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Climate Change and Water Availability in Western Nepal

Vishnu Prasad Pandey[1]*, Sanita Dhaubanjar[1],
Luna Bharati[1], Bhesh Raj Thapa[1]
[1]International Water Management Institute (IWMI), Nepal Office
***E-mail: v.pandey@cgiar.org**

Abstract

The response of any hydrological system to climate change may differ depending on characteristics of the system. Such studies are lacking for basins in Western Nepal. This paper, therefore, argues for a need to re-phrase the context of Western Nepal in more positive light and then analyses how a projected change in climate may impact on water availability of the region with a case of Chamelia watershed. A hydrological model in SWAT (Soil and Water Assessment Tool) environment is developed for the purpose. Future climate is projected using a set of five Regional Circulation Models (RCMs). Then response of streamflow with projected change in climate is assessed. Results show the developed model performance is adequate to represent hydrological characteristics of the watershed. Future is projected to be warmer (high model consensus) and slightly wetter (more uncertainty), with winter and pre-monsoon season receiving more rainfall. Under the projected future changes, simulated stream flow is projected to change across future periods and seasons. The results are expected to be useful for future water resource and water infrastructure planning in the area.

Keywords: Climate change, Hydrological modeling, Springshed, SWAT, Western Nepal

Introduction

Climatic trends in Nepal reveal significant warming in recent decades [1] and climate change (CC) scenarios for Nepal across multiple general circulation models (GCMs) show considerable convergence on continued warming, with projected increase in averaged mean temperature of 1.2°C by 2050 and 3°C by 2100 respectively [2]. Climate change may alter the response of the hydrologic systems [3] potentially causing the disappearance of natural springs, loss or functional change in wetlands, increased variability in streamflow, and glacier retreat [4]. As water is a crucial resource for the socio-economic development of Nepal, it is important to understand likely impacts of CC on future water availability and incorporate them in future water resource planning. Such studies, however, are limited, particularly in Western Nepal.

Western Nepal is generally perceived as one of poorest regions in the country with high poverty, low literacy, limited development, very little market access, and similar disadvantages. Such perceptions highlight the inadequate understanding of the untapped natural resources potential of the region. We argue that the prevailing perception of Western Nepal should be re-phrased to reflect the region's tremendous potential. The region has high per capita water availability compared to other regions. Natural resources are also abundant and tourism potential is high. Western Nepal comprises of Karnali and Mahakali basins with 62.2 billion-cubic-meters (BCM) of water resources annually [5], accounting for 28% of the total available water resources in Nepal. With steep slopes and meandering rivers, Western Nepal also offers tremendous potential for hydropower development. As per IWMI [6], there are 150 identified hydropower projects under various stages of development here, with proposed installed capacity ranging from 0.5 MW to 6,720 MW. They include 19 projects of storage type, which are planned and/or proposed. Total estimated installed capacity of all these projects is more than 21,000 MW. Implementing all these projects will contribute to energy security and fuel economic growth for national prosperity.

However, to achieve sustainable and integrated water management in the long-run, we have to make sure water is used wisely as a "resource". For that, we need to get a clear and precise answer to following questions: How much water is available at the location of interest and point of time (Month)? What is the extent of climate change (CC) in the area? What will be the implication of CC on water resources availability and its spatiotemporal distribution? Furthermore, we need to consider both rivers and springs to understand the role of surface and groundwater (GW) in the larger picture of water availability. In this context, this study sheds light on two projects being implemented by International Water Management Institute (IWMI) in Western Nepal. One project focuses on local level management of springs while the other delves into basin-scale analysis for sustainable water resources development. Results from the latter study focusing on hydrological modeling are discussed in more detail from the perspective of climate change implications for water availability.

Springshed Study

Majority of people in the mid-hills of Nepal rely on GW as the primary source of water for in domestic usage, irrigation, and small-scale industrial activities. GW systems also play an important role in regulating river flows, particularly by maintaining the base-flow. Considering the importance, a project titled "Building Climate Resilience of Watersheds in Mountain Eco-Region (BCRWME)" is being implemented by IWMI together with the Department of Soil Conservation and Watershed Management (DSCWM), the Government of Nepal. The four-year project (2015 – 2019) is supported by Climate Investment Fund and Nordic Development Fund (NDF) administered by the Asian Development Bank (ADB) with the goal to improve climate resilience in mountain eco-regions. The DSCWM is working in 108 village development communities spread across six districts and two basins (West Seti and Budhi Ganga), implementing various types of interventions to help increase year-round water availability in the springs. Potential interventions include afforestation, on-farm water conservation, infiltration recharge ponds, bioengineering for gully protection, social fencing, etc. IWMI is leading research activities at two of these project sites located in Doti and in Baitadi districts (Fig. 1) to further understand springshed hydrology. The objectives of the study are to understand the land and water processes that affect water availability in springs, and recommend evidence-based watershed intervention/ management plans for spring-shed management.

