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Climate Change Impact on the Hydrological Characteristics of Tamor River Basin in Nepal Based on CMIP6 Models

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Abstract

This study investigated the change in discharge at the Tamor River Basin(TRB) outlet due to climate change in future. Precipitations and temperature time series data were used in the HEC-HMS model for the baseline (historical) period of 1989-2009 to simulate the model.Then, evaluated the potential changes in discharge at the outlet of the basin under future climatic condition using the latest set of scenarios from ten Coupled Model Inter-comparison Project, phase 6 (CMIP6) models dataset for the future period (2021-2095) under two shared socio-economic pathways (SSP245 and SSP585). The study found that, annual average discharge in the river is increases due to climate change. Seasonal variation in river flows is expected to decrease only in post monsoon season under scenarios SSP245 in FF and SSP585 in NF. However, monthly variation in river flows is expected to increase in most of the months and decrease in the May, October, April under scenarios SSP585 in NF, June under scenarios SSP585 in NF, September under scenarios SSP585 in NF and November under scenarios SSP585 in NF. Overall, increasing pattern of river discharge poses risk on natural hazards such as floods, landslides, and soil erosion in the future. Our finding is expected to help understand the hydrological characteristics of Tamor River, future benefit associated with increase in average annual discharge in the river like, hydropower production, irrigation scheme etc., and adaption measure that can reduce risks associated with increase in hydrological flow in the river.

Keywords

Climate change, CMIP6, HEC-HMS modelling, Hydrological change, Tamor River Basin

1. Introduction

Climate change is a complex occurance that the scientific community is studying closely due to the threat it poses to long-term human progress [1]. Changes due to climate impacts water resources capability of a river basin [2] by means of change in precipitation pattern, temperature and associated alterations in snow melt, evapotranspiration and river discharge [3].It ultimately affects water resources availability, both quantity and quality, and associated water use sectors such as irrigation, hydropower, environmental uses, etc. Aside from climate change, the urbanization and land use also increases the non-pervious area within the watershed, which can then contribute to the increasing of the runoff from the watershed by reducing the infltration. Therefore, understanding changes in hydrological characteristics with climate change is important for sustainable use and management of a country's water resources. Analyses of output from climate models are especially useful for evaluating how climate change affects hydrological characteristics, drought analysis and hydropower generations including multi-model efforts.

Selecting a suitable Global Climate Model (GCM) or Regional Climate Model (RCM) among multiple GCMs/RCMs for an area is a challenging task.To reduce unpredictability in climate model selection, an ensemble of several climate models is commonly used [4]. The Working Group on Coupled Modeling developed the Coupled Model Intercomparison Project (CMIP) inside the World Climate Research Program framework to better understand using a multi-model context. The CMIP has now started its sixth phase (CMIP6), with climate models improving several parameterization methods for major physical and biogeochemical climate system processes [5]. The majority of modeling groups are publishing new simulations together with documentation of their model evolution from CMIP5 to CMIP6 [6]. CMIP6 data is based on a new set of scenarios based on various socioeconomic assumptions [7]. The Shared Socioeconomic Pathways (SSPs) generate several socio-economic scenarios and radiative forcing pathways through the end of the twenty-first century based on these assumptions. The SSP scenarios focuses on changes in drought risk, intensity and changes in precipitations and hydrological runoff [8].The GCM/RCM model outputs are further subjected to bias correction using appropriate method such as empirical quantile mapping [9] to make climate model outputs suitable for local applications.

The Himalayan areas are complex hydrological systems with significant variety in vegetation, soils, topography, and spatially and temporally varying snow-melt patterns and snow cover, making assessing climate change's hydrological impacts difficult [10]. The changing climate is a driver that induces the shifts in hydrological regimes by changing different parameters of the hydrologic cycle such as precipitation, temperature and evaporation. The extreme hydrological events have increased, both in magnitude and frequency, in Nepal [11] as across the globe [12] [13] [14]. The frequency and magnitude are expected to vary widely, from decreasing to increasing, over different topographical regions in Nepal. The impacts of climate change are higher in the Himalayan region, where runoff is highly influenced by the glacier and melting of snow due to changing temperature patterns. One of the world's most vulnerable region for climate change is the Hindukush Himalayan region due to highly diverse topographic and climatic variations [15]. The Tamor River Basin (TRB) also lies in the Hindukush Himalayan region, so the basin is vulnerable to climate change. This study aims to assess hydrological changes in the TRB due to projected change in future precipitation and temperature.

