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# Climate Change Impact Assessment on Stream flow of Ganjal River, India

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**ABSTRACT**

Hydrological models often predict a changing situation, necessitating further research into models to make water resource management more realistic. This study uses soil and water assessment tool (SWAT) model to analyse the possible effect of climate change on the future streamflow of the Ganjal river watershed. It is located in middle sub-basin of the Narmada River, India. The model was calibrated for 1988-2007 and validated for 2008-2015 using monthly discharge data at the watershed outlet. The calibrated model was then run for the future (2025-52) using climate model output. The study of climate change is completed using the Representative Concentration Pathway scenarios, RCP 4.5 and 8.5 of three different General Circulation Models (GCM). The downscaled output of these GCM from the Coordinated Regional Downscaling Experiment (CORDEX) has been used in this study after bias correction. The findings demonstrate the significance of climate change's effect on streamflow.

***Keywords:*** *Climate change, CORDEX, RCP, Streamflow, SWAT model*

## Introduction

Due to anthropogenic activities, major shifts in the Earth's climate parameters are expected. Climate Models lead to a better understanding and predictability of future climate activity. The key meteorological parameters that impact the hydrology of a watershed are precipitation, maximum and minimum temperatures. Climate change effect evaluation of watersheds is therefore required, as many processes in the watershed have an impact on water conservation and farming practices.

One of the most appropriate methods to examine the potential climate change variation of the Earth's atmosphere on a large and regional scale is the application of the General and Regional circulation model (GCM and RCM) (Taylor *et al.*, 2012). In hydrological research, RCP 4.5 and 8.5 scenarios have been commonly used (Jayanthi and Keesara, 2019; Pandey *et al.*, 2019) To understand potential hydrological elements, these scenarios are very important. RCM enhances the model simulation compared to GCM for regional studies (Frei *et al.*, 2003) as GCM fails to model dynamics of local sub-grid operations (Salvi *et al.*, 2013). Furthermore, RCM often shows significant biases in simulated rainfall and temperature data, so they need to be corrected for bias before using them in a hydrological model (Teutschbein and Seibert, 2012).

SWAT has been extensively used for hydrological models to study climate change impact on water resources (Aawar and Khare, 2020; Anand and Oinam, 2019; Githui *et al.*, 2009; Reddy *et al.*, 2018). However, there are only a few studies available that reflect IITM-RegCM4 RCM for the effect of climate change on watersheds (Singh and Saravanan, 2020).

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In India, it is estimated that except the Godavari, major basins, including Narmada, would face water scarcity by 2050 (Mujumdar, 2008). However, to estimate it study at subbasins levels are necessary. Singh and Saravanan (2020) used RegCM4 CSIRO MK3.6.0 to study climate change impact on Wunna, Bharathphuza and Mahanadi watersheds. They found out Wunna watershed will face water availability issues in the future out of the three. Saraf and Regulwar (2018) used CGCM3 and HadCM3 climate models and found out that future runoff increases in the upper Narmada basin. Jayanthi and Keesara (2019) uses four GCM data (ACCESS 1.0, CNRM-CM5, CCSM4, MPI-ESM-LR) downscaled by CCAM RCM to study climate impact on the Phakal watershed in the Telangana district. They estimated a decrease as high as 57% in future streamflow.

The current study aims to assess climate change impact on streamflow and major water balance component (Precipitation, surface runoff, evapotranspiration, water yield) to learn more about streamflow variability, using CORDEX climate data in the SWAT model of Ganjal watershed located in the middle Narmada River subbasin.

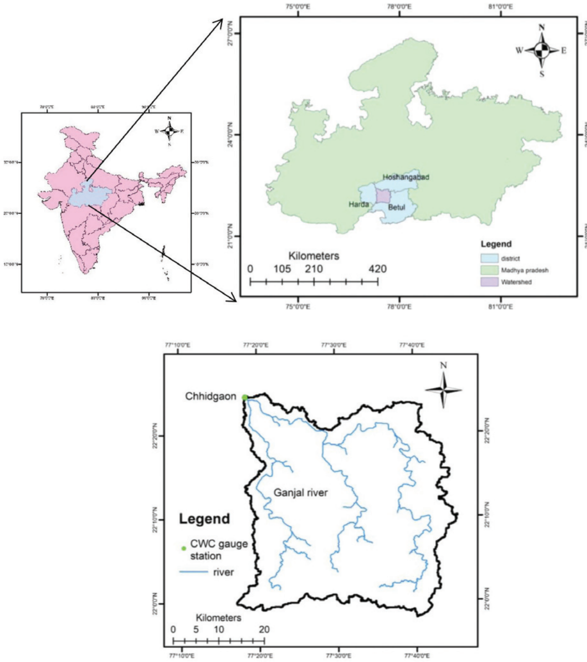



**Fig. 1.** Location of Ganjal river

## Materials and methods

### Study area

The Ganjal river is located in the middle sub-basin of the Narmada River. It originates in the Satpura range in the Betul district of Madhya Pradesh, India. It is joined by Morand river, in Hoshangabad district. The Central Water Commission of India has a gauging station just downstream of the confluence point covering a drainage area of about 1729 km$^2$ approximately. This station was selected for watershed delineation. The watershed lies in the district of Harda, Hoshangabad and Betul in Madhya Pradesh (21°502– 22°252N and 77° 15′ –77°452E) (Fig. 1). Tropic of cancer passes through Narmada basin and Ganjal river lies south of this line. Narmada basin has a hydrological system that is quite complex. Only few studies have been done on streamflow for river in its subbasins.

