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Impact of Climate Change on Streamflow and water balance in Kankai-Mai River Basin

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Abstract

Kankai-Mai River basin(KRB) is purely rain-fed and consists of perennial rivers originating from mid-hills of the Mahabharat range. Projections of precipitation and temperature show the vulnerability of the hydrological regime to climate variability. The impact of climate change in the river flow is limitedly known in Nepal and is also in the case of the Kankai-Mai. In order to assess the climate change, impact on the hydrology of the Kankai river, the Soil and Water Assessment Tool (SWAT) was used. The baseline scenario was developed in the SWAT based on the precipitation and temperature time series data for 1990-2005. The future climatic dataset (2021-2095) was prepared using a set of four latest generation Coupled Model Inter-comparison Project (CMIP6) models under two Shared Socioeconomic Pathways (SSP245 and SSP585) to assess future discharge. From the study, it was projected that there will be a continual increase in average monthly temperatures (both maximum and minimum) for all three future time periods (the 2030s, 2060s, and 2080s) with the more profound rise in winter and pre-monsoon seasons. The average annual precipitation was projected to vary between -2.44% to +23.15% for both SSP 245 and SSP 585 scenarios with the appreciable decrease during dry months while considerable increases were found during wet months. The extremities of rainfall estimated to be very high in wet months and low in dry months were reflected in basin discharge. Modeling results have shown that under both scenarios, the monthly discharges are projected to get fluctuated between -34.6% to +39.2% for all the future periods causing annual discharge to change between -3.4% to 18.1%. The study demonstrated that the temperature will increase in the future in the basin with erratic rainfall patterns affecting the discharge at the basin.

Keywords

Climate change, CMIP6, Hydrology, Kankai, SWAT

1. Introduction

Nepal, a Himalayan country with about 6000 rivers, the major sources of which are mostly the melting of glaciers and snow, is prone to the adversities of changing climate [1][2][3].

Studies of climate change globally and especially in the context of Nepal provide evidence of increasing temperature and changing rainfall patterns. The variation in the major climate variables- precipitation and temperature- bring about change in hydrological characteristics of rivers, the result of which affects the water availability in the basin [4]. There is a large gap in the understanding of the possible impact of climate change in Nepal due to fewer studies and poor measured data quality [5]. The recent studies of climate change in South Asian countries using the latest new generation Global Circulation Model (CMIP6) insinuate the stronger warming of over 6 °C and the annual rainfall to vary between -5.8% to 95.6% in the context of Nepal [6]. Acknowledging the impact of climate change from the studies in the global scenarios and in Nepal, a clear understanding regarding the variation in climatic variables (temperature and precipitation) bringing the change in streamflow is necessary for the sustainable operation and efficient planning of water related projects like hydropower plants and irrigation [7][8]. SWAT is one of the most widely-used watershed-scale simulation tools used around the world to address watershed questions and is capable of predicting the effect of soil, land use, and management on water. It has been used in thousands of scientific studies and published in peer-reviewed articles as its scientific acceptance is well established. The efficacy of model was also found to be well-fitting in different basins of Nepal providing good results [9][10] [11]. Climate change scenarios are developed based on outputs of selected new generation CMIP6 global circulation models driven by different socioeconomic assumptions termed as Shared Socioeconomic Pathways (SSPs). The bias-corrected climate data were fed into calibrated and validated SWAT model to study the impact of projected climate change on the hydrological regime of the Kankai-Mai basin.

