponding to RCP 4.5 scenario. In the same time, for RCP 8.5 scenario maximum streamflow has increased by 117 % and minimum streamflow decreased by 40 %. The maximum and minimum evapotranspiration values of RCP 4.5 scenario have changed by 48 % and –20 % respectively, against the average evapotranspiration of baseline. For RCP 8.5 scenario, maximum and minimum evapotranspiration values have changed by +49 % and –19 %, with reference to the average evapotranspiration of baseline. Average value of evapotranspiration has increased by 10.67 % for RCP 4.5 scenario and 18.56 % for RCP 8.5 scenarios, concerning the average evapotranspiration value of baseline.

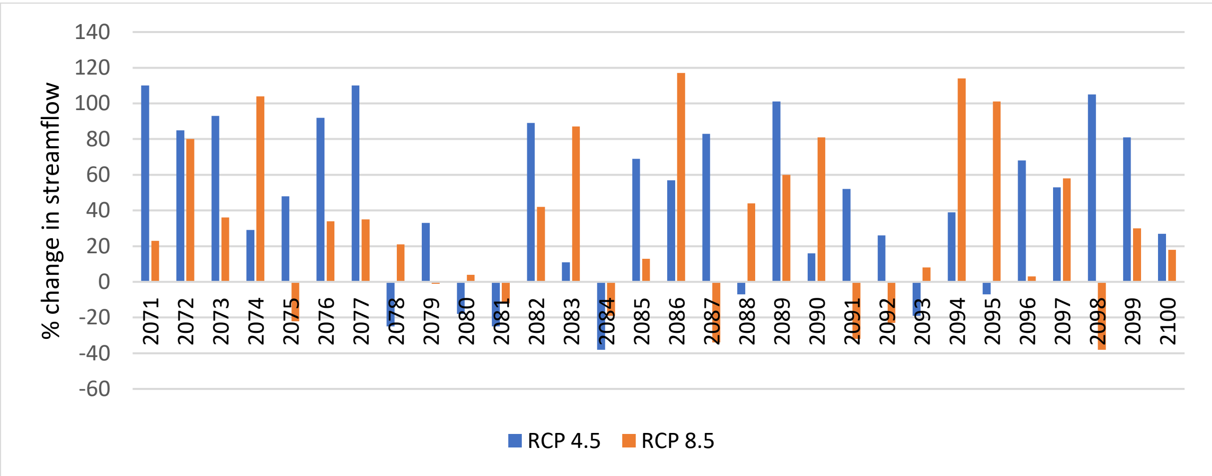

Fig.8 Percentage change in stream flow for RCP scenario for (2071-2100) with respect to baseline (1980-2010)

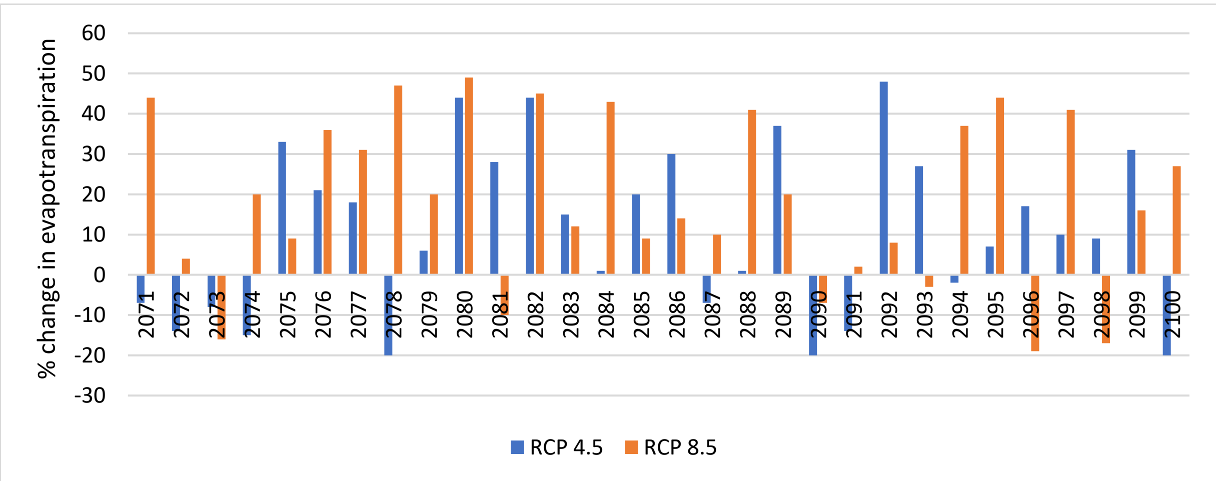

Fig.9 Percentage change in evapotranspiration for RCP scenario for (2071-2100) with respect to baseline (1980-2010)