### SWAT Model

SWAT is a semi distributed, watershed scale hydrological model. Based on the river network and topography, it works on separating the basin into subbasins. These are consequently grouped into hydrological response units (HRUs) with homogenous surface, slope and land use characteristics. The model can simulate different hydrological processes, including projected hydroclimate variations, considering future climate forecasts (Neitsch *et al.,* 2011). Details of SWAT model can be obtained from document of SWAT 2012 (https://swat.tamu.edu/).

For this study, the Soil conservation service - curve number (SCS-CN) is used in hydrological model for measuring surface runoff. It is one of the most effective methods for estimating runoff from daily rainfall data(Aawar and Khare, 2020; Ghoraba, 2015; Setegn *et al.,* 2008)

In this study, Penman-Monteith procedure is used to estimate potential evapotranspiration (PET) (Allen, 1986).

### Input Data

For analysis, SWAT hydrological model requires physiographical data input like land use land cover data, digital elevation model, weather data and soil data. The ORNL DAAC (https://daac.ornl.gov) database has been used to obtain LULC of the study region and reclassified in SWAT format (Roy *et al.,* 2016). It consists of major LULC classes of Forest, Agriculture, grassland, barren land and water (Figure. 2 (a)). Digital elevation model (DEM*)* is raster data containing elevation data at a point in a given region. In this study, ASTER (https://search.earthdata.nasa.gov/search) 30 x 30 m DEM was processed to delineate watershed boundary (Fig. e 2 (b)). The food and agricultural organisation (FAO) soil database has been used to obtain soils in the study area. The watershed mainly has two soil clayey loam and clay (Fig. 2 (c)). Clay loam contains 37% clay, 28% Silt and 34% sand, whereas clay texture soil has 57% clay, 25% silt and 18% sand.

Weather details like daily rainfall, maximum and minimum temperature were downloaded from the Indian Meteorological Department (IMD) for 30 years (1985–2015) and utilised in the hydrological

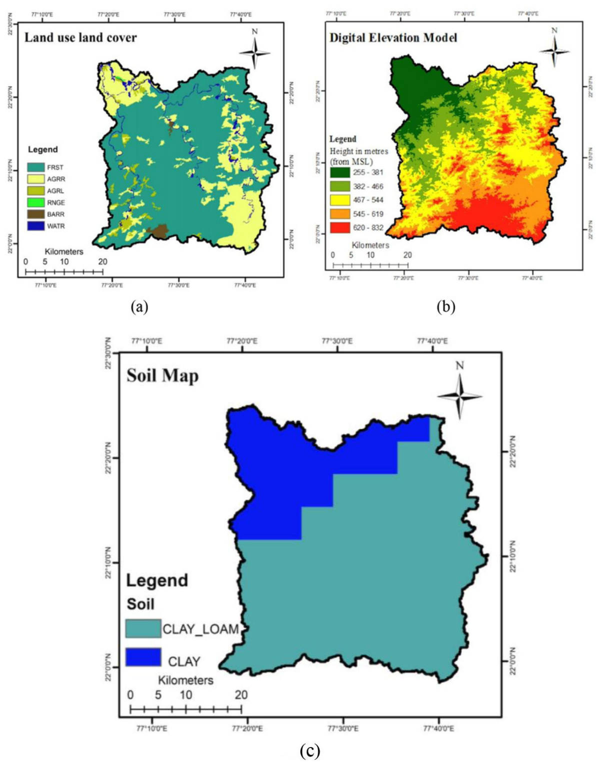



**Fig. 2.** Ganjal watershed map of (a) LULC (b) DEM (c) Soil

model. IMD provides free gridded data in the size of 0.25°×0.25° for precipitation and 1°× 1° for temperature for India.

River discharge data is required to conduct calibration and validation of model. River flow data of Chhidgaon station (1988-2015) were obtained from India-WRIS (https://indiawris.gov.in/). Data was portioned into calibration (1988-2007) and validation period (2008-2015).

### CORDEX data

In general, several CMIP5 models output is used to address future climate issues in the context of global climate change. CORDEX downscaled climate data were obtained from Centre for Climate Change Research - Indian Institute of Tropical Meteorology, Pune (CCCR-IITM). The resolution of CORDEX data is 0.44° × 0. 44°. In this study, GCM downscaled on IITM-RegCM4 RCM has been used (Giorgi *et al.*, 2012). RegCM4 performs admirably in the Indian subcontinent (Dubey *et al.*, 2020; Mall *et al.*, 2018; Singh and Saravanan, 2020). It can simulate the current climate throughout the study region (Gao and Giorgi, 2017). In this study, IITM-RegCM4 (CCCMA-CanESM2), IITM-RegCM4 (NOAA-GFDL-ESM2), IITM–RegCM4 (CNRM-CM5) has been used, which are especially downscaled for the Asian region by IITM (Table 1).