To this end, IWMI is monitoring climatic parameters (precipitation, temperature, relative humidity, wind speed and solar radiation), spring discharge, and stream hydrology by establishing on meteorological and one hydrological station at each site. Isotopes samples have also been collected over two years and analyzed to identify potential sources and/or area of recharge to the springs [7]. Isotope analysis has also helped understand the types of different springs and their relation to surface and groundwater. Combining data from hydro-meteorological monitoring, hydro-geological survey and isotope analysis, we are developing a conceptual model to describe spring hydrological process in the study watersheds. Furthermore, we aim to assess the response of springs under various scenarios of changes/interventions and evaluate the effectiveness of watershed interventions on enhancing water availability in springs in current and future climate conditions.

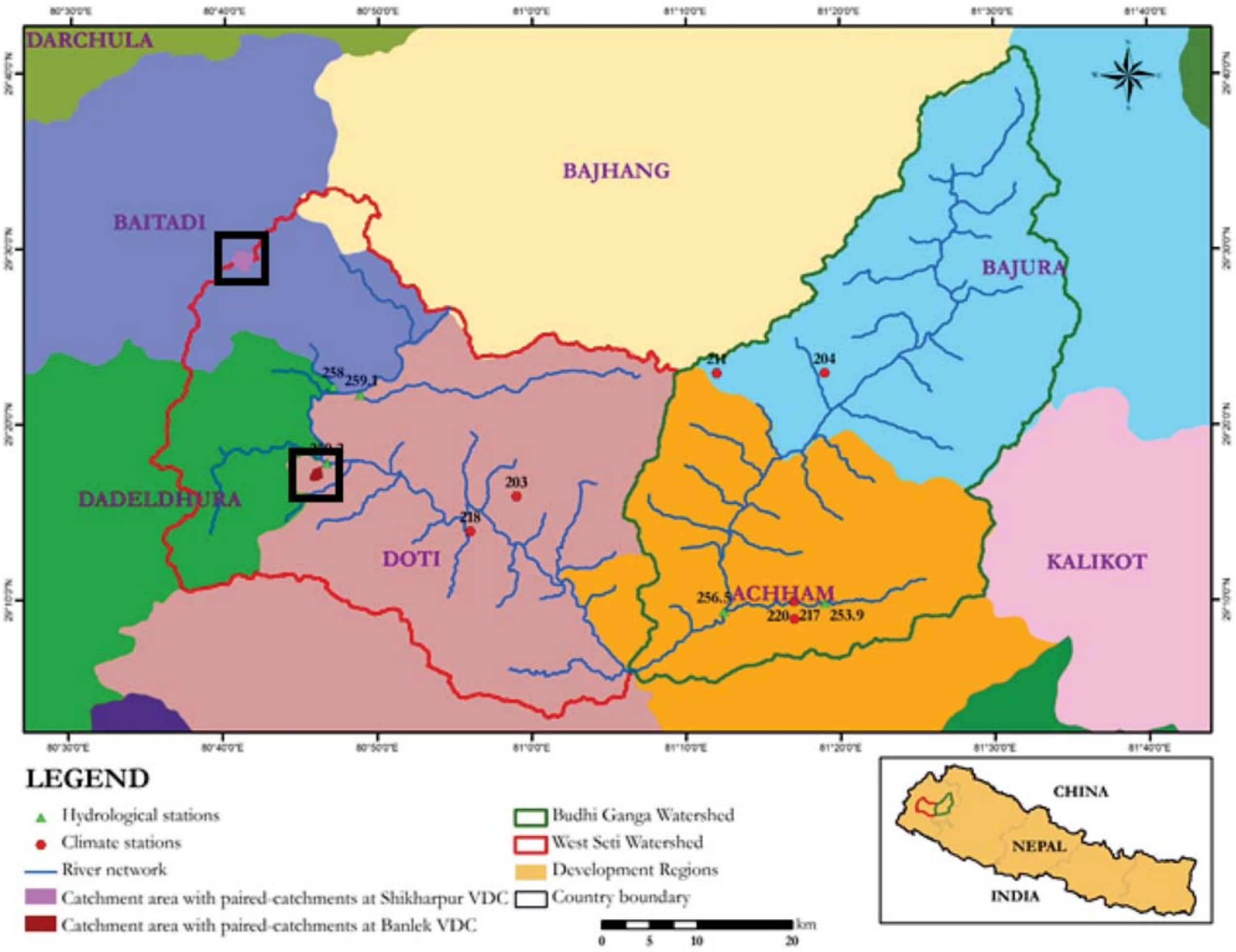


Figure 1. Location of two watersheds under BCRWME project in Doti and Baitadi districts for spring-shed study

Hydrological Modeling

Context of study area

Considering the need to have better scientific knowledgebase of river basins in Western Nepal, IWMI is implementing “DigoJalBikas (DJB) project” with funding support from United States Agency for International Development (USAID). The three-year project (April 2016 – March 2019) focuses on Karnali, Mahakali and Mohana basins in Western Nepal. One of the components of the project is river basin characterization, which includes database development, hydrological modeling, and climate change impact assessment on water availability across the basins over time. The results from hydrological modeling will be fed with a hydro-economic model to evaluate trade-offs of various water development pathways for the region. Two hydrological models are developed for the region, namely, Karnali-Mohana, and Mahakali. In this paper, we describe a case of Chamelia watershed, a tributary of the Mahakali River (Fig. 2).

