Future Climate Change Impacts on the Stream Flow—A River Basin Scale Assessment

T. I. Eldho and Rakesh Kumar Sinha

Abstract The effect of climate change (CC) variation results in considerable changes in hydrology leading to large-scale socio-economic impacts. Further studies demonstrate that long-term climate change in the river basins is giving rise to frequent hydro-meteorological extremes such as floods and droughts. In this study, the future CC impacts on a river basin scale are assessed and effects on stream flow are estimated using a hydrological model SWAT (Soil and Water Assessment Tool). The methodology adopted is demonstrated using a case study of the Muvattupuzha river basin (MRB) in Kerala, South India. The CC impacts for the future up to 2100 are obtained from the ensembled values of 5 GCMs including CCCMA CanESM2; CNRM CM5; MPI ESM MR; MPI ESM LR and BNU ESM. The hydrologic model was calibrated and validated at two river gauge stations using monthly river streamflow data. The results indicated that mean annual surface runoff in the near, mid, and far future would be decreasing under both RCP 4.5 and 8.5 while RCP 8.5 showing worse conditions than RCP 4.5, in the future. Furthermore, the projected results indicate that the surface runoff would be higher in both RCP scenarios during winter and summer, while the monsoon period largely demonstrates a reverse trend, that can lead the water scarcity in the river basin. The results of this study can be helpful to policymakers for appropriate water resource management, considering climate change scenarios for moderate and worse conditions in the future period.

Keywords Climate change · River basin · SWAT model · Surface runoff · Hydrology

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1 Introduction

In the last few decades, throughout the world, the adverse impacts of climate change (CC) on the water resources are widely reported. As per the IPCC report [4], in the future this impact is expected to be more severe. However, the CC impacts can considerably vary from one region to another. Due to CC and its impacts, many places may face scarcity of freshwater, flooding or may subject to water quality issues. Thus, especially in tropical regions, sustainable use of water resources becomes the core of the local and national strategies and politics. Due to increase in population and various activities, the demand for water has increased many times, causing an imbalance in the supply and demand of water [16]. In maintaining the global water balance, the tropical regions play a key role. The humid tropics cover almost 25% of Earth's land surface, with tropical forests covering approximately 50% of this area [11]. The land use changes in this region drastically changes the annual mean streamflow [12, 14, 15].

In India, there is a huge variation of climatic conditions, ranging from tropical in the south to temperate and alpine in the Himalayan north. In most of India, the monsoon is the major source of precipitation (i.e., 80% of precipitation is from monsoon). In most parts of India, the climate variation is reflected by the rising temperature leading to high evapotranspiration, and the intensities and nature of precipitation are considered to have a significant impact on various hydrological processes. Many of the available studies show that the effect of climate variation on hydrological regimes is significant, and such effects will likely continue to increase in the future. In the literature, number of studies are available that tried to investigate river basin scale CC impacts [5, 14]. As reported by Kim et al. [6], the CC impacts under different RCP (Representative Concentration Pathways) emission scenarios on surface runoff in the Hoyea River basin, Korea, and is more than the effects of LULC change. Givati et al. [3] reported the impacts of CC on runoff for the Upper Jordan basin. According to them, due to CC, there can be a significant decrease of runoff approximately by 11% and 16% for the near and far future, respectively, under RCP 4.5 and 16% and 44%, respectively, under RCP 8.5. Thus, there is a need to investigate the hydrological response related to CC on a river basin scale. In this study, a methodological framework is presented for the river basin scale CC impact assessment. The changes in streamflow were analyzed using the SWAT watershed simulation model. The Muvattupuzha river basin (MRB) located in central Kerala, South India is taken as a case study. The main objectives of this paper are the assessment of climate change impacts at the sub-basins scale for near (2016–2040), mid (2041–2070), and far (2071–2100) future for RCP 4.5 and RCP 8.5 emission scenarios.

2 Study Area

The Muvattupuzha River is one of the major perennial rivers in Central Kerala (Fig. 1). It has a length of about 121 km and has a catchment area of 1554 km^2 (Table 1). The river basin lies between north latitudes 9° 40′–10° 10′ and east longitudes 76° 30′–77°. Due to data availability issues, the present study is confined up to Vettikkattumukku in the downstream, covering the river course of almost 116 km length. The remaining length of river is part of other river confluences and backwaters. The region receives an annual mean rainfall of about 3500 mm. The area enjoys a tropical humid climate. Figure 1 shows the location of MRB. Figure 1b shows the DEM (Digital Elevation Model) of the river with basin, 1c shows the sub-basins and 1d shows the soil map [2].

In MRB, in most months of the year, rainfall is significant and has short dry seasons. In this humid tropical basin, the annual temperature typically varies from 22 °C to 35 °C and is rarely below 20 °C or above 37 °C. The average wind speed over the basin is more than 9.2 km/hr. It also experiences a seasonal variation in perceived relative humidity. In the river basin, the surface soil pattern is more than 70% of lateritic soil and the remaining riverine alluvium and brown hydromorphic soil (Fig. 1d).