2. Study area

The TRB is located in Nepal's eastern region, covering Taplejung, Panchthar, Terhathum, and Dhankuta districts. The Tamor River is originating from Mt. Kanchenjunga and meets the Sunkoshi and Arun at Tribenighat to form a huge Saptakoshi [16]. The total length of the river is about 190 Km and the major tributaries of the river are Ghunsa Khola, Sibuwa Khola,Kabeli River, and Mewa Khola. The TRB is a sub-basin of the Koshi River Basin. TRB, with the catchment area of 6044.47 km^2 is located between longitude $87°10'4.8''E$ to $88°11'45.6''E$ and latitude $26°50'42''N$ to $27°57'7.2''N$; and varies in topography from 129 m to 8376 m shown in Figure 1,thus topographic variation is marked as like most of the River Basin in Nepal.

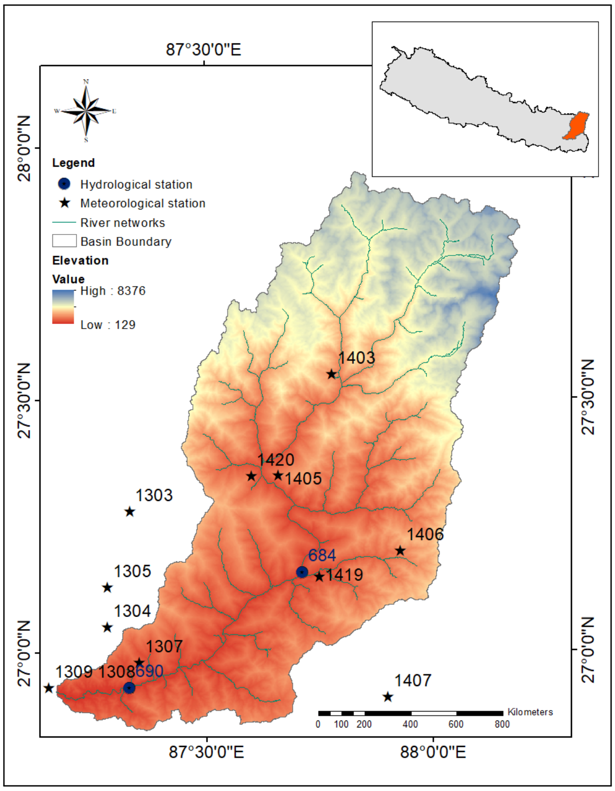

Figure 1: Location, hydro-meteorological stations, and elevation details of Tamor River Basin

3. Methodology and data

The study uses a model-based technique to examine the effects of future climate projections on TRB's hydrological regime. The flowchart of the adopted technique is shown in Figure 2, and the sub-sections that follow discuss it in detail.

Multiple CMIP6-GCMs were used to forecast the future climate. The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) was used to examine hydrological features in the baseline period (1989-2009) and predicted changes in three future periods – near future (2021-2045), mid future (2046-2070), and far future (2071-2095). In terms of future data available for analysis, the future is separated into three categories: near future, mid future, and far future.

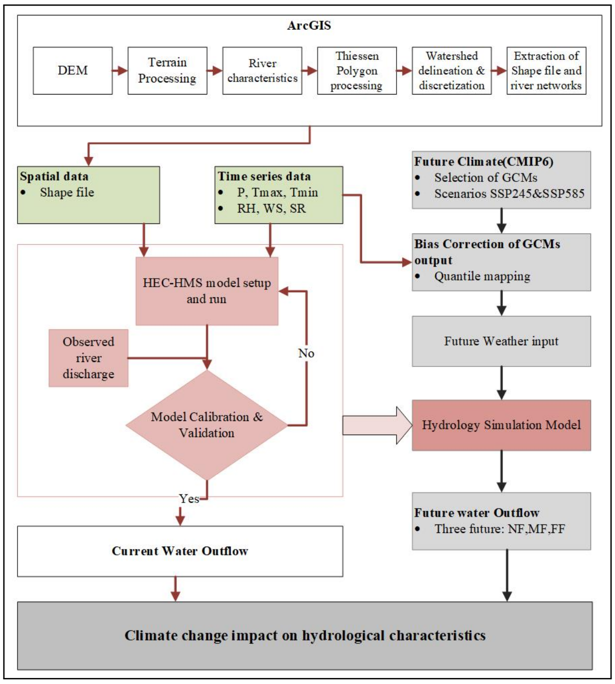

Figure 2: Methodological framework for assessing climate change impacts on hydrological regime in Tamor River Basin (TRB) using HEC-HMS model. DEM is Digital Elevation Model, NF, MF and FF refer to Near Future, Mid Future, and Far Future respectively.