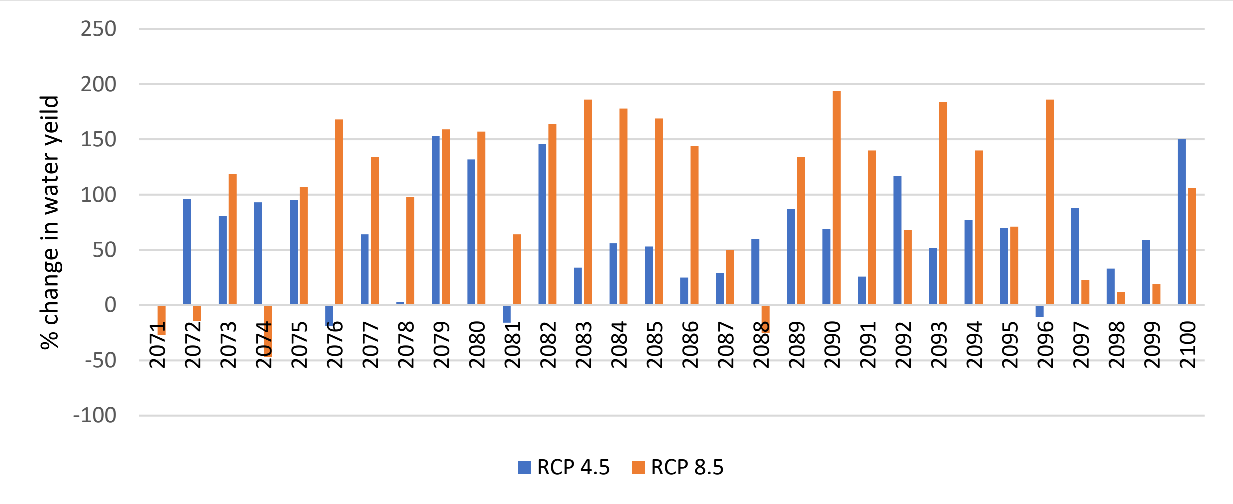

Fig.10 Percentage change in water yield for RCP scenario for (2071-2100) with respect to baseline (1980-2010)

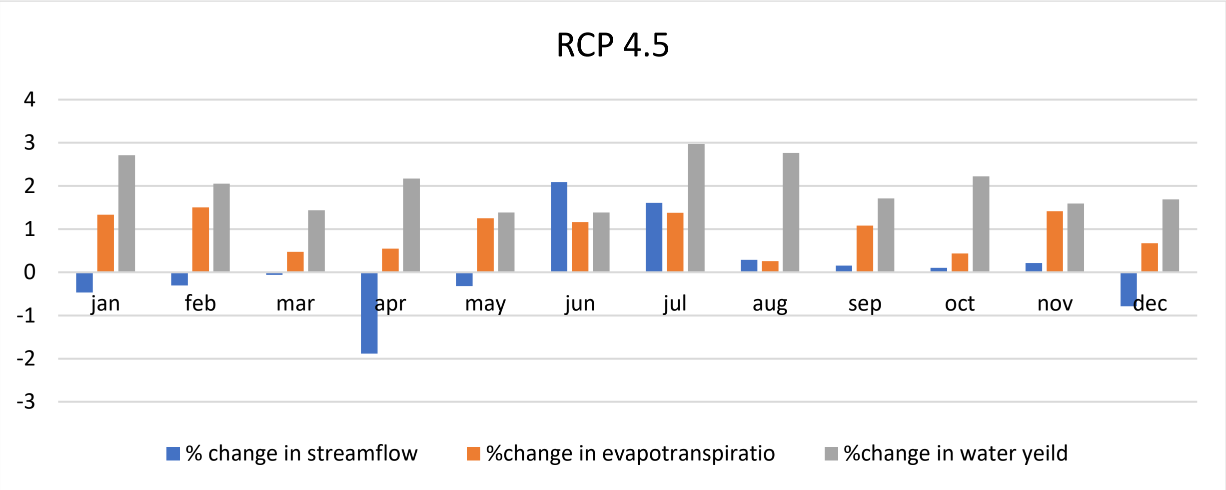

Fig.11 Percentage change in water balance for RCP 4.5 scenario for (2071-2100) concerning baseline (1980-2010)