### SWAT model setup

This study uses ArcSWAT 2012 graphical user interface to set up SWAT hydrological model. ASTER DEM was used to delineate the watershed. In SWAT, each watershed is divided into HRU and each of them is a unique combination of land use, slope and soil (Neitsch *et al.*, 2011). In Ganjal watershed total of 29 HRU were generated based on land use, soil and slope definition. IMD provides only daily rainfall and temperature data. So other data (solar radiation, relative humidity, wind speed) re-

**Table 1**. Climate model used for the study

| RCM | Driving GCM | GCM modelling organisation |
|---|---|---|
| IITM-RegCM4 | CanESM2 | Canadian Centre for Climate Modelling and Analysis (CCCma), Canada |
| | GFDL-ESM2M | National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), USA |
| | CNRM-CM5 | Centre National de Recherches Me´te´orologiques (CNRM), France |

quired for model were generated using SWAT weather generator. Output file provides streamflow a daily, monthly and yearly basis. Simulated streamflow at monthly time step is used to calibrate the model as monthly timestep is most accurate for calibration in the SWAT model (Srinivasan *et al.*, 2010). After calibration, monthly fitted parameters were written in Arc SWAT model. This calibrated model was then run with future climate data for studying future climate impact on streamflow. The methodology adopted is shown in Fig. 3.

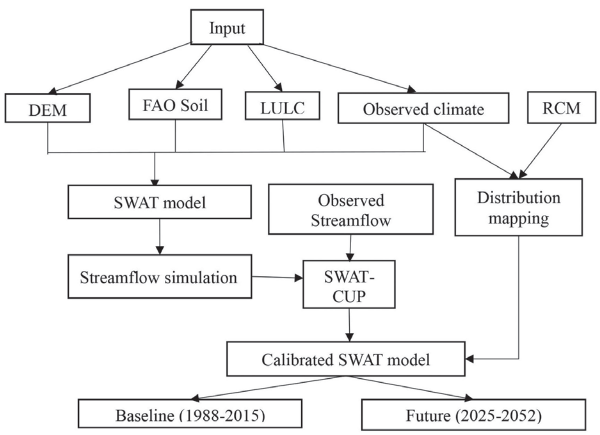



**Fig. 3.** Methodology followed in study

## SWAT calibration, validation and uncertainty analysis

The SWAT model calibration, validation and sensitivity analysis were performed in SWAT- CUP, open-source software using the SUFI-2 algorithm (Abbaspour *et al.*, 2004). To perform calibration, first sensitive parameters were identified using a built-in global sensitive analysis tool (Table 3). Subsequently, 14 parameters were determined, listed in Table 2. Higher absolute value of t-test means high sensitivity and lower p-value is more significant. CN2 (SCS Curve number), SOL_K (Saturated hydraulic conductivity) GW_DELAY (groundwater delay) and CH_N2 (Manning's n) are most sensitive parameter among 14 selected parameter (Table 3). In SUFI-2 algorithm, parameter uncertainty accounts for all uncertainties (conceptual model, input, etc.) (Abbaspour *et al.*, 2004).

**Table 2.** Sensitive parameter and their fitted value

| Sr. No. | Sensitive parameter | Fitted parameter | Minimum value | Maximum value |
|---|---|---|---|---|
| 1 | R__CN2.mgt | 0.068 | -0.2 | 0.20 |
| 2 | V__ALPHA_BF.gw | 0.847 | 0.00 | 1.00 |
| 3 | V__GW_DELAY.gw | 48.89 | 30.00 | 450 |
| 4 | V__GWQMN.gw | 0.458 | 0.00 | 2.00 |
| 5 | V__ESCO.bsn | 0.448 | 0.10 | 1.00 |
| 6 | V__EPCO.bsn | 0.261 | 0.10 | 0.70 |
| 7 | R__GW_REVAP.gw | 0.183 | 0.02 | 0.20 |
| 8 | V__REVAPMN.gw | 108.5 | 0.00 | 500 |
| 9 | R__SOL_K(..).sol | -0.283 | -0.80 | 0.80 |
| 10 | V__OV_N.hru | 0.130 | 0.01 | 0.20 |
| 11 | R__SOL_AWC(..).sol | 0.728 | 0.10 | 0.80 |
| 12 | V__CANMX.hru | 66.5 | 20 | 80 |
| 13 | V__CH_N2.rte | 0.379 | 0.01 | 0.40 |
| 14 | R__HRU_SLP.hru | -0.181 | -0.5 | 1.00 |

## Bias correction and climate model selection

**Table 3.** Ranking of sensitive parameter on basis of sensitivity analysis

| Rank | Sensitive parameter | t-stat | p-value |
|---|---|---|---|
| 1 | R_CN2.mgt | 10.45 | 0.00 |
| 2 | R__SOL_K(..).sol | -6.23 | 0.00 |
| 3 | V__GW_DELAY.gw | -5.87 | 0.00 |
| 4 | V__CH_N2.rte | 3.89 | 0.00 |
| 5 | V__ALPHA_BF.gw | 2.59 | 0.01 |
| 6 | V__OV_N.hru | 1.5 | 0.133 |
| 7 | V__GWQMN.gw | -1.27 | 0.202 |
| 8 | V__ESCO.bsn | 1.17 | 0.243 |
| 9 | R__HRU_SLP.hru | 1.04 | 0.298 |
| 10 | V__CANMX.hru | 0.82 | 0.414 |
| 11 | V__EPCO.bsn | -0.65 | 0.515 |
| 12 | R__GW_REVAP.gw | -0.48 | 0.628 |
| 13 | R__SOL_AWC(..).sol | 0.29 | 0.766 |
| 14 | V__REVAPMN.gw | 0.28 | 0.778 |

Temperature and precipitation simulations from climate models often exhibit significant biases due to systemic model errors, limiting the usage of data as direct input for hydrological models. On a daily time step, bias correction procedures are used to reduce the difference between observable and simulated climate variables (Teutschbein and Seibert, 2012).