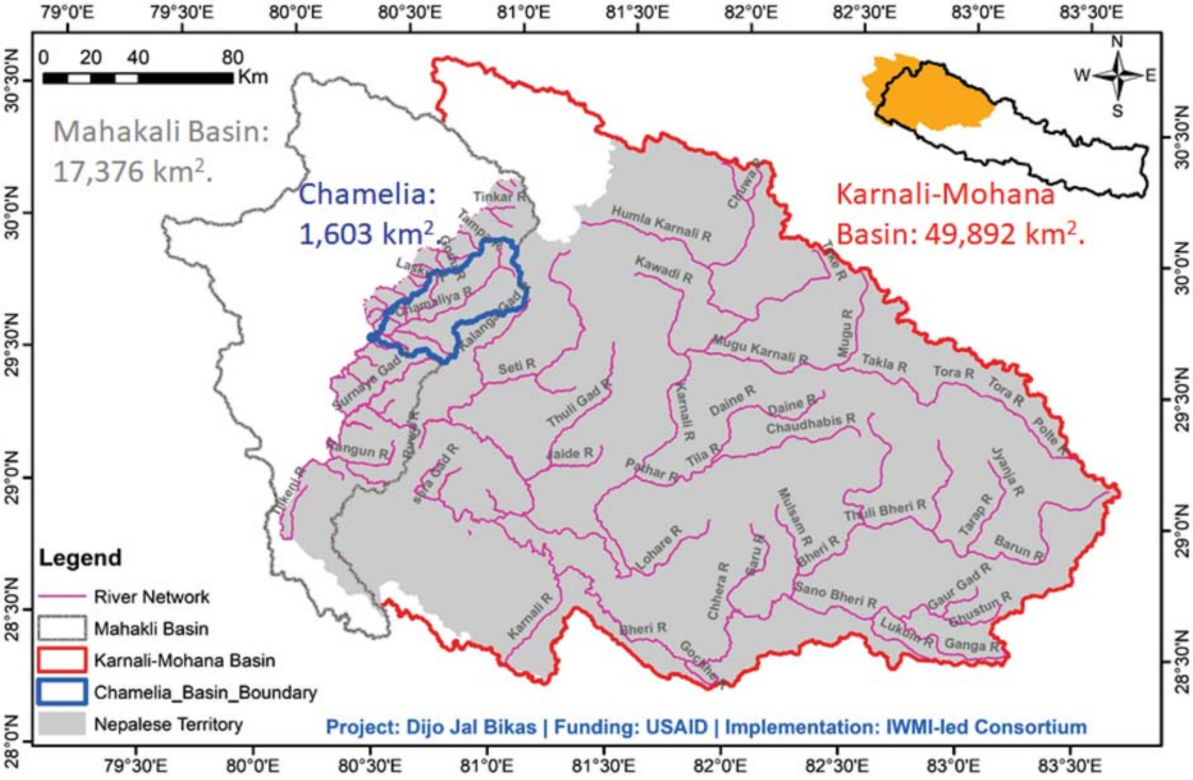


Figure 2.Location of DJB basins and Chamelia watershed in Western Nepal.

Chamelia is the largest watershed in the Nepalese side of the Mahakali Basin covering an area of 1,603 km2. According to the data from Department of Electricity Development (DoED), Chamelia has 14 hydropower projects at various stages of development, with individual capacity ranging from 1 to 40 Mega-Watts (MW), and a total capacity of 214 MW [8]. The topography varies from 505 to 7,090 meters-above-mean-sea-level (masl) (Fig. 3a); land use/cover ispredominantly forest (40%) and rainfed agriculture (28%) (Fig. 3b); and soil type is dominated by EutricRegosols (23.8%), EutricCambisols (24.5%), and GelicCambisols (22.0%) (Fig. 3c).

Methodology

Fig. 4 depicts the methodological framework for hydrological model development and CC impact assessment adopted in this study. Soil and Water Assessment Tool (SWAT) [9, 10] was set up, calibrated, and validated in the ArcSWAT2012 environment for the Chamelia watershed to simulate hydrology. Spatial and temporal data were prepared in the SWAT-compatible format [11].