Comparing with the average water yield of baseline, maximum water yield will be increasing by 159 % for RCP 4.5 and 194 % for RCP 8.5 scenarios, and minimum water yield is decreasing by 25 % and 45 % for RCP 4.5 and RCP 8.5 scenarios, respectively. Average water yield has increased by 63.33 % for RCP 4.5 and 102.03 % for RCP 8.5 scenarios respectively, with respect the average value of baseline.

Analysis of monthly average data shows that there is slight decrease in streamflow during non-monsoon period, but during monsoon streamflow increased by around 2.1% for RCP 4.5 and 2.9% for RCP 8.5. due to warming up of the globe, there is an increase in evapotranspiration through out the year peaking during the summer months of May, June and July. For RCP 4.5 evapotranspiration is expected to increase by 1.2% and for RCP 8.5 it is expected to rise by 4.76%. Similarly, water yield has been found to increase throughout the year. For RCP 4.5 water yield is expected to rise 2.9% and 4.1% for RCP 8.5.

5. Conclusion

This paper has different aspects related to hydrological modelling studies: (1) successfully applied the SWAT model setup for watershed (2) calibrations and validation have been carried out for the ungagged catchment using the observed flow data of the adjacent gaged catchment. Several evaluation parameters such as coefficient of determination (R2), Nash–Sutcliffe prediction efficiency (ENS) were used to evaluate the model

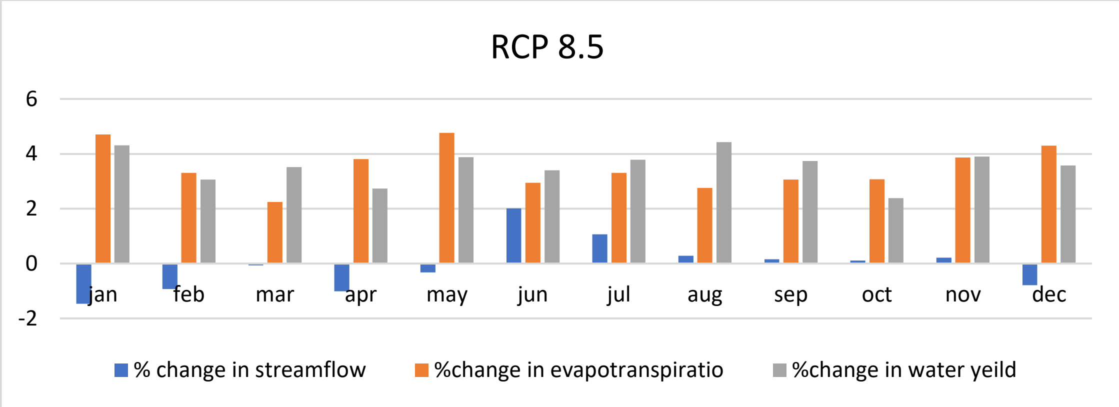

Fig.11 Percentage change in water balance for RCP 8.5 scenario for (2071-2100) concerning baseline (1980-2010)

predictions against the observed values (3) computethe water balance component of the watershed in context of climate change. (4) In the monsoon season, rainfall, evapotranspiration and water yield increased by significant amount for GHG scenario (A2 and B2) respectively concerning the base line scenario (5) this study will be very useful for decision-makers to assess the benefits best management practices at the watershed level.

Projections of multi-GCMs indicated that both temperature and precipitation will increase in the future. However, streamflow is likely to decline in the future mainly due to an increase of evapotranspiration in a warming world. It would bring the challenging for the water resources management. Monthly streamflow is likely to increase from August to September but decline in winter and spring. As August and September are wet season, it makes a more uneven distribution of annual cycle of streamflow.

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