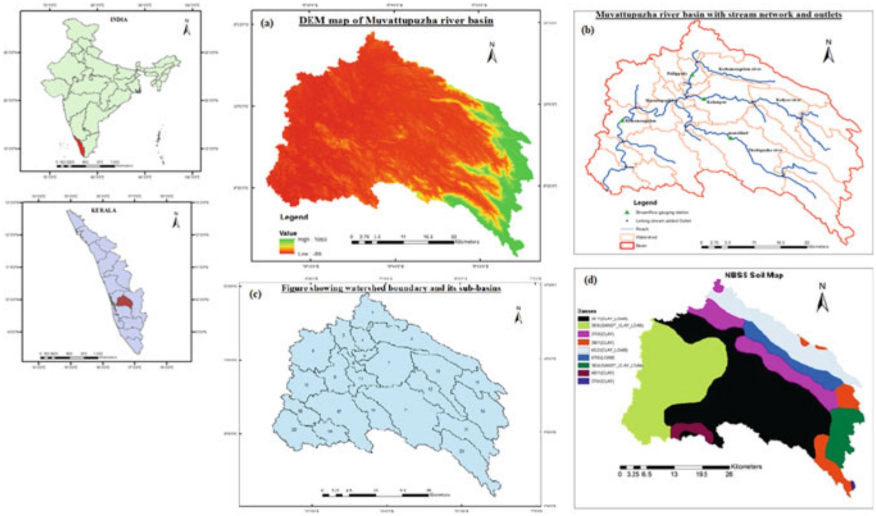


Fig. 1 Details of Muvattupuzha river basin—Location map, **a** digital elevation model, **b** stream network, **c** sub-basins, and **d** soil of the study area

Table 1 Input data used for Muvattupuzha River Basin

Input data	Resolution	Source
Digital Elevation Model (DEM) Cartosat	30 m	NRSC: National Remote Sensing Centre (http://www.nrsc.gov.in/)
LULC map	30 m	Landsat imageries (http://earthexplorer.usgs.gov/)
Basin Soil data	Toposheet	National Bureau of Soil Survey (NBSS)
Meteorological data (precipitation and temperature (min. and max.))	0.25° (daily)	Indian Meteorological Department (IMD)
Meteorological data (solar radiation, relative humidity, and wind velocity)	0.25° (daily)	Climate Forecast System Reanalysis (CFSR)
Hydrological data (streamflow)	Daily	Central Water Commission (http://www.india-wris.nrsc.gov.in/)

3 Materials and Methodology

3.1 Data Description

The DEM (digital elevation model) was generated using Cartosat, with 30 m resolution. The required soil data was collected from Government agencies (NBSS, Nagpur). The land use land cover (LULC) was obtained using Landsat data (30 m resolution). The meteorological data (IMD, 0.25°) such as rainfall and temperature were used as input data for the simulation of the hydrologic model. The Climate Forecast System Reanalysis data of relative humidity, solar radiation, and wind velocity were collected and interpolated at 0.25° as the same grid points to precipitation data. Gauge-discharge data at the Ramamangalam and Kalambur measuring stations were taken from IWRIS (Indian-Water Resources Information System) open data source for the time 1986–2015 (http://www.india-wris.nrsc.gov.in). The soil data used in the present study were acquired from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur. The DEM used for delineating watershed was Cartosat DEM of 30 m (1 arc-second) resolution. Table 1 gives input data details, resolutions, and sources.

3.2 Future GCM Database

For the future data, the statistical downscaled climate variables, namely precipitation, minimum and maximum temperature, relative humidity, and wind were collected from other INCCC projects for five Coupled Model Intercomparison Project 5 (CMIP5) using GCM (general circulation model) simulations in daily time steps (Table 2) [2]. As a part of the project funded by the Indian National Committee on

Table 2 Input data used for the future period in the present study

Model	Institution	Spatial resolution	Scenarios
CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8° × 2.8°	RCP 4.5 and 8.5
BNU ESM	Beijing Climate Center, China Meteorological Administration	2.8° × 2.8°	RCP 4.5 and 8.5
CNRM CM5	Centre National de Recherches Meteorologiques/ Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	1.4° × 1.4°	RCP 4.5 and 8.5
MPI ESM LR	Max Planck Institute for Meteorology (MPI-M)	1.8° × 1.8°	RCP 4.5 and 8.5
MPI ESM MR	Max-Planck-Inst. for Meteorology	1.87 × 1.87	RCP 4.5 and 8.5

Climate Change (INCCC), Ministry of water resources, Government of India, statistically downscaled climate variables were made available for India (http://www.regclimindia.in/). For the CC impact assessment using RCP 4.5 and RCP 8.5 emissions scenarios, all GCMs contained essential variables corresponding to historic and projected climate data. The output from the five GCMs including CCCMA CanESM2; MPI ESM LR; CNRM CM5; MPI ESM MR; and BNU ESM, respectively, are the source of predictor data used for precipitation downscaling for future RCP scenarios. A brief description of the GCM datasets, resolution, and scenarios is given in Table 2.

3.3 GCM Climate Data Analysis

After the bias correction, the statistics of the observed and GCM-simulated climate variables of rainfall, maximum (T_{max}), and minimum temperature (T_{min}) for the MRB are illustrated for ensemble data in a Taylor diagram as shown in Fig. 2. This indicates all variables correlation are in an acceptable range. Hence, they are used for further hydrological parameter analysis, for the river basin.

