

# *Assessment of the Effect of Climate Change on the Hydrology in Seti Gandaki River Basin : A Case Study of Seti Khola Hydropower Project*

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## Research Paper

# *Assessment of the Effect of Climate Change on the Hydrology in Seti Gandaki River Basin : A Case Study of Seti Khola Hydropower Project*

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## ABSTRACT

Climate change poses substantial challenges for the development of hydropower. In this country, there are numerous perennial rivers that are unused. Understanding past, present, and future changes in temperature and precipitation will help to adapt to climate change. Using the RCP4.5 and RCP8.5 scenarios, this study investigates how rainfall, maximum temperature, and minimum temperature have been impacted by climate change in the Seti Gandaki River, Nepal. The Soil and Water Assessment Tool (SWAT) was set up for this study with a calibration period from 2009 to 2015 and a validation period from 2015 to 2018, both with a 3-year warm-up period. Temperature and precipitation projections for the future were obtained from the Canadian Earth System Model Version 2 (CanESM2). Using the Statistical Downscaling Model (SDSM), large-scale atmospheric variables from the National Centre for Environmental Prediction/National Centre for Atmospheric Research reanalysis (NCEP/NCAR) datasets were downscaled for several emission scenarios. Two distinct scenarios, RCP4.5 and RCP8.5 of the CanESM2 model, were applied to observe the change in precipitation, maximum temperature, and minimum temperature for future periods (2022-2040, 2046-2064). In the RCP4.5 and RCP8.5 scenarios for the years 2022–2040, respectively, it was found that precipitation would drop by 3% and 1.07% annually, the maximum temperature would fall by 0.03% and increase by 0.11%, and the minimum temperature would rise by 0.37% and 0.44%. Under the RCP4.5 and RCP8.5 scenarios, respectively, for the years 2046–2064, precipitation would drop by 5.07% and 0.57%, the maximum temperature would increase by 0.08% and 0.21%, and the minimum temperature would also increase by 1.45% and 1.60%. Additionally there has been a noticeable drop in flow.

**Keywords:** SWAT, SDSM, Climate change, RCP 4.5, RCP 8.5, Streamflow

## INTRODUCTION

Climate change has become a major global issue. It is determined by identifying the variations in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle levels, and other meteorological factors within a particular area over an extended duration (Basnet et al., 2020). The earth's climate system is continuously changing as a result of human activity, which has led to an increase in temperature, changes in precipitation patterns, and the melting of snow-glaciers. The Intergovernmental Panel on Climate Change (IPCC) foresees an increase in the average temperature of about 1°C by 2025 and a 3°C rise by the end of the following century (Mansell, 1997). Climate change is a key global challenge of the twenty-first century. This research uses the Soil and Water Assessment Tool to evaluate how climate change will affect the hydrology of the Andasa watershed (2013–2099). It projects temperature increases of 0.4–8.5 °C and variable changes in rainfall, which could have negative effects like increased potential evapotranspiration, decreased stream flow, and decreased soil water. Adaptive agricultural water management strategies may be necessary in response to these moisture constraints ———(Tarekegn et al., 2022).

Using SWAT hydrological model, under A1B emission scenarios, annual stream flow is expected to decrease by 2.4% to 4.4%, while changes in sediment load range from -1.4% to 4.5% (Nguyen Khoi and Suetsugi, 2013). In order to assess the effects of climate change on soil erosion, this study examines how well the Soil and Water Assessment Tool (SWAT) model simulates sediment flow in arid and semi-arid watershed areas. To do this, the Sequential Uncertainty Fitting ver. 2 (SUFI-2) algorithm is used for uncertainty assessment and calibration. The study's findings show satisfactory results after a 3-year validation period and identify important parameters for sensitivity analysis ———(Hosseini and Khaleghi, 2020). The effectiveness of the Statistical Downscaling Model (SDSM) in obtaining local-scale temperature and precipitation data from global climate models is assessed in this study. Reasonable results are obtained when using predictors from the observed climate, but the reliability is decreased when using predictors from the General Circulation Model. This indicates the difficulties and constraints associated with downscaling for hydrologic modeling in Québec river basins (Gagnon et al., 2005). The CGCM4/CANESM2 global climate model and the Statistical Downscaling Model (SDSM) are used in this study to project future variations in temperature and precipitation in the Gandaki River basin, Nepal. It is found that both temperature and precipitation have been increasing overall, with the arid region spotting the highest rise in precipitation. Spatial consistency is observed for temperature but not for precipitation across different emission scenarios and future periods (Shrestha et al., 2021).

Utilizing the CanESM2 dataset downscaled with the Statistical Downscaling Model (SDSM), this study addresses the high uncertainty in Himalayan climate change predictions. The results show projected increases in temperature and precipitation across representative concentration pathways (RCPs) up to 2100, with implications for geodisasters and future management strategies in the region (Khadka and Pathak, 2016). With a notable decrease in temperate and polar climates, this study evaluates climate boundary shifts in Nepal from 1960 to projected near/mid-future (1950s: 2040–2060 /1970s: 2060–2080) using the Köppen–Geiger

classification scheme. This highlights the significance of this information for various sectors, including agriculture, disaster risk reduction, and infrastructure planning under various Representative Concentration Pathways (RCPs) — (Talchabhadel and Karki, 2019). By creating high-resolution climate projections for Ethiopia, Kenya, and Tanzania using large-scale climate variables and observed daily data from 211 stations, this study addresses the problem of coarse spatial resolution in global climate models (GCMs). The Statistical Down-Scaling Model (SDSM) is used to create 20 ensembles for current (1961–2005) and future (1961–2100) under RCP2.6, RCP4.5, and RCP8.5 climate scenarios, improving the applicability of climate projections for impact assessment and adaptation studies at the regional and local level — (Gebrechorkos, Hülsmann and Bernhofer, 2019).