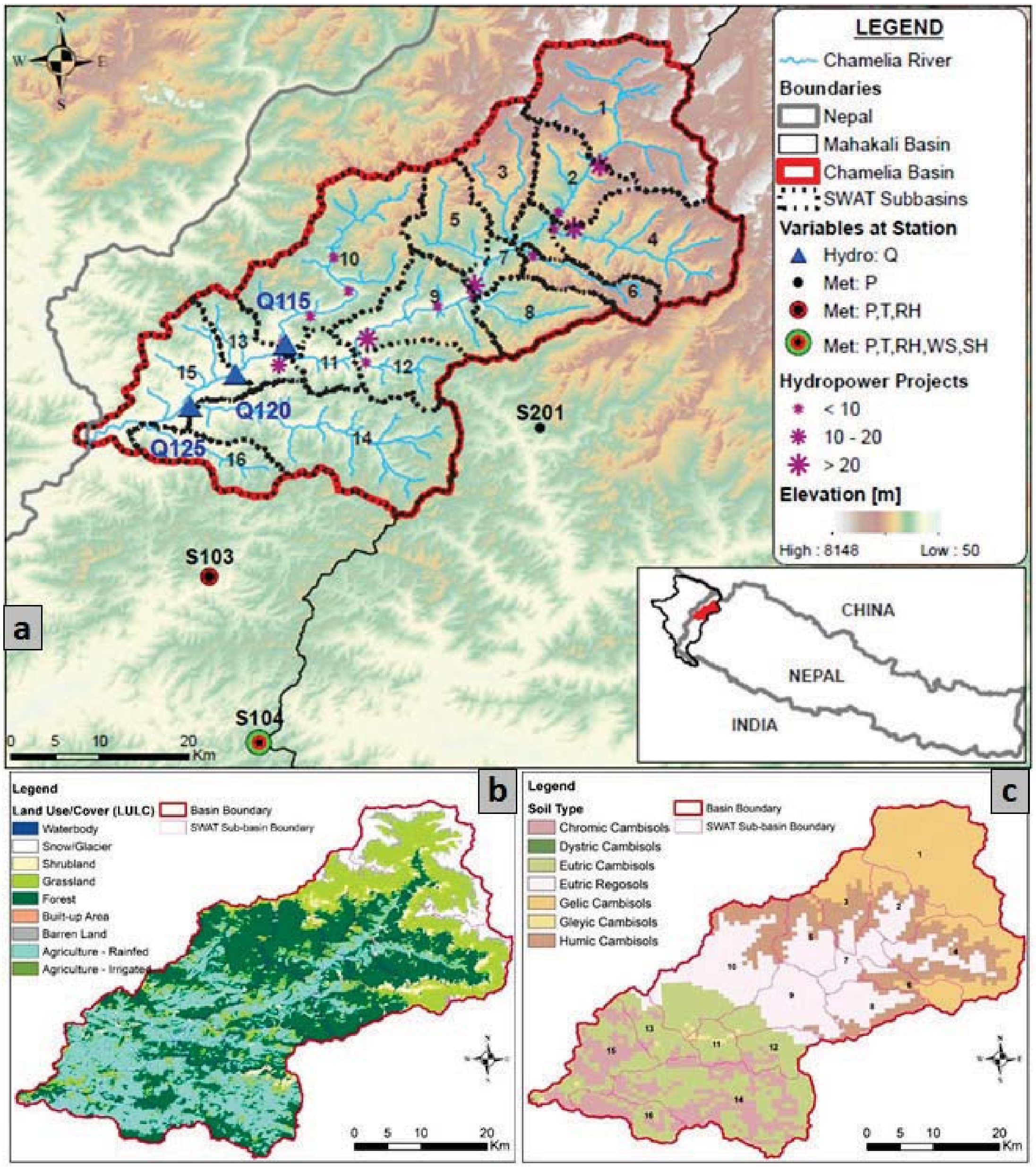


Figure 3.Spatial distribution of topography (a), land use/cover (b), and soil type (c) in Chamelia watershed.

The watershed was discretized into 16 sub-watersheds (Fig. 3a) and 225 hydrologic response units (HRUs). Ten elevation bands at an interval of 500m were defined to model the process of snowmelt and orographic distribution of temperature and precipitation. Weather input was fed in the form of daily rainfall (3 stations), maximum and minimum temperatures (2 stations), relative humidity (2 stations), wind speed (1 station) and solar radiation (1 station). The model was calibrated at two hydrological stations (Q120 and Q125, see Fig. 3a for their locations) against daily observed river flow for the period of 2001-2007 and further validated for the period of 2008-2013. SWAT-CUP was used for sensitivity analysis and auto-calibration, which was followed by additional manual calibration to keep physically based parameters within a reasonable range.