3.4 Hydrologic Modeling Using SWAT Model

The hydrologic model SWAT was developed by the United States Department of Agriculture–Agricultural Research Service (USDA–ARS) [1]. The SWAT model can be used to predict various hydrological variables and assess the impact of land use land cover changes, sediment, and agricultural chemical yields. It is a semi-distributed continuous-time varying model that can be used for the prediction of

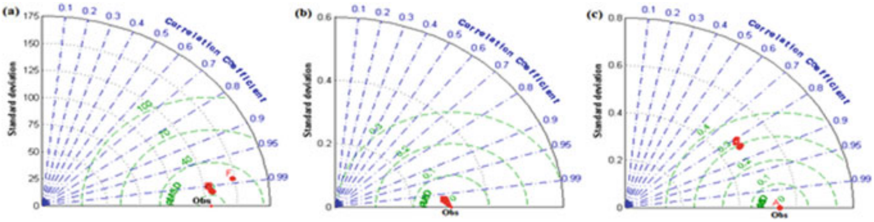


Fig. 2 Taylor diagram for study area: **a** rainfall (mm/month), **b** $T_{\max}$ (°C), and **c** $T_{\min}$ (°C) for the MRB

various hydrological variables and water quality parameters at a watershed scale. We can use various time steps of daily, weekly, or monthly. In the SWAT model, the major components include weather conditions, hydrology, soil properties, plant growth, land management, nutrients, pesticides, bacteria, etc. In SWAT model, we divide the basin into sub-basins and then into units of unique soil/land use characteristics called hydrological response units (HRUs). In the modeling process, the HRUs are defined as homogeneous spatial units characterized by similar geomorphologic and hydrological properties. While modeling, a specific HRU land unit considered may contain a sandy loam, walnut orchards, and a slope of up to 5%. For the problem considered, user can specify land cover, soil area, and slope thresholds. A complete description of SWAT model can be found in [9]. SWAT model provides several water management options to improve its ability to predict streamflow such as irrigation, water transfer, etc. The model provides five sources of water for irrigation including reservoirs, shallow and deep aquifers, and sources from outside the watershed. Further details of SWAT hydrological model can be also found in Neitsch et al. [10].

3.5 *Methodological Framework*

For the hydrological impact assessment of CC, a general methodological framework was developed in this study for river basin scale analysis. The flow chart of the methodological framework developed is given in Fig. 3.

Following are the step-by-step procedures adopted in this study.

- Extraction and database development of input data such as DEM, LULC, Soil, and climatic parameters.
- Data preprocessing such as making inputs data for SWAT model and Landsat image classification for historical LULC.
- Obtain the future climate data after bias correction for the selected 5 GCMS [2] (the GCMS used are BNU, CNRM, CAN-ESM, MPI-LR, and MPI-MR) http://www.regclimindia.in/.
- Develop the SWAT model for the considered study area.

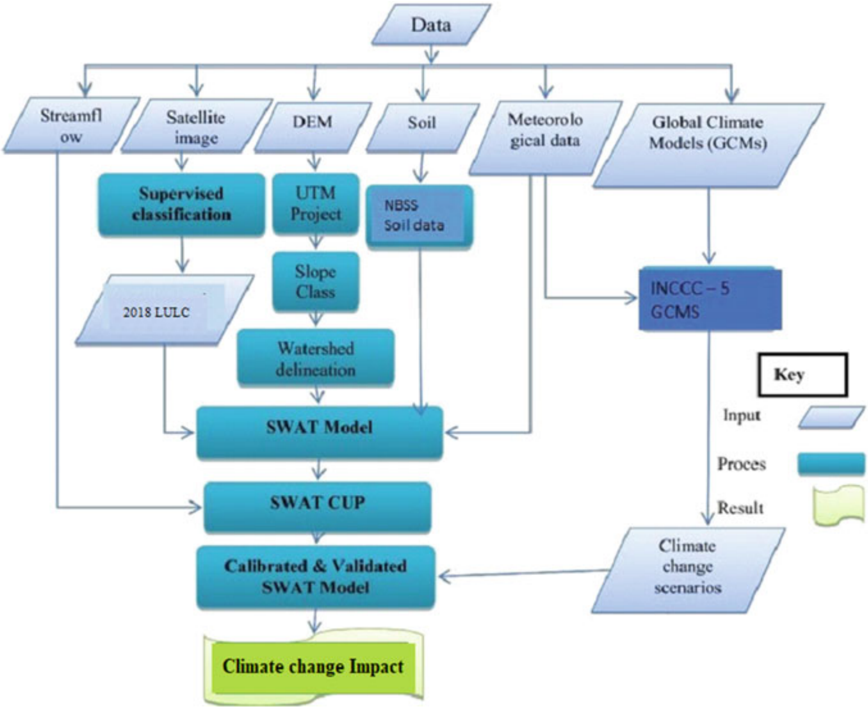


Fig. 3 SWAT Modeling procedure for climate change impact assessment on River Basin Scale

- SWAT model calibration and validation.
- Assessing the impact of historical and future CC and its effects on hydrological components and streamflow.

Based on the analysis, derive the conclusions and recommendations.