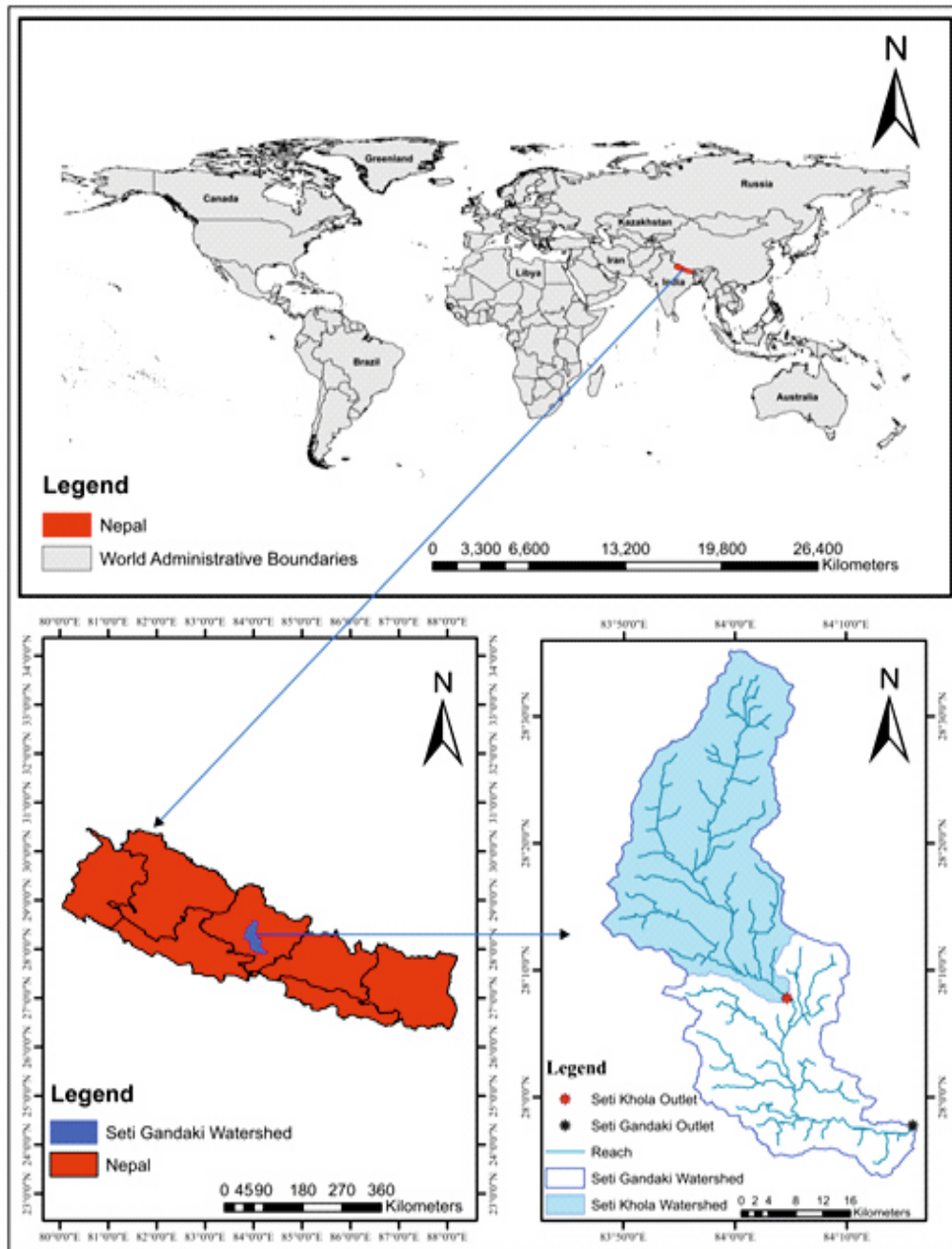
This paper presents the Statistical Downscaling Model (SDSM), a decision support tool employing a strong statistical downscaling method to produce various cost-effective, single-location scenarios for daily surface weather variables — (Wilby, Dawson and Barrow, 2002). The results of the study show significant fluctuations in temperature (−7% to +7%) and precipitation (+12% to +50%), and stream flow in the basin varies from −40% to +85% (Maharjan et al., 2021). In the Karnali River basin of Nepal, this study uses the Soil and Water Assessment Tool (SWAT) to demonstrate the tool's good performance in hydrological simulation. It focuses on water balance and the contribution of snowmelt, finding that snowmelt accounts for about 12% of the annual runoff volume (Dhami et al., 2018).

Increasing trends in annual rainfall and maximum and minimum temperatures are noted, and this leads to a projected increase in annual stream flow of 6–12.5%, with positive changes in monthly runoff patterns for water users in the future — (Mishra et al., 2018). This study focuses on evaluating the impact of climate change on precipitation, maximum temperature, and minimum temperature in the Seti Gandaki River in Kaski, Nepal, emphasizing the significance of considering climate variability in the planning, design, and operation of hydraulic structures, particularly for hydropower, as it is a reliable, cost-efficient, and low-carbon source of energy. The research involves downscaled climate data to observe variations in precipitation and temperature.

## MATERIALS AND METHODS

### Study Area

The Seti Khola Hydroelectric Project, a run-of-river system with an installed capacity of 22 MW and a gross head of 68 meters and a design plant discharge of 39.91 m<sup>3</sup>/s, is located in Bharatpokhari, Pokhara-33, Kaski, Nepal. Currently under construction, the dam site is located at latitude 28°7.82'49" and longitude 84°4.65'39.5". Catchment area was approximately 858.35 km<sup>2</sup> (Fig. 1).



## Data Used

Data used in SWAT are Digital Elevation Model (DEM), soil type, land use and land cover, and weather information.