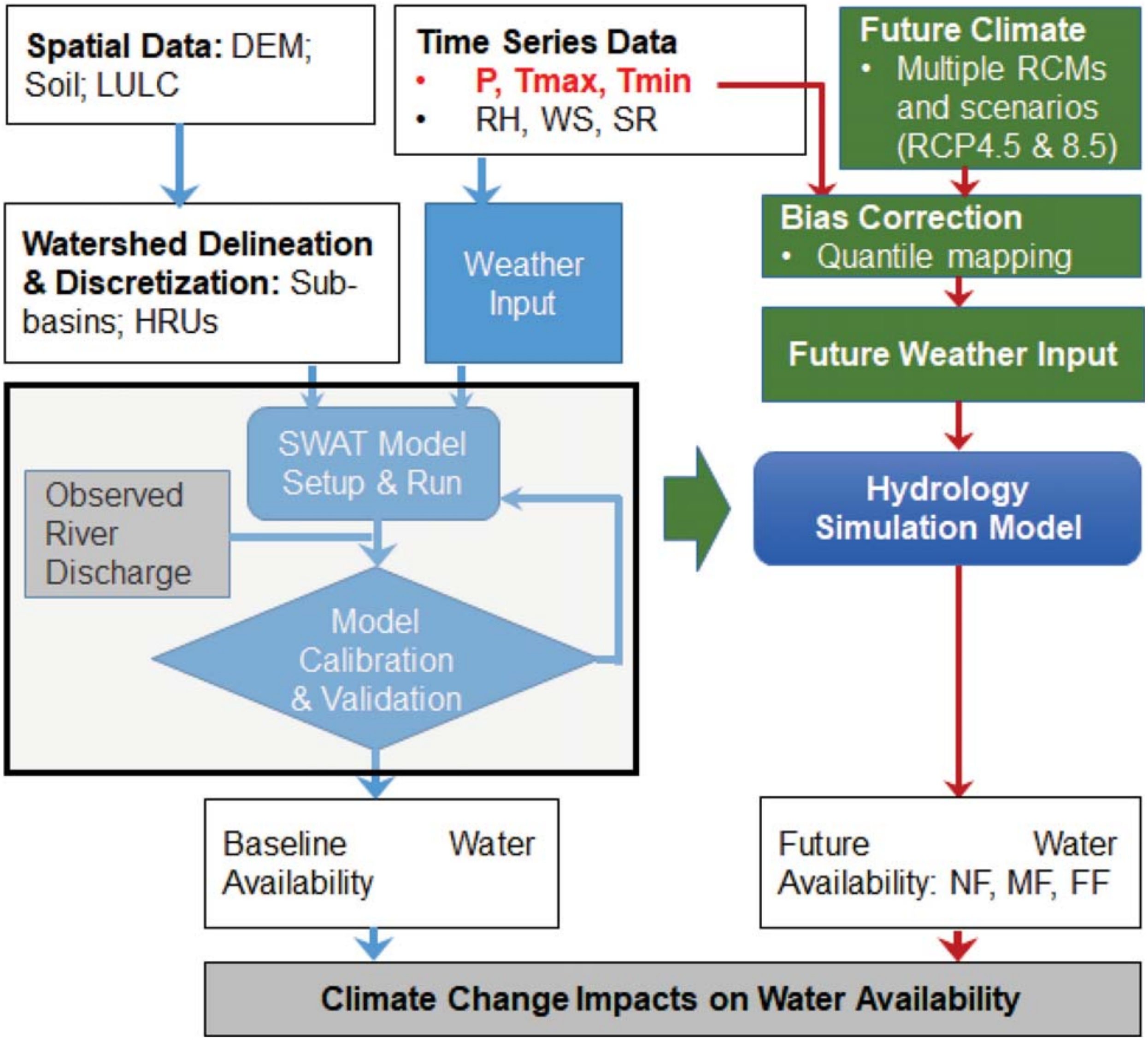
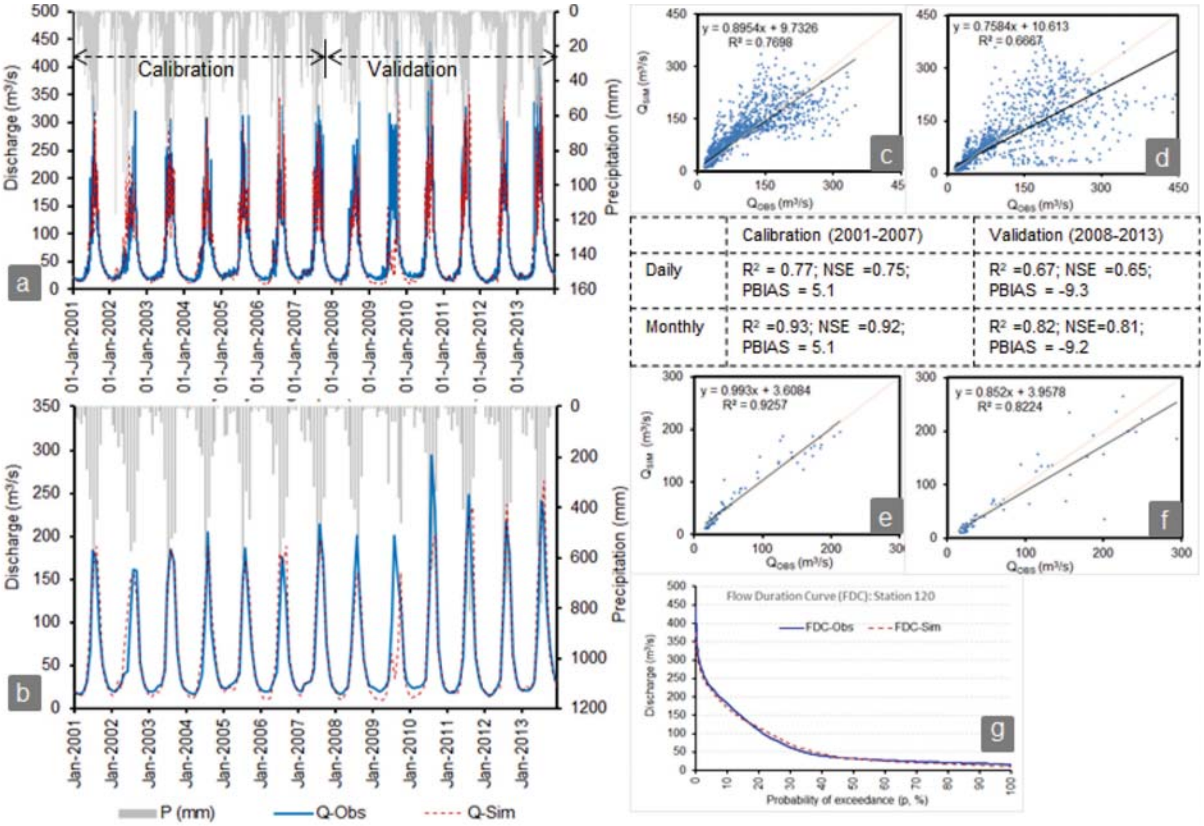


Figure 4. Methodological framework adopted in this study.