4 Results and Discussion

4.1 LULC Analysis

For the Muvattupuzha river basin, the classified LULC (land use land cover) of 2018 was utilized to analyze condition of the basin. Landsat image was procured for 2018 to determine the land cover variation. Before classification and topographic correction, the selected Landsat image was corrected for atmospheric interference by using the dark-object subtraction method. To avoid the cloud related issues, the image used in this study was obtained in the post-monsoon season (October). For image classification, the supervised maximum likelihood technique was used [7].

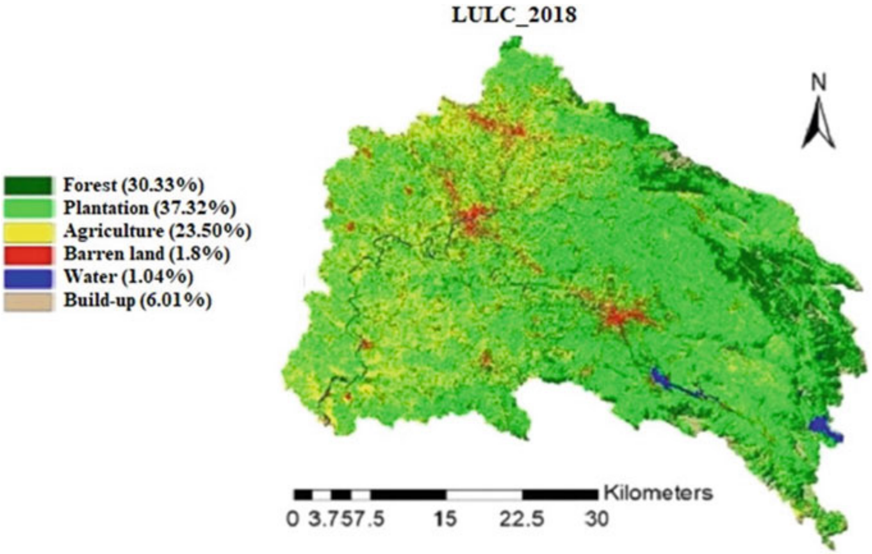


Fig. 4 Land use land cover map of Muvattupuzha basin–2018

Figure 4 shows the result of maximum likelihood classification of Landsat image for the year 2018. The area of each class was calculated considering the pixel count and total area (study area). The types of land use present in the study area are identified as 6 classes of: water bodies (WATR), agricultural land (AGRL), forest land (FRST), barren land (BARR), urban land (URBN), and plantations (RUBR). As per the LULC classification, plantation is the most prominent land use with 37.32%, followed by forest with 30.33%, agriculture with 23.5%, built-up with 6.01%, water with 1.04%, and barren land with 1.8%.

4.2 Calibration and Validation of the SWAT Model

The hydrological model SWAT is calibrated for streamflow at two gauge stations Kalambur (Sub-basin 7) and Ramamangalam (Sub-basin 15) for a period of 10 years starting from 1991 to 2000. The model was run monthly, and 5 years were given as warm-up period to the model before the simulation output starts. We have taken 1000 simulations for the identification of sensitive parameters for discharge in SWAT-CUP for calibration using SUFI2 by LH procedure, in which observed and computed outputs were compared at the considered river gauging station. The model was calibrated by adjusting ten sensitive parameters for streamflow which includes five related to surface runoff (CN2, SOL_AWC, EPCO, ESCO, SUR_LAG) and other five related to base flow (ALPHA_BF, GW_DELAY, GW_REVAP, RCHRG_DP, GWQMN) as given in Table 3.

Table 3 SWAT model parameters and their fitted values used in calibration and sensitivity analysis

No	Parameters	Description	Process range		Fitted value
1	CN2	SCS CN II Value–initial	Runoff	±0.1	0.06 (r)
2	SOL_AWC	Available water capacity of the soil layer	Soil	0–1	0.42 (v)
3	SURLAG	Surface runoff lag time	Runoff	0.1–10	0.18 (v)
4	ESCO	Compensation factors for soil evaporation	Evaporation	0–0.8	0.23 (v)
5	EPCO	Compensation factors–Plant uptake	Soil	0.1–0.7	0.37 (v)
6	ALPHA_BF	Base flow alpha factor (day)	Groundwater	0–1	0.52 (v)
7	GW_DELAY	Groundwater delay (days)	Groundwater	10–300	35.88 (v)
8	GW_REVAP	Groundwater “revap” coefficient	Groundwater	0.02–0.2	0.07 (v)
9	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Groundwater	0–300	2.9 (v)
10	RCHRG_DP	Deep aquifer percolation factor	Groundwater	0–1	0.82 (v)

Note Here (r) is the value existing that is multiplied; (v) is the value existing that is replaced by the given value

Figure 5 shows the output from SWAT-CUP after calibration, which clearly shows that simulated streamflow closely matches with the observed value for both stations with an R^2 and NSE value of 0.87 and 0.86 respectively for Kalambur station and an R^2 and NSE value of 0.89 and 0.85 respectively for Ramamangalam station (Table 4). According to Moriasi et al. [8], calibration results are in an acceptable range.