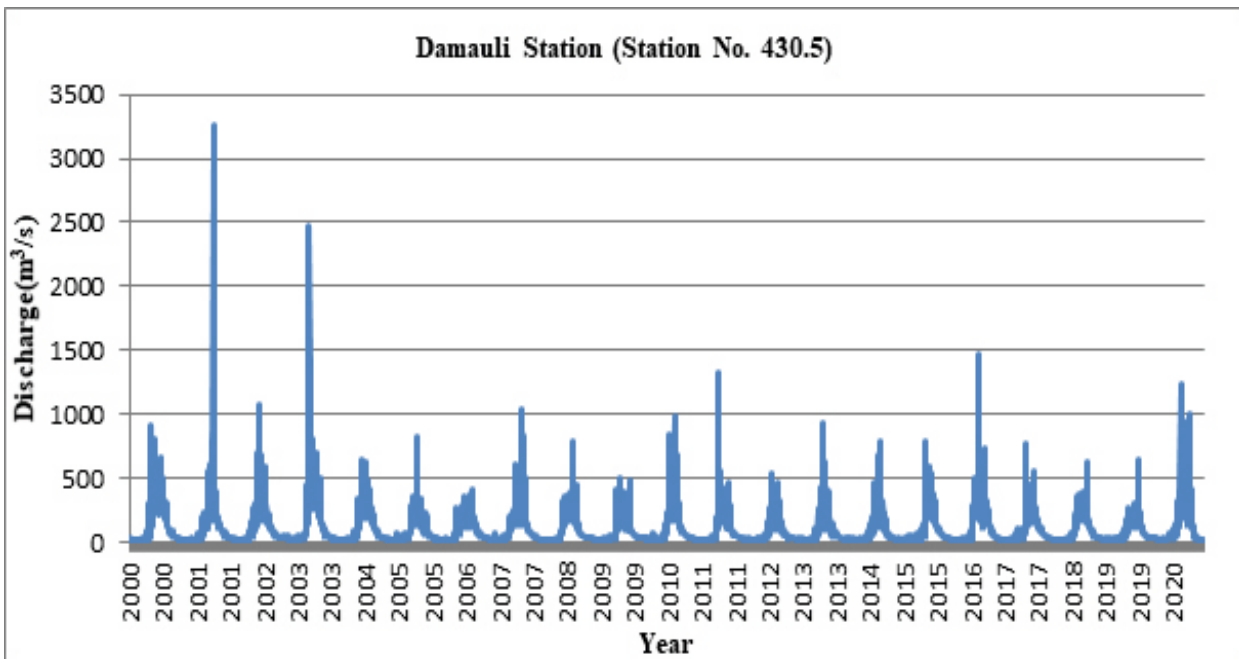
## Hydro-climatic data

The datasets, their sources/resolution used in this study are presented in Table 1.

**Table 1.** Sources of Datasets

S.N.	Data Type	Resolution	Source
1	Digital Elevation Model (DEM)	30 m	Shuttle Radar Topography Mission (SRTM)
2	Land use / Land cover	30 m	<a href="http://rds.icimod.org/Home/DataDetail?metadataId=1972729">http://rds.icimod.org/Home/DataDetail?metadataId=1972729</a>
3	Soil data		FAO Digital Soil Map
4	Rainfall and Temperature	Daily	Department of Hydrology and Meteorology (DHM), Nepal
5	Daily Discharge	Daily	Department of Hydrology and Meteorology (DHM), Nepal

Daily discharge data of Seti Gandaki River at Damauli station (Station no. 430.5) was collected from DHM for 2000 to 2020. The peak observed flow of 3259 m<sup>3</sup>/s was recorded on 22nd August, 2001 (Fig. 2).

**Fig. 2** Time series discharge data at Damauli Station (2000-2020)

For the modelling purpose, data from six rain gauge stations were gathered from Nepal's Department of Hydrology and Meteorology (DHM) between 1990 and 2020. The temperature and rainfall data that were absent were replaced with -99. The maximum recorded temperature recorded was 40.2°C in 2001 8<sup>th</sup> November at Khairenitar station and the minimum temperature recorded was 1.4°C (Table 2).

**Table 2.** List of Weather Stations

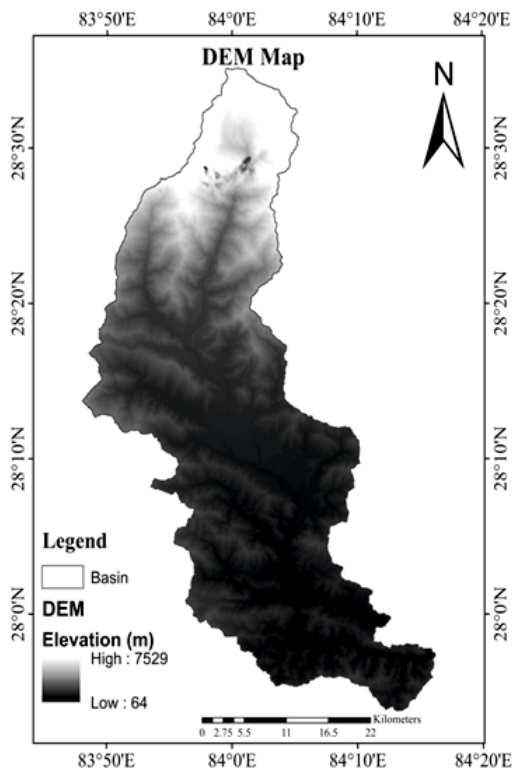
S.N.	Index	Station	Longitude (E)	Latitude(N)	Elevation(m)
1.	804	Pokhara Airport	28.13	84.00	827.00
2.	811	Malepatan	28.07	84.07	856.00
3.	815	Khairenitar	28.02	84.06	500.00
4.	817	Damauli	27.58	84.17	358.00
5.	818	Lamachaur	28.16	83.58	1070.00
6.	824	Siklesh	28.22	84.06	1820.00

### Digital Elevation Model

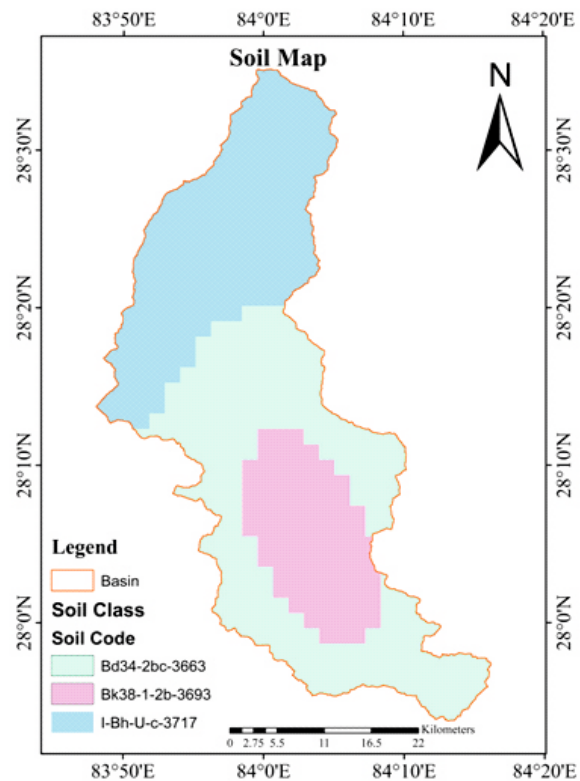
The Digital Elevation Model (DEM) of 30 m resolution from the Shuttle Radar Topography Mission (SRTM) was used and elevation ranges from 64 m to 7529 m (Fig. 3).