In this study, CMhyd (Climate Model data for hydrologic modeling) tool was used to bias correct RCM data (Rathjens *et al.,* 2016). This tool has different methods embedded in it to perform bias correction. Among them, distribution mapping is found better in studies as compared to other methods for removing biases for both temperature and precipitation (Teutschbein and Seibert, 2012). Moreover, distribution mapping has performed well in different studies (Jayanthi and Keesara, 2019; Pandey *et al.,* 2019; Tarekegn *et al.,* 2021)

The basic idea behind distribution mapping is to create a transform function to conform the distribution function of RCM data to the observed distribution function of observed data (Nauman *et al.,* 2019; Teutschbein and Seibert, 2012). In this study, thirty-year simulated historical data of climate model (1975-2005) was overlapped with IMD observed data of the same period for evaluating biases and creating transform function. CMhyd tool performs this task and applies the same transform function to correct historical and future simulations of RCM. For evaluating bias-corrected model performance NSE and $R^2$ have been used. IITM-Regcm4 RCM has data available for six GCM and two scenarios, RCP4.5 and RCP8.5. All six models were evaluated for the study region. In this study, top three climate models among six, representing study area were chosen for future simulation in SWAT. This method of climate model selection based on best performing model for observed data of temperature and precipitation conforms to other studies (Nauman *et al.,* 2019; Pandey *et al.,* 2019). Finally, NOAA-GFDL-ESM2, CNRM-CM5 and CCCma-CanESM2 having the highest $R^2$ and NSE with observed temperature and precipitation for the historical period were selected to run SWAT model in future (Table 4). The $R^2$ and NSE for maximum temperature ranges from 0.86 to 0.9 and 0.86 to 0.89. For minimum temperature $R^2$ ranges from 0.93 to 0.94 and NSE from 0.93 to 0.94. It shows monthly maximum and minimum temperature has very good correlation with IMD data for all six-climate models. However, the precipitation does not correlate that well. It varies from 0.41 to 0.61 for $R^2$ and NSE from 0.30 to 0.53. Out of three selected models, the performance of NOAA-GFDL-ESM2 and CNRM-CM5 is satisfactory for precipitation and for CCCma-CanESM2 is low as compared to these two. Previous studies also show that regardless of GCM/RCM selection, most of the models fail to capture the observed trend of precipitation for the historical period (Moriasi *et al.,* 2007; Reddy *et al.,* 2018).

## Results

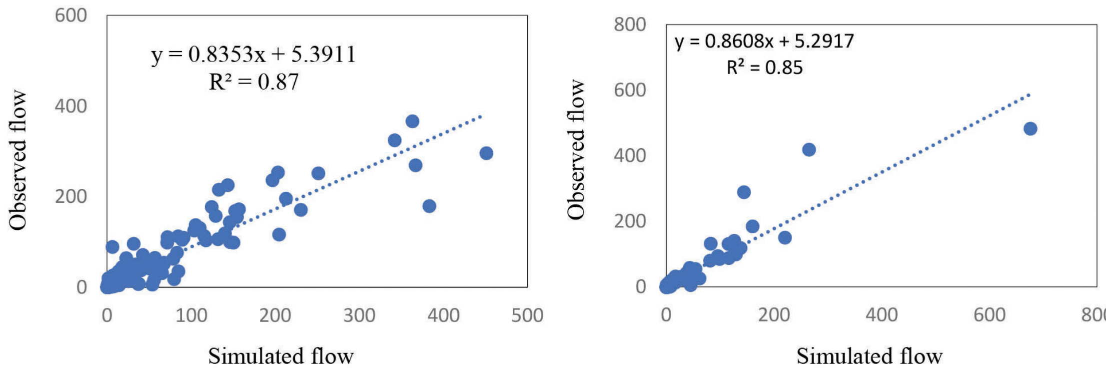
### Calibration and validation results

The SWAT model calibration was performed on a monthly basis in SWAT - CUP. Chhidgaon station of Ganjal watershed has continuous discharge data available till 2015. So the whole period was divided into calibration (1988-2007) and validation period (2008-2015). An initial model was set up from 1985 to 2015. The first three years (1985-1987) were considered as a warm-up year.

During calibration (1988-2007) $R^2$ value for streamflow is 0.87 and NSE is 0.87. For validation (2008-2015) $R^2$ and NSE obtained are 0.85 each

**Table 4**. Performance evaluation of climate model data on comparing with observed data for the historical period (1975-2005)

| Climate model | Maximum Temperature | | Minimum Temperature | | Precipitation | |
|---|---|---|---|---|---|---|
| | $R^2$ | NSE | $R^2$ | NSE | $R^2$ | NSE |
| CCCma-CanESM2 | 0.87 | 0.86 | 0.93 | 0.93 | 0.52 | 0.45 |
| NOAA-GFDL-ESM2 | 0.87 | 0.87 | 0.93 | 0.93 | 0.61 | 0.52 |
| CNRM-CM5 | 0.90 | 0.89 | 0.94 | 0.94 | 0.60 | 0.53 |
| MPI-ESM-MR | 0.86 | 0.86 | 0.93 | 0.93 | 0.47 | 0.38 |
| IPSL-CM5A-LR | 0.87 | 0.88 | 0.93 | 0.93 | 0.45 | 0.32 |
| CSIRO-Mk3.6 | 0.87 | 0.86 | 0.94 | 0.94 | 0.41 | 0.30 |




(a) Calibration (b) Validation

**Fig. 4.** Correlation between monthly observed and simulated streamflow of Ganjal river in (a) calibration (1988-2007) and (b) validation (2008-2015)

(Table 5). This shows very good performance of the SWAT model (D. N. Moriasi *et al.,* 2007). Thus, calibrated model can be used for future climate change impact studies.