4.3 Impact of Climate Change on Streamflow at the Basin Scale

In this study, to investigate the impacts of CC on streamflow, simulations were carried out by keeping LULC fixed for 2018 and altering the climate continuously for the baseline period (1986–2015) and future (2016–2100). For future periods, the outputs are aggregated into three-time slices: T1 (2016–2040), T2 (2041–2070), and T3 (2071–2100) for both emission scenarios (RCP 4.5 and 8.5). To quantify the changes in streamflow, the SWAT model was simulated using 5 downscaled, bias-corrected

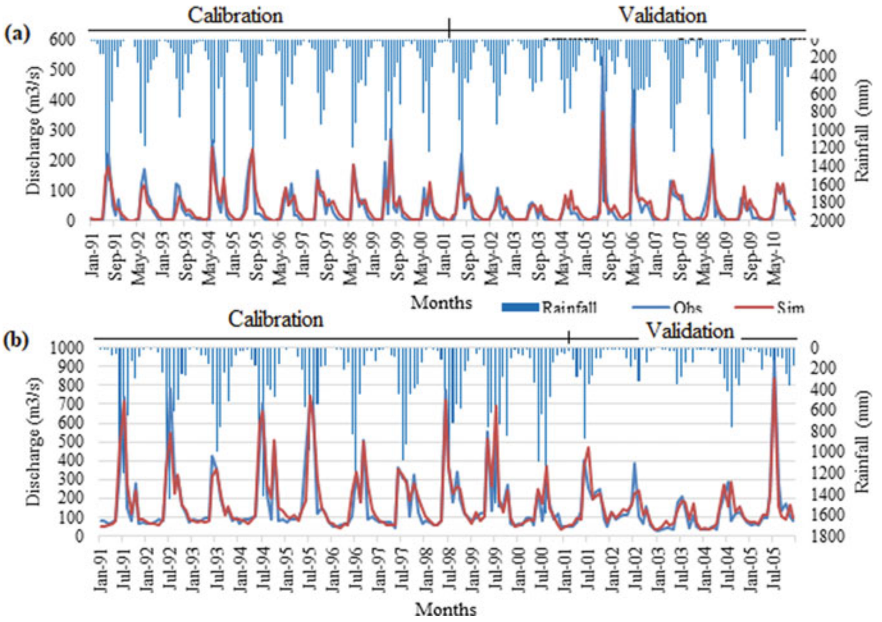


Fig. 5 Comparison of monthly streamflow value between the observed and calculated for the calibration and validation **a** Kalambur, **b** Ramamangalam

Table 4 Calibration and validation—Hydrologic model performance criteria

Gauging Site	Calibration (1991–2000)			Validation (2001–2005)		
	R^2	NSE	PBIAS	R^2	NSE	PBIAS
Kalambur	0.87	0.86	−9.0	0.90	0.89	−8.7
Ramamangalam	0.89	0.85	−2.4	0.81	0.75	−10.5

GCMs ensemble outputs (RCP 4.5 and 8.5), and the simulation results obtained are compared with baseline period (1986 to 2015) simulation results. In this study, the model simulation results obtained are referred to as Q_{clim}. In the next section, the results are presented using ensembled data of all 5 GCMs.

4.4 Ensemble of All Five GCMs Analysis

Figure 6 shows the mean precipitation of all five GCMs and ensembled for RCP 4.5 and 8.5 for near, mid, and far future. These indicated rainfall will be more in north part areas and less in the south part areas and sub-basins. The rainfall varies between mostly 1400–4500 mm among the sub-basins level in the MRB but showed a slightly decrease in comparison to historical rainfall. Using the projected rainfall and climate

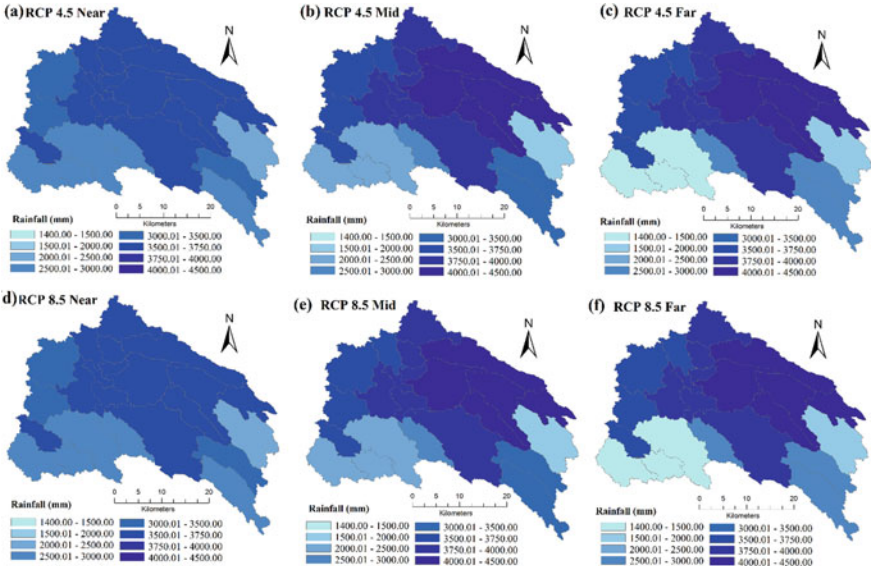


Fig. 6 Spatial distributions of precipitation for near, mid, and far future time slices of RCP 4.5 and 8.5 emission scenarios

parameters such as temperature, wind, solar radiation, etc., SWAT model has run for various scenarios, and results are presented here.