3.1 Data and sources

Topographical analysis was carried out using a Digital Elevation Model (DEM) of 30m resolution based on Shuttle Radar Topography Mission (SRTM) [17]. Precipitations at 13 stations, the maximum and minimum temperatures at 6 stations, relative humidity at 3 stations, wind speed at 1 station, and sunshine hours at 2 stations were obtained from the Department of Hydrology and Meteorology(DHM), Government of Nepal. Data quality was assessed by visual plotting graphs, single/double mass curves, and data reading. Stations with a large amount of missing data were removed from the analysis. Missing precipitation data were fill by Normal Ratio Method [18] and missing data in other meteorological variables were filled based on long-term average daily values. Future precipitation, maximum, and minimum temperature data were extracted for the period 2021-2095 using five CMIP6-GCMs under two scenarios (SSP245 & SSP585) obtained from [19]. Biases in the GCM data were corrected based on an empirical quantile mapping method.

3.2 Hydrological modeling

A hydrological model of the TRB was developed using HEC-HMS. It is a semi-distributed conceptual hydrological model that is capable of simulating hydrological processes of a watershed to derive river discharge and water balance. A basin model is used to provide a physical representation of a watershed. Daily precipitation, long-term average monthly potential evapotranspiration, basin runoff flow (for calibration and validation), and basin geographic information are all included in the simulated runoff as production. A basin model, meteorological model, control parameters, and input data (time series data) make up the HEC-HMS model's configuration [20]. The twenty nine sub-basin and twenty one reaches are designed while considering different hydropower and hydrological stations in the basin shown in Figure 3.

Two hydrological stations Majhitar(Q684) and Mulghat(Q690) are used for calibration and validation the model. At Q684, the observed discharge data from 2001-2004 was used for calibration and from 2005-2008 was used for validation; and at Q690, the observe discharge data from 2004-2006 was used for calibration and from 2007-2008 was used for validation. The performance statistics of the model are evaluated using the coefficient of determination (R2), Nash-Sutcliffe efficiency (NSE), and percentage bias (PBIAS).

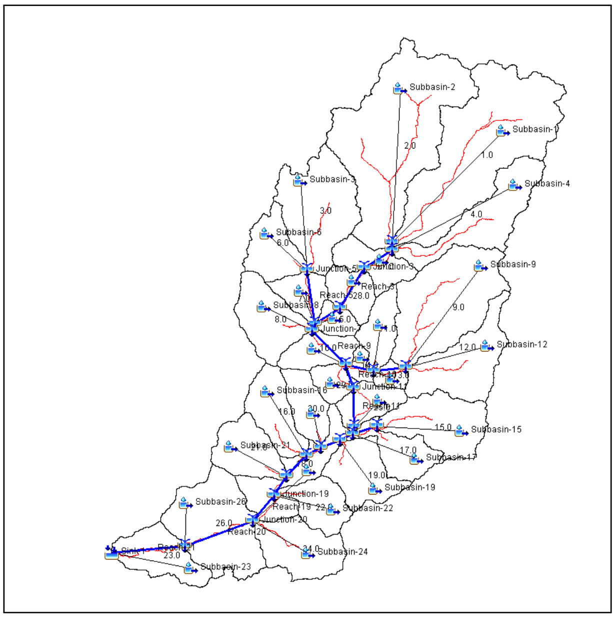

Figure 3: Basin model showing different subbasin and reaches.

3.3 Climate change impact assessment

A calibrated and validated hydrological model was used to analyze the impact of climate change. The calibrated and validated model was fed projected future precipitation and temperature to simulate projected future hydrology under five CMIP6 GCMs with two scenarios (SSP245 & SSP585). Changes in projected future hydrological characteristics compared to the baseline is reported as climate change impact on hydrological characteristics. Impact assessment can also help businesses and the general public to understand climate change and its consequences.