**Table 5.** Evaluation of SWAT model performance

| Station | Calibration | | Validation | |
|---|---|---|---|---|
| | $R^2$ | NSE | $R^2$ | NSE |
| Chhidgaon | 0.87 | 0.87 | 0.85 | 0.85 |

## Projected change in precipitation and temperature

Ganjal river receives rainfall only in summer monsoon (June to Sept) (Figure 6), which is also the case for other watersheds in the Narmada basin. Changes in the future period (2025-2052) rainfall and temperature were calculated relative to baseline (1988-2015) data. Analysis indicates a decrement in average annual rainfall of watershed in both RCP scenarios for all climate models (Figure 6). The decrease in rainfall is more significant in RCP 4.5 than 8.5. The percent change in average annual rainfall is shown in figure 6 for both RCP scenarios. Under

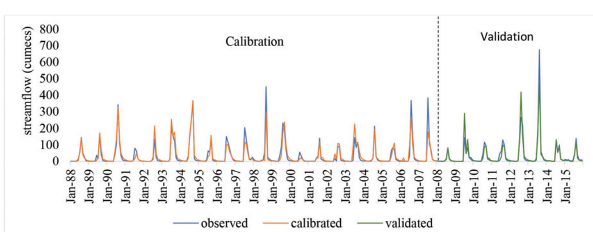



**Fig. 5.** Graphical representation of observed streamflow with SWAT simulated streamflow for calibration (1988-2007) and validation (2008-2015) period

RCP 4.5 scenario, NOAA-GFDL-ESM2 shows highest decrement of 63.92%, followed by CCCMA-CanESM2 (48.49%) and CNRM - CM5 (27.76%). In RCP 8.5 scenario, decrement ranges from 22.67% to 44.52%. CCCMA-CanESM2 shows highest decrement of 44.52%, followed by NOAA-GFDL-ESM2 (32.79%) and CNRM-CM5 (22.67%).

NOAA-GFDL-ESM2 in RCP 8.5 scenario shows a significant increase in precipitation for summer (Jan to May) and winter months (Oct to Dec) compared to other models and baseline data Fig. 6(d). In summer, the precipitation increased by 75% and 52% in winter compared to the baseline.

The average annual temperature for both scenarios shows an increment in future across all models. In their annual cycle, both maximum and minimum temperatures have two maxima. In maximum temperature, first peak was observed in the month of May where the temperature reaches around 40 °C, before arrival of monsoon and the secondary peak is observed in October, after monsoon has passed. Under RCP 4.5, highest increase in maximum temperature is predicted by NOAA-GFDL-ESM2 of +1.19 °C while under RCP 8.5 CCCMA-CanESM2 shows highest increase in maximum temperature of + 1.12 °C. CCCMA – CanESM2 and CNRM- CM5 shows + 0.8 °C and +0.67 oC increase under RCP 4.5. Under RCP 8.5 NOAA-GFDL-ESM2 and CNRM-CM5 shows increment of +1.11°C and +0.8 °C.

For minimum temperature both scenario shows increasing trend. RCP 8.5 shows more increment in minimum temperature than RCP4.5. For RCP 4.5 increase in minimum temperature ranges from +0.89 °C to +1.25 °C. CCMA-CanESM2, CNRM-

CM5 and NOAA-GFDL-ESM2 predict increment of +1.25 °C, + 0.89 °C and +1.18 °C Under RCP 8.5 increase in minimum temperature for CCCMA-CanESM2, CNRM – CM5 and NOAA-GFDL-ESM2 are +1.55 °C, + 1.01 °C and 1.35 °C.

### Impact on water balance component

The calibrated hydrological model was run for baseline period (1988-2015) with IMD observed data and then for future period (2025-52) using climate model data to analyse how streamflow is impacted by climate variables. The average annual values of different water balance components (precipitation, surface runoff, water yield and evapotranspiration) of baseline and future period is shown in table 6. A wide range of rainfall is projected by climate models. All the models show a decrease in precipitation (PRECIP) for future period (Table 6).

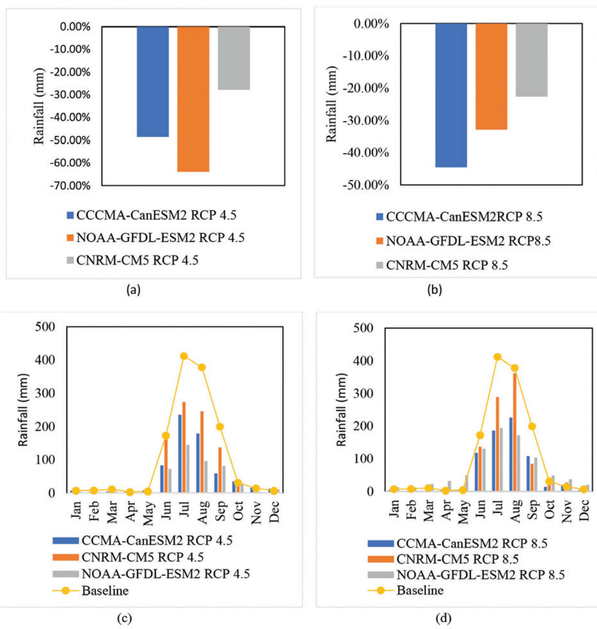



**Fig. 6(a).** Average annual rainfall comparison with baseline rainfall for Ganjal watershed for RCP 4.5 (b) Average annual rainfall comparison with baseline rainfall for Ganjal watershed for RCP 8.5 (c) Average monthly precipitation (2025-2052) comparison with baseline rainfall (1988-2015) for RCP 4.5 (d) Average monthly precipitation (2025-2052) comparison with baseline rainfall (1988-2015) for RCP 8.5