Figure 7 shows the variation of evapotranspiration (ET) for each sub-basin for the considered near, mid, and far future for both RCP 4.5 and 8.5 at sub-basin scale. The ET is mostly depending upon the precipitation, temperature, and land use variations of the study area. In MRB, ET is more in north side areas and less in south side because of high precipitation and more plantation and agriculture in respective regions. Figure 7 shows slight variations in ET among different time slices as well as RCPs scenarios because of variations in rainfall and temperature.

Figure 8 shows the simulated mean surface runoff of each sub-basins for all different time slices and scenarios. Figure 9 shows the simulated time series of runoff at the watershed outlet for various scenarios. Figure 10 gives the time series intercomparison of runoff at the watershed outlet for RCP 8.5 and 4.5 scenarios for near, mid, and far future continuously.

The simulated Q_{clim} (change in surface runoff) for the future period under both scenarios (RCP 4.5 and 8.5) were compared to the corresponding values of all sub-basins from the baseline period (1986 to 2015), as given in Fig. 11. It can be observed that change in annual Q_{clim} for all the time slices is moderate to highly significant for the future periods to RCP 4.5 and 8.5 CC scenarios. In general, Q_{clim} was predicted to decrease in sub-basins more toward the main stream. In particular, the Q_{clim} decreased from the baseline period by 8.33%, 6.5%, and 11.24% in RCP 4.5 and 11.7%, 8.72%, and 17.33% for RCP 8.5 from T1, T2, and T3 period, respectively.

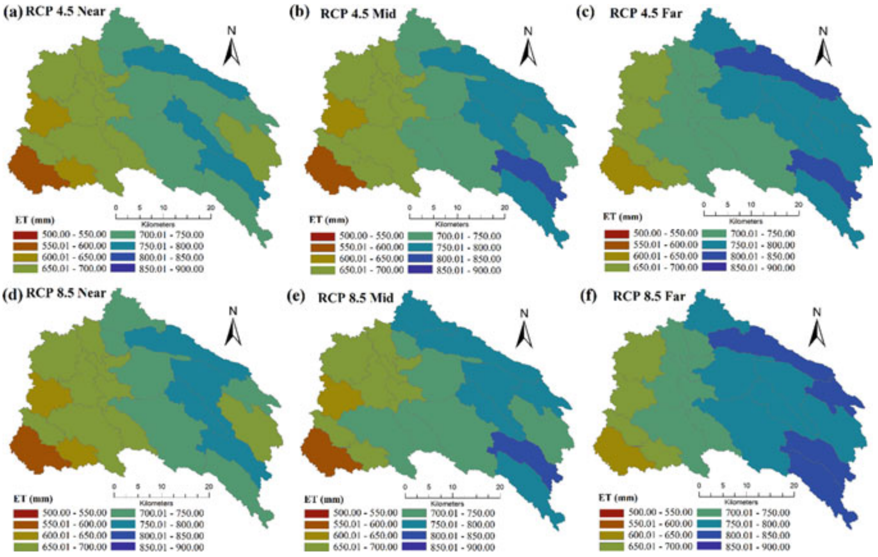


Fig. 7 Spatial distributions of actual ET for near, mid, and far future of RCP 4.5 and RCP 8.5 emission scenarios

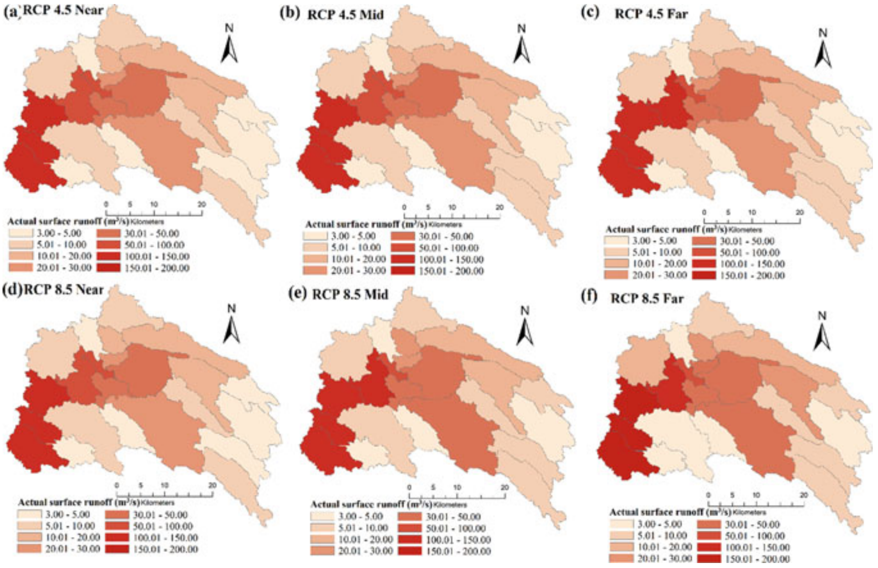


Fig. 8 Spatial distribution of surface runoff (m^3/s) for near, mid, and far future of RCP 4.5 and RCP 8.5 emission scenarios