4. Results and Discussion

4.1 Hydrological model performance

After fixing all the parameters and the model is run the first time, the output of the rainfall-runoff model is compared with the measured discharge at the known gauge station. Those parameters which impact the high output of simulation with slide change in value are called sensitive parameters. The sensitivity of the parameters can be analysis be manually by changing the value (within the range) in the different methods or by automatically at the particular point by using tools computational point manager at known discharge location. After changing the parameters, the hydrograph also changes, and those parameters which affect high output discharge can be noted and run the model. Out of many parameters, some of them were found to be sensitive which are impervious (%), lag time, conductivity, Groundwater coefficient 1 & 2, and maximum storage.

In the station Q684, comparison of observed versus simulated flow is shown in Figure 4 to Figure 9 for both calibration and validation periods. From Figure 4 to Figure 9 different graphs show, the model simulates the flow very well and hydrographs of simulated flow are in good agreement with rainfall patterns in both calibration and validation periods. The daily performance statistics parameter for calibration, coefficient of determination (R2 =0.81), Nash-Sutcliffe efficiency (NSE=0.81) and the volume difference between observed and simulated values of 10.86% and for validation, coefficient of determination (R2 =0.81), Nash-Sutcliffe efficiency (NSE=0.81) and the small volume difference between observed and simulated values of 0.61%, show the model have very strong predictability capacity. During the calibration and validation period model predict the same R2 and NSE performance statistics parameter but different volume difference between observed and simulated flow at the station shows data used for the calibration and validation is different.

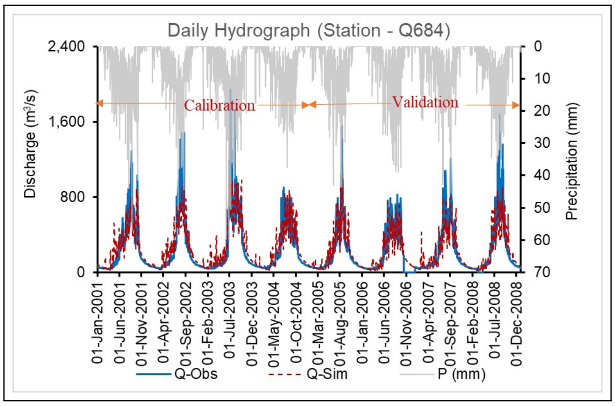

Figure 4: Observed versus simulated daily hydrograph at Q684(Majhitar)

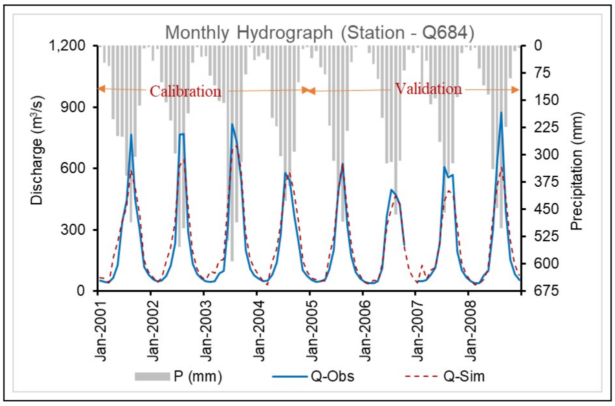

Figure 5: Observed versus simulated monthly hydrograph at Q684(Majhitar)

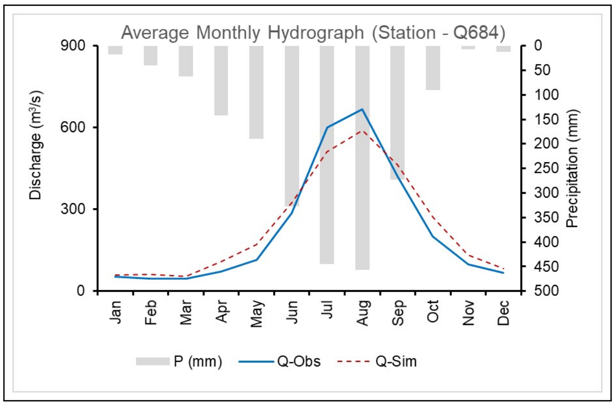

Figure 6: Observed versus simulated average monthly hydrograph at Q684(Majhitar)

