Major Project Report On

"Climate change impact assessment on streamflow of Ganjal River using SWAT Model"

Submitted in partial fulfillment of the requirements

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submitted by

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DECLARATION

I, Adarsh Singh, Roll No. 2K19/ENE/07 student of M.Tech (Environmental Engineering), hereby declare that the project Dissertation titled “Climate change impact assessment on streamflow of Ganjal river using SWAT model ” which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of and Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

Place: **Delhi** **Adarsh Singh**

Date:31/07/21

CERTIFICATE

I hereby certify that the Project Dissertation titled “Climate change impact assessment on streamflow of Ganjal river using SWAT model” which is submitted by **Adarsh Singh**, 2K19/ENE/07, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place:

Date:

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The success of Major project requires help and contribution from numerous individuals and the organization. Writing the report of this project work gives me an opportunity to express my gratitude to everyone who has helped in shaping up the outcome of the project. I express my heartfelt gratitude to my project guide **Dr. Geeta Singh** for giving me an opportunity to do my Major project work under her guidance. Her constant support and encouragement have made me realize that it is the process of learning which weighs more than the end result.

Adarsh Singh

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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 the Soil Water Assessment Tool (SWAT) model to analyse the possible effect of climate change on the future streamflow of the Ganjal river watershed, a 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. Calibration and validation of the SWAT model were carried out in SWAT-CUP using the SUFI-2 algorithm. The coefficient of determination (R^2) and Nash Sutcliffe efficiency (NSE) were 0.87 in calibration, whereas in validation was 0.85 each. The outcome indicates that the simulated and observed flow have a good match. 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 RCP 4.5 and 8.5 scenarios from three different GCM. The downscaled output of these GCM from CORDEX has been used in this study after bias correction. The findings demonstrate the significance of climate change's effect on water resources, as it has a significant impact on streamflow.

Keywords: Climate change. CORDEX. RCP, SWAT model

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The survival of living things is dependent on water. It is a vital factor for economic development and growth of agriculture and industry, especially in view of the increasingly growing population and urbanization. Climate change and its instability can alter the region's hydrological cycle and hydrological regime and can have direct effect on region's water supplies. It is therefore important to examine the possible impacts of climate change on the availability of hydrology and water supplies. In order to resolve concerns related to water management, it is important to examine and measure the various elements of the hydrological processes taking place within the region of interest. Impact assessment is typically carried out through the development of a calibrated and validated watershed hydrological model and the prediction of potential stream flow for various scenarios of climate change.

The development of Remote Sensing techniques and Geographic Information System abilities has facilitated and enhanced the widespread use of watershed models worldwide. A watershed is comprised of land areas and channels and may have lakes, ponds or other water bodies. GIS is an appropriate method for the efficient management of broad and complex databases and for the digital representation of watershed characteristics used in hydrological modelling.

SWAT (Soil and water assessment tool) is one such model. It is a river basin scale model used to build large complex watersheds to measure the effect of land management practices. SWAT is a public domain enabled model that is actively funded by the USDA Agricultural Research Service at the Blackland Research & Extension Center in Temple, Texas, USA. Based on the river network and topography, it works on the principle of separating the basin into sub- basins, and then these are consequently grouped into hydrological Response units (HRUs) with special surface, slope and land use characteristics. The model is capable of simulating different different hydrological processes, including projected hydroclimate variations, taking into variations, taking into account future climate forecasts (Neitsch *et al.*, 2011).

1.1. SWAT Model

SWAT is one of the most commonly used simulation methods for the watersheds. It can forecast the impact of soil, land use and management on water and water quality. It is computationally efficient and uses readily- available inputs. The U.S. Department of Agriculture-Agricultural Research Service has developed the SWAT model (USDA-ARS). Based on the river network and topography, it works on separating the basin into sub-basins. These are consequently grouped into hydrological response units (HRUs) with special surface, slope and land use characteristics. The model can simulate different hydrological processes, including projected hydroclimate variations, taking into account future climate forecasts (Neitsch et al., 2011). The SWAT model is based on the water balance equation, shown in Eq.1

$$S_t = S_o + \sum_{k=0}^{k=1}(R_d - Q_{sur} - E - W_s - Q_g) \quad (1)$$

Where, S_t = final soil water content after t days in S_0 = initial soil water content in mm, R_d = amount of precipitation in mm on day k, Q_{sur} = amount of surface runoff on day k in mm, E = amount of evapotranspiration on day k, W_s= amount of water entering vadose zone in mm on day k, Q_g = amount of return flow in mm on day k.

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, shown in Eq.2. (Aawar & Khare, 2020; Ghoraba, 2015; Setegn et al., 2008; Sisay et al., 2017)

$$Q_s = \frac{(P_{day} - 0.2S_r)^2}{(P_{day} + 0.8S_r)} \quad (2)$$

Where Q_s is a daily surface runoff (mm), P_{day} is the depth of daily rainfall (mm) and S_r is retention parameter (Eq.3)

$$S_r = 25.4\left(\frac{1000}{CN} - 10\right) \quad (3)$$

Where C.N. is the curve number ranging from $0 \leq$ C N $\leq$100. In this study, Penman-Monteith procedure was used to estimate potential evapotranspiration (PET) (Allen, 1986).

1.2 Objectives of the Study

The primary objective of the thesis are:

- To build GIS inputs required by SWAT model
- To setup SWAT hydrological model of Ganjal river basin, a tributary of Narmada River.
- To calibrate and validate the model using SWAT – CUP
- To assess future climate change impact on streamflow and major water balance component (Precipitation, surface runoff, evapotranspiration, water yield) using CORDEX climate data in the SWAT model of Ganjal watershed.

CHAPTER 2

LITERATURE REVIEW

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. It is widely acknowledged that the cumulative effects of climate, land cover, and human activities result in changing runoff. 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 & 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 & Seibert, 2012). SWAT has been extensively used for hydrological models to study climate change impact on watershed in India and around the world. Some of the studies are shown below:

Anand & Oinam (2019):

They studied climate change impact on Manipur River basin by combining SWAT model and downscaled data of Hadley Centre Coupled Model (HadCM3) climate model. RCP 2.6,4.8 and

8.5 scenarios were used by them to evaluate effect of climate change on hydrological parameter. The SWAT model was set up for 1990 - 2017. They used bias corrected HadCM3 model output to enumerate the impact of changing climatic conditions on water resources and to quantify the uncertainties using three alternative future climatic scenarios for the 2050s and 2090s decades. They found maximum increase of annual precipitation of 70% during 2081 – 2100 with respect to baseline period (1990- 2017) for RCP 8.5. Increase for precipitation for 2090s decade is more than 2050s decade across all RCP scenarios. The annual average temperature rise was found to be more for 2090s than 2050s decade. The highest scenario RCP 8.5 saw an increase of +40.9 m^3/sec in discharge for time period 2081-2100, while the lowest scenario RCP 2.6 saw an increase of +3.90 m^3/sec in the time period 2046-2064. Water yield and PET under all the RCP scenarios increases for both 2050s and 2090s decades. Annual average runoff was 148.30 m^3/sec for baseline period. This found to be increasing across all RCP scenario for both period 1946-1964 and 1982-2100. Other hydrological parameter like potential evapotranspiration (PET), evapo-transpiration (ET) and water yield were also compared with baseline period. They found highest increase of +104.18 mm in PET for RCP 8.5 scenario for period 2081 – 2100. Highest ET increase of +308.67 mm was predicted for RCP 8.5 scenario for period 2046 – 2064 whereas maximum increase in water yield was predicted for RCP 8.5 scenario for 1981-2100.

Saraf & Regulwar (2018):

They used SWAT model to study climate change impact on runoff generation in upper Godavari River. They used statistical downscaled product of two GCM, Hadley Centre Coupled Model, Version 3 (HadCM3) and the Canadian Centre for Climate Modelling and Analysis's Coupled Global Climate Model, Version 3 (CGCM3) to study the impact. The sequential uncertainty fitting approach was used to calibrate the SWAT model. During calibration and validation, the Nash–Sutcliffe efficiency (NSE) and the determination coefficient (R^2) were employed to assess performance. During calibration, both NSE and R^2 were 0.63, and during validation, they were 0.71. The SWAT simulation results revealed that by the end of the twenty-first century, Scenarios A2 and A1B (CGCM3 model) will have increased runoff by 70 percent and 61 percent, respectively, and Scenarios A2 and B2 will have increased runoff by 47 percent and 36 percent (HadCM3 model).

Jayanti & Keesara (2019):

They studied climate change impact on Phakal watershed, situated in Krishna River basin, India. This catchment provide water to Phakal lake which is medium irrigation project in Telangana River. They used SWAT model with downscaled product of four climate models (ACCESS, CNRM, CCSM, MPI) from CORDEX repositories to study future impact on streamflow. The SWAT model was setup with baseline period 1985 – 2005.calibration and validation show good results with R^2 0.71 and 0.68 and NSE 0.66 and 0.65. These two statistical parameters were used to evaluate performance of SWAT model. SUFI-2 algorithm was used in SWAT – CUP to calibrate model. After calibration climate model data were given as input to predict impact on stream flow. Future period was divided into early century (2005-2040), midcentury (2005 -2040) and end century (2071-2099). SWAT model was run for both scenario RCP 4.5 and RCP8.5. The simulated streamflow showed decreasing trend in future on comparing to baseline. In early century CCSM predicted peak of 22 m^3/sec while other three model predicted peak of 8 m^3/sec for RCP 4.5. For early century and RCP4.5 scenario ACESS, CCSM, CNRM, MPI-ESM showed -30.3%, +16.8%, -40.4% and -30% change in streamflow when compared to baseline period. For mid-century all four model ACESS, CCSM, CNRM, MPI-ESM showed -19.9%, -4.2%, -21.5% and -17.2% change in streamflow when compared to baseline period. For end century ACESS shows +6.2% while CCSM, CNRM and MPI-ESM showed -3.1%, -19% and -16.9% as compared to baseline streamflow under RCP 4.5. Under RCP 8.5 scenario all climate model shows decrease in streamflow. For early century ACESS, CCSM, CNRM, MPI-ESM showed -40.1%, -50.5%, -38.9%, -36.1% change in streamflow. For mid-century scenario ACESS, CCSM, CNRM, MPI-ESM showed -30.1%, -40.1%, -34.3% and -36.7%. For end century highest decrement in streamflow was observed for CCSM i.e., -57.4% whereas ACESS, CNRM, MPI-ESM showed -17.3%, -31.4% and -47%.

Singh & Saravanan (2020) :

They studied climate change impact on hydrology component using CORDEX climate model with SWAT hydrological model. They studied three watershed of Wunna, Bharathpuzha and Mahanadi river. They used only one RegCM4 CSIRO- Mk3.6.0 CORDEX South Asia of RCM model to asses climate change impact. They addreseed future response of runoff, sediments, blue water and green water storage and future water stressed components for all watersheds. SWAT model was setup for baseline period (2001-2016). Calibrated and validated SWAT model was run for future period (2021 – 2050) using bias corrected climate model data. They found out average annual surface runoff of Wunna shows decrease in RCP 4.5 scenario (490.13 mm/yr) and increase in RCP 8.5 scenario (545.81 mm/yr) as compared to baseline runoff of 497.74 mm/yr.They also found out blue water and green water is going to decline in future for wunna watershed in RCP 4.5 and increase in RCP8.5. Sediment is going to increase under both scenario. For Bharathpuzha watershed under both scenarios sediment showed rise in the eastern part of watershed. Average annual surface runoff showed increase , 685.53 mm/yr in RCP4.5 and 962.31 mm/yr in RCP 8.5 as compared to baseline 311.22 mm/yr.The blue water and green water storage shows rise in in RCP 8.5 scenario except in western region under RCP4.5 scenario. In Mahanadi watershed , surface runoff showed decreasing trend , 386.22 mm/yr under RCP 4.5 and 374.01mm/yr under RCP8.5 as compared to baseline period of 506.62

mm/yr. sediment yeild showeddecreas in both scenario. The blue water showed increase in future but greenwater storage showed decrease in some part of subbasin.

Reddy et al., (2018) :

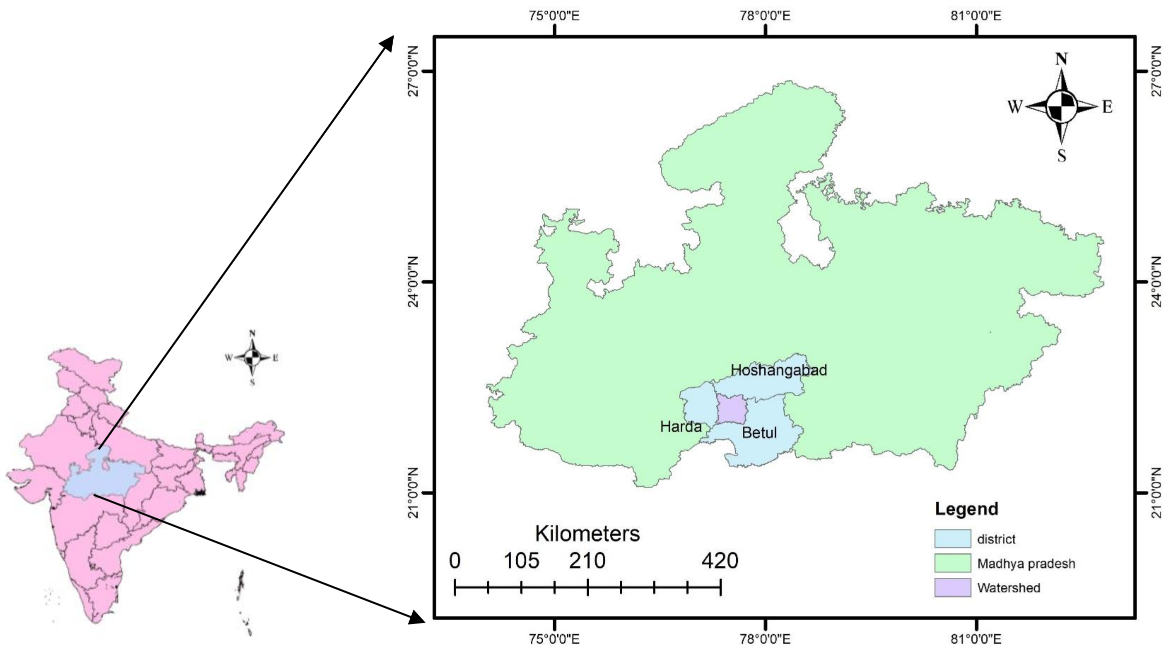
They studied climate change impact on West Nishnabotna Watershed using climate model data and SWAT hydrological model. The model was calibrated using SWAT – CUP. Calibrated SWAT model was then run for future (2041 – 2069) for prediction of streamflow. They selected four climate model CRCM–CCSM, CRCM–CGCM3, RCM3 – CGCM3 and RCM3–GFD. NSE and R^2 for calibration (1992-1999) period were 0.81 and 0.85 and for validation period (1984-1991) were 0.6 and 0.68.After calibration andvalidation SWAT model was run for future period with bias corrected climate model data .The result of this study showed RCM3-GFDL predicts streamflow very close to observed average annual streamflow for baseline period out of the four selected. CRCM – CCSM and CRCM-CGM3 predicted decreasing percentage change of -12.28% and -8.72% for future period (2050-2069) whereas RCM3-CGCM3 and RCM3 – GFDL predicted increasing percentage change of +3.51% and +14.95%.

CHAPTER 3

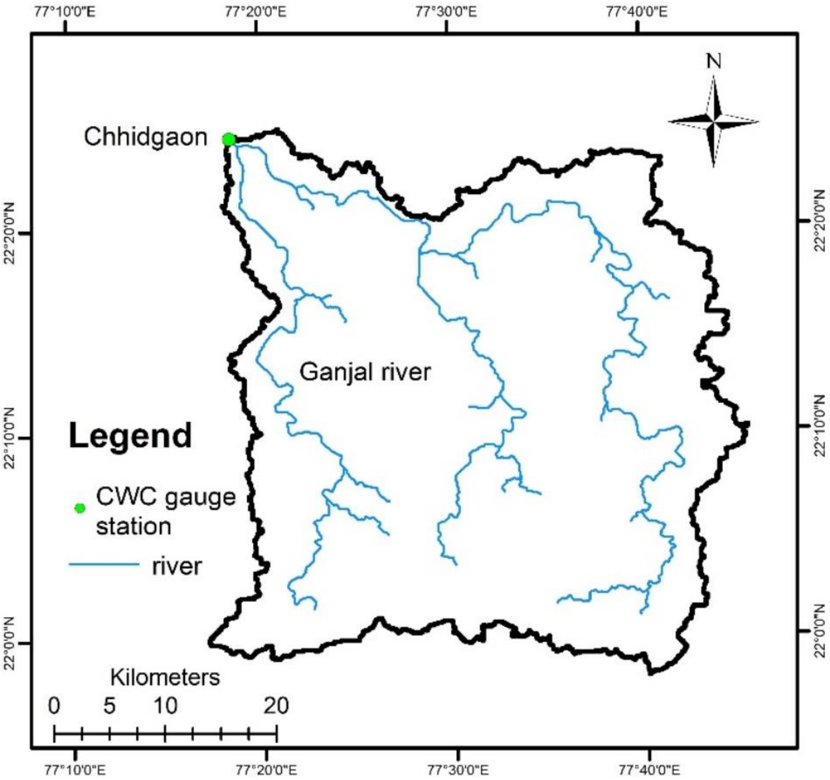
STUDY AREA

3.1 River Location

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. The length of Ganjal river is 110.8 km (approx.). The study area lies in the district of Harda, Hoshangabad and Betul in Madhya Pradesh (21°50′– 22°25′N and 77° 15' –77°45′E) (fig.3.1)



(a)



(b)

Fig. 3.1 study area (a) Madhya Pradesh map showing location of watershed (b) Ganjal river watershed

3.2 Climate

All three district lie very close to tropic of cancer. All three district witness all the season. Harda district is located at anaverage height of 302 m from sea level. Being close to tropic of cancer max temperature reaches upto 48°c and minimum upto 6°C with average annual rainfall of 916mm. Hoshangabad district is located at an average height of 331m from sea level. The average max. and min. temperature here is 40°C and 19°C.Hoshangabad district receive an average annual rainfall of 1250 mm. Betul is situated at average height of 365 m above sea level . The maximum and minimum temperature reaches upto 48°C and 17.9°C.

CHAPTER 4

DATA SOURCES

For analysis, SWAT hydrological model requires physiographical data input like Land use land cover data, digital elevation model, weather data and soil data.