### Soil Data

It was discovered that these three soils are part of Hydrological group "C" of loamy texture based on user soil in the Arc SWAT database (Fig. 4, Table 3).



**Fig. 3** Digital Elevation Model of Seti Gandaki Watershed



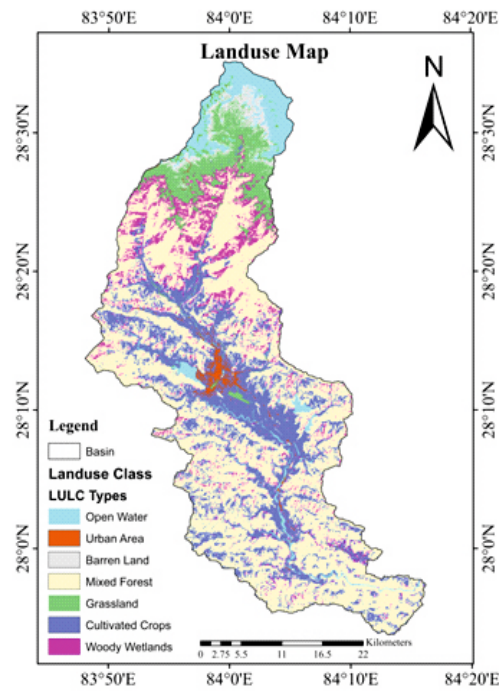
**Fig. 4** Soil classification of Seti Gandaki Watershed

**Table 3.** Soil-type distribution in Seti Gandaki watershed

S.N.	Soil Code	% Coverage
1.	Bd34-2bc-3663	44.00
2.	Bk38-1-2b-3693	19.00
3.	I-Bh-U-c-3717	37.00

### Landuse Data

From the National Land Cover Monitoring System of Nepal (NLCMS), land cover data was downloaded i.e. Land Cover Nepal 2019.tif. The necessary polygon for the watershed was resampled. After clipping the required boundary, projection of landcover and reclassification was done (Fig. 5, Table 4).

**Fig. 5** Landuse classification of Seti Gandaki watershed**Table 4.** Land Use Distribution in Seti Gandaki Watershed

S.N.	Landcover Class According to NLCD	% Coverage
1.	Open Water	6.00
2.	Urban Area	1.00
3.	Barren Land	2.00
4.	Mixed Forest	52.00
5.	Grassland	9.00
6.	Cultivated Crops	23.00
7.	Woody Wetlands	7.00

## Hydrological Modelling

With available input datas, the Soil and Water Assessment Tool (SWAT) was run. For the calibration and validation of the model, the SWAT calibration and Uncertainty Procedure Sequential Uncertainty Fitting (SWAT CUP SUFI-2) technique was used. To assess the effect of climate change Statistical Downscaling Model 4.2 (SDSM) was used (Fig. 6). Calibration and validation of model was performed at Seti Damauli station. At Seti Khola hydropower impact of climate change were studied.

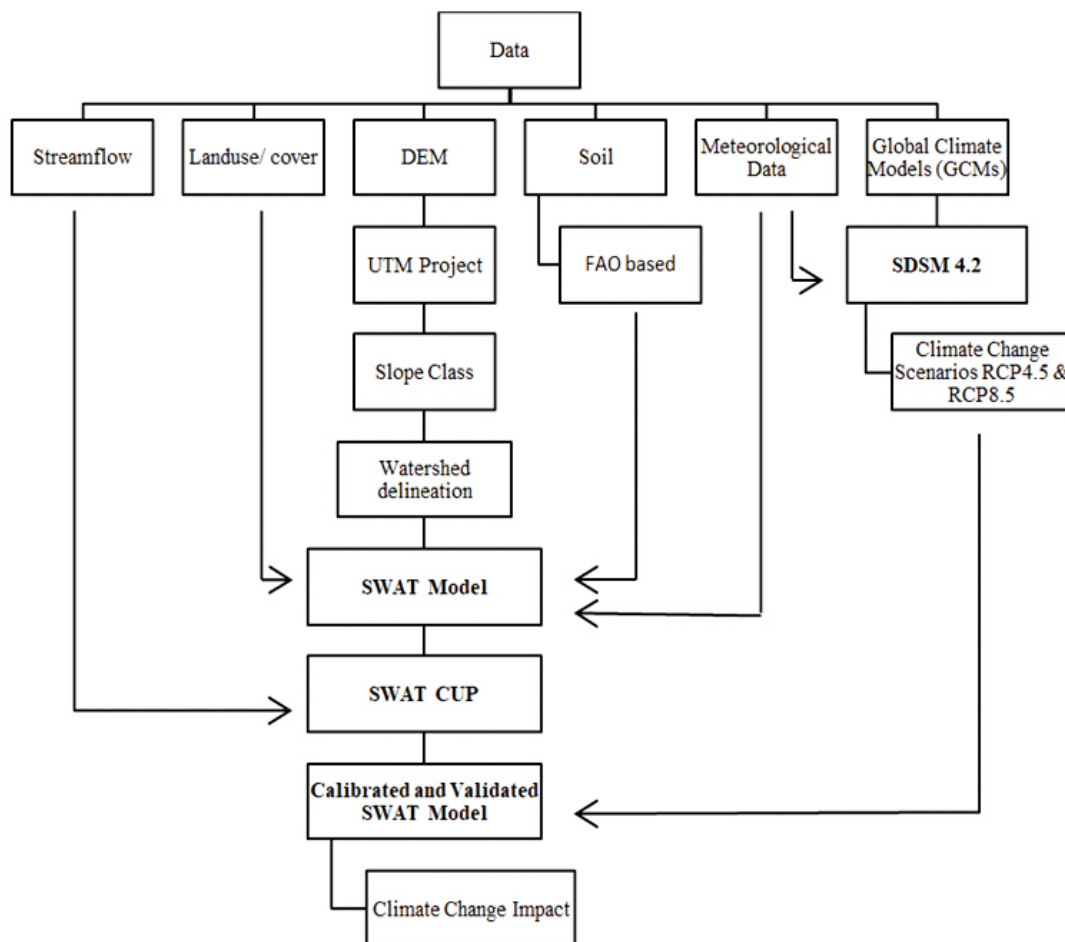


Fig. 6 Methodological flow chart of the research.