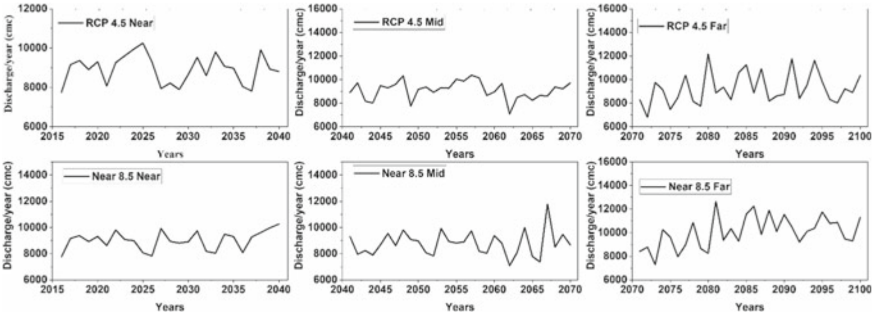


Fig. 9 Simulated time series of runoff at the watershed outlet for various scenarios-(i) RCP4.5-near; (ii) RCP4.5-mid; (iii) RCP4.5-far; (iv) RCP8.5-near; (v) RCP8.5-mid; (vi) RCP8.5-far

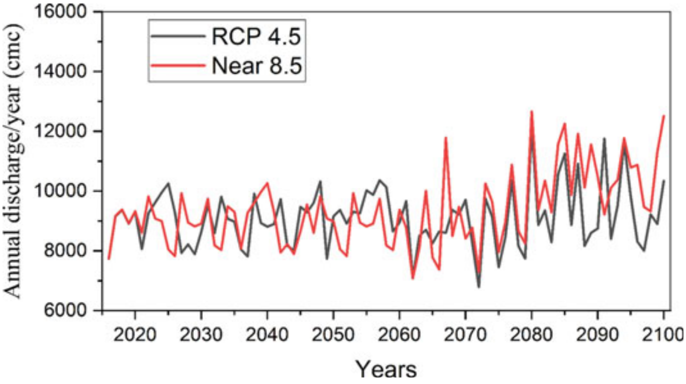


Fig. 10 Comparison of simulated time series of runoff at the watershed outlet for various scenarios of RCP 4.5 and RCP 8.5 for 2010–2100

The result shows more urbanization in downstream showing less rainfall in the future and affecting surface runoff. In most of the cases considered, change in Q_{clim} for all the time slices of near, mid, and far future are found to be moderate to highly significant indicating possible impacts of CC on the hydrologic response of the catchment. The monthly, seasonal, and annual changes in streamflow for the future periods are shown in Fig. 12 according to RCP 4.5 and 8.5 CC scenarios. It is observed that streamflow was predicted to decrease in the wet season (June to September) and increase in the dry season (October to May), though there were some variations between various scenarios and among the future periods.

In particular, the maximum streamflow increased by 2.45–65.30% under RCP 4.5, and 288.29% under RCP 8.5 in April. Meanwhile, the streamflow decreases in monsoon months mostly June and July approximately 40–48% under both RCP 4.5 and 8.5. Because of the higher unexpected precipitation during the summer rain and early monsoon period (March–May), it is important to forecast seasonal changes in water resources within the catchment associated with future CC. The impacts