Table 4.1 Data required for modelling and their Sources

Data	Source
Land use land cover	ORNL DAAC - NASA (https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_ id=1336)
Soil Map	FAO (https://data.apps.fao.org/map/catalog/srv/eng /catalog.search#/metadata/446ed430-8383-11db-b9b2-000d939bc5d8)
DEM	ASTER 30m (https://search.earthdata.nasa.gov/search)
Meteorological data	IMD grided data (https://www.imdpune.gov.in/Clim_Pred_LRF_New/ Grided_Data_Download.html)
River discharge data	India – WRIS (https://indiawris.gov.in)
CORDEX climate data	CCCR-IITM Pune (http://cccr.tropmet.res.in/home/cordexsa_datasets.jsp)

4.1 Land use land cover

LULC of India was obtained from The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). LULC of three district Hoshangabad, Betul and harda is shown in fig. 4.1. The data are provided at 100 m resolution for India.These are originally classified in International Geosphere-Biosphere Programme (IGBP) classification scheme. So, these were reclassified in SWAT format later

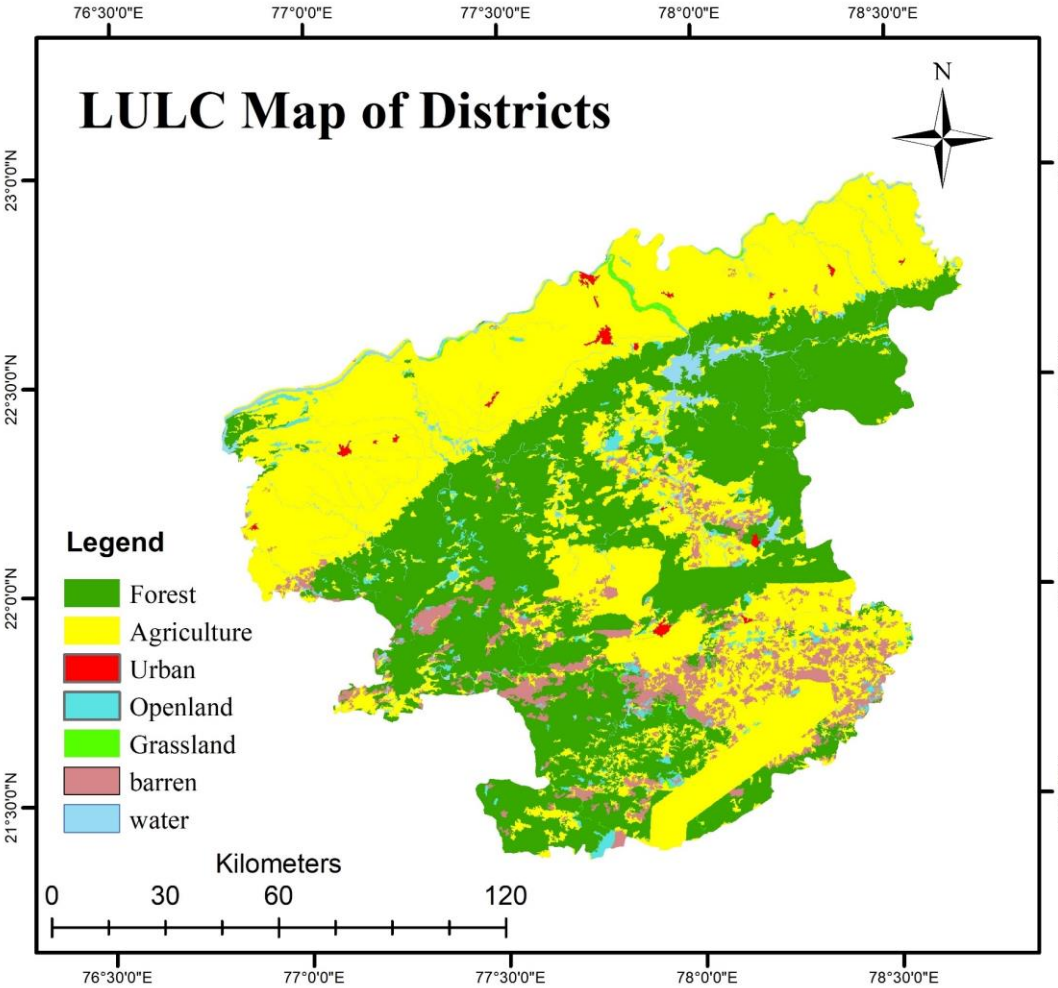


Fig.4.1 LULC map of Harda, Hoshangabad and Betul districts

4.2 Soil Map

Soil map data is taken from Food and Agriculture organization (FAO) soil database. Fig. 4.2 shows soils in all three districts with five different FAO soil codes. In this database soils are differentiated at a spatial resolution of 10 kilometers. Almost 5000 soils are present in this database. The three districts in which Ganjal watershed lies have 5 types of soil. Bv12-3b-

3696, Bv12-3b-3697 and 1-Bc-Lc-3714 have Clay loam texture while Vc43-3ab-3861and Vp20-3a-3866 have clay texture as per FAO.

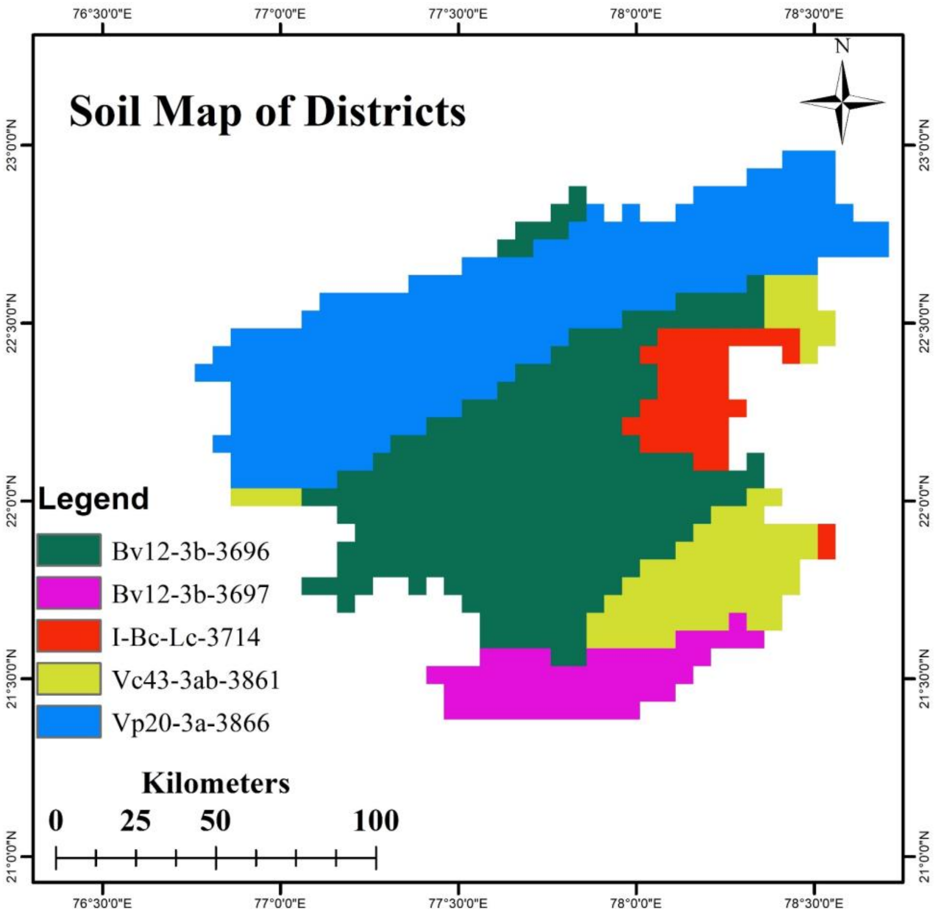


Fig.4.2 Soil map of Harda, Hoshangabad and Betul districts

4.3 Digital Elevation Model

Relief has a big influence on how runoff processes evolve, therefore digital elevation models are crucial in any spatially distributed hydrologic research.

The primary determinant of water runoff and buildup in channels, resulting in floods, altimetry is a crucial dataset in runoff modelling. The digital elevation model is also useful for estimating the terrain's slope and flow direction, which are then utilized to define drainage basins that correspond to a measuring gauge.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is one of five sensors onboard of Terra satellite launched by NASA. The ASTER DEM is available freely for users to download and use. ASTER V3 data used in this study is latest in this series made available in 2019 for public use. It has spatial resolution of 30m. The three-district used to lie in six DEM so all six were downloaded and then mosaiced for the study area. Later this DEM was used to delineate the watershed. Fig.4.3 shows downloaded DEM

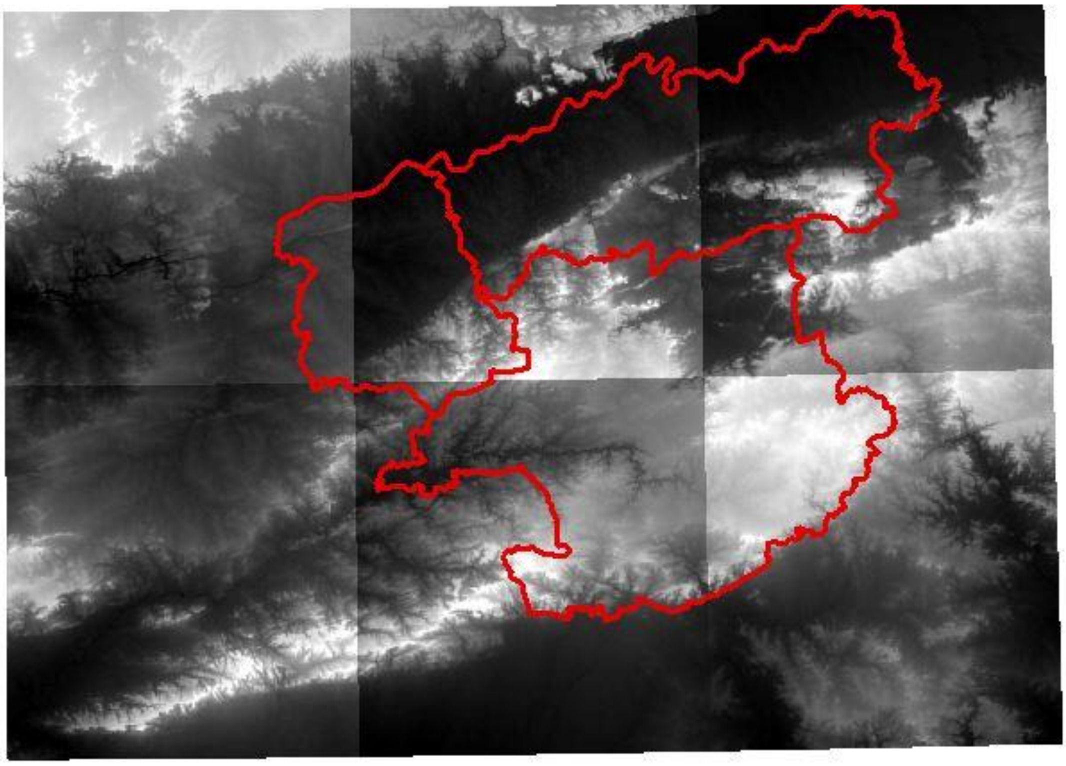


Fig.4.3 DEM tiles for district of Harda, Hoshangabad and Betul districts

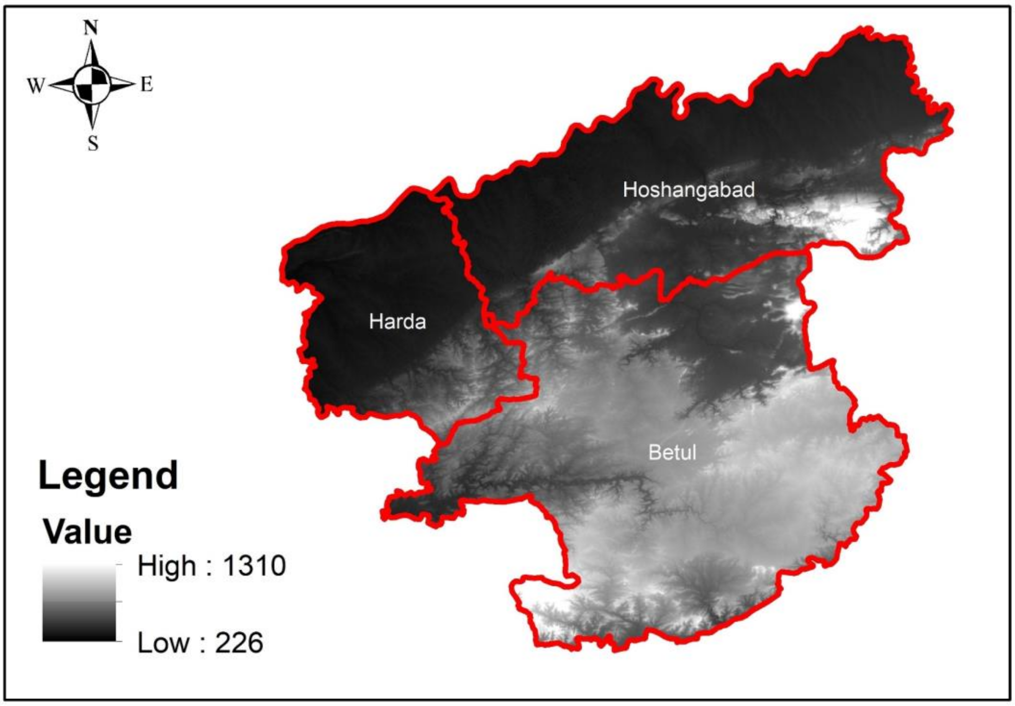


Fig.4.4 Mosaic DEM for district of Harda, Hoshangabad and Betul districts

4.4 Meteorological data

Indian meteorological department provide free grided data for whole India. Rainfall data are provided at high resolution of 0.25° x 0.25° while max. and min. temperature are provided at 1° X 1° resolution. Daily precipitation, maximum and minimum temperature were obtained from this database for a time of 30 years (1985–2015) and utilized in the SWAT hydrological model.

4.5 Ganjal river discharge data

The most essential components of water resource management are water information in the public domain, which is an initiative of the India-WRIS Project with the goal of disseminating data in the public domain. This database was initiated through MoU signed between CWC, ISRO and Ministry of Jal Shakti. It is managed by National Water Informatics center (NWIC). Ganjal river has only one CWC gauge station named Chhidgaon.

It has continuous data for period (1988-2015) without any missing value. This daily data was downloaded and used for calibration and validation of SWAT model.

4.6 CORDEX Climate data

In general, several CMIP5 models' output is used to address present and 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 & Saravanan, 2020). It can simulate current climate features throughout the study region (Gao & 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 the Indian Institute of Tropical Meteorology (IITM-India).

Table 4.2 Climate model used for the study

RCM	Driving GCM	GCM modelling organization
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

CHAPTER 5

Methodology

5.1 Project methodology

In this study first SWAT model was setup in ArcGIS using ArcSWAT interface. Then it was calibrated and validated using SWAT-CUP software. It is free tool and available to SWAT community through SWAT official website (https://swat.tamu.edu/software/swat-cup/).

After calibration for the base period (1978-2015) it was run for future using climate model data (2025-52) to study climate change impact on water balance component and streamflow.

Climate model data were provided by CCCR – IITM Pune in NETCDF format. They were extracted and bias corrected using Cmhyd tool. This tool is free and available to SWAT community through SWAT official website (https://swat.tamu.edu/software/cmhyd/)

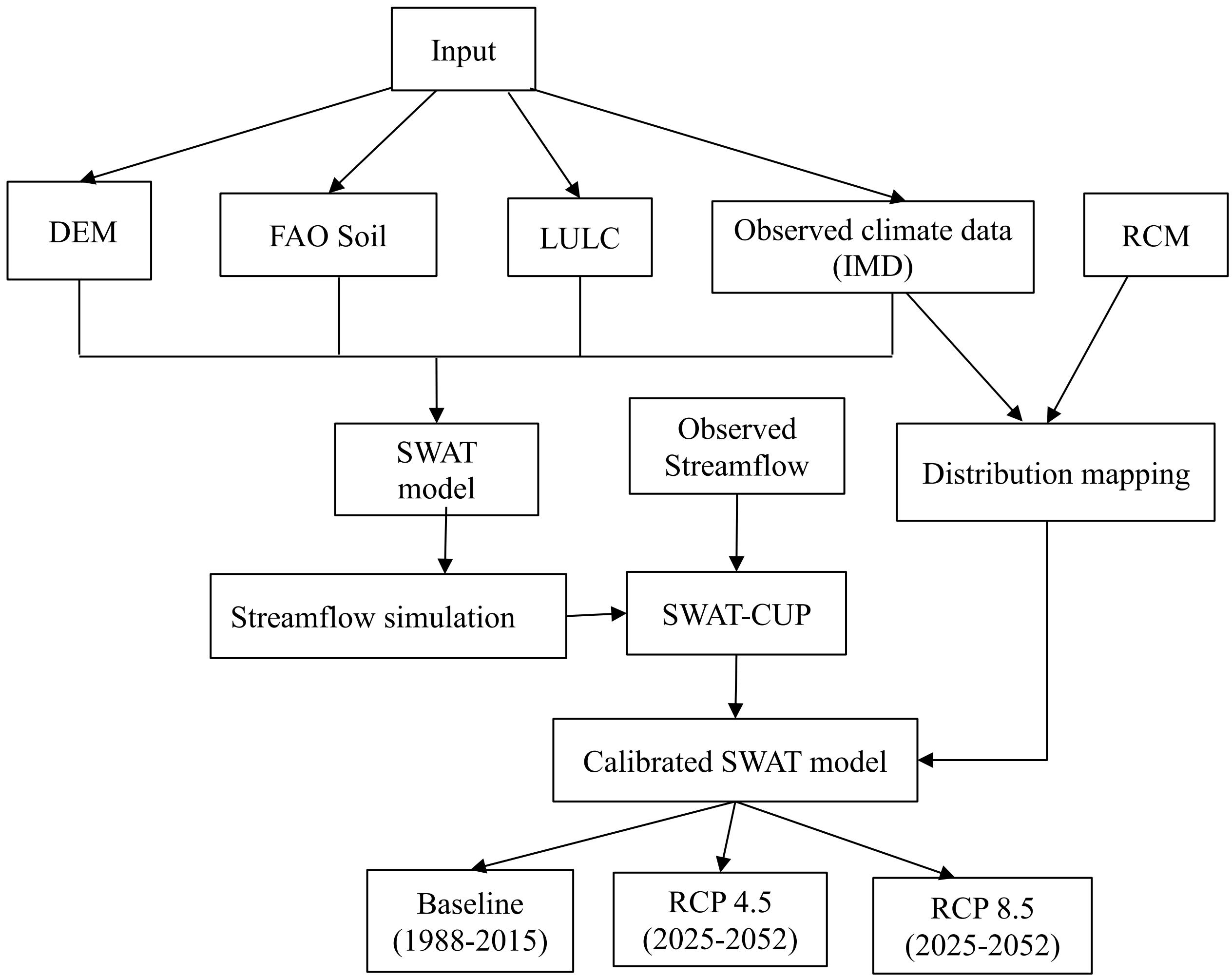


Fig.5.1 project methodology

5.2 SWAT Model Setup

To setup SWAT project first we need to cross check and reproject raster data to UTM projection. As our study, area lies in WGS 1984 zone 43 Northern Hemisphere all inputs like LULC, soil map and DEM were reprojected. Setting up SWAT model require four steps-

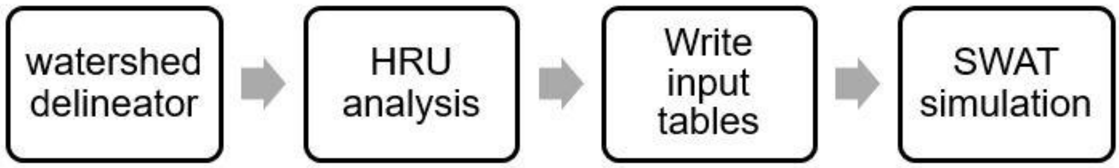


Fig.5.2 SWAT model setup flow diagram

5.2.1 Watershed Delineator

ASTER DEM of the study area 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). Watershed delineator is incorporated in SWAT toolbar with the help of which watershed was delineated from DEM. CWC gauge station Chhidgaon was used as outlet point to delineate watershed.