## Evaluation of Model Performance

The performance of the model is assessed by comparing the simulated and observed discharge data's mean, standard deviation, maximum daily discharge, and total discharge (Krause et al., 2005). Four statistical indices the coefficient of determination ( $R^2$ ) the Nash-Sutcliffe efficiency (NSE), the percentage bias (PBAIS), and the RMSE-observations standard deviation ratio (RSR) were used to evaluate the effectiveness of the model.

$$R^2 = \frac{(\sum_{i=1}^n (Q_{obs} - \bar{Q}_{obs}) \times (Q_{sim} - \bar{Q}_{sim}))}{\sqrt{\sum (Q_{obs} - \bar{Q}_{obs})^2} \sqrt{\sum (Q_{sim} - \bar{Q}_{sim})^2}} \quad \dots(1)$$

$$NSE = 1 - \left[ \frac{\sum_{i=1}^n (Q_{obs} - \bar{Q}_{sim})^2}{\sum_{i=1}^n (Q_{obs} - \bar{Q}_{obs})^2} \right] \quad \dots(2)$$

$$PBIAS = \left( \frac{\sum (Q_{obs} - \bar{Q}_{sim})}{\sum Q_{obs}} \right) \times 100 \quad \dots(3)$$

$$RSR = \frac{\sqrt{\sum_{i=1}^n (Q_{obs} - \bar{Q}_{sim})^2}}{\sqrt{\sum_{i=1}^n (Q_{obs} - \bar{Q}_{obs})^2}} \quad \dots(4)$$

where,  $Q_{obs}$  denotes the observed discharge,  $\bar{Q}_{obs}$  the average observed discharge, and  $Q_{sim}$  denotes simulated discharge.

## RESULTS AND DISCUSSIONS

### SWAT Model Run

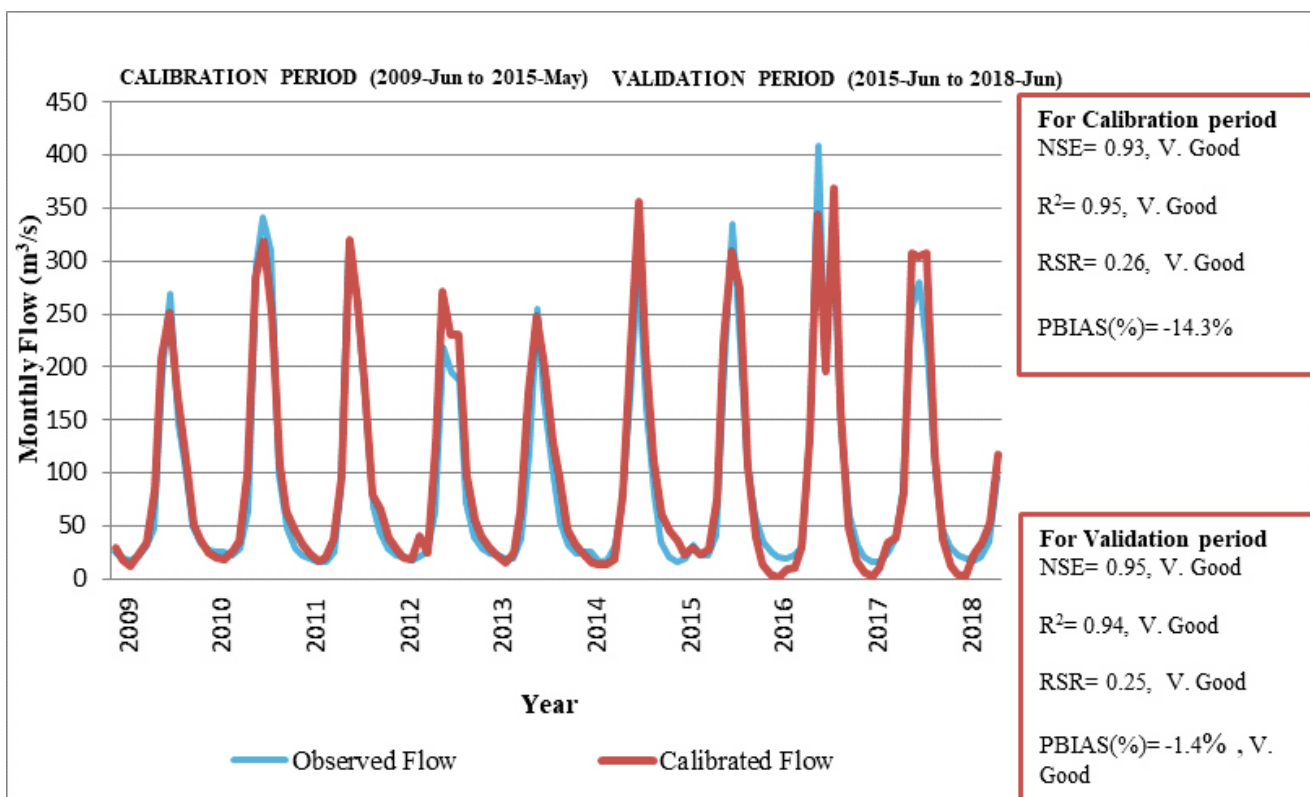
The watershed delineation in SWAT generated Seti Gandaki watershed area 1459.91 km<sup>2</sup>. Additionally, with threshold of 5 km<sup>2</sup>, 145 subbasins and 678 HRU's were generated. For subbasin number 139, the calibration period was taken from 2009 to 2015, and the validation period was taken from 2015 to 2018, both with a 3-year warm-up period of time. Using SWAT-CUP, taking 7 input parameters with objective function NSE, performing 500 simulations, were iterated for calibration and sensitivity analysis of parameters in this study (Table 5, Table 6, Fig. 7). The most sensitive parameters have p-value less than 0.05 and higher absolute t-value (Abbaspour, 2015).