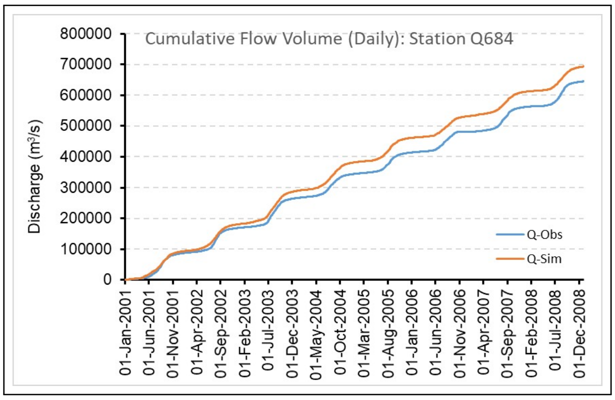

Figure 7: Observed versus simulated cumulative flow volume at Q684(Majhitar)

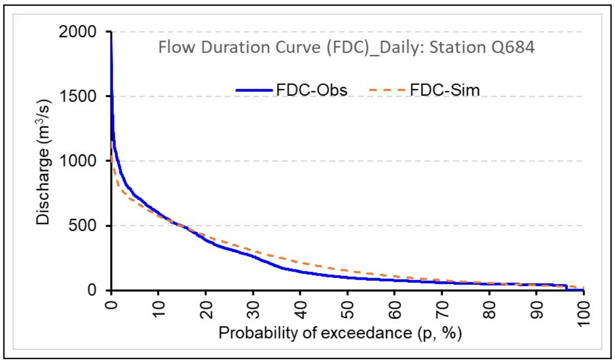

Figure 8: Observed versus simulated daily Flow Duration Curve (FDC) at Q684(Majhitar)

	Calibration (2001-2004)	Validation (2005-2008)	Entire Period (2001-2008)
Daily	R^2=0.81, NSE=0.80, PBIAS=10.86	R^2=0.81, NSE=0.80, PBIAS=0.61	R^2=0.81, NSE=0.80, PBIAS=6.08
Monthly	R^2=0.94, NSE=0.92, PBIAS=9.08	R^2=0.92, NSE=0.91, PBIAS=0.29	R^2=0.92, NSE=0.91, PBIAS=6.00

Figure 9: Performance statistics parameter at Q684(Majhitar)

In station Q690, comparison of observed versus simulated flow is shown in Figure 10 to Figure 15 for both calibration and validation periods. From Figure 10 to Figure 15 different graphs show, the model simulates the flow very well and hydrographs of simulated flow are in good agreement with rainfall patterns in both calibration and validation periods. The daily performance statistics parameter for calibration, coefficient of determination (R2 =0.79), Nash-Sutcliffe efficiency (NSE=0.78) and the small volume difference between observed and simulated values of 2.87% and for validation, coefficient of determination (R2 =0.77), Nash-Sutcliffe efficiency (NSE = 0.77) and the volume difference between observed and simulated values of 11.28%, show the model have very strong predictability capacity.

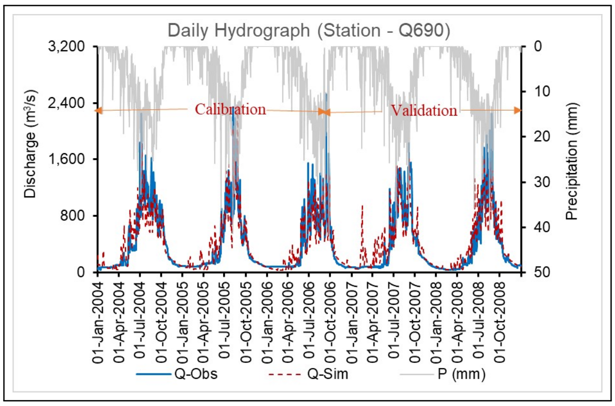

Figure 10: Observed versus simulated daily hydrograph at Q690(Mulghat)