Following steps were used in watershed delineation window –

1. In DEM projection setup option, setting Z unit to m
2. Clicking flow direction and accumulation
3. Giving minimum area value
4. Clicking create streams and outlet
5. Removing all automatically generated outlet point
6. Clicking 'Add' in manual edit option to add Chiddgaon (CWC gauge station) as outlet
7. Clicking delineate watershed to generate watershed

Table 5.1 CWC Gauge station details

Gauge Station	Latitude	Longitude
Chhidgaon	22.4058	77.3078

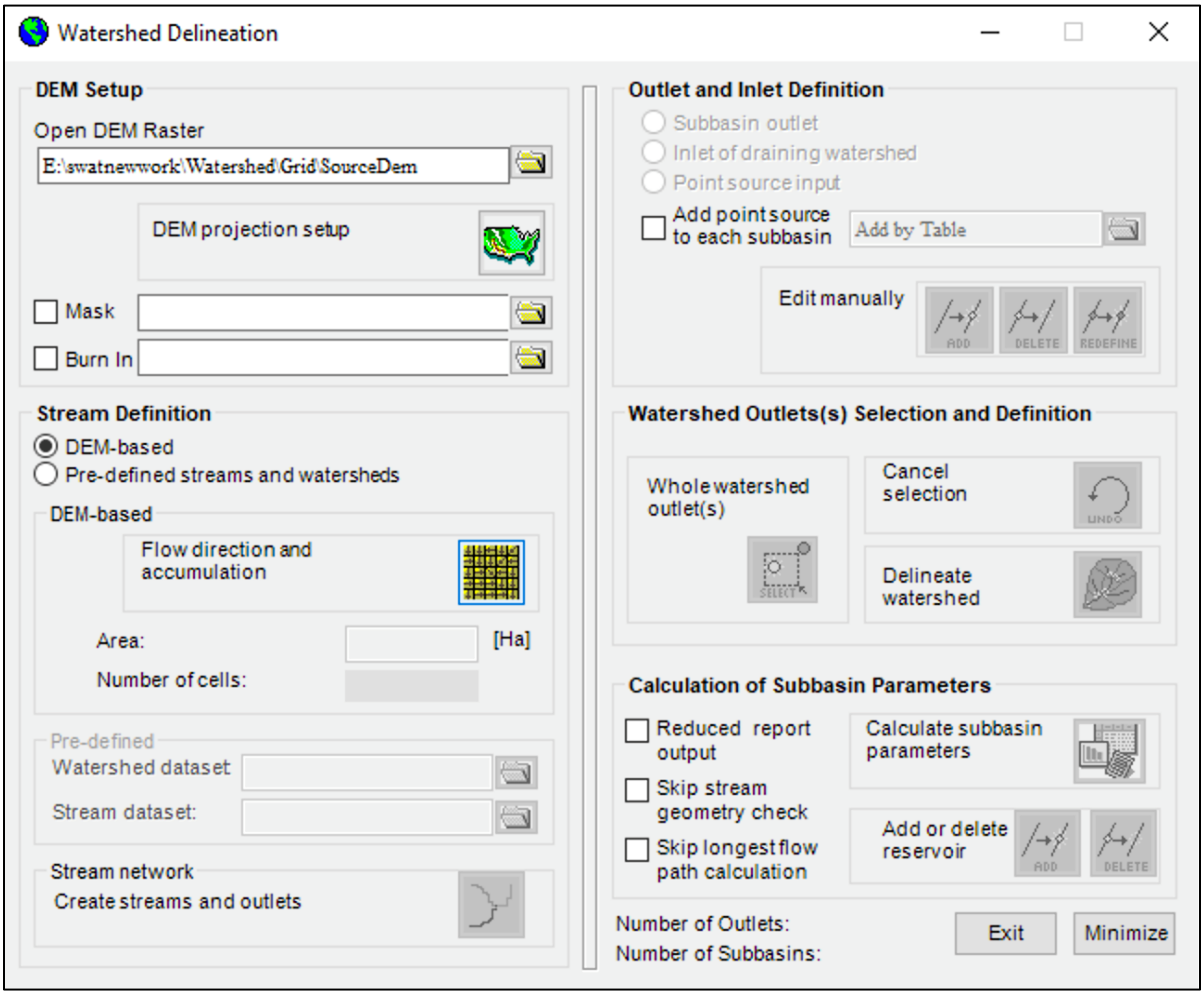


Fig.5.3 watershed delineation window

5.2.2 HRU Analysis

In SWAT, each watershed can be divided into sub watershed and each sub watershed is divided into HRU (hydrological response unit) .Each HRU is a unique combination of land use, slope and soil (Neitsch et al., 2011).

To conduct HRU analysis we need to provide land use data, soil data and slope definition and overlay. First step is providing LULC map for the watershed. LULC map already prepared was utilized after reclassifying them in SWAT Format with help of look up table. A text file was prepared to reclassify into SWAT format

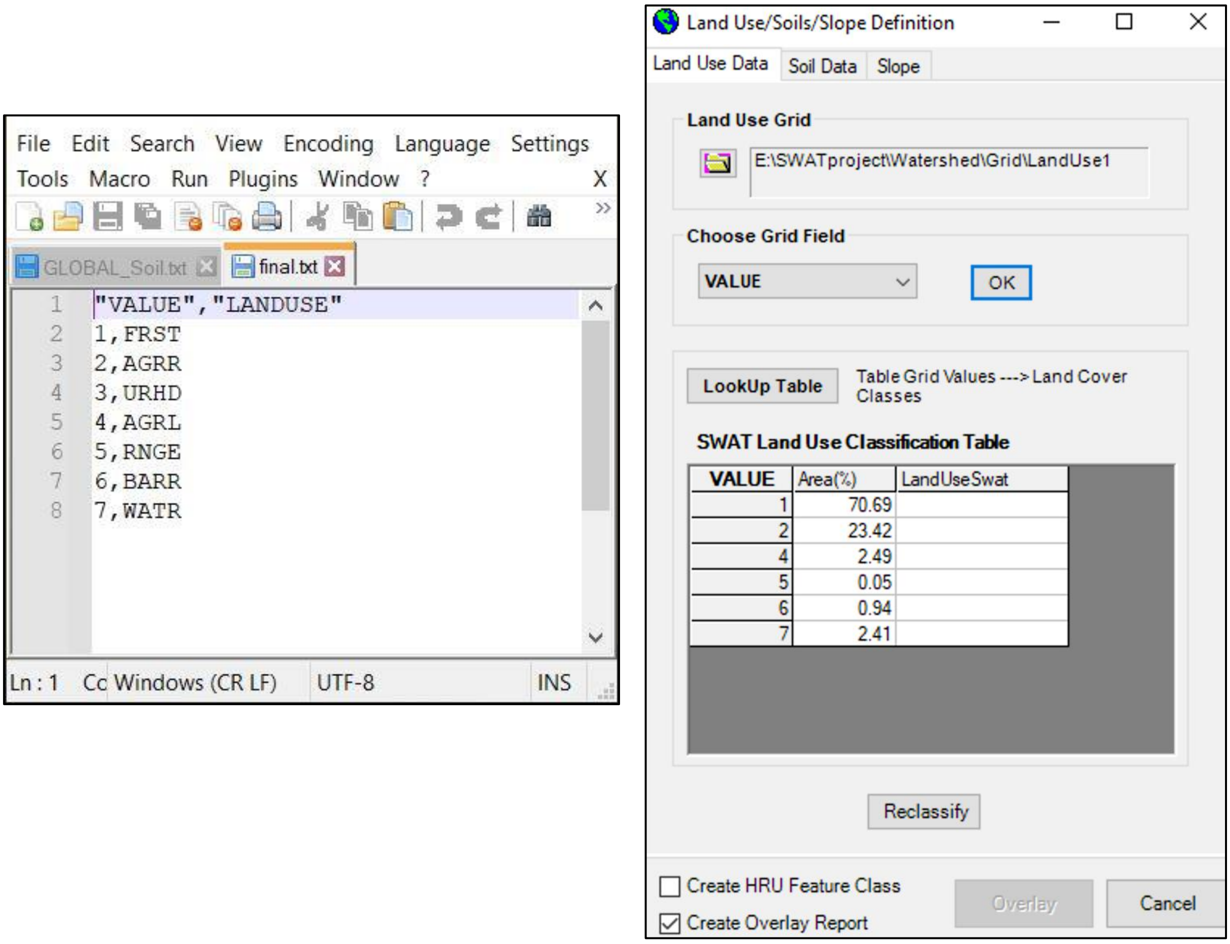
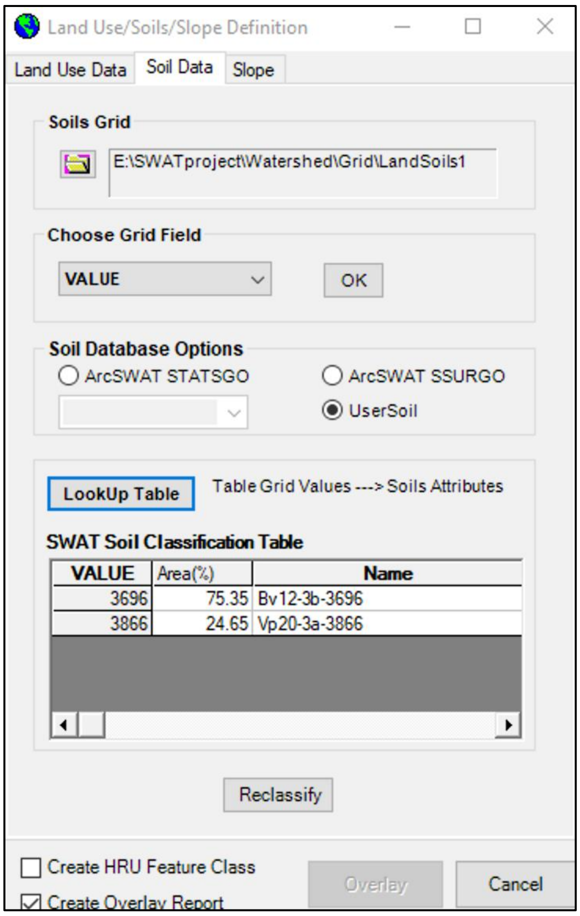


Fig.5.4 Land use definition window

After adding land use, second step is to add soil map. Already prepared and projected soil map of district was added as soil data.

After adding soil data, slope classes are added. It is up to user how many slope classes to add. In this study we have taken 5 slope classes. After overlaying all classes, we need to give HRU definition. HRU thresholds needs to be define by user, it merges the lower classes with upper one in generated HRU. Lower value gives us lower classes and larger value give us more classes but it does not impact on streamflow or discharge result. As our study area is small threshold value for land use, soil and slope was given as 5%, 10% and 5%. After giving HRU definition land use, slope and soil map of watershed get generated. Total 29 HRUs were generated for Ganjal river watershed.



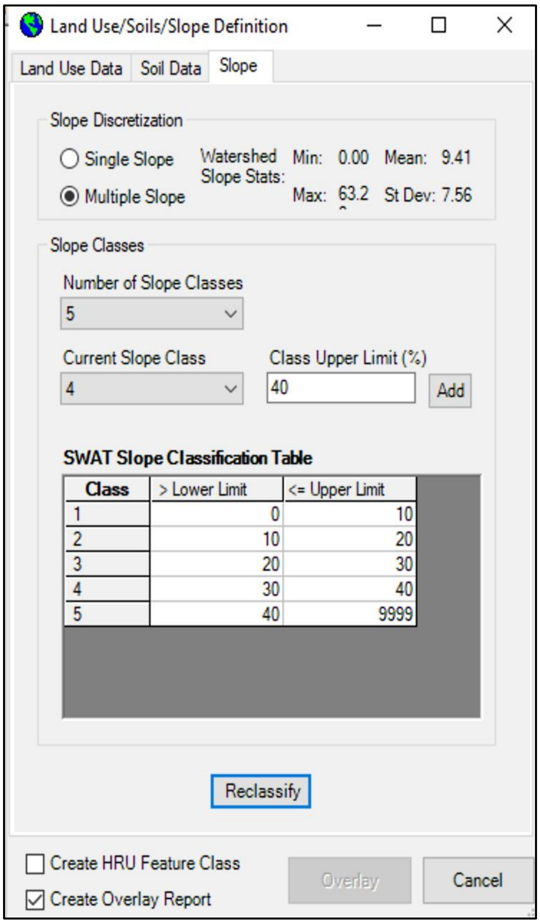
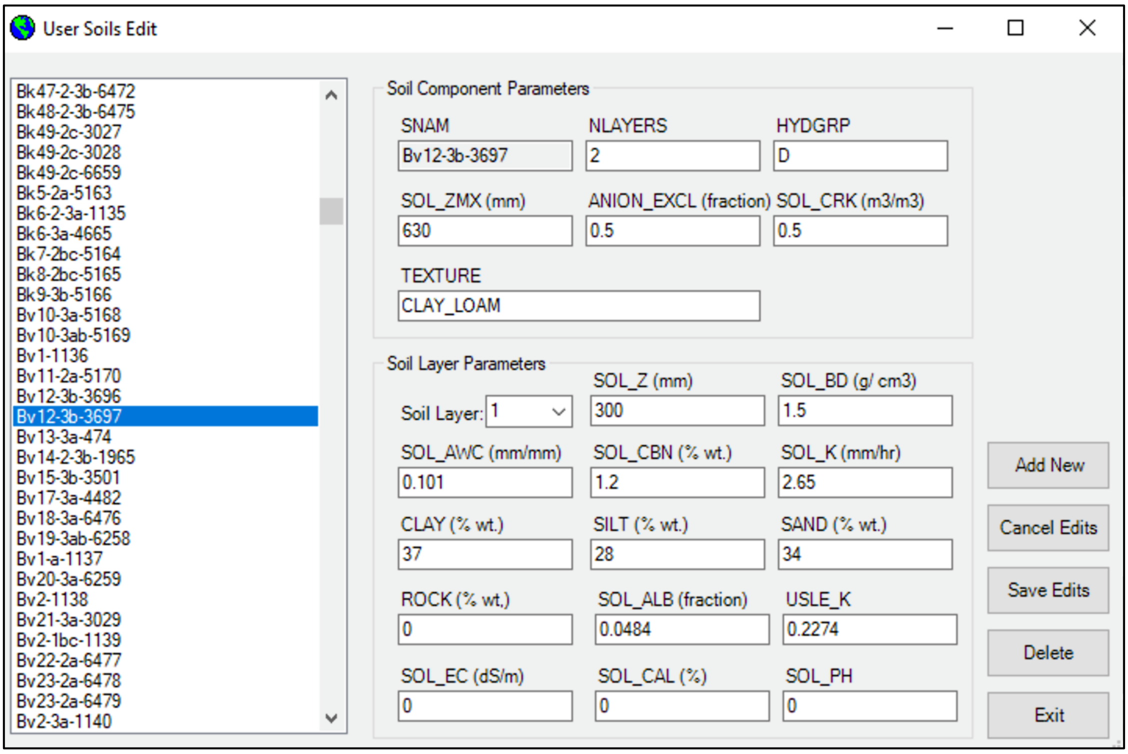
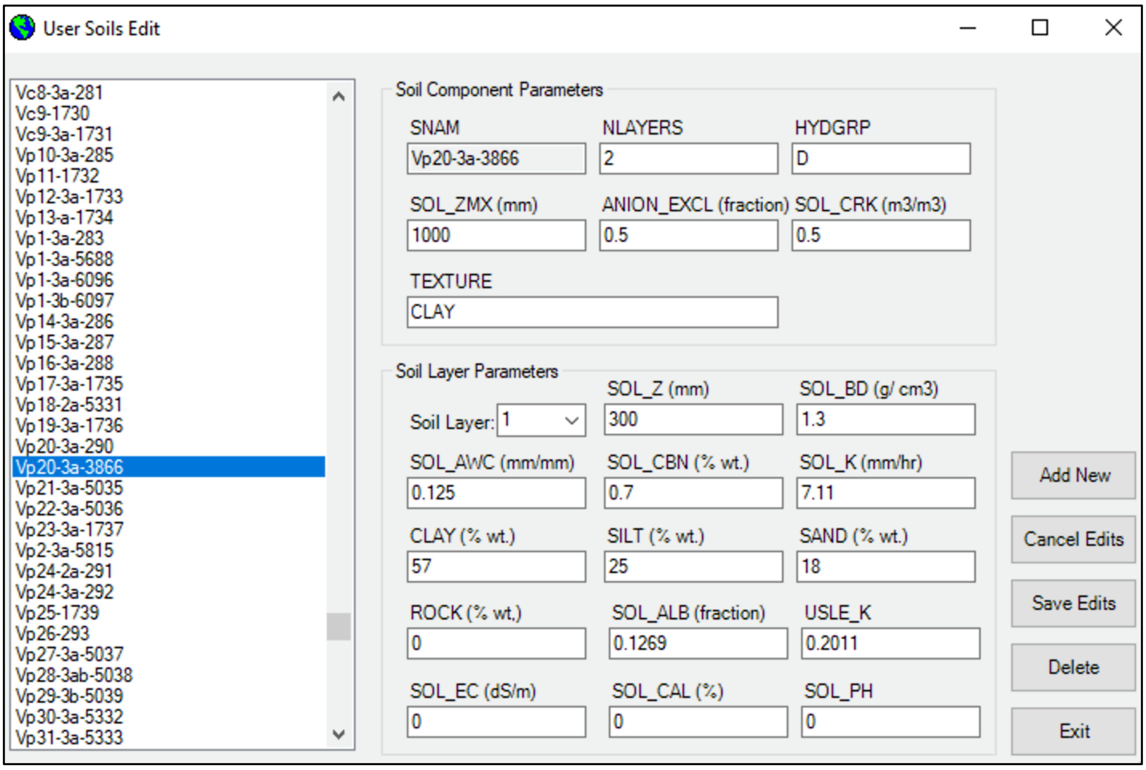