Model performance

There is a good agreement between the model simulated and observed streamflow values during calibration as well as validation periods (Figs. 5). The model reasonably simulates the hydrological regime for daily and monthly flows, reproducing daily flow duration curve (FDC),and keeping statistical parameters (R2, NSE, and PBAIS) within a reasonable range. Additionally, the hydrological response pattern follows the rainfall pattern at all the stations, for both daily and monthly simulations. Based on the general performance rating criteria developed by Moriasi et al. [12], for both monthly and daily time steps, model calibration results are "very good (NSE>0.65)" for the stations Q120. The performance at other station (Q115) is also reasonably good. The simulated results can, therefore, be used for further analysis of water availability.



	Calibration (2001-2007)	Validation (2008-2013)
Daily	R² = 0.77; NSE =0.75; PBIAS = 5.1	R² =0.67; NSE =0.65; PBIAS = -9.3
Monthly	R² =0.93; NSE =0.92; PBIAS = 5.1	R² =0.82; NSE=0.81; PBIAS = -9.2

Figure 5. Comparison of observed versus simulated stream flows at Q120 (Karkalegaon) station: a) Hydrograph for daily simulation, b) Hydrograph for monthly simulation, c &d) Scattered plots for daily calibration and validation, e & f) Scattered plots for monthly flow calibration and validation, e) Flow duration curve (FDC, daily).

Projected Future Climate

Future climate (precipitation, maximum temperature, and minimum temperature) projected by following five RCMsunderRCP4.5 and 8.5 scenarios were considered: ACCESS_CCAM, CNRM_CCAM, MPI.ESM_CCAM, MPI.E.MPI_REMO, and ICHEC_RCA4. Please refer Pandey et al. [11] for the description of those RCMs. They were extracted at three climatic stations as shown in Fig. 3a. The raw RCM projections were then bias corrected using quantile mapping method. The bias-corrected time series were averaged to generate ensemble to reduce the uncertainty in climate projection seen across individual RCMs. Then projected change inclimate with respect to baseline (1980-2005)was estimated for three future time frames: near future (NF, 2021 – 2045), mid-future (MF, 2046-2070), and far-future (FF, 2071-2095). The period of 1980-2005 was considered as the baseline. Future projections are discussed based on that at climatic station 103.

Projected Future Precipitation

Annual total precipitation for the baseline and future periods show no obvious trend (Fig. 6). However, the range of projection increases while moving from NF to FF. It indicates an increase in uncertainty range when we progress further into the future. Considering the range of predictions as a measure of uncertainty, the annual and monsoon precipitations show the least uncertainty in the projection, whereas post-monsoon precipitation shows the high level of uncertainty for all the scenarios and futures considered.