**Table 5.** Adjusted parameter values for SWAT Calibration with Sensitivity Rank and Fitted Values

Parameter name	Fitted Value	Range	t-stat	p-value	Sensitivity	Remarks
1:R_CN2.mgt	-0.68	-0.73 to -0.45	-0.95	0.33		SCS Runoff Curve Number
2:V_ALPHA_BF.gw	0.79	0.78 to 0.95	1.5	0		Base flow Alpha Factor (days)
3:V_GWQMN.gw	635.36	456.46 to 785.92	9.69	0	Very Sensitive	The threshold depth of water in the shallow aquifer required for return flow to occur(mm)
4:V_GW_REVAP.gw	0.19	0.18 to 0.2	0.97	0.33		Groundwater "revap" coefficient
5:V_REVAPMN.gw	489.82	484.67 to 491.31	0.08	0.93	Less Sensitive	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)
6:V_SOL_AWC(..).sol	0.22	0.09 to 0.35	-12.22	0	Most Sensitive	Available water capacity of the soil layer
7:V_ESCO.hru	0.004	0.004 to 0.009	-0.52	0.60		Soil Evaporation Compensation factor

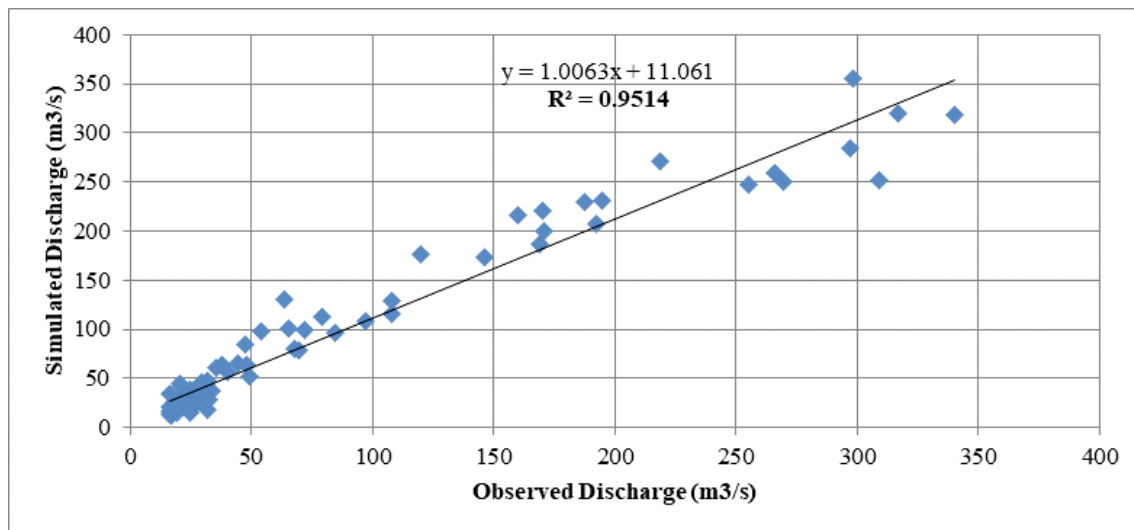
**Table 6.** Hydrologic models performance rating for stream flow (Moriassi et al., 2007)

Performance rating	RSR	NSE	PBIAS %
V. Good	$0.00 \leq \text{RSR} \leq 0.50$	$0.75 \leq \text{NSE} \leq 1.00$	$\text{PBIAS} \leq (+)10$
Good	$0.50 \leq \text{RSR} \leq 0.60$	$0.65 \leq \text{NSE} \leq 0.75$	$(+)10 \leq \text{PBIAS} \leq (+)15$
Satisfactory	$0.60 \leq \text{RSR} \leq 0.70$	$0.50 \leq \text{NSE} \leq 0.65$	$(+)15 \leq \text{PBIAS} \leq (+)25$
Unsatisfactory	$\text{RSR} > 0.70$	$\text{NSE} \leq 0.50$	$\text{PBIAS} \geq (+)25$

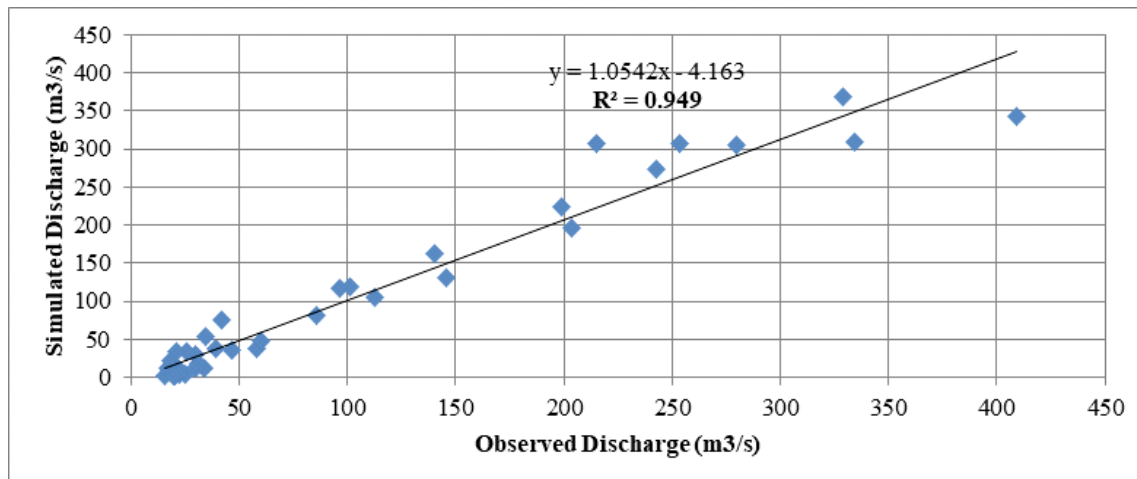


**Fig. 7** Monthly Observed and Calibrated flow hydrograph at Damauli Station

The calibrated values exhibited a strong statistical performance with  $R^2$  of 0.95, NSE of 0.93, and RSR of 0.26. Overall, the performance found to be very good, except for a slightly lower PBIAS at -14.3%, indicating good performance. In the validation period, the performance statistics of the model showed  $R^2$ , NSE, RSR, PBIAS% as 0.95, 0.94, 0.25, and -1.4% respectively. In comparison to the calibration period, the statistical performance parameters during the validation period exhibited the following changes:  $R^2$  remained unchanged, NSE increased by 1%, RSR decreased by 1%, and PBIAS decreased by 12.9%.