Fig.5.5 Soil data definition window

Fig.5.6 Slope definition window

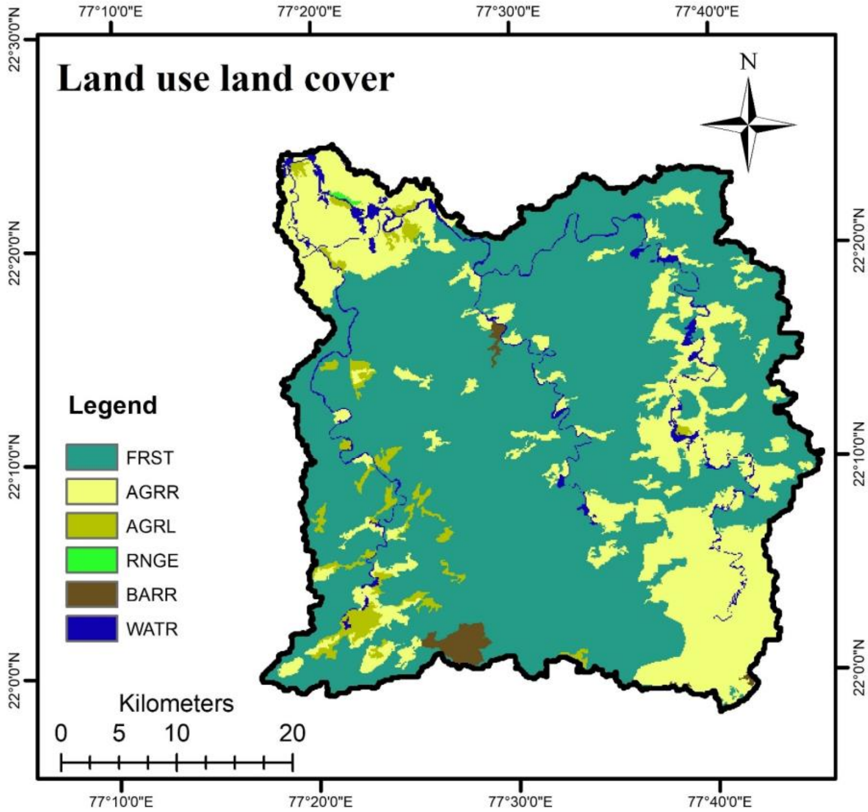


(a)



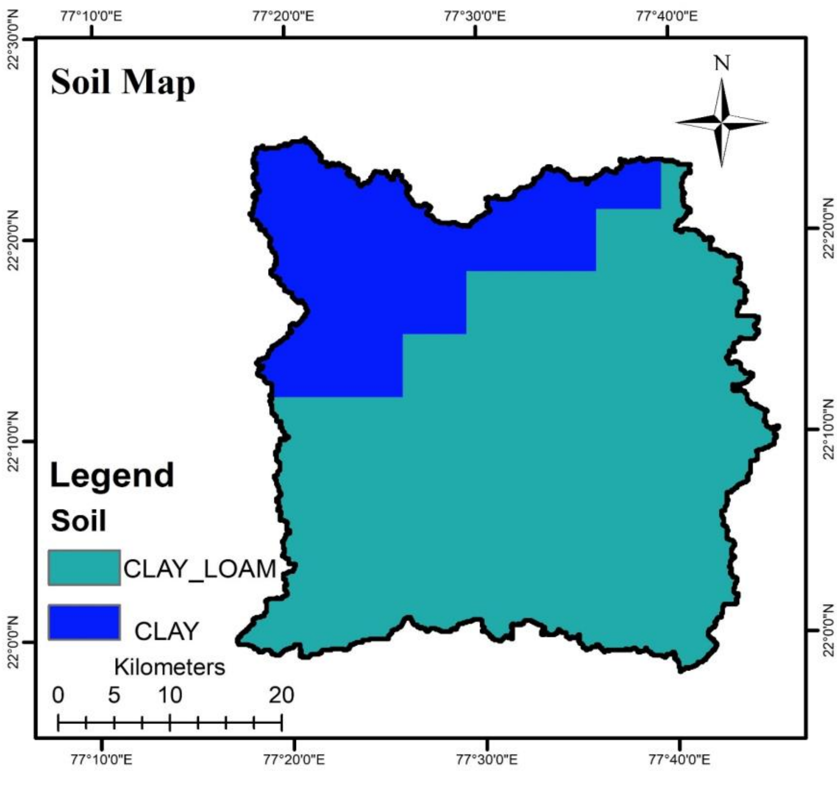
(b)

Fig.5.7 FAO soil details of watershed



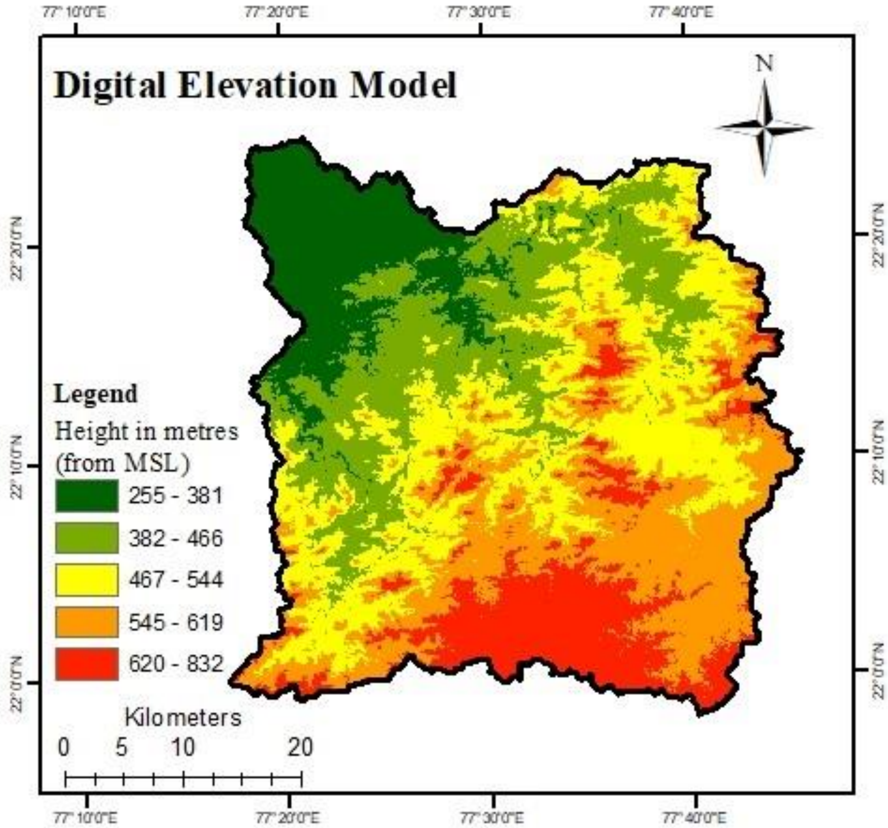
77°10'0"E
77°20'0"E
77°30'0"E
77°40'0"E
22°30'0"N
22°20'0"N
22°10'0"N
22°0'0"N
Land use land cover
N
Legend
FRST
AGRR
AGRL
RNGE
BARR
WATR
Kilometers
0 5 10 20

(a)



77°10'0"E
77°20'0"E
77°30'0"E
77°40'0"E
22°30'0"N
22°20'0"N
22°10'0"N
22°0'0"N
Soil Map
N
Legend
Soil
CLAY_LOAM
CLAY
Kilometers
0 5 10 20

(b)



(c)

Fig. 5.8 Ganjal watershed (a) LULC (b) Soil (c) DEM

5.2.3 Weather data setup and write input table

This stage entails reading weather data as well as creating input tables. Selecting weather station files such as rainfall data, temperature data, and the weather generator file allows the basin's weather data to be defined. The rain gauge sites are shown in the rainfall data definition tab. The SWAT-acceptable format for the rain gauge locations table was used. The daily time step precipitation data for all of the sites was stored in distinct text files that the SWAT database automatically chose from their location.

In the temperature data tab, the temperature locations table was similarly submitted. The (0.25° x 0.25°) grid sites in the basin were used to determine the precipitation and for temperature (1° x 1°) grid sites were used. IMD provides only daily rainfall and temperature data. So other data (solar radiation, relative humidity, wind speed) were generated using SWAT weather generator during simulation. SWAT weather generator uses climate data file containing average climate data of 83 years from WGEN_user to calculate this missing value. For India it is provided on SWAT official website (https://swat.tamu.edu/data/india-dataset/).

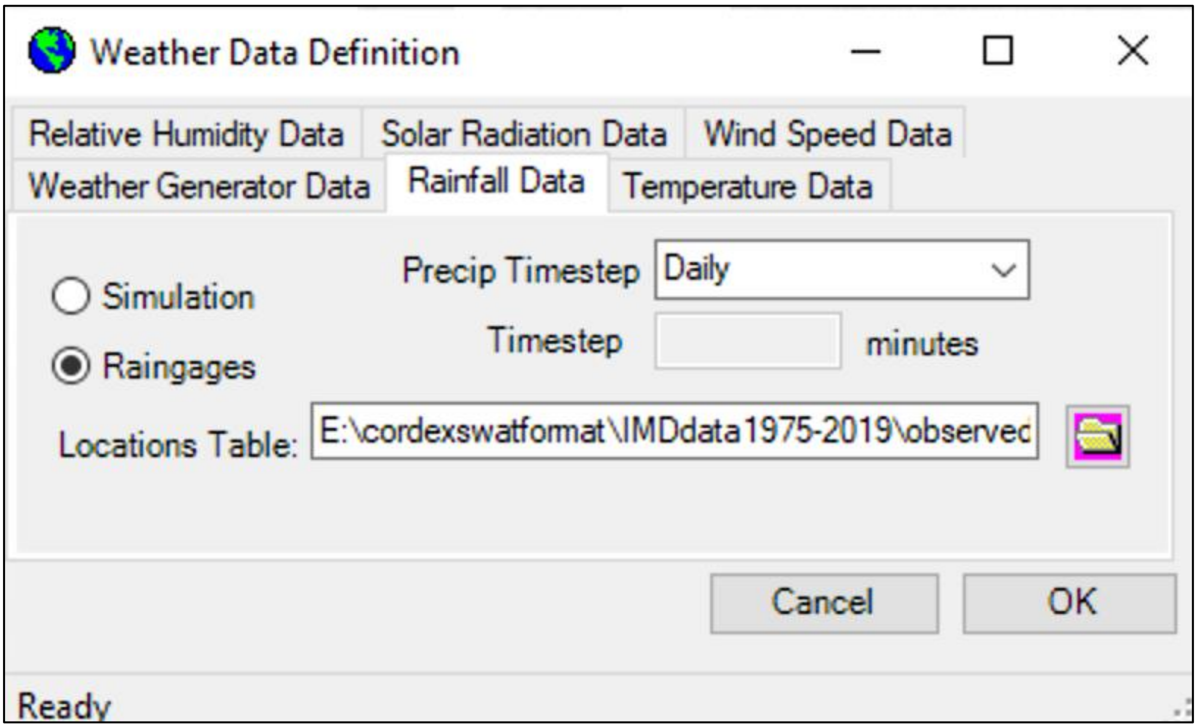


Fig.5.9 Weather data form

The next setup is to write SWAT input table. This tool will only work if date format on your PC is set as mm/dd/yyyy otherwise will give error. Other than that, if all data till now is in correct form it will create table automatically on selecting all. All file needs to show 'completed' satus before doing final SWAT setup.

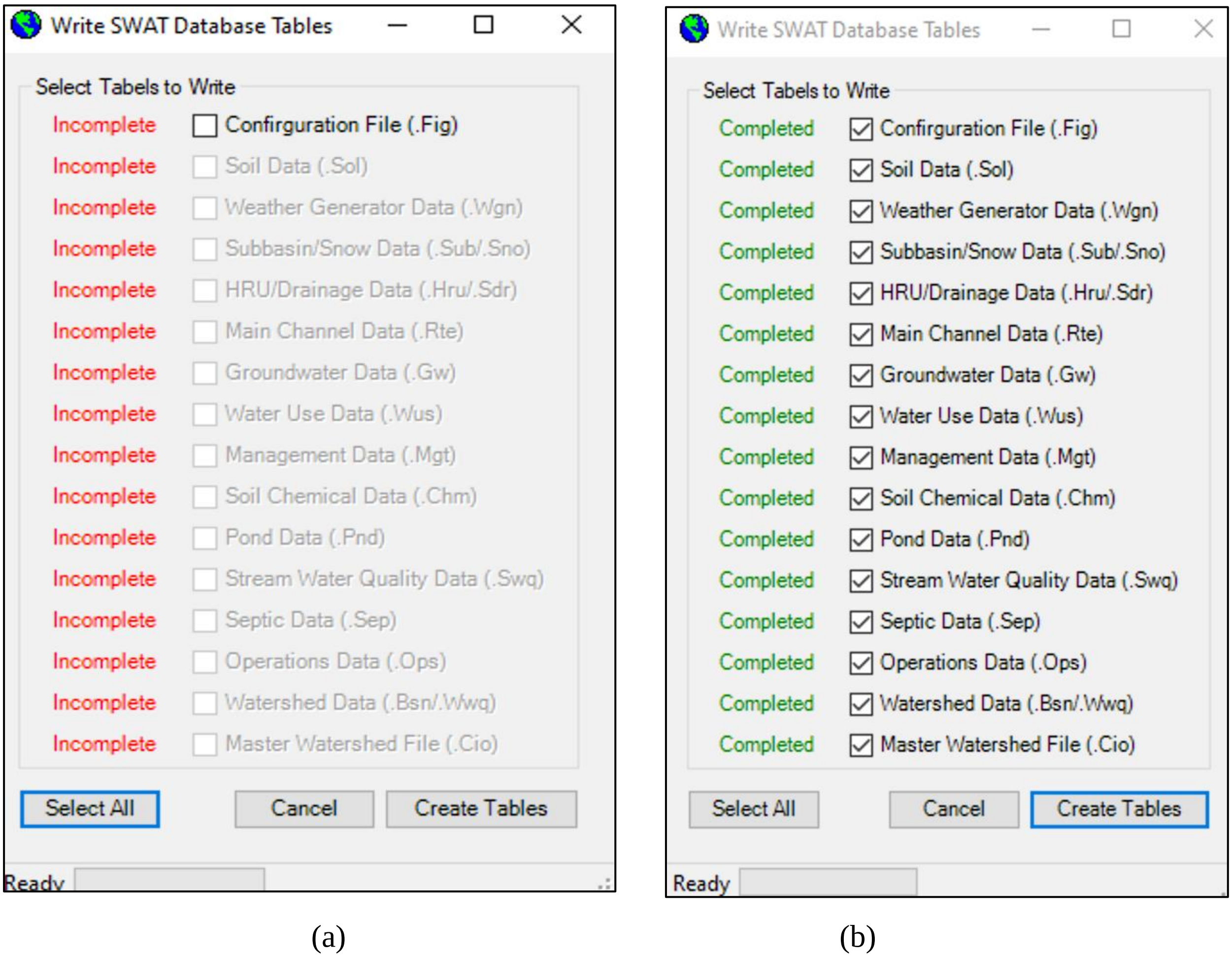


Fig. 5.10 The (a) incomplete (b) completed SWAT table form

5.2.4 SWAT Simulation

After setting up all the file the final step is to run SWAT simulation. Simulation period is selected from 1975 – 2015 as observed data from CWC was available for Chiddgaon gauge station without any missing value. Three years from 1975 -1978 was taken as warm up period. SWAT manual recommend minimum three years of warm up period. The result is not generated for warm up period, it is used by SWAT for internal calculations. The Run SWAT button becomes activated after a successful SWAT Setup. The last SWAT run is permitted, which takes time to process all of the data.

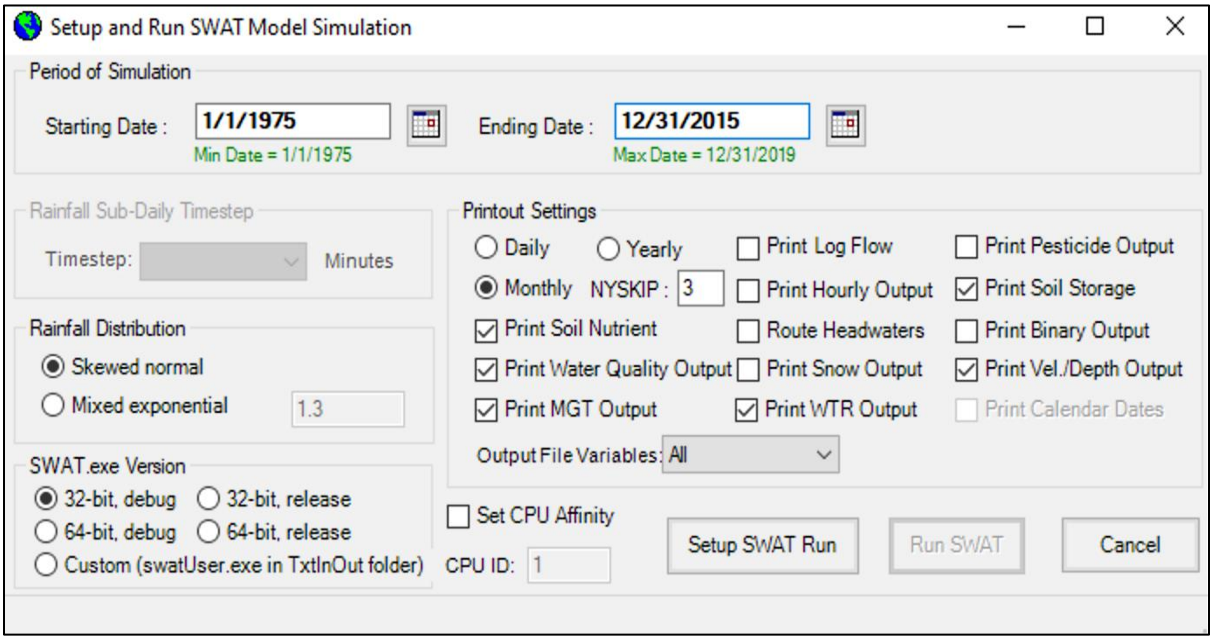


Fig. 5.11 SWAT setup form

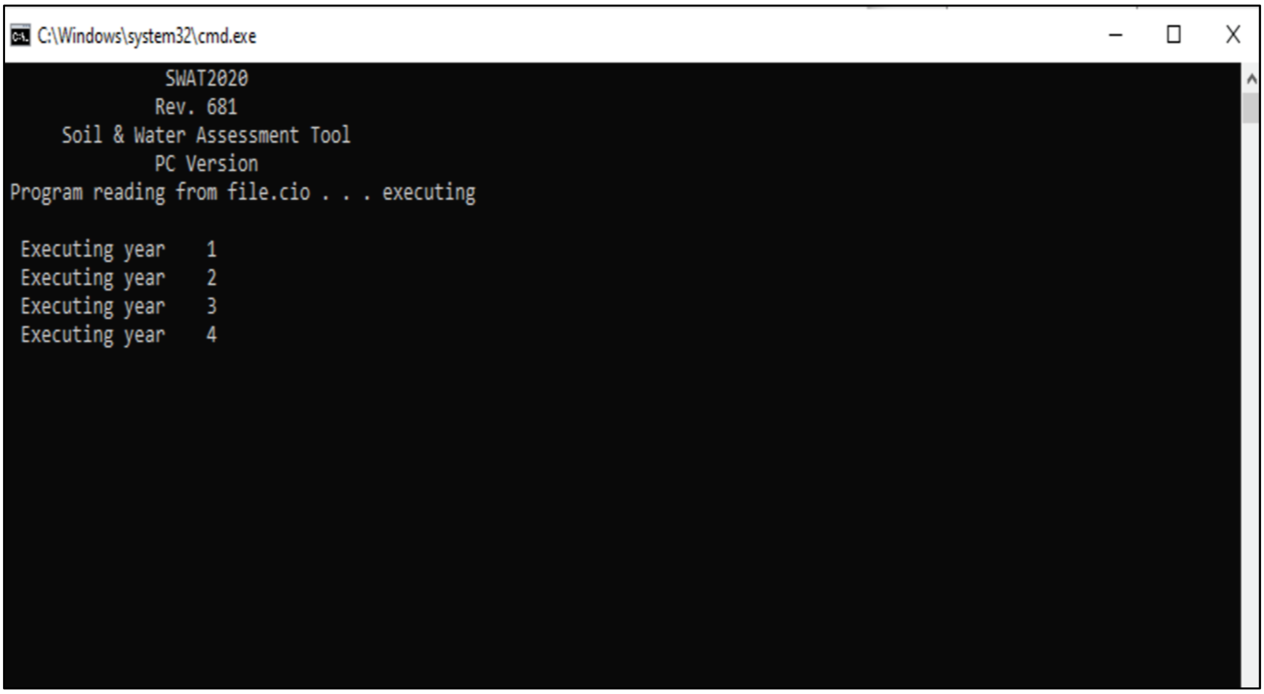


Fig. 5.12 SWAT model execution

5.2.5 Output

In this step saved file in 5.1.4 were imported to database. These files were further imported to excel for the purpose of analysis and plotting. The first simulation was run for (1975 – 2015) with first three year as warm up period. This time period was chosen as for this period continuous streamflow data was available without any missing value.