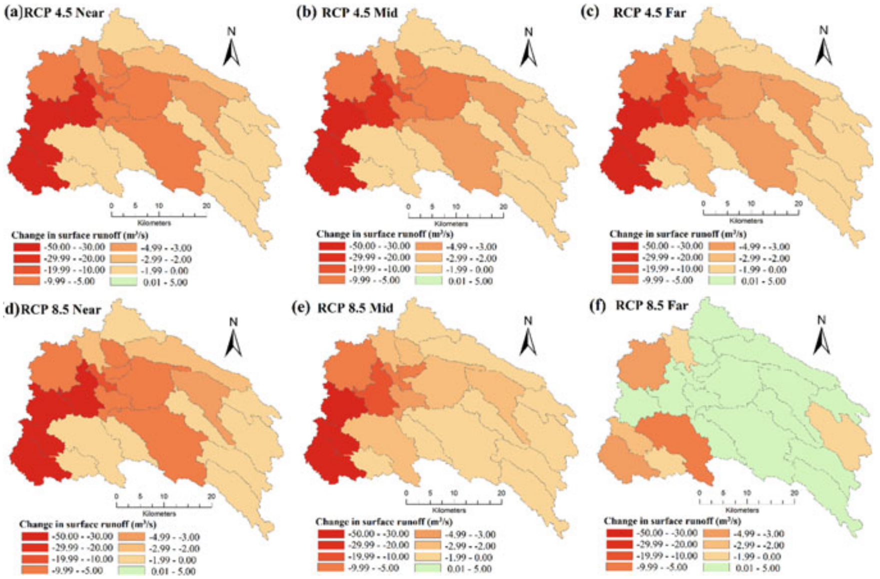
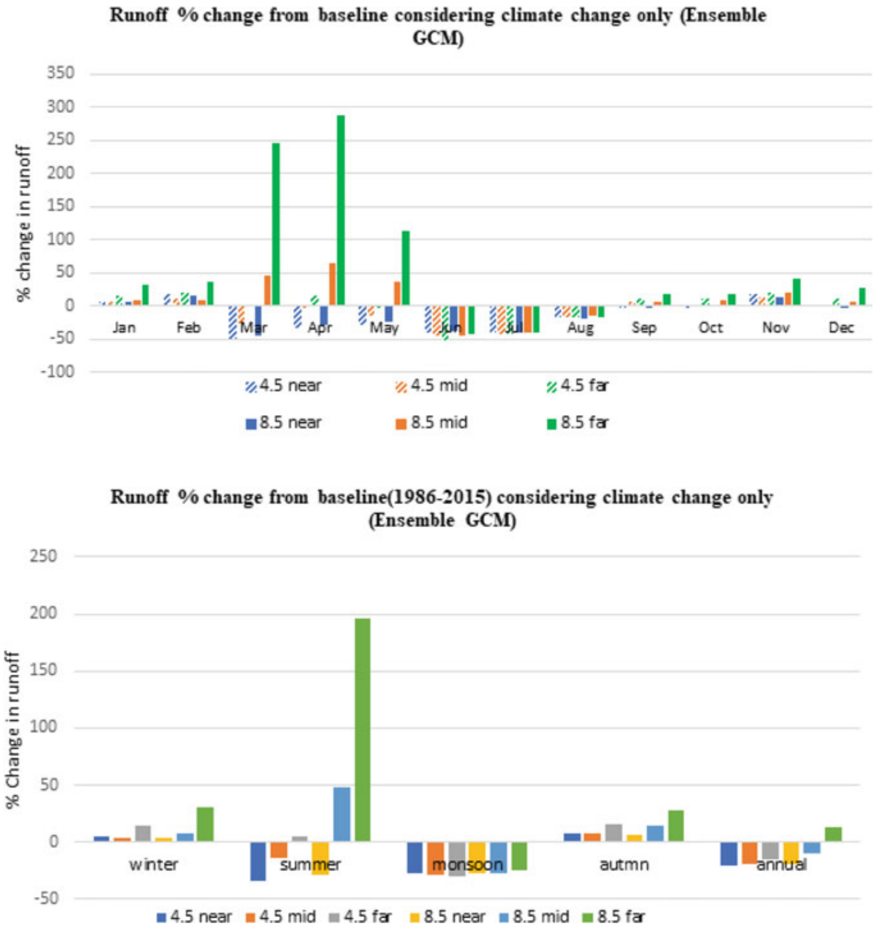


Fig. 11 For MRB, the spatial distribution of changes in the future surface runoff for the three different scenarios of CC between 2011 and 2099 for RCP 4.5 and RCP 8.5. **a** RCP4.5 (2011–2040); **b** RCP4.5 (2041–2070); **c** RCP4.5 (2071–2099); **d** RCP8.5 (2011–2040); **e** RCP8.5 (2041–2070); **f** RCP8.5 (2071–2099) in the MRB

of distinct climate change are more visible in the seasonal streamflow than does the monthly streamflow. The general pattern indicated an increase in winter and summer flow and a decrease in monsoon flow (but not all months) though there were some variations among the RCP 4.5 and 8.5 scenarios. The streamflow in winter and summer increased by 4.46–7.76% and 34.13–47.96%, respectively, under RCP 4.5 and by 4.0–30.16%, and −13.21–195.66%, under RCP 8.5.


Runoff % change from baseline considering climate change only (Ensemble GCM)

Runoff % change from baseline(1986-2015) considering climate change only (Ensemble GCM)

Fig. 12 Quantification in changes in streamflow for the three-time periods (near, mid, and future) relative to the baseline period. **a** Mean monthly streamflow changes. **b** Mean seasonal and annual streamflow changes in the MRB

5 Conclusions

In this study, a methodological framework for climate change (CC) impact assessment on a river basin scale is presented and used for assessment of the impacts of CC on streamflow in the Muvattupuzha river basin, in Kerala, India. The different climate scenarios for RCP 4.5 and RCP 8.5 till 2100 were used in the study. The SWAT model has been used in the hydrological modeling. Ensembled rainfall for near, mid, and far future showed a decrease due to CC by 6.05%, 5.90%, and 4.52% for RCP 4.5 and 7.32%, 6.52%, and 5.72% for RCP 8.5 emission scenarios, in comparison to the baseline. Ensemble of surface runoff show decreasing trend from the baseline period by 8.33%, 6.5%, and 11.24% in RCP 4.5 and 11.7%, 8.72%, and 17.33% for RCP 8.5 from T1, T2, and T3 period, respectively. For monthly and seasonally, the results indicated that the monthly streamflow decreased mainly in monsoon months like June, July, and August, and other remaining months showing increasing in streamflow under both RCP 4.5 and 8.5 emission scenarios.

For the considered river basin, the water resources planning for the long term must be adjustable and resilient to the changing pattern of CC impacts. Furthermore, both planners and policymakers should develop a land use strategy for reducing the adverse impacts of LULC changes in the river basin considered. The present study will be useful for long-term climate change impacts assessment and long-term water resources planning of the concerned basin and the same methodology can be extended to other river basins.

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