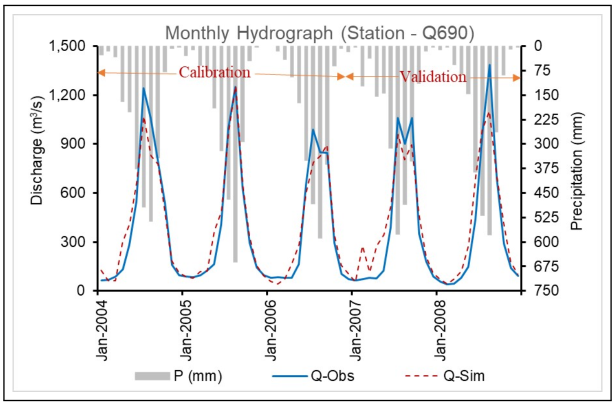

Figure 11: Observed versus simulated monthly hydrograph at Q690(Mulghat)

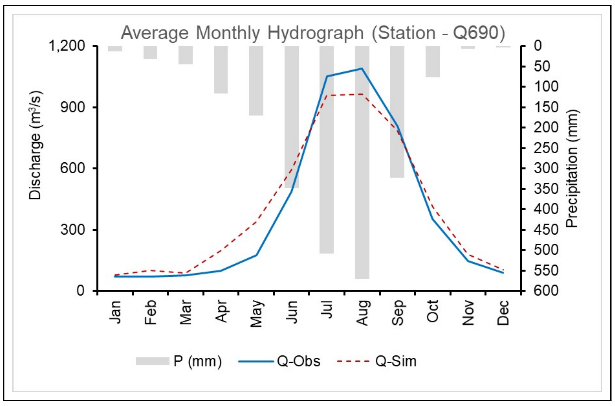

Figure 12: Observed versus simulated average monthly hydrograph at Q690(Mulghat)

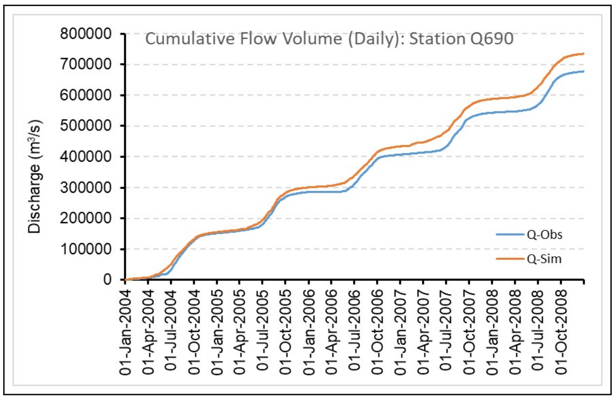

Figure 13: Observed versus simulated cumulative flow volume at Q690(Mulghat)

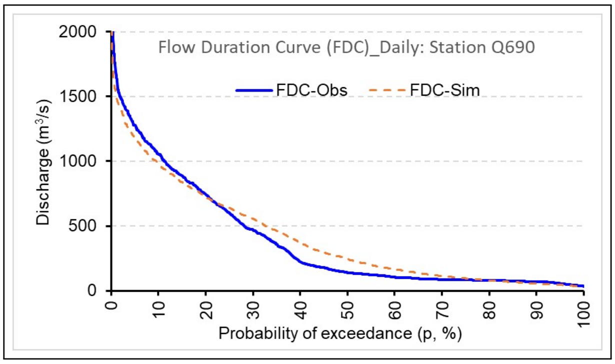

Figure 14: Observed versus simulated daily Flow Duration Curve (FDC) at Q690(Mulghat)

	Calibration (2004-2006)	Validation (2007-2008)	Entire Period (2004-2008)
Daily	R^2=0.79, NSE=0.78, PBIAS=2.87	R^2=0.77, NSE=0.77, PBIAS=11.28	R^2=0.78, NSE=0.78, PBIAS=6.16
Monthly	R^2=0.95, NSE=0.95, PBIAS=2.92	R^2=0.92, NSE=0.90, PBIAS=11.58	R^2=0.94, NSE=0.92, PBIAS=6.31

Figure 15: Performance statistics parameter at Q690(Mulghat)

4.2 Current (baseline) hydrological characteristics

Long term average annual(1989-2009) discharge at the outlet of the basin is 426.5 m^3/s. and average annual volume in the river is 13,454.1 MCM/year. The average monthly discharge at the basin outlet is estimated to vary from 86.9 m^3/s. (in February) to 1052.9 m^3/s. (in August). The average seasonal discharge on winter(DJF) season is 99.7 m^3/s, on pre-monsoon(MAM) season is 221.7 m^3/s., on monsoon(JJAS) season is 877.2 m^3/s. and on post monsoon(ON) season is 309.7 m^3/s. respectively. The 90th percentile flow available in the river is 52.6 m^3/s.