It has resulted in a decrease of surface runoff (SURQ) and water yield (WYLD) (table6). WYLD is the net amount of water contributing to streamflow (surface runoff + lateral flow + groundwater contribution to streamflow – transmission loss). It is one of the critical components that must be estimated in order to ensure the long-term management of the investigated area's water resources (Adeogun *et al.*, 2014).

For the baseline period, the watershed has annual

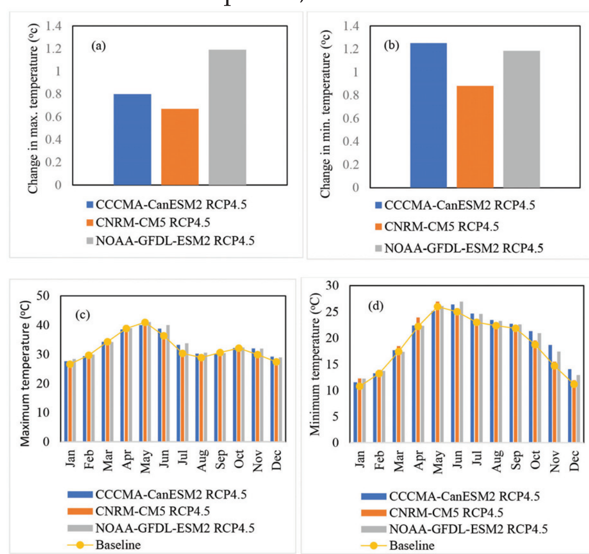



**Fig. 7(a).** Change in Average annual maximum temperature (b) change in Average annual minimum temperature (c) average monthly maximum temperature variation (d) Average monthly minimum temperature variation

**Table 6**. Average annual water balance component of Ganjal watershed

| Model | Scenario | PRECIP (mm/year) | SURQ (mm/year) | WYLD (mm/year) | E.T. (mm/year) |
|---|---|---|---|---|---|
| | Baseline | 1247.2 | 532.3 | 684.71 | 566 |
| CCCMA | RCP4.5 | 642.4 | 241.74 | 250.38 | 399.5 |
| | RCP 8.5 | 691.9 | 279.92 | 288.61 | 414.1 |
| NOAA | RCP4.5 | 450 | 182.7 | 186.13 | 275.2 |
| | RCP 8.5 | 838.2 | 153.4 | 188.04 | 653.7 |
| CNRM | RCP 4.5 | 901 | 320.92 | 341.76 | 567.5 |
| | RCP 8.5 | 964.5 | 388.67 | 420.44 | 551 |

average precipitation (PRECIP) of 1247.20 mm. The average monthly precipitation is shown in figure.6. Evapotranspiration (ET) is a significant cause of loss of water in watershed. SURQ remains the primary source of streamflow during baseline and for future period.

Under RCP 4.5, future and baseline period minimum ET was observed in May. In RCP 8.5 also all model except NOAA shows lowest ET in May. The peak of ET was observed in September month for the baseline period. For future scenarios it varies from July to September for different models. ET begins to build up in the basin when the temperature rises in March or April. As peak approaches in May month, the soil becomes too dry to do evaporation, thus all models ET output reach a minimum. Whereas under RCP8.5 NOAA-GFDL-ESM2 shows increase in rainfall in summer (Jan to May) and winter month (oct to dec) as compared to other model simulation. Thus, providing more water for ET. Average monthly rainfall analysis shows it receives the lowest rainfall in the month of Feb (12.05 mm/year), resulting in low water availability causing minimum ET in Feb.

SURQ and WYLD peak for baseline was observed in August month. They both follow similar trend as expected (Figure 10). As monsoon, arrive in June SURQ and WYLD start in June reaching their maximum value in August.

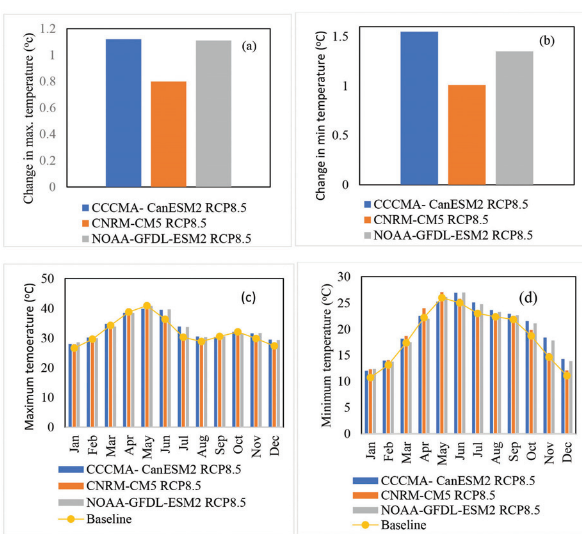



**Fig. 8**(a) Change in Average annual maximum temperature (b) change in Average annual minimum temperature (c) average monthly maximum temperature variation (d) Average monthly minimum temperature variation

Under RCP 4.5 NOAA-GFDL-ESM2 predicts the lowest precipitation. Thus, having low availability of water to contribute as streamflow. Under RCP 8.5 its precipitation increases significantly but it has an overall maximum ET of 653.7 mm/year resulting in low water for WYLD and SURQ. ET is dominating in this case resulting in almost no significant difference in WYLD between both scenarios. Thus, NOAA under both scenario shows the lowest value for Average annual SURQ and WYLD.