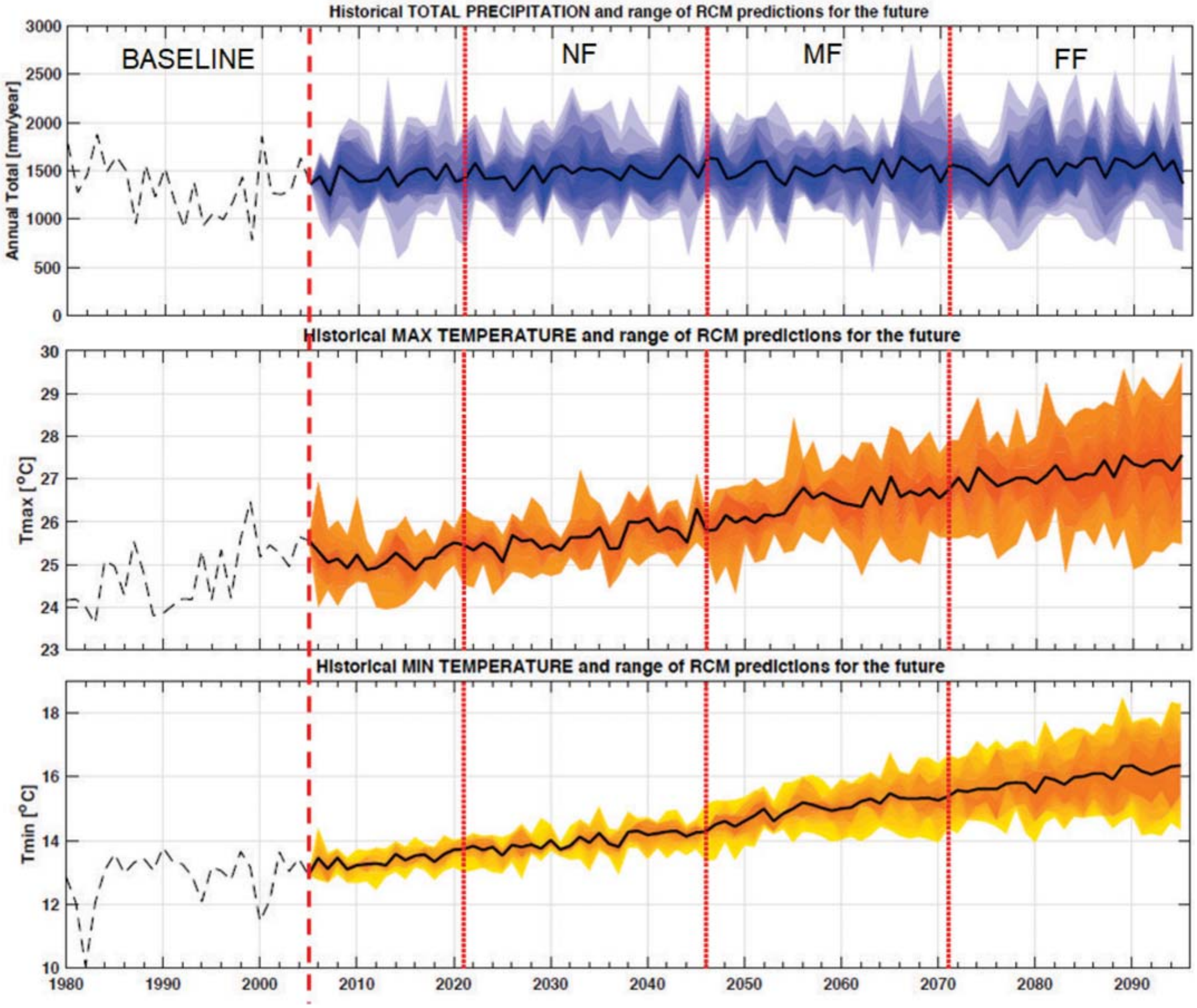


Figure 6. Trends in long-term average annual total precipitation and max/min temperature at station 103. Baseline period shows observed data while future timeframes show range of bias-corrected projections from different RCMs for both RCP scenarios.

Average annual values of precipitation are projected to increase up to 15% over three future periods (Table 1). However, annual changes are not representative of the seasonal changes. Only MAM (pre-monsoon) season follows consistent increasing trends from NF to FF as annual values; albeit, the rate of change is higher for MAM season compared to the annual ones. Median for most cases lies within the +/-50% range, which indicates that RCMs predict an increase in seasonal precipitation for some years whereas the decrease in other years.

Table 6: Projected changes in total precipitation [mm] at seasonal and annual scales at st103 station based on an ensemble of five RCMs under RCP scenarios for three future periods

Change from baseline [%]			DJF	MAM	JJAS	ON	Annual
Baseline [mm]			111.8	206.0	982.5	39.3	1340.7
RCP 4.5	NF	Mean [%]	22	26	5	15	10
	MF	Mean [%]	37	28	3	18	10
	FF	Mean [%]	35	39	5	16	13
RCP 8.5	NF	Mean [%]	22	29	6	18	11
	MF	Mean [%]	13	38	11	12	15
	FF	Mean [%]	16	44	8	42	15

Notes: DJF is December-January-February (Winter Season); MAM is Mach-April-May (Dry Season); JJAS is June-July-August-September (Rainy/Monsoon Season); ON is October-November (Post-Monsoon Season)

Projected Future Temperature

Unlike precipitation, average annual time series of the projected temperature shows a clear increasing trend until the end of the century for both maximum and minimum temperatures (Fig. 6).

Maximum temperature: All changes for all RCMs, RCPs, and futures indicate increase with both means and medians lying above zero. The projected average annual maximum temperature for RCP4.5 scenarios, based on an ensemble of five RCMs, are gradually increasing compared to the baseline over three future periods by 0.9°C (for NF), 1.4°C (for MF) and 1.6°C (for FF). It is increasing across all the seasons too, but the amount of increase is not consistent. Winter (DJF) temperature is projected to increase more for all the three futures and two scenarios considered, followed by dry (or pre-monsoon; MAM) season.

Minimum temperature: There is more model consensus and certainty that future minimum temperatures will increase. The average annual minimum temperature is projected to increase from the baseline value by 0.9°C, 1.7°C, and 2.0°C for NF, MF, and FF, respectively, under RCP4.5 scenarios. In case of RCP8.5 scenarios, the rate of increase is significantly higher; up to 3.9°C increase from the baseline period for FF. The increasing trend is consistent across all the seasons and for both the scenarios; albeit the rate of increase varies with the season. The higher rate of increase is projected for summer (JJAS) and winter (DJF) seasons for both the scenarios.

Climate Change Impacts on Water Availability

Change in water availability in terms of streamflow under a projected change in future temperature and precipitation was simulated using the calibrated and validated SWAT model. The analysis was made at annual as well as seasonal scales. Changes in streamflow due to the projected change in precipitation and temperature were analyzed at Q120hydrological station located near to the outlet of the Chamelia (Fig. 3a). The results are shown in Fig. 7.