2. Study Area

Kankai-Mai River basin is a watershed consisting of network of perennial rivers [1] located in the easternmost part of Nepal, that originate from mid-hills of the Mahabharat range. It particularly flows from the Illam district in the north down to the Jhapa district in the south and ultimately meets the Mahananda River Basin of India [12]. The study area, however, is almost entirely located in the Illam district. The location coordinates for the study area lies between 26°41' to 27°07' to 87°41' to 88°08'. The outlet for the study area is taken as hydrological station Mainachuli situated at the latitude of 26°41' and longitude of 87° 52' at Jhapa district bordered with Illam. The major tributaries of the Kankai River are Jogmai, Puwa Khola, Mai Khola, and Deu Mai Khola as shown in Figure 1. The watershed has a total area of 1167.45 sq. km. Topographically, the elevation band ranges from the maximum elevation of 3604 m to the minimum elevation of 124 m. About 85% of the catchment area lies below 2000m and about 40% of the area lies below 1000m. The Kankai Mai river basin is purely a rain-fed watershed as it doesn't experience snow since it originates from mid-hills of the Mahabharat range. The temperature and rainfall in the area depend on variation in altitudes. There occurs a range of climatic differences elevation-wise from cold tropical in the northern highlands to subtropical in the southern lowlands [12]. While rivers overflood in monsoon inundating southern plains of Jhapa due to excessive rainfall, rainfall is very low in winter almost drying up the river. Monsoonal rainfall inundates the rivers of the Kankai-Mai basin since 80% of total rainfall that occurs throughout a year occurs during the monsoon season. Seasonally, the temperature inside the basin reaches about 35°C in the summer in the southern lowlands and dive during winter to below 2°C in the

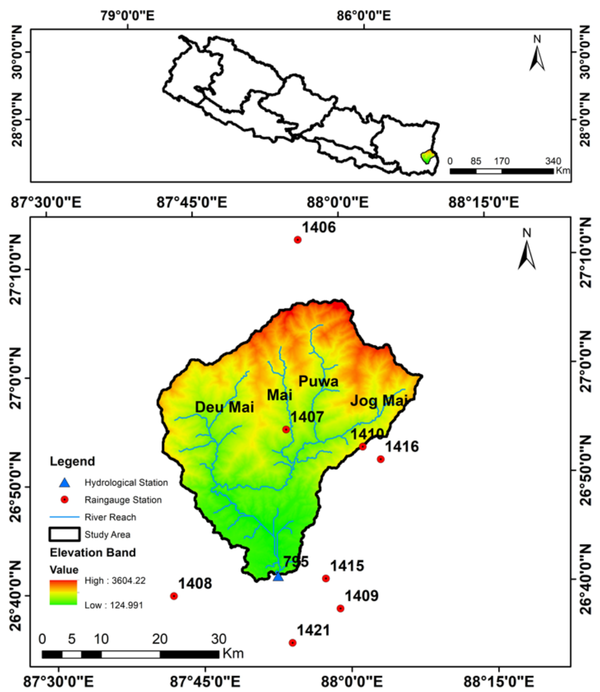


Figure 1: Location of Study area including hydro-meteorological stations, river reaches, tributaries of Kankai river and topography across the Kankai river basin.

upper hills of the basin. From the economic perspective, the Kankai river is an economic boon to the country. The river is important for irrigation projects irrigating southern fertile plains as well. The groundwater springs are the principal source of water in hilly areas while deep tube wells are in southern plains. The watershed is dominated by forest and agricultural lands and accordingly principal occupations for the majority of communities here are agriculture and animal husbandry. Besides the watershed area has a huge potential for hydropower generation. More than twelve hydropower plants are in either the construction phase or in the operation phase.

3. Materials and Methods

3.1 Hydro- Meteorological Data

Weather data collected from Department of Hydrology and Meteorology (DHM) throughout the basin were used as input to the SWAT model for setting up and further analysis of model. Out of 10 meteorological stations lying inside/around the Kankai-Mai watershed, six stations were considered for this study and obtained the daily meteorological data from 1990-2009. The other four stations data had