**Impact on streamflow**

The calibrated SWAT model was further used to estimate streamflow for a future period (2025-2052). Figure 10 shows the average monthly streamflow comparison of baseline (1988 – 2015) with the future period under each scenario RCP4.5 and RCP 8.5. As Ganjal watershed receives rainfall during the mon-

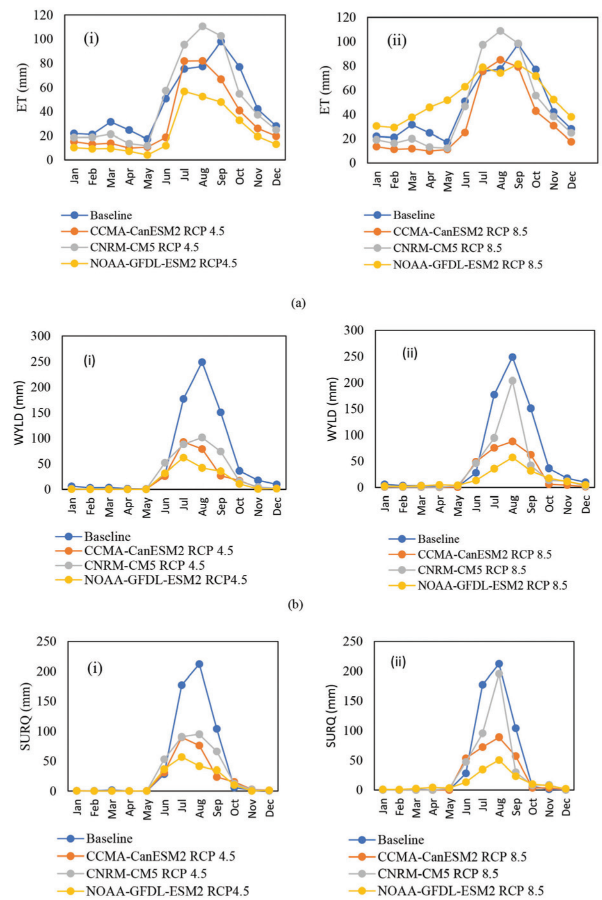



**Fig. 9.** Comparison of average monthly value of different water balance component (a) Evapotranspiration (ET) (b) water yield (WYLD) (c) surface runoff (SURQ) in both (i) RCP 4.5 and (ii) RCP 8.5

soon season (June to Sept), these months are major contributors to streamflow. The simulation of streamflow from all three models shows a reduction as compared to baseline. This decrease was reasonably expected as precipitation is decreasing in the study area for future scenarios.

CCCMA-CanESM2 shows a decrease of 64.4% in average annual streamflow for RCP 4.5 (Fig. 11). In comparison, RCP 8.5 shows a decrease of 59 % as compared to baseline. For RCP 4.5 the average monthly streamflow study shows a shift in the peak of streamflow from month of august to July with peak value of 58 $m^3/s$. For the baseline, peak was observed in August month having a value of 166 $m^3/s$. This shift of peak is due to significant increase in precipitation in July month (235.31 mm) than August (178.5 mm). As ET remains same during these months, for RCP 4.5 scenarios precipitation was dominating factor. In comparison, RCP 8.5 shows approx. peak of 53 $m^3/s$ in July and 51 $m^3/sec$ in August. Although under RCP 8.5 scenario, month of August receives more rainfall, ET was also maximum result in lowering august peak. For RCP 8.5, in September, streamflow remains more than the RCP 4.5 as more precipitation occur in month of September for RCP 8.5 scenario (109 mm) as compared to RCP 4.5 (59 mm) (Figure 6).

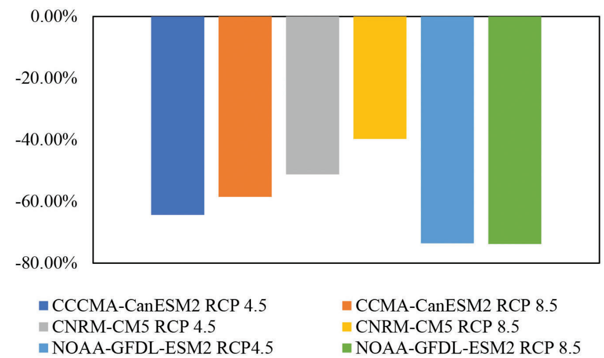



**Fig. 11.** Comparison of average annual streamflow with baseline streamflow

CNRM-CM5 shows a decrease of 51.2 % and 40% in average annual streamflow value in RCP4.5 and 8.5 (Fig. 12). In this case, for both RCP scenarios peak is observed in August same as baseline period. RCP 4.5 shows a peak value of 67.3 $m^3/sec$ and for RCP 8.5 peak value is 129 $m^3/sec$.