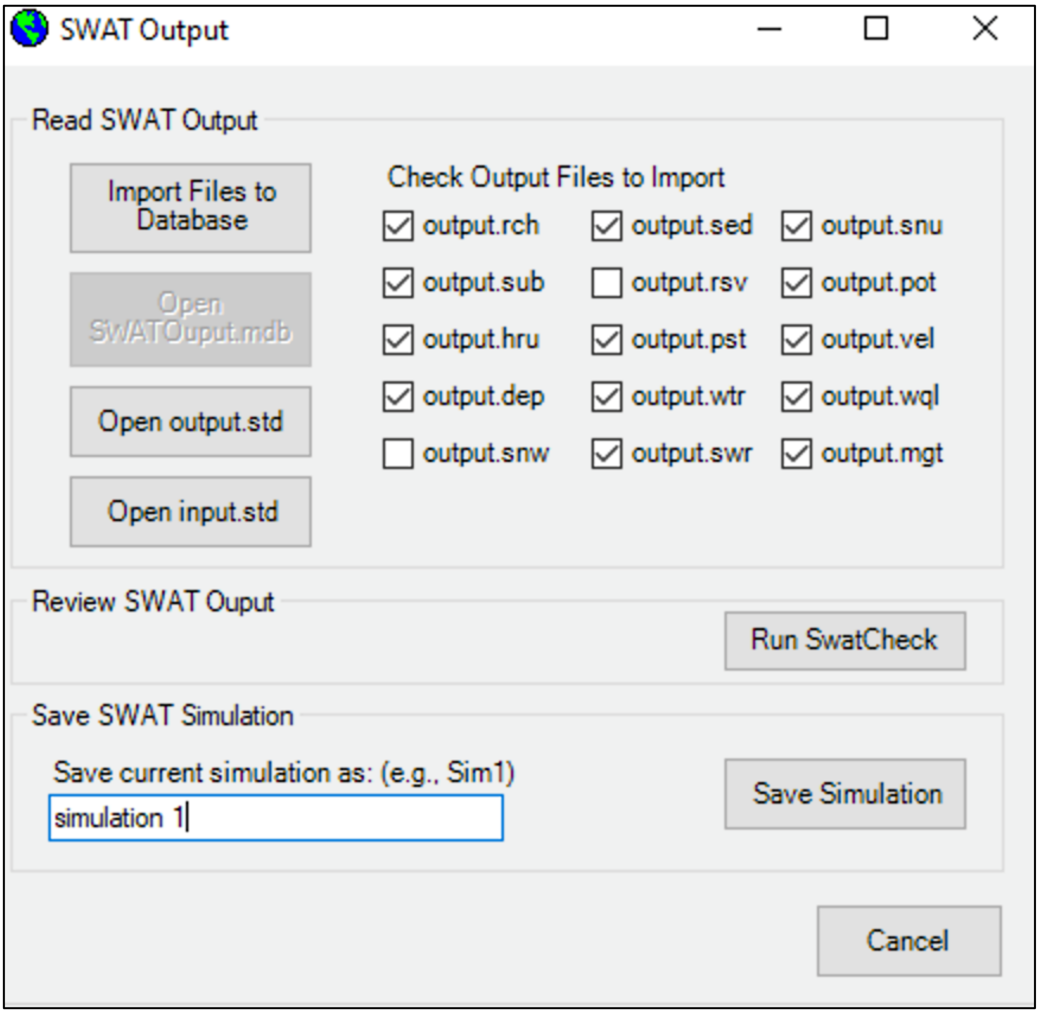


Fig. 5.13 output window

5.3 SWAT CUP Sensitivity analysis and Calibration

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).In SUFI-2 algorithm, parameter uncertainty accounts for all uncertainties (conceptual model, input, etc.) (Abbaspour et al., 2004). Sensitivity analysis is a method for determining how altering input parameters affects model outputs.

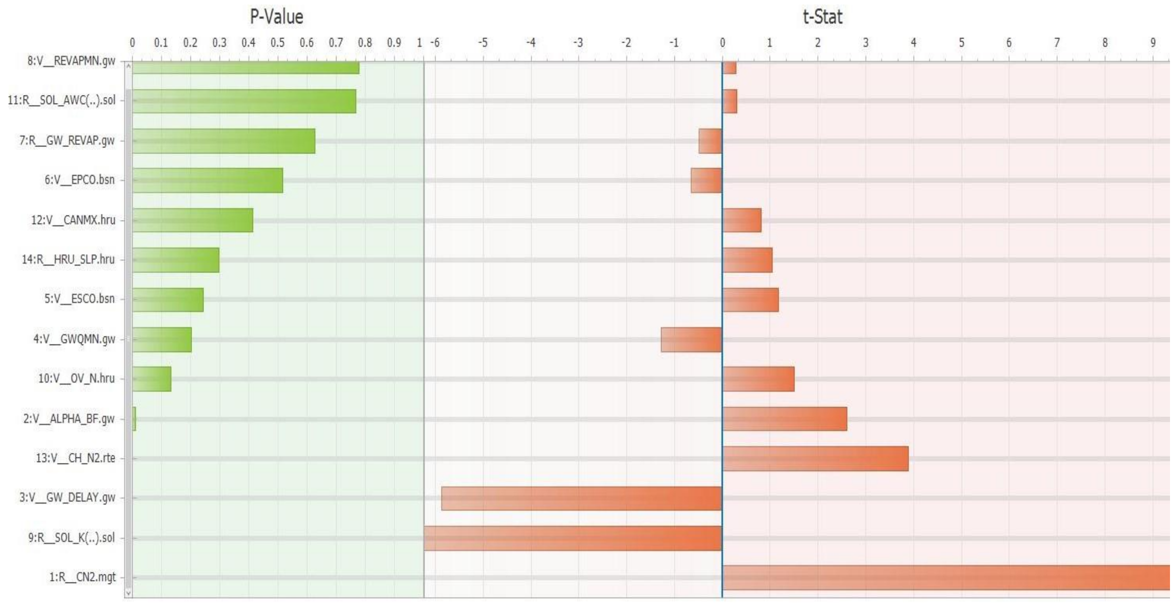
To calibrate streamflow, we need to convert observed daily data downloaded from WRIS – India website to monthly data as monthly streamflow calibration is found to happen best in SWAT-CUP (Srinivasan et al., 2010). It was done using Pivot table in excel. After converting to monthly data, it needs to be formatted into form suitable for SWAT – CUP. In order to see the impact of parameter on model result 500 simulations were performed for chhidgaon gauging station.

In this study total 14 parameters were selected on basis of sensitivity analysis and literature review (Jayanthi & Keesara, 2019; Mishra & Lilhare, 2016; Pandey et al., 2019; Rickards et al., 2020) shown in table 5.2

Higher absolute value of t-test means high sensitivity and lower p-value is more significant (fig.5.14). 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 5.2 Calibrated Parameter

Sr.No.	Sensitive parameter	Fitted parameter	Minimum value	Maximum value
1	R__CN2.mgt	0.0684	-0.2	0.2
2	V__ALPHA_BF.gw	0.847	0	1
3	V__GW_DELAY.gw	48.899998	30	450
4	V__GWQMN.gw	0.458	0	2
5	V__ESCO.bsn	0.4483	0.1	1
6	V__EPCO.bsn	0.2614	0.1	0.7
7	R__GW_REVAP.gw	0.18326	0.02	0.2
8	V__REVAPMN.gw	108.5	0	500
9	R__SOL_K(..).sol	-0.2832	-0.8	0.8
10	V__OV_N.hru	0.13027	0.01	0.2
11	R__SOL_AWC(..).sol	0.7279	0.1	0.8
12	V__CANMX.hru	66.5	20	80
13	V__CH_N2.rte	0.37933	0.01	0.4
14	R__HRU_SLP.hru	-0.1805	-0.5	1



The v__ parameter name indicates that the existing parameter value is to be replaced with the supplied value, whereas the r__ parameter name indicates that the existing parameter value is to be multiplied.

Fig. 5.14 Sensitivity analysis

Table 5.3 sensitive parameter ranking

Rank	Sensitive parameter	t-stat	p-value
1	R__CN2.mgt	10.45	0
2	R__SOL_K(..).sol	-6.23	0
3	V__GW_DELAY.gw	-5.87	0
4	V__CH_N2.rte	3.89	0
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

5.4 SWAT Model Performance

In this study SWAT model performance is evaluated using the Nash–Sutcliffe efficiency coefficient (NSE) and the determination coefficient (R^2). For flow simulation model performance is considered very good if $0.75 < NSE < 1$ and $0.75 < R^2 < 1$ (D. N. Moriasi et al., 2007).

Table 5.4 Performance indicator

Formula	Name of indicator
$R^2 = \frac{(\Sigma[X_i - X_{av}][Y_i - Y_{av}])^2)}{\Sigma[X_i - X_{av}]^2 \Sigma[Y_i - Y_{av}]^2}$	regression coefficient
$NSE = 1 - \frac{\Sigma[X_i - Y_i]^2}{\Sigma[X_{av} - Y_{av}]^2}$	Nash–Sutcliffe efficiency coefficient

R^2 = linear regression coefficient between observed and simulated data; X_i and Y_i = the observed and simulated discharge values, respectively, X_{av} and Y_{av} = the mean of observed and simulated discharge values.

5.5 Climate Model Selection and Bias correction

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 & Seibert, 2012). In this study, CMhyd (Climate Model data for hydrologic modeling) tool is 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 & Seibert, 2012). Moreover, distribution mapping has performed well in different studies (Jayanthi & Keesara, 2019; Pandey et al., 2019; Smitha et al., 2018). In this study we have used CMhyd tool to extract and bias correct climate model data from their NETCDF format. CMhyd tool interface is shown in fig.5.15

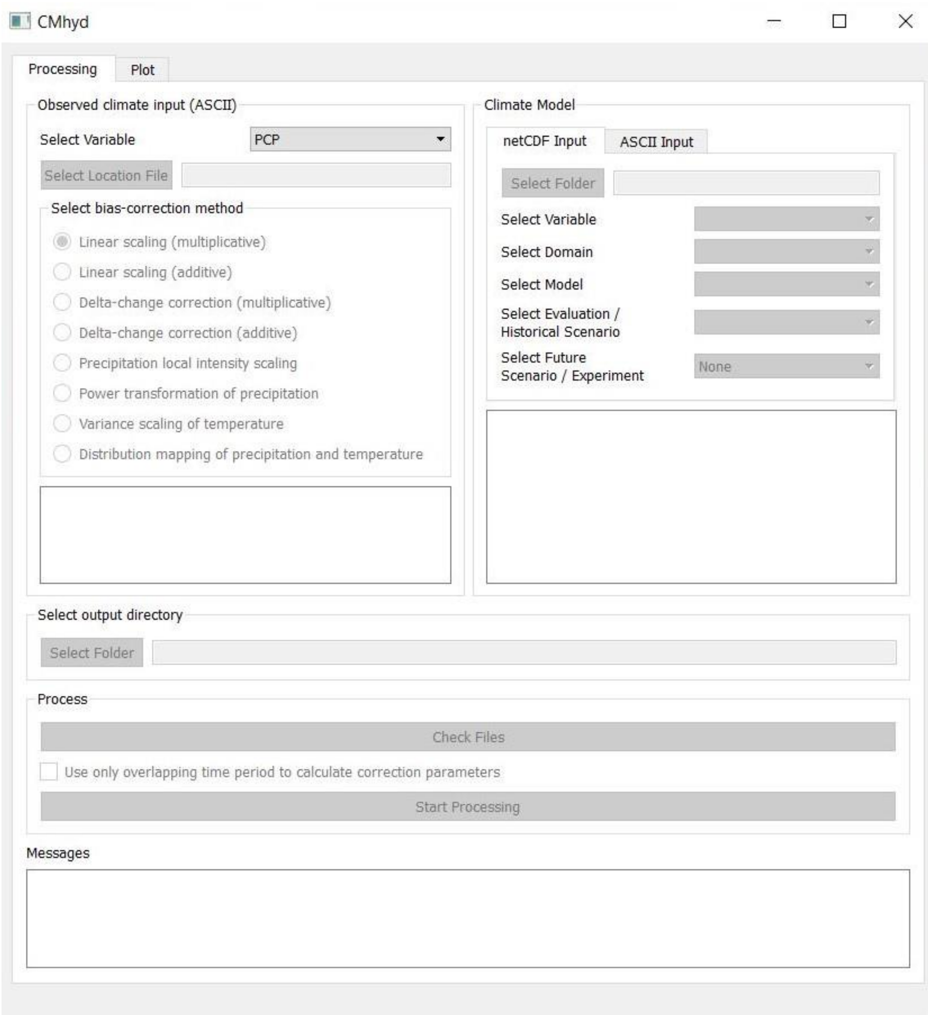


Fig. 5.15 CMhyd tool interface

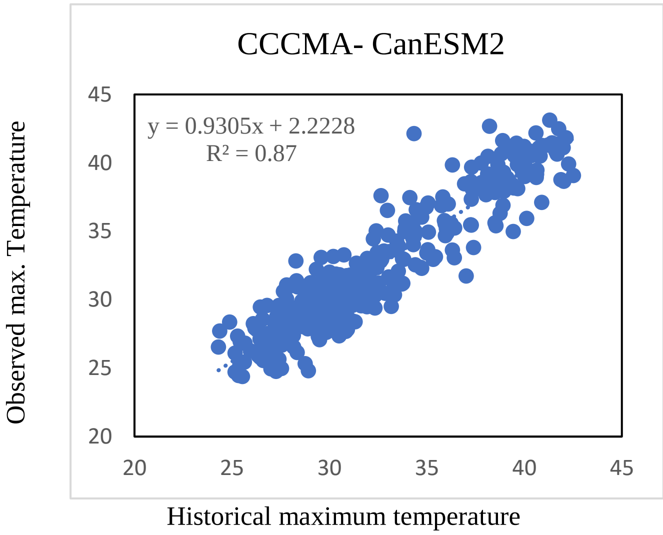
The basic idea behind distribution mapping is to create a transform function to conform the distribution function of raw environment variables (RCM data) to the observed distribution function of observed data (Tarekegn et al., 2021; Teutschbein & Seibert, 2012). In this study, thirty-year simulated historical 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 perform this task and apply same transform function to correct historical and future simulations of RCM. For evaluating bias-corrected model performance, NSE and R^2 have been used in this study.The bias correction result is consistent with other studies (Gaur et al., 2021; Heo et al., 2019)

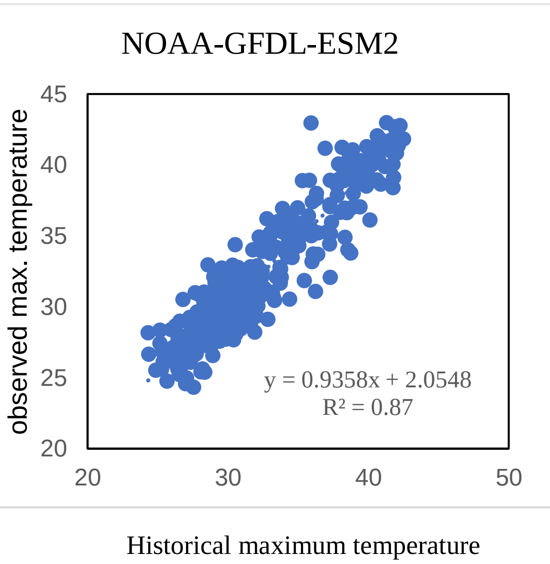
IITM-Regcm4 RCM has data available for six GCM and two scenarios, RCP4.5 and RCP8.5. All six models were evaluated for the study region. In this study, top three climate models among six, representing study area were chosen for future simulation in SWAT. This method of climate model selection based on best performing model for observed data of temperature and precipitation is quite common (Nauman et al., 2019; Pandey et al., 2019).

Finally, NOAA-GFDL-ESM2, CNRM-CM5 and CCCma-CanESM2, having the highest R^2 and Nash and Sutcliffe efficiency coefficient (NSE) with observed temperature and precipitation for the historical period were selected to run SWAT model in future (table 3). 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 compared to these two. In previous studies, it is also seen that regardless of GCM/RCM selection, most of the models fails to capture the observed trend of precipitation for the historical period (Mishra & Lilhare, 2016).