**Fig. 8** Coefficient of determination for monthly flow calibration (2009-2015) at Damauli station



**Fig. 9** Coefficient of determination for monthly flow validation (2015-2018) at Damauli station

## Climate Change Impact Assessment

Climate change impacts were seen on three indicators: precipitation, maximum temperature and minimum temperature. One Climate station (Khairanitar) was taken to see the effect of climate change using Statistical Downscaling Model 4.2.9 (SDSM). For the historical year NCEP predictors were used for weather generation and for future year GCM predictors were used for scenario generation. The current climate period was taken for the period 2001-2019, and future climate conditions for two periodic years 2022-2040, and 2046-2064 were calculated under RCP4.5 and RCP8.5 scenarios respectively. The research findings indicated that, between 2022 and 2040, annual precipitation is expected to decrease by 3% and 1.07% under the RCP4.5 and RCP8.5 scenarios, respectively. Looking ahead to the period from 2046 to 2064, the study suggests an annual precipitation decrease of 5.07% and 0.57% under the RCP4.5 and RCP8.5 scenarios, respectively (Fig. 10).

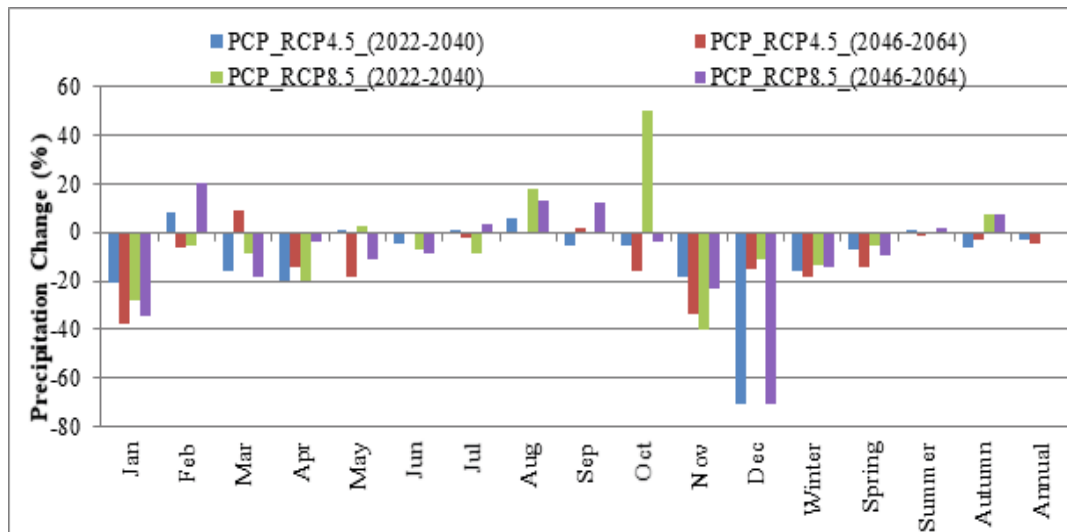


Fig. 10 Projected average monthly and seasonal precipitation changes under different scenarios

Likewise, the research findings indicated a decrease of 0.03% and an increase of 0.11% in maximum temperatures under the RCP4.5 and RCP8.5 scenarios, respectively, for the period 2022-2040. Similarly, for the years 2046-2064, there was an increase of 0.08% and 0.21% in maximum temperatures under RCP4.5 and RCP8.5 scenarios (Fig. 11). The study also highlighted an increase of 0.37% and 0.44% in minimum temperatures under RCP4.5 and RCP8.5 scenarios for the years 2022-2040, and a further increase of 1.45% and 1.60% for the years 2046-2064 (Fig. 12). Subsequently, using downscaled daily predictands (precipitation, maximum and minimum temperature), were incorporated into the SWAT Model in the weather generator as input, revealing a significant decrease in discharge (Fig. 13).

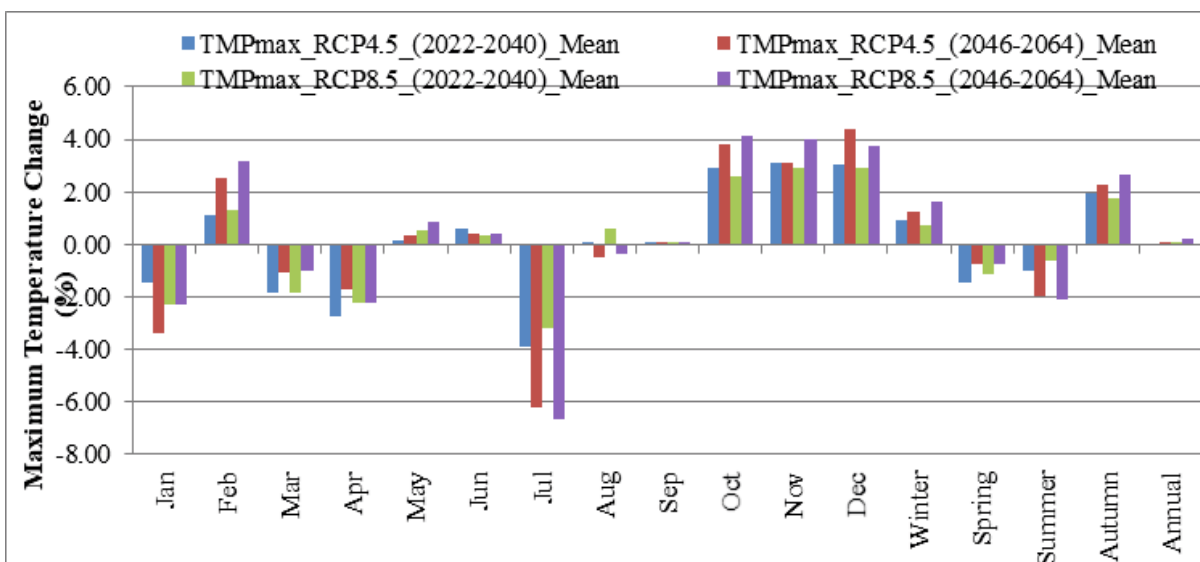


Fig. 11 Projected average monthly and seasonal maximum temperature changes under different scenarios