4.3 Projected change in hydrological characteristics

The calibrated and verified HEC-HMS model was used to simulate the climate change impacts on hydrological characteristics using projected future rainfall and temperature time series based on an ensemble of selected five GCMs for two scenarios. Changes in hydrological characteristics over the outlet of the basin is analysed to understand the change in discharge on the river under projected future climate. Future discharge under different scenario is compare with the baseline discharge at the basin outlet shown in Figure 16.

The average annual flow at outlet of the basin for the baseline period is estimated 426.5 m^3/s,which under SSP245 scenarios are projected to increase by 9.4%, 11.45% and 17.9% for Near Future(NF), Mid Future(MF) and Far Future (FF) respectively. Under SSP585 scenarios, it is also projected to increase by 4.4%, 10.5% and 23.7% for NF, MF and FF respectively. Intra-annual fluctuations in anticipated changes, on the other hand, differ between the scenarios and future time periods analyzed. Projected changes under both the scenarios vary from -11.1%(May) to 32.9% March)in NF,17.2%(May) to 41.3% (March)in MF,and -8.92 (October) to 47.34%(March)in FF.The flow volume in the Tamor River is projected to increase across most of the months except May and October in all future. However, on April under scenarios SSP585 in NF is decreases by -1%, on June under scenarios SSP245 and SSP585 in NF is decreases by -1.4% and -1.7%, on November under scenarios SSP585 in NF also decreases by -0.3%. On May and October flow volume is decreases in the most of the future and scenarios. However, on May under scenarios SSP585 in FF is increases by 2.4% and on October under scenarios SSP245 in MF and under scenarios SSP585 in FF is increases by 2.3% and 7.1%. Even though the future average annual flow is predicted to exceed, future flow volume is expected to drop in May and October. Seasonal discharge is only decreases in post

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baseline(m3/s)	91.4	86.9	89.1	194.7	381.2	635.5	1014.7	1052.9	805.7	421.9	197.4	120.8	426.5
SSP245-NF	17.8	23.5	31.2	4.9	-11.1	-1.4	17.3	15.7	6.3	-5.3	8.6	12.1	9.4
SSP245-MF	12.3	35	41.3	3.6	-9.9	9.6	15.3	17.1	4.6	2.3	8.6	15.4	11.4
SSP245-FF	6.3	25.4	47.3	7.9	-2.5	0.1	16.3	17.7	4.3	-8.9	4.3	14.7	17.9
SSP585-NF	9.1	12.2	32.9	-1	-9.2	-1.7	11.4	10.8	-1.1	-10.9	-0.3	2.4	4.4
SSP585-MF	13.7	26.7	34.3	4.1	-17.3	3.1	15.7	19.2	7.3	-1.1	7.1	12	10.5
SSP585-FF	21.6	27.1	47	7.7	2.4	16.8	26.3	31.1	20.8	7.1	16.1	21.7	23.7

Figure 16: Projected change [%] in river flow at the outlet of the Tamor River)

monsoon season under scenarios SSP245 in FF and SSP585 in NF. The increase in the flow volume from December to March is due to the melting of snowmelt and ice and decrease in the flow due to the precipitations pattern in the TRB.

5. Conclusions

In the study, a well calibrated and verified HEC-HMS hydrological model was developed and applied to assess impacts of climate change on hydrological characteristics in the Tamor River Basin located in Eastern Nepal. Changes in future hydrological characteristics was projected based on an ensemble of selected GCMs for five consensus cases. Projected future precipitation and temperature was fed with calibrated/validated HEC-HMS model to simulate projected future hydrology. The average annual discharge at baseline period was 426.5 m^3/s, which under both scenarios, is projected to increase in all future periods. However, monthly variation in river flows is expected to increase in most of the months and decrease in the May, October, on April under scenarios SSP585 in NF, on June under scenarios SSP585 in NF, on September under scenarios SSP585 in NF and on November under scenarios SSP585 in NF. Having no threat for annual discharge in the river, in most of the months, average monthly discharge is also projected to increases except May and October. Seasonal discharge is only decreases in post monsoon season under scenarios SSP245 in FF and SSP585 in NF. The melting of snow and ice on the TRB, however, adds to an increase in river flows from December to March.

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