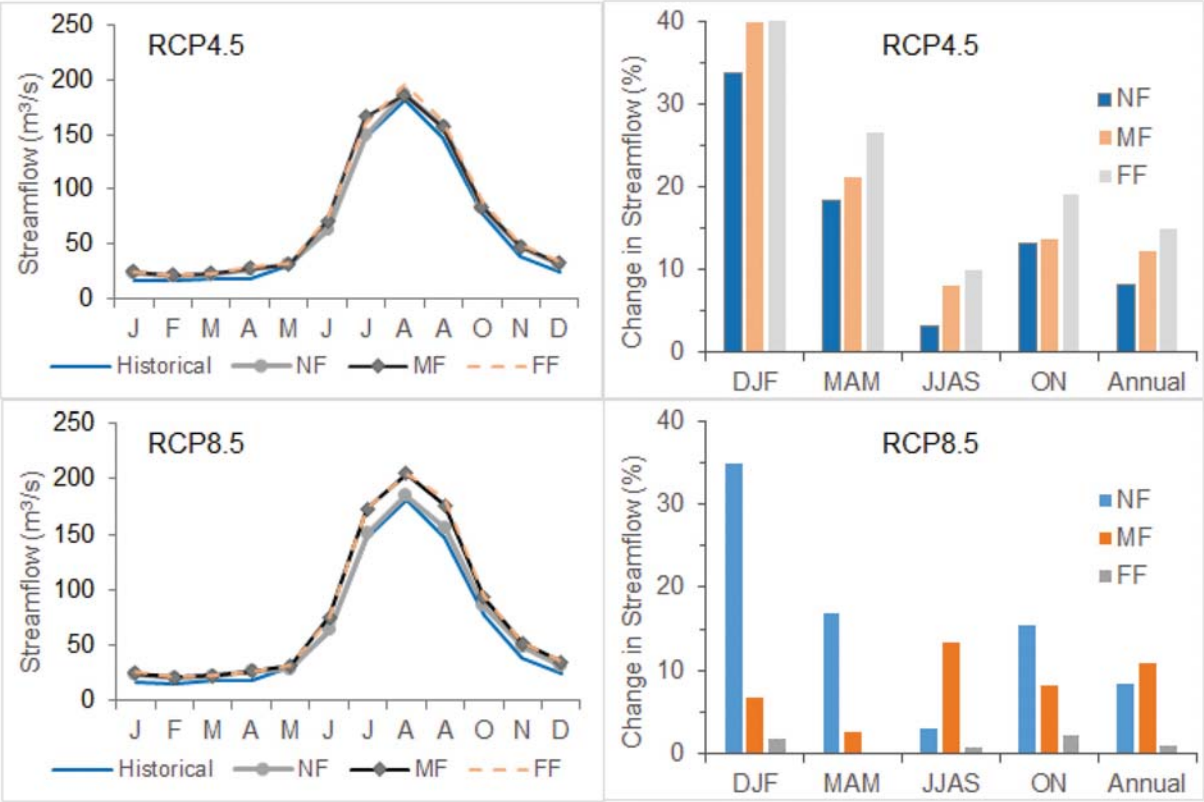


Figure 7. Change in simulated stream-flow at the st120 hydrological station of Chamelia watershed under future climate represented by the ensemble of the five bias corrected RCM outputs.

However, increase instream-flow is maximum for winter (DJF) and pre-monsoon (MAM) The projected changes instream-flow for an ensemble of the five RCMs show increasing trends for annual as well as seasonal values, for all the future periods and scenarios considered (Fig. 7). Average annual stream-flow is projected to increase gradually from NF towards MF under both the scenarios. For RCP4.5, the annual values are projected to increase by 8.2% in NF, 12.2% in MF, and 15.0% in FF. Such a significant increase was also reported for other watersheds in Nepal [13, 14]. The projected increasing trend is consistent across all the seasons (Fig. 7). Seasons compared to other seasons. Considering RCP4.5 scenarios, projected increase in winter season (DJF) flow is 33.8% in NF, 39.8% in MF, and 41.6% in FF. The increase instream-flow is mostly contributed by increases in precipitation. The increase in total stream-flow is less compared to increase in precipitation because of loss of some precipitation by evapotranspiration.

Conclusions

SWAT model developed in this study is capable to adequately simulate water availability and its spatiotemporal distribution in the Chamelia watershed in Western Nepal. The results in the watershed show that projected precipitation is likely to increase both annually and across the seasons, however, more in winter and pre-monsoon seasons. In case of temperature, both maximum and minimum temperatures are projected to increase, but with a higher rate of increase for minimum temperature. The climate change is projected to alter the future periods and seasons. The magnitudes of change during the winter (DJF) and pre-monsoon (MAM) seasons are even more than in the annual average. While hydrological modeling is yet to be applied to spring-shed studies, isotope analysis has provided promising results. Increased understanding of springs in the study areas has been gained by identifying potential recharge zones for springs using isotopes.

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