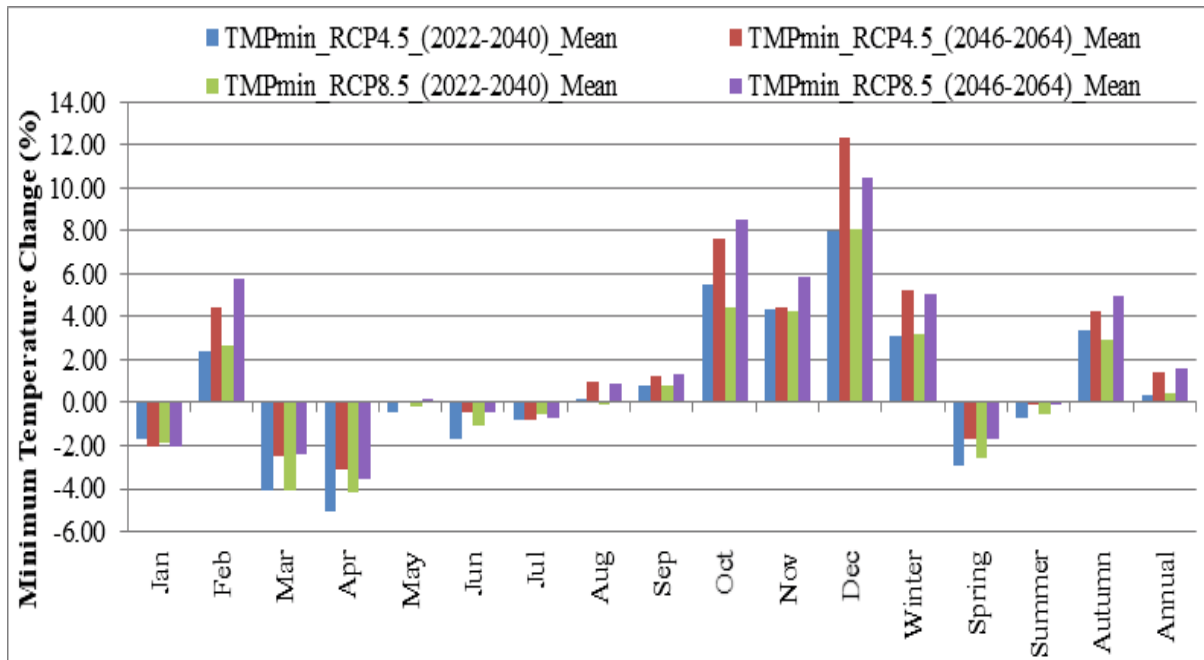


Fig. 12 Projected average monthly and seasonal minimum temperature changes under different scenarios

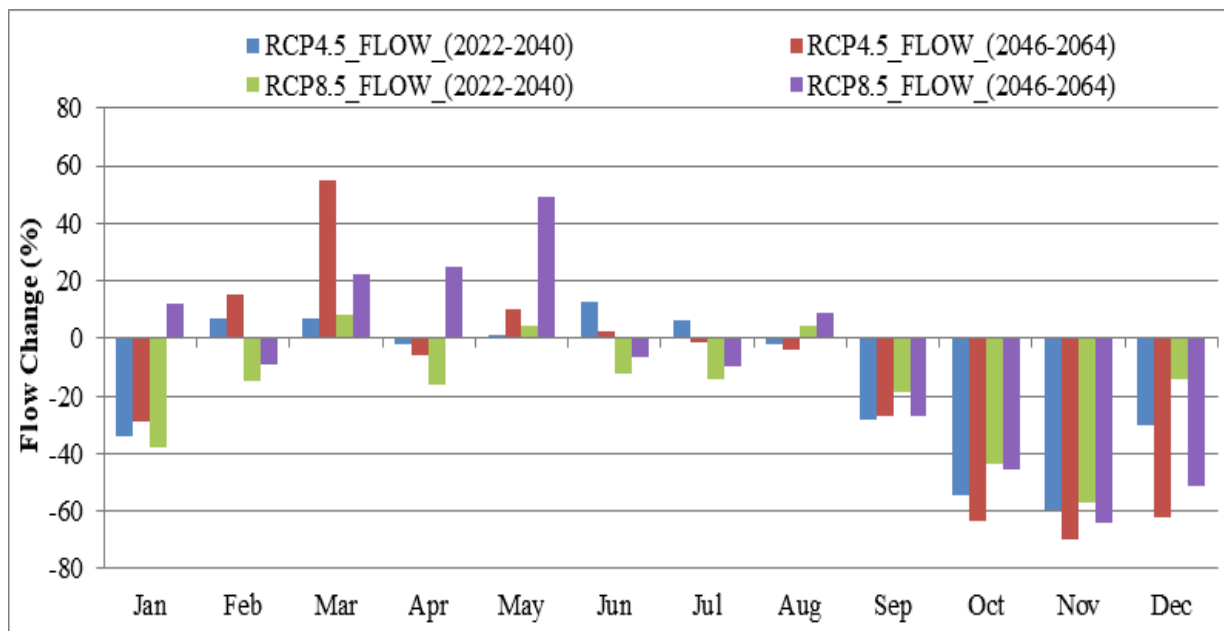


Fig. 13 Projected mean monthly flow changes under different scenarios

## CONCLUSIONS

This study focuses on how precipitation, maximum temperature, and minimum temperature in ungauged basins are affected by climate change. SWAT was used to obtain the discharge of an ungauged basin, with a calibration period spanning from 2009 to 2015, and a validation period from 2015 to 2018 both with a 3-year warm-up duration. In this study, SDSM was employed to downscale climate data in Seti Gandaki River Basin, Nepal. Based on past climate data, two downscaling scenarios (RCP4.5 and RCP8.5) were used to estimate future climatic changes for the years 2022–2040 and 2046–2064. The study found a notable decrease in flow over time, and seasonal changes showed higher temperatures and less precipitation. The applicability of SWAT and SDSM in the study area is deemed effective. To reduce and mitigate climate change-induced disasters impacts, this study could be useful for better future planning.

This research examined the influence of climate change analyzing historical data from 2001 to 2019 using NCEP predictors and projecting future trends for the periods 2022–2040 and 2046–2064 using GCM predictors. By observing monthly variations in precipitation and average maximum and minimum temperatures, valuable insights were gained for planning the construction of structures in the Seti Gandaki River Basin. This approach can lead to cost and time savings, as well as an extended lifespan for the structures. Additionally, the discharge data from the ungauged basin serves as a useful reference for conducting feasibility studies in the basin. To make Global Climate Models (GCMs) suitable for local application, they need to be downscaled. Policymakers and government officials should consider the impacts of climate change in planning, designing, and operating to reduce losses from extreme weather events. Hence, existing hydropower plants should adopt appropriate measures when constructing civil engineering structures to address these climate shifts.

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