Table 5.5 Performance evaluation of climate model data

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-Mk 3.6	0.87	0.86	0.94	0.94	0.41	0.30





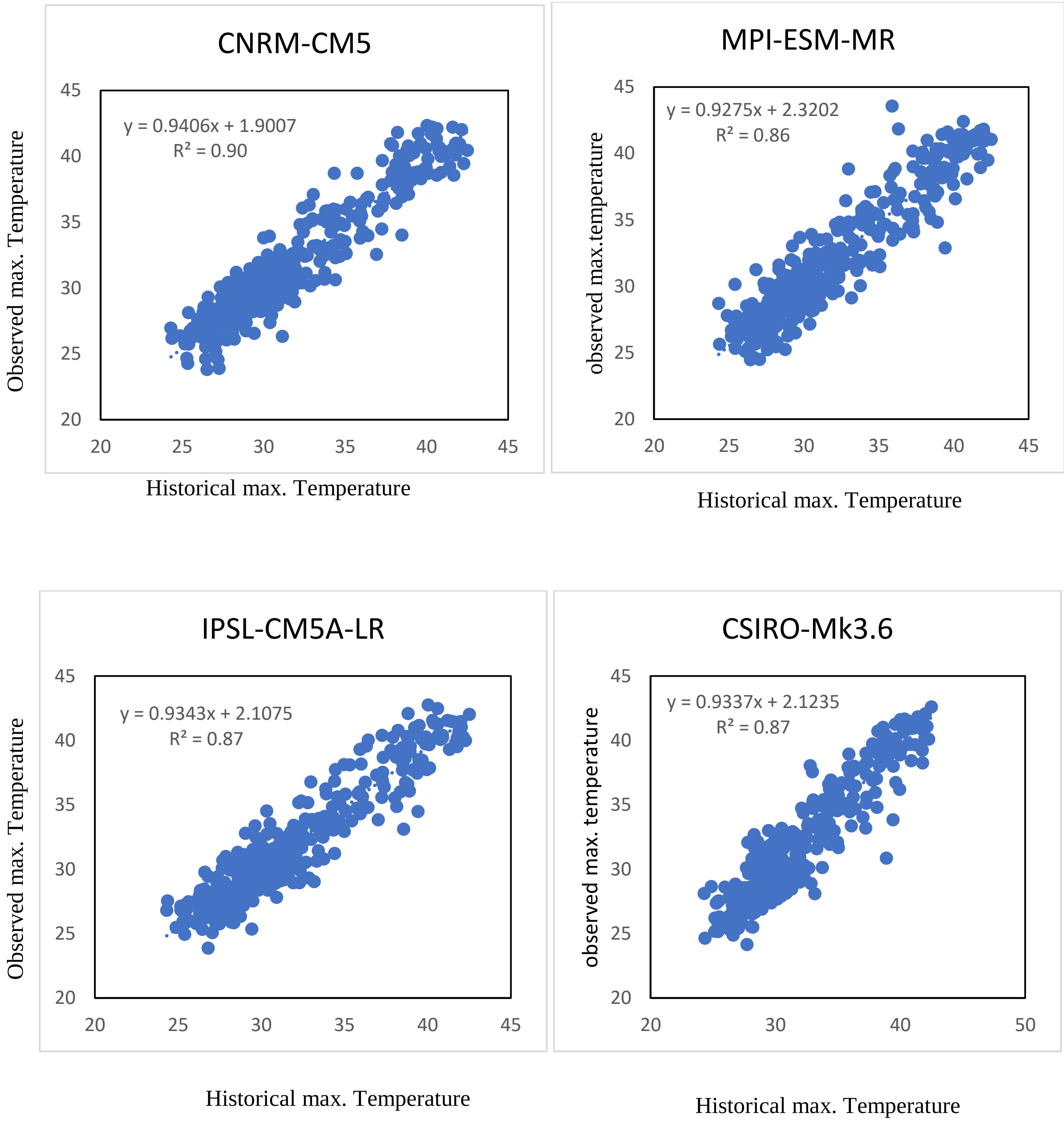


Fig. 5.16 Correlation between IMD and different climate models maximum temperature for historical period

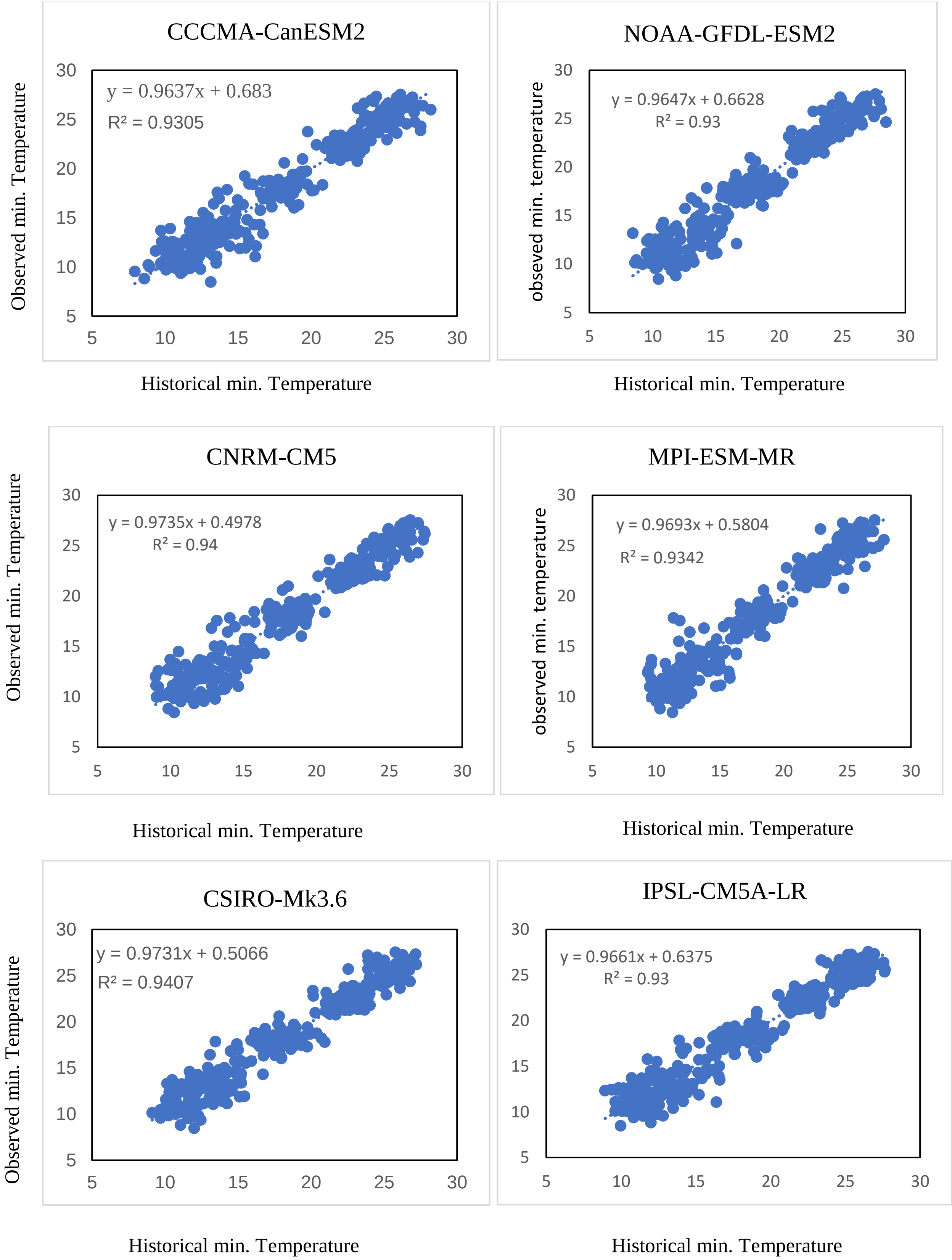


Fig. 5.17 Correlation between IMD minimum temperature and different climate models minimum temperature temperature for historical period

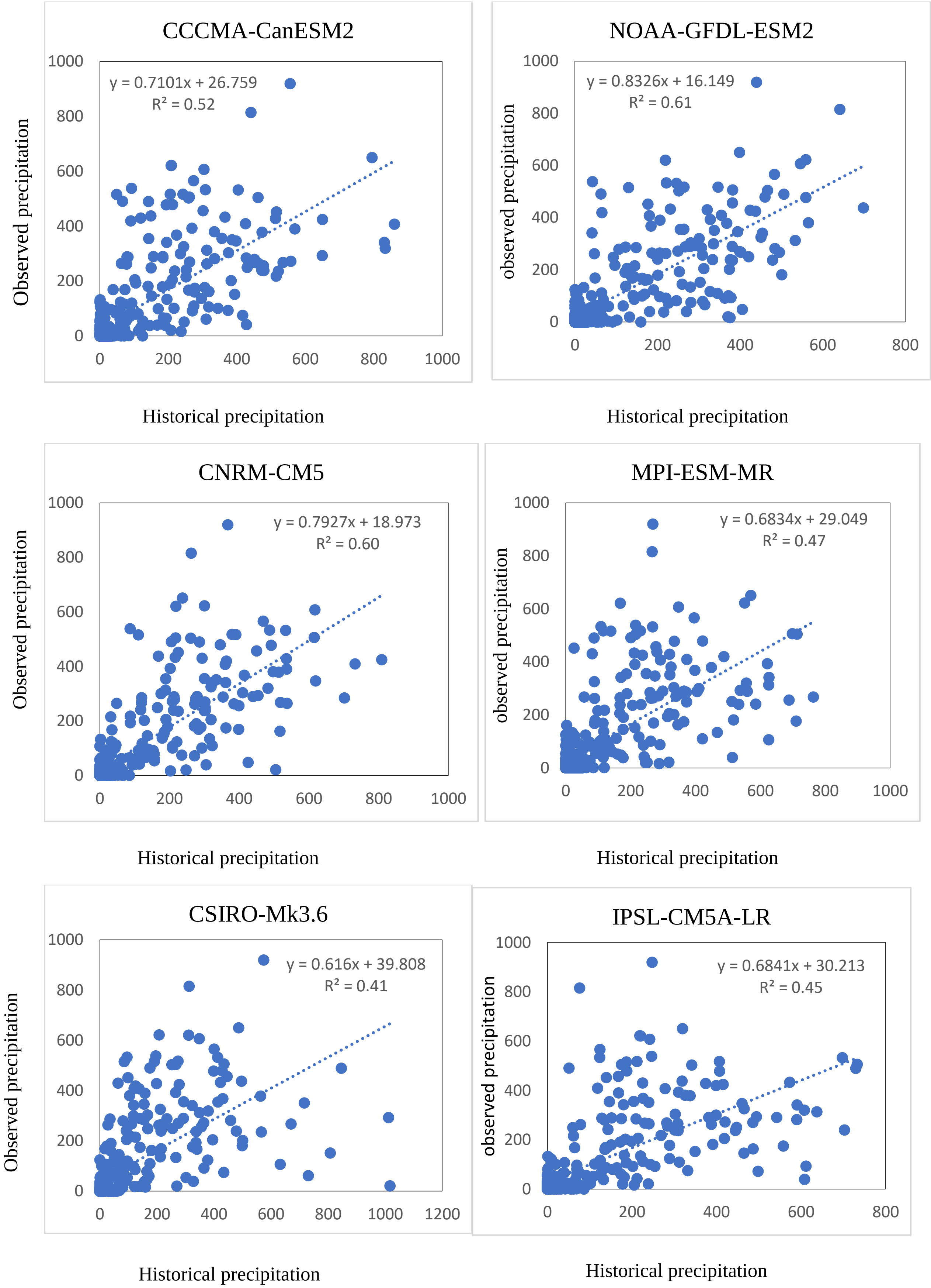


Fig.5.18 Correlation between IMD and different climate models precipitation for historical period

6. Results

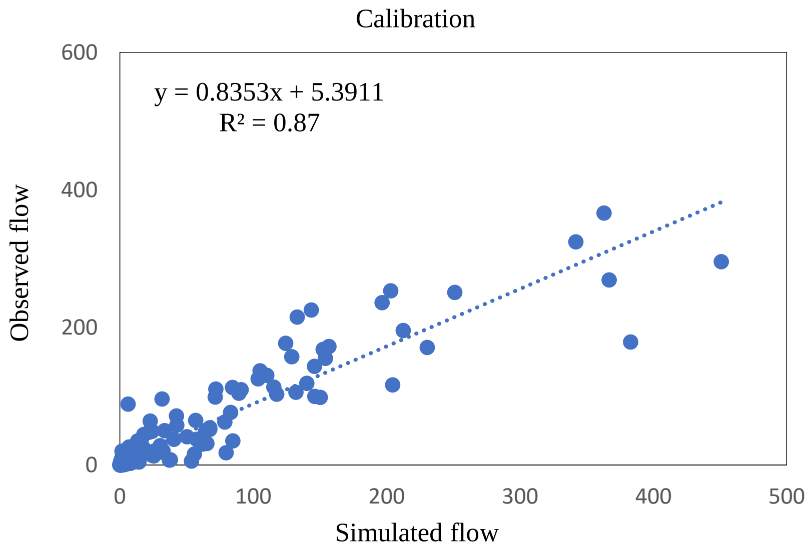
6.1 calibration and validation

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 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. Table 5 shows the outcome of the calibration and validation process. Fig.6.1 shows correlation between observed and simulated flow and fig.6.2 represents it graphically.

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. This shows very good performance of SWAT model. For flow simulation model performance is considered very good if $0.75 < NSE < 1$ and $0.75 < R^2 < 1$ .Thus, calibrated model can be used for future climate change impact studies.

Table 6.1. Evaluation of SWAT model performance

Station	Calibration		Validation	
	R^2	NSE	R^2	NSE
Chhidgaon	0.87	0.87	0.85	0.85



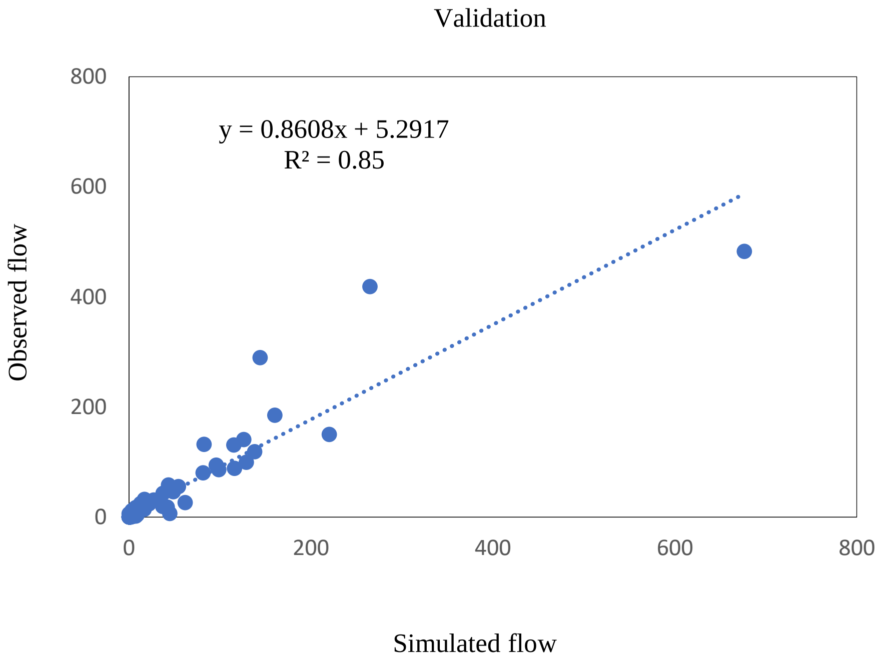


Fig.6.1 Correlation between monthly observed and simulated streamflow of Ganjal river in calibration (1988-2007) and validation (2008-2015)

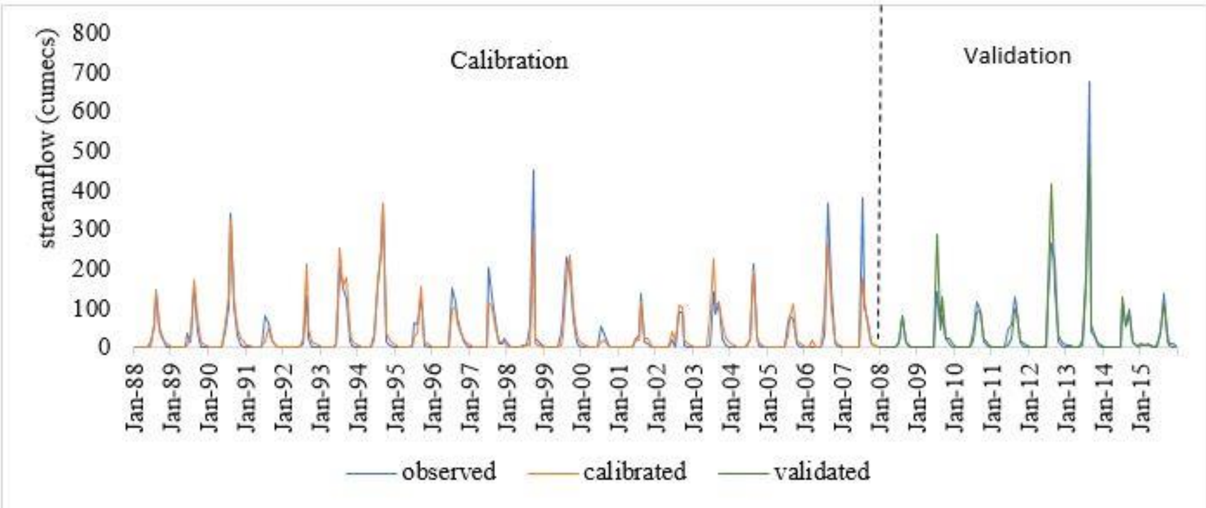


Fig. 6.2 Graphical representation of observed streamflow with SWAT simulated streamflow for calibration (1988-2007) and validation (2008-2015) period

6.2 Projected change in precipitation and temperature

Ganjal river receives rainfall only in summer monsoon (June to Sept) (figure 6.4), 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 6.3). 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 6.3 for both RCP scenarios. Under 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.6.4(b)). 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 ^{o} 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 ^{o} C while under RCP 8.5 CCCMA-CanESM2 shows highest increase in maximum temperature of +1.12 ^{o} C. CCCMA – CanESM2 and CNRM- CM5 shows + 0.8 ^{o}C and +0.67 ^{o}C increase under RCP 4.5. Under RCP 8.5 NOAA-GFDL-ESM2 and CNRM-CM5 shows increment of +1.11^{o}C and +0.8^{o}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

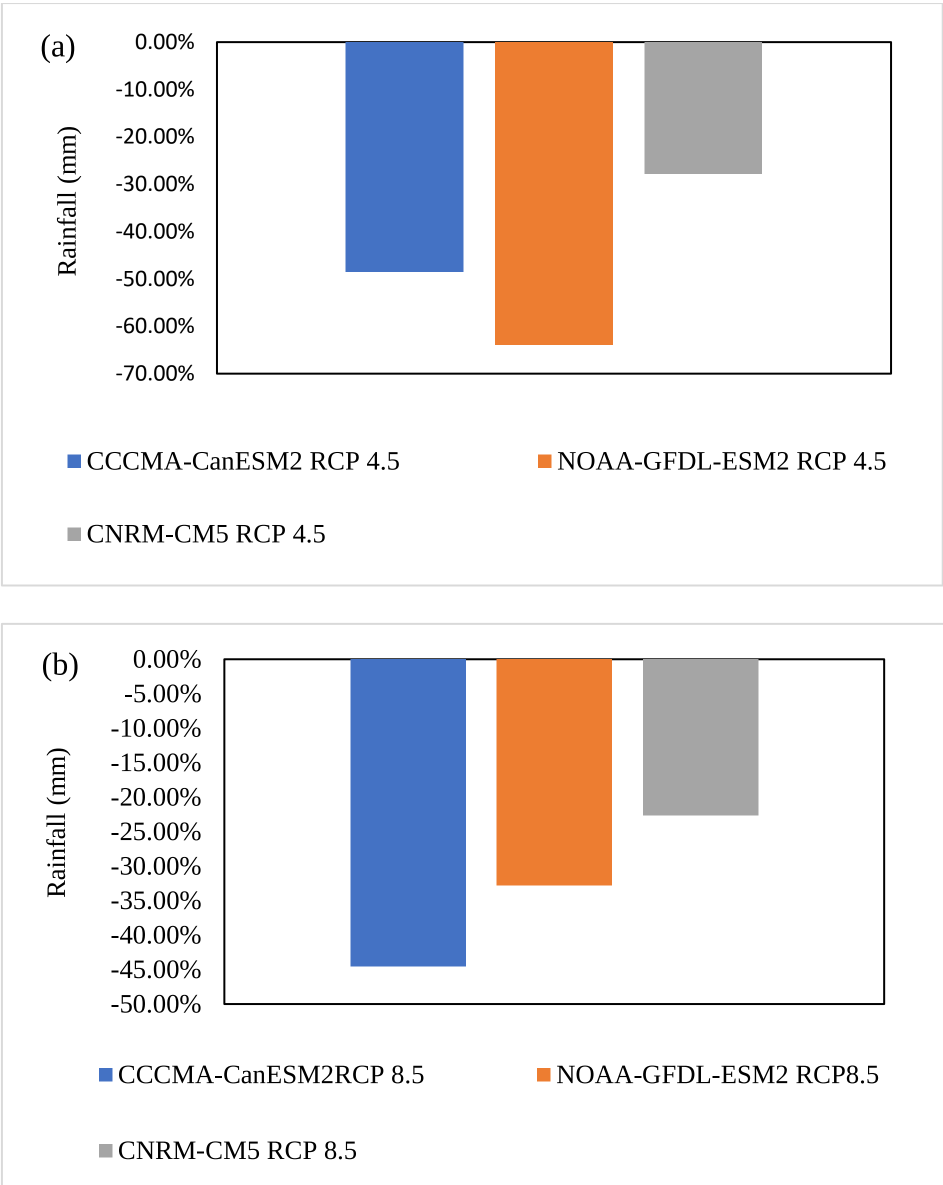


Figure 6.3 Average annual rainfall comparison with baseline rainfall for Ganjal watershed for (a)RCP 4.5 (b) RCP 8.5