NOAA-GFDL-ESM2 shows a decrease of 74 % in average annual streamflow value under RCP4.5 and 8.5 scenarios (Figure 12). A shift of peak for streamflow was observed from August to July for

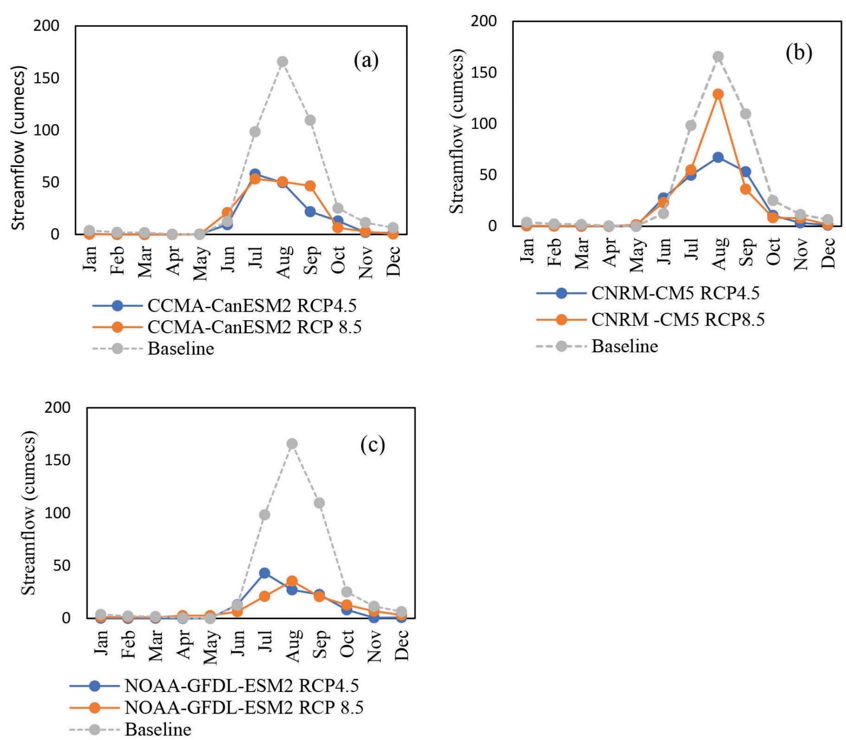



**Fig. 10.** Average monthly streamflow at outlet of Ganjal watershed for (a) CCCMA- CanESM2 (b) CNRM – CM5 (c) NOAA-GFDL-ESM2

RCP 4.5. This shift is due to more precipitation in July month (145 mm) than in august (95.6mm). The ET values of 56 mm in July and 53 mm in August show no significant difference, so rainfall remains critical. Under RCP4.5 july peak has value of 43 $m^3/s$ whereas for RCP 8.5 peak remains in August month with a value of 35.4$m^3$/sec.

## Discussions

The results show climate change in future is going to adversely impact SURQ, WYLD and hence streamflow. The baseline results of ET, SURQ and WYLD complement with previous study done for other watershed in Narmada river basin (Goswami and Kar, 2017). The decrease in future SURQ, WYLD and streamflow is due to decrease in rainfall predicted and increase in temperature. The shift in peaks of streamflow in future is due to change in rainfall pattern. The decreasing streamflow and precipitation is documented for other regions of India such as phakal lake in basin of Krishna river (Jayanthi and Keesara, 2019) and Brahmani river in odisha (Islam *et al.*, 2012). The identical seasonality of precipitation and streamflow indicates a water-limited system in which flow conditions are tightly connected to the precipitation regime, as is common in most water-limited systems (Pumo *et al.*, 2016).

Although this study tries to compensate various uncertainty in climate models and hydrological model, there are certain limitations. Future assessment of different water balance component and streamflow is done using LULC of year 2005. The result will be impacted by future irrigation schemes and other land use pattern changes in the study area.

## Conclusion

This research attempted to assess the plausible consequences of climate change on streamflow of Ganjal river. To achieve this goal SWAT model has been used. It was calibrated and validated for baseline (1988-2015) and then used to simulate future scenario (2025-2052). According to the findings, the SWAT model works well for Ganjal watershed located in the middle sub-basin of the Narmada River. The calibration and validation $R^2$ of 0.87, 0.85, and NSE values of 0.87 and 0.85 show a very good SWAT model performance.

**The main findings of this study are as follows:**

1. NOAA-GFDL-ESM2, CNRM-CM5 and CCMA-CanESM2 climate model perform better than other downscaled GCM under IITM-Regcm4 for Ganjal watershed region, located in middle subbasin of Narmada River.
2. The hydrology of the Narmada River basin is mostly determined by rainfall. Surface runoff and total water yield occur mainly in monsoon season (June to September). Surface runoff is major source of streamflow in Ganjal watershed.
3. In future, precipitation is going to decrease in Ganjal river watershed. As a result of which the basin is going to be stressed for water availability in future. Decrement in streamflow can be as higher as 74% as shown by NOAA-GFDL-ESM2 under both RCP scenarios. Under RCP 8.5 for NOAA-GFDL-ESM2, evapotranspiration become key factor resulting in large decrease of total water yield and hence streamflow.
4. In future, minimum and maximum temperature is going to increase across all scenario. Increase in minimum temperature is more than maximum temperature. RCP 8.5 increase in minimum temperature is more significant. The maximum temperature ranges from +0.8 °C to +1.2 °C. for RCP 4.5. Under RCP 8.5 it varies from +0.8 °C to +1.1 °C. For minimum temperature increment varies from +0.88 °C to +1.25 °C under RCP 4.5 whereas under RCP 8.5 it varies from +1 to +1.55 °C

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