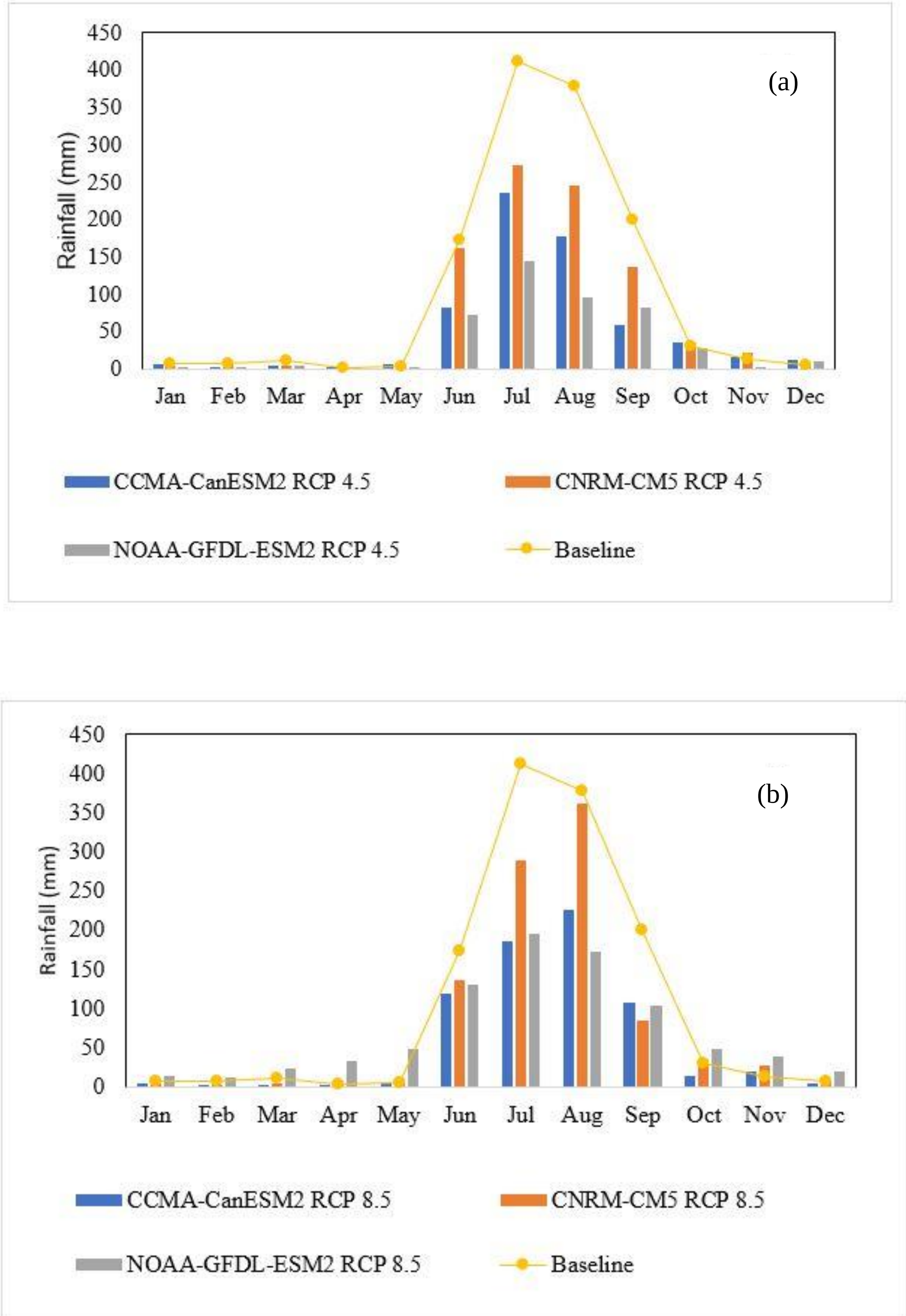


Figure 6.4 Average monthly rainfall comparison with baseline rainfall for Ganjal watershed for (a)RCP 4.5 (b) RCP 8.5

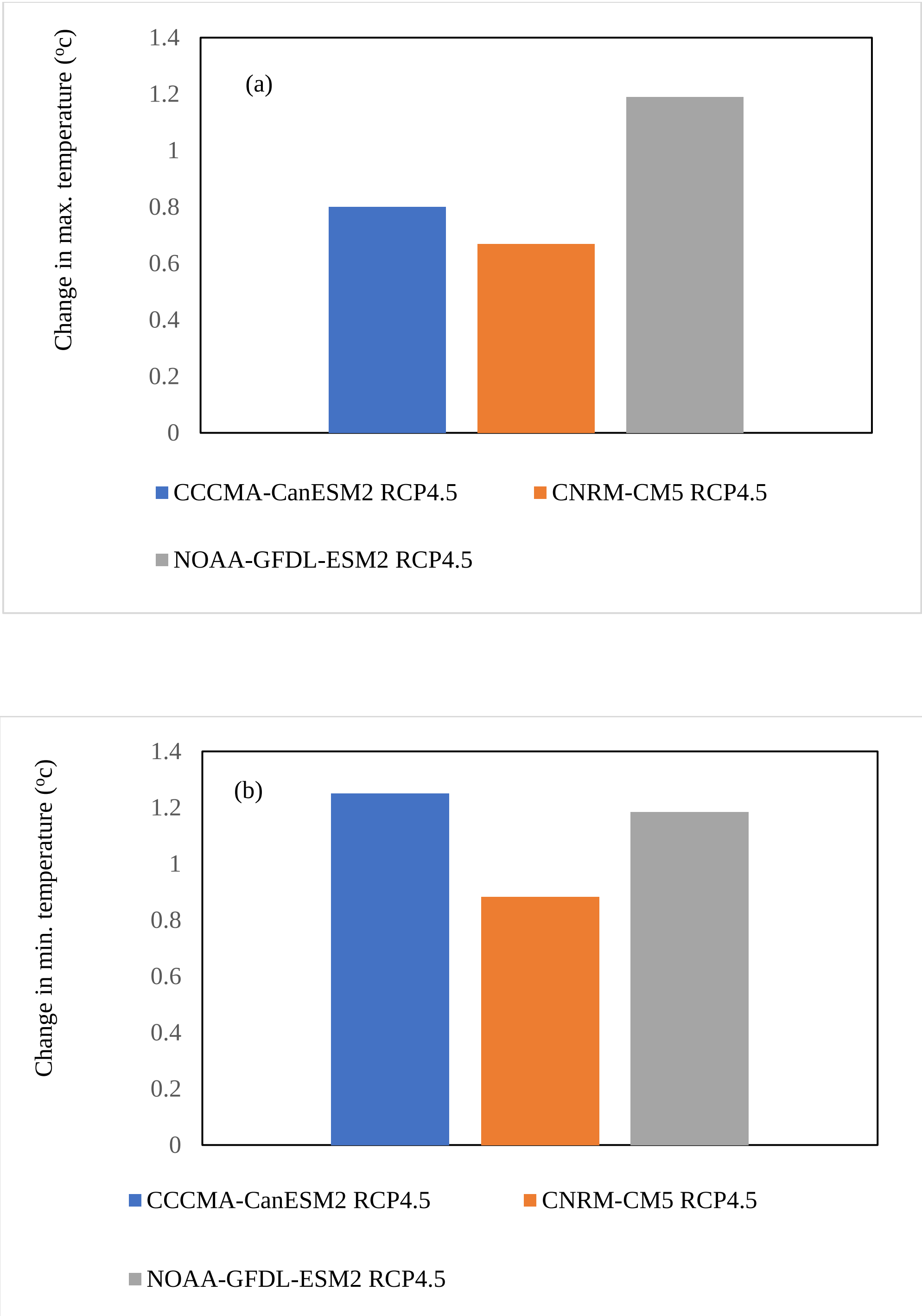
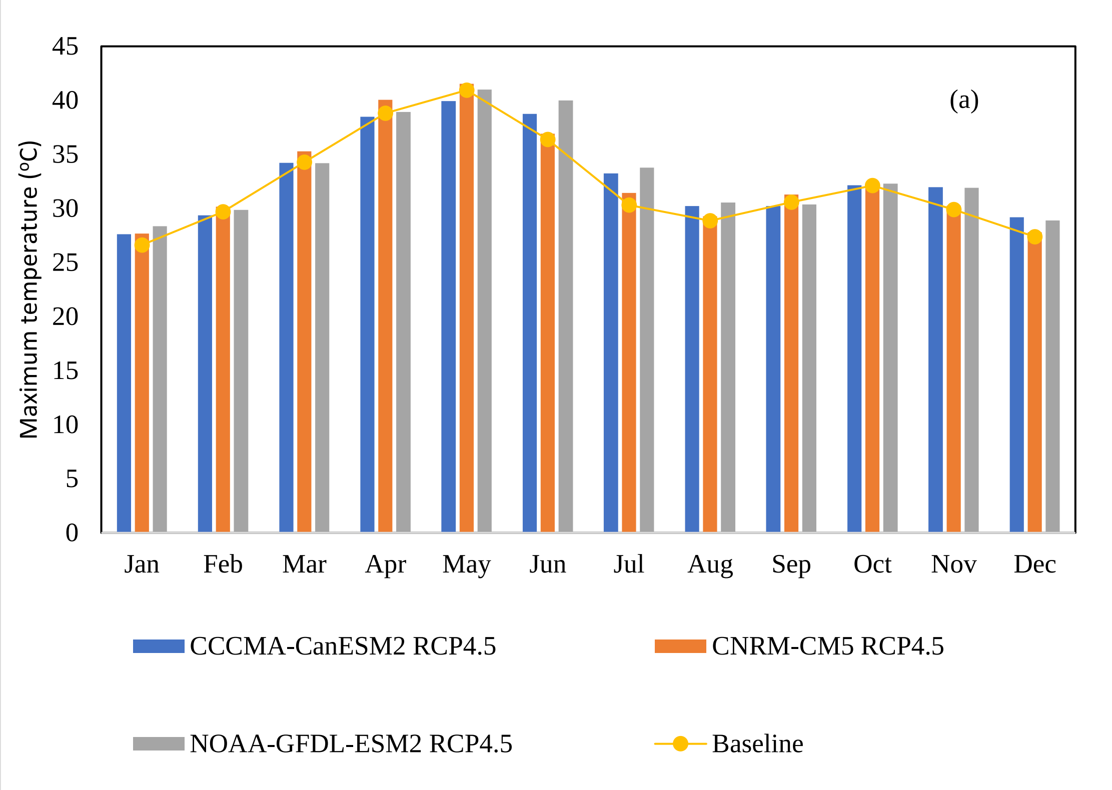


Fig.6.5 change in average annual (a) maximum and (b) minimum temperature as compared to baseline period for RCP 4.5



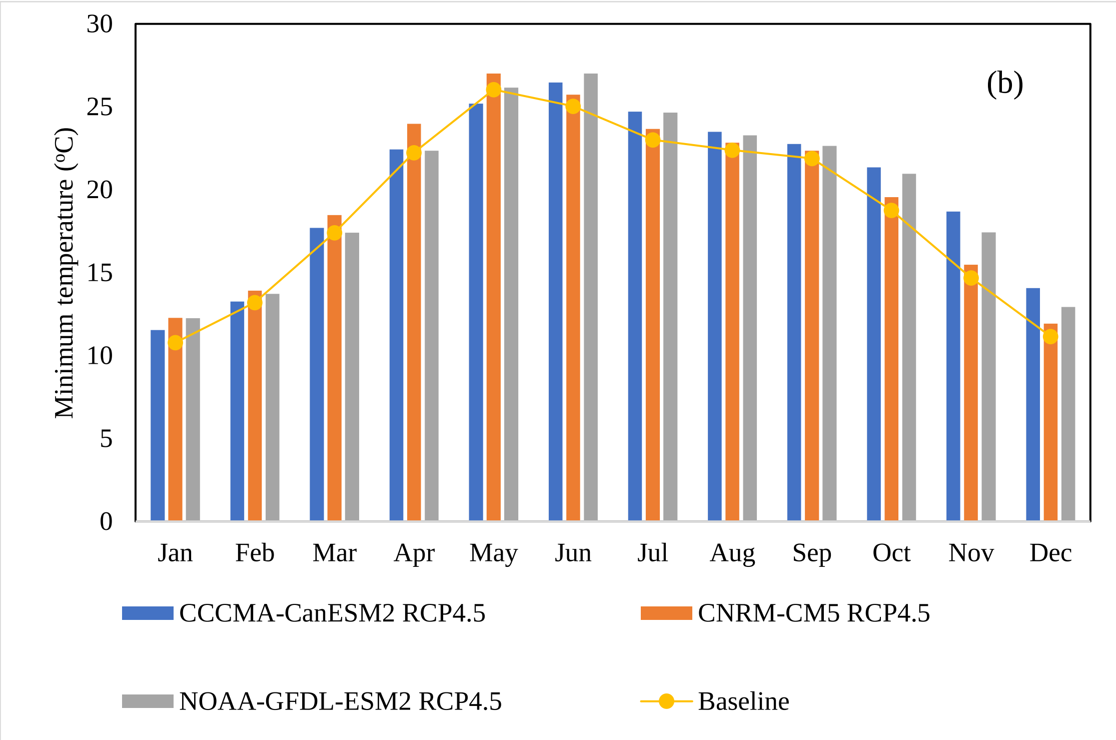


Figure 6.6 average monthly (a) maximum temperature and (b) minimum temperature variation for RCP 4.5

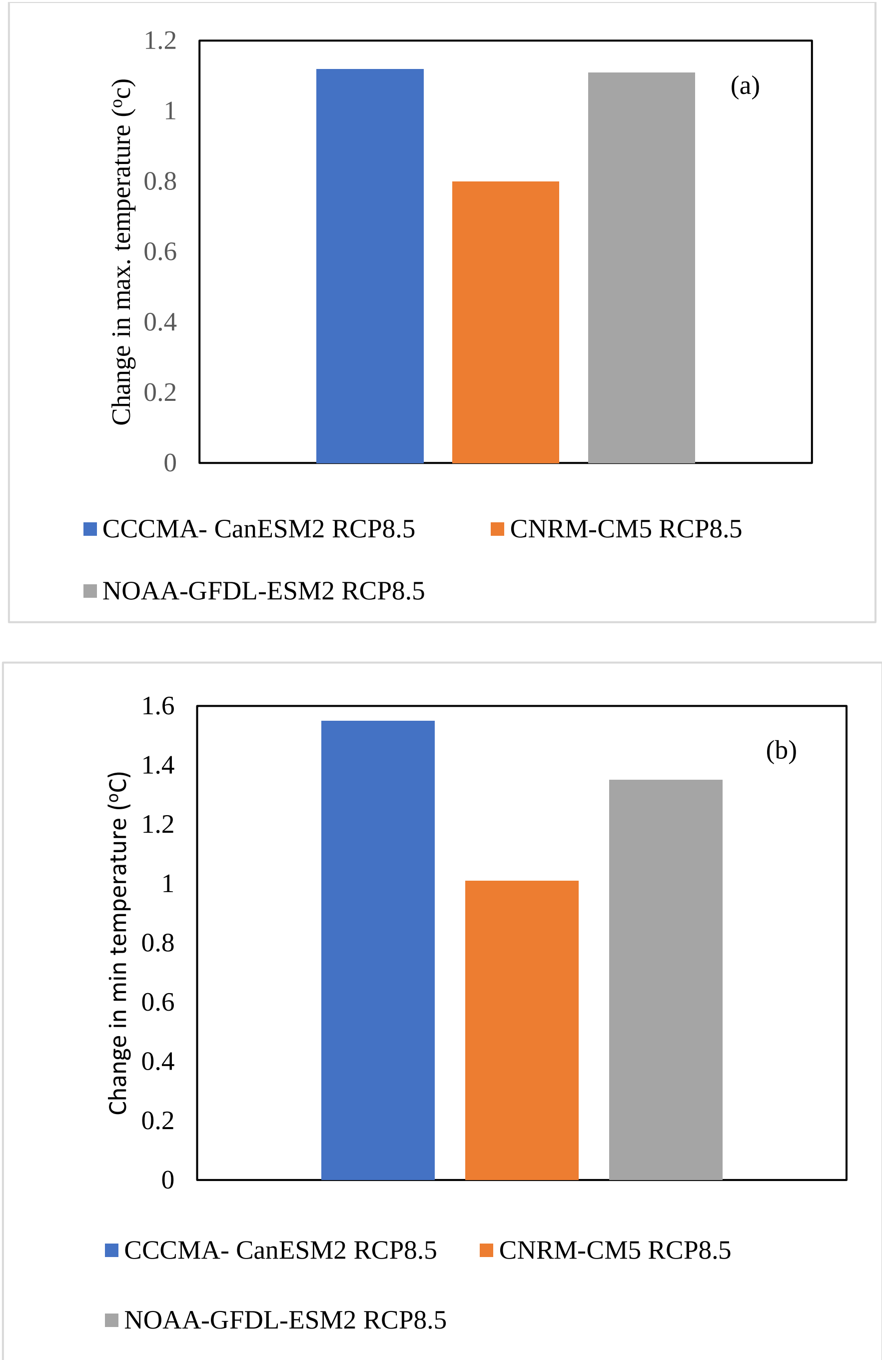
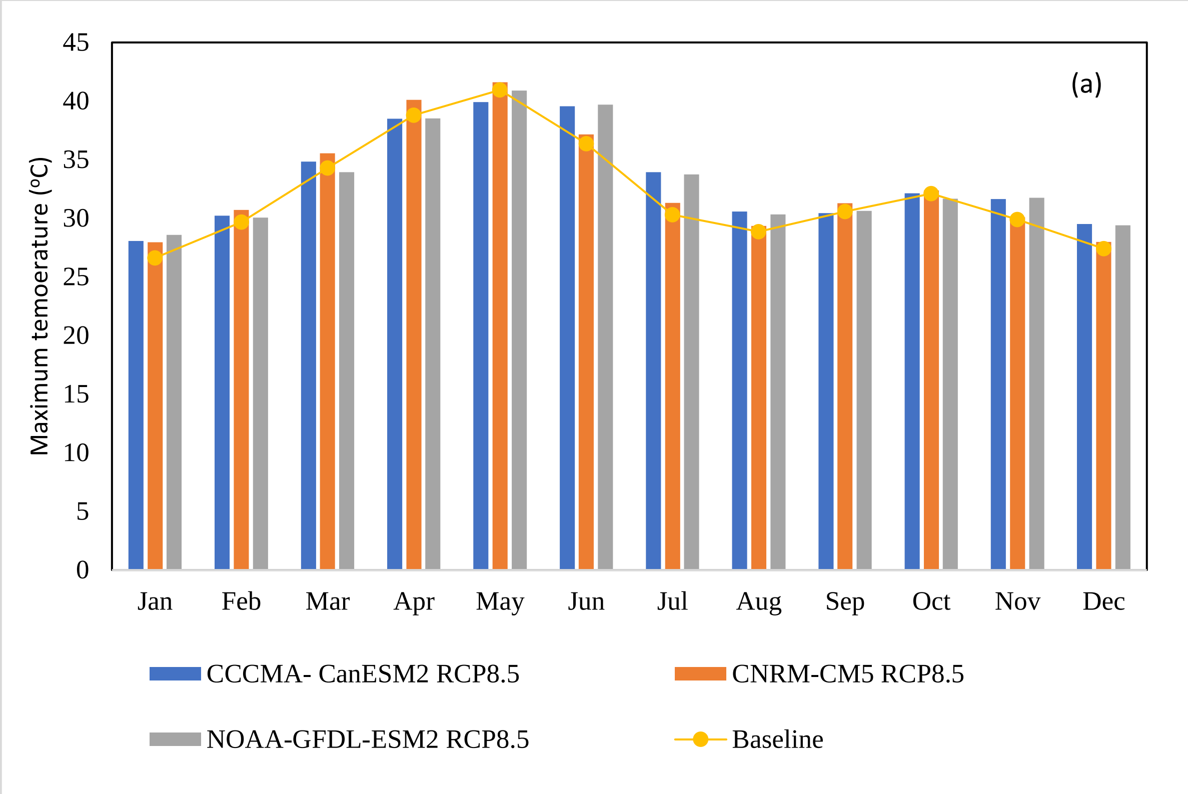


Figure6.7 change in Average annual (a) maximum and (b) minimum temperature as compared to baseline period for RCP 8.5 scenario



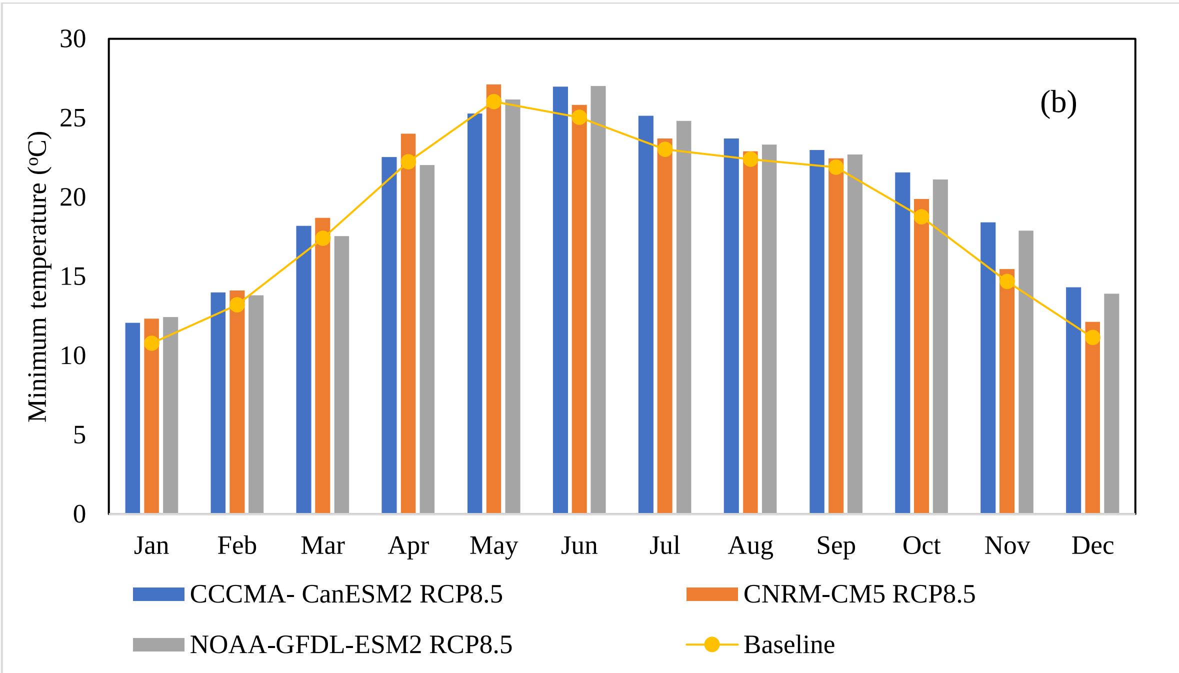


Figure 6.8 average monthly (a) maximum temperature variation (b) minimum temperature variation for RCP 8.5 scenario

6.3 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. 2 .A wide range of rainfall is projected by climate models. All the models show a decrease in precipitation (PRECIP) for future period (table 6). 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 average precipitation (PRECIP) of 1247.20 mm. The average monthly precipitation is shown in figure.6.4. 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.

Table 6.2 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-CanESM2	RCP4.5	642.4	241.74	250.38	399.5
	RCP 8.5	691.9	279.92	288.61	414.1
NOAA-GFDL-ESM2	RCP4.5	450	182.7	186.13	275.2
	RCP 8.5	838.2	153.4	188.04	653.7
CNRM-CM5	RCP 4.5	901	320.92	341.76	567.5
	RCP 8.5	964.5	388.67	420.44	551

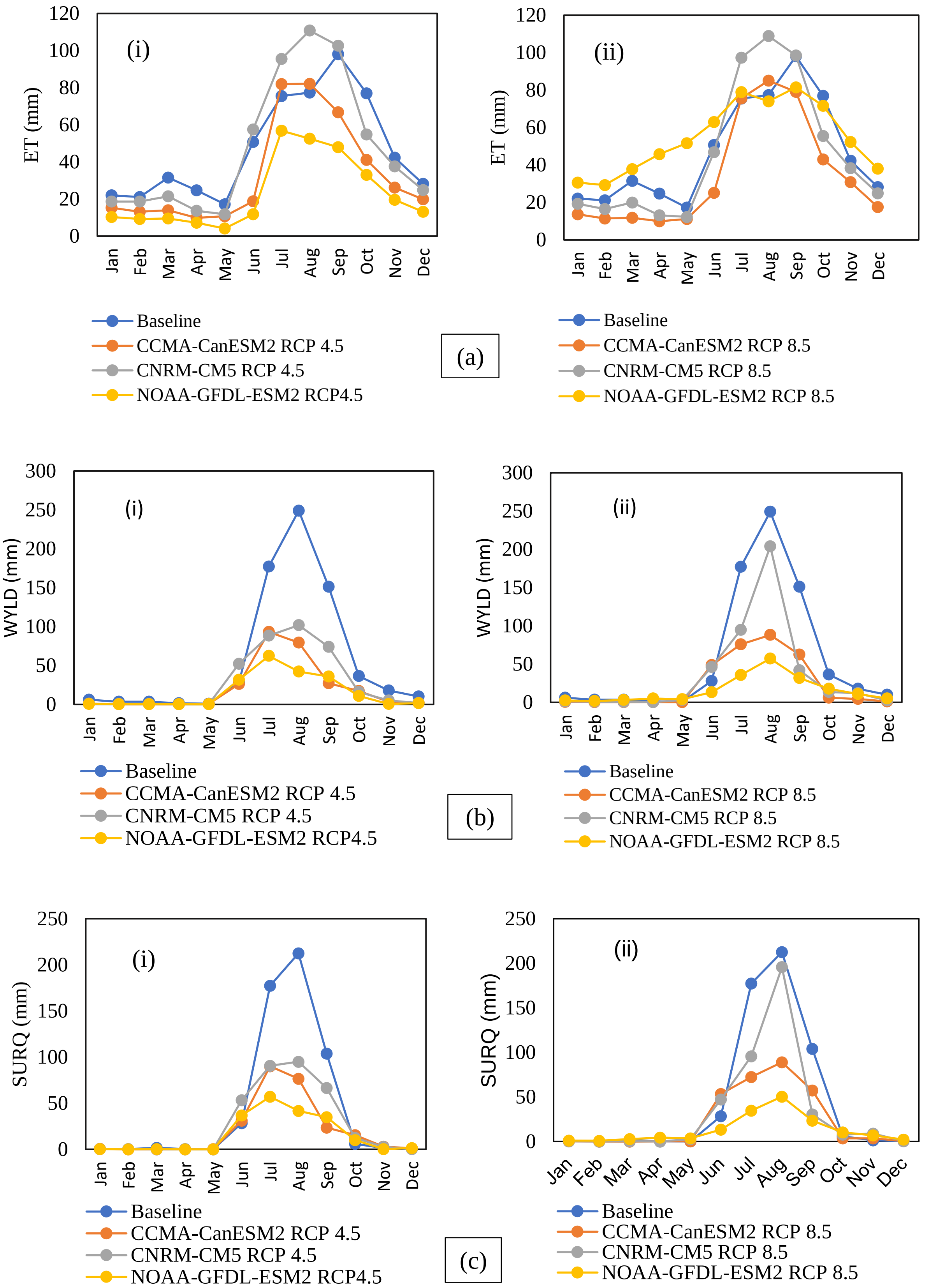


Figure 6.9 Comparison of average monthly value of different water balance component (a) Evapotranspiration (ET) (b) water yield (WYLD) (c) surface runoff (SURQ) in both (i) RCP 4.5 and (ii) RCP 8.5

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 (figure10). As monsoon, arrive in June SURQ and WYLD start in June reaching their maximum value in August.

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-GFDL-ESM2 under both scenario shows the lowest value for Average annual SURQ and WYLD.

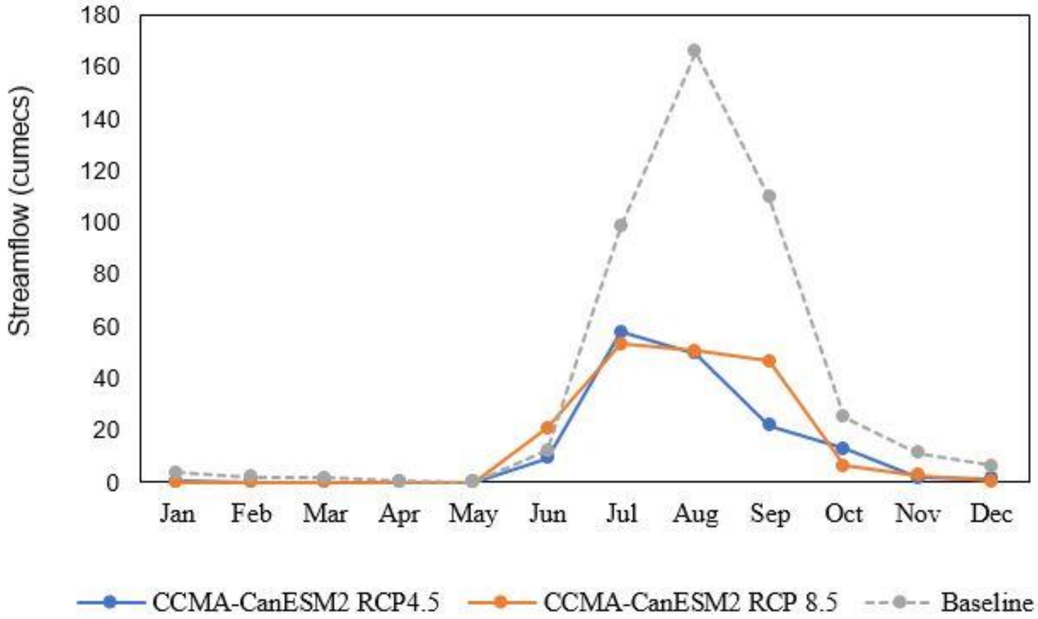
6.4 Impact on streamflow

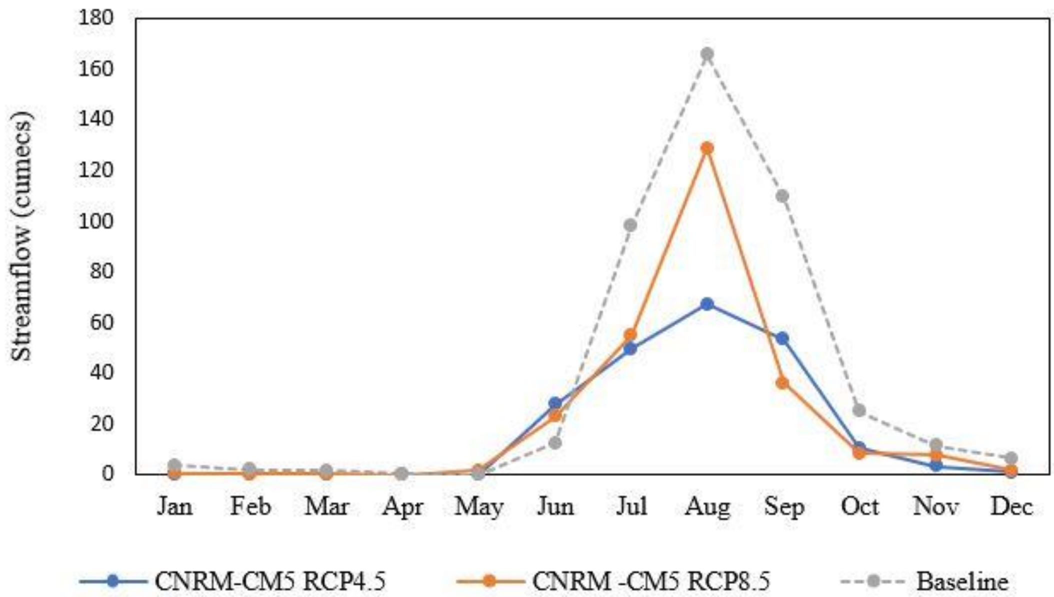
The calibrated SWAT model was further used to estimate streamflow for a future period (2025-2052). Figure 6.10 shows the average monthly streamflow comparison of baseline (1988 – 2015) with the future period under each scenario RCP4.5 and RCP 8.5. As Ganjal watershed receives rainfall during the monsoon 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 (figure 6.11). 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) (figure6.10).

CNRM-CM5 shows a decrease of 51.2 % and 40% in average annual streamflow value in RCP4.5 and 8.5 (figure 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 6.11). A shift of peak for streamflow was observed from August to July for 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 35.4m^3/sec.





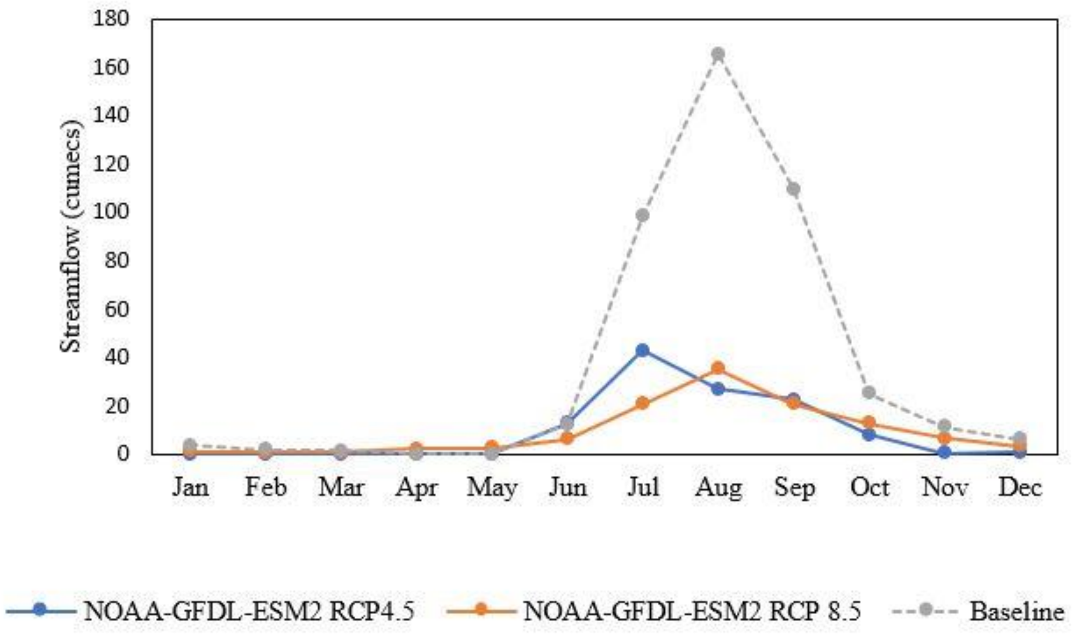


Figure 6.10 Average monthly streamflow at outlet of Ganjal watershed for (a) CCCMA-CanESM2 (b) CNRM – CM5 (c) NOAA-GFDL-ESM2

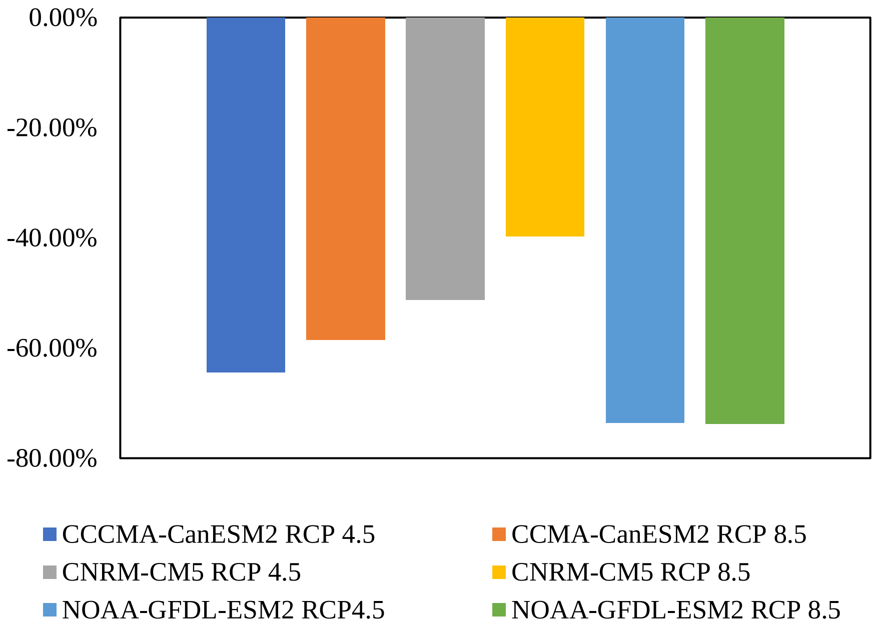


Figure 6.11 comparison of average annual streamflow with baseline streamflow

7. 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 & 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 & 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 constant LULC map .The result will be impacted by future irrigation schemes and other land use pattern changes in the study area.

9. 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 high 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 ^{o}C to +1.2 ^{o}C. for RCP 4.5. Under RCP 8.5 it varies from +0.8 ^{o}C to +1.1 ^{o}C. For minimum temperature increment varies from +0.88 ^{o}C to +1.25 ^{o}C under RCP 4.5 whereas under RCP 8.5 it varies from +1 to +1.55^{o}C

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