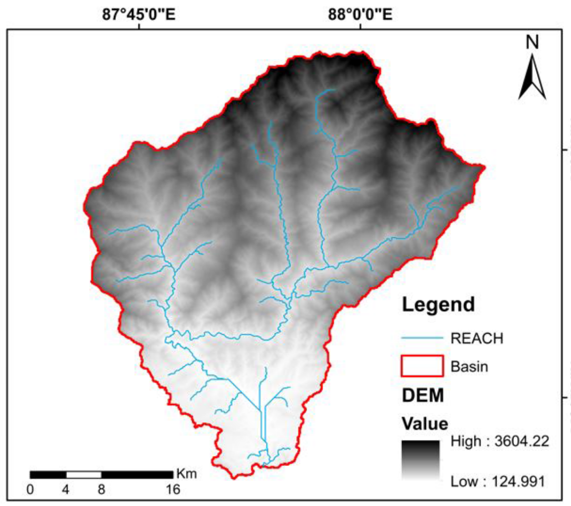


Figure 2: Digital Elevation Model of KRB

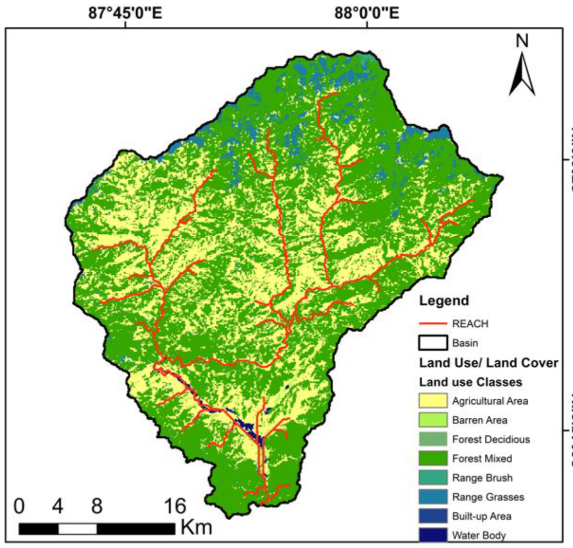


Figure 3: Land use/ cover map of KRB

large gap in the observation with respect to selected six stations. The six selected meteorological stations for the study are 1406, 1407, 1408, 1410, 1415 and 1416. Altogether there are six climatic stations recorded in the vicinity of Kankai Basin, namely Terhathum (1314), Taplejung (1405), Illam Tea Estate (1407), Kanyam Tea Estate (1416), Phidim (Panchthar) (1419) and Gaida(Kankai) (1421). Daily minimum and temperature data of all these six stations available from 1990-2009 were collected from DHM. The relative humidity inputs were prepared from four gauging stations-1407, 1416, 1419, and 1421 lying inside/around the basin and were also obtained from department of Hydrology and Meteorology. Daily discharge data for the outlet hydrological station Mainachuli was available for the period from 1978-2009 and the discharge data from 1990-2005 was used for analysis. The description of Hydro-meteorological stations has been summed up in Table1.

3.2 Spatial Data

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 30 m resolution was used in the study. The elevation model shows variation in altitude from 124m to 3604 m as in Figure 2.

International Center for Integrated Mountain Development (ICIMOD) has prepared the land cover map for Nepal which is available at 30 m resolution, was used in the study. Land cover Map consisting of eight land classes for the KRB is shown in Figure 3. The overall basin is dominated by forest which covers 61.1% of entire basin area.

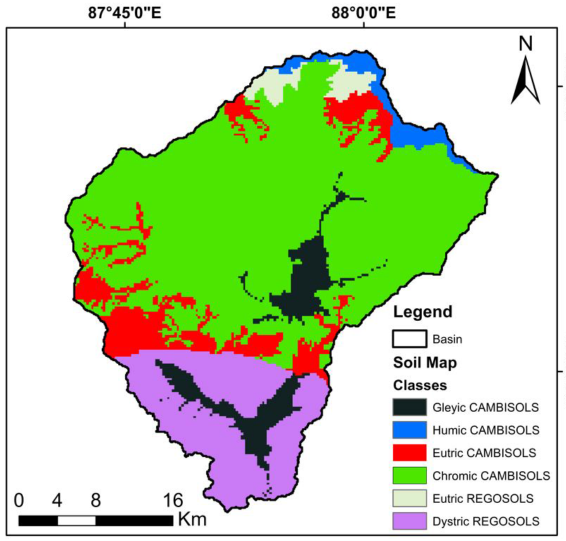


Figure 4: Soil Map of the Kankai watershed

The soil map used for the study is a 1:1 million scale map provided by Soil and Terrain Database Programme. The soil map of the KRB is presented in Figure 4. Among six different soils identified for the basin Chromic CAMBISOLS soil was found to be dominated with the share of about 62% of whole basin area.

3.3 Climate change data for the basin

The global circulation model (GCM) used in the study is CMIP6. Thirteen CMIP6 models under four different shared socioeconomic pathways SSP126, SSP245, SSP370, SSP585 were available in the

Table 1: Distribution of hydro- meteorological stations inside/around the Kankai-Mai Basin

SN	Station ID	Station Name	District	Lat.	Long.	Altitude (Masl)	Types of Station
1	1314	Terhathum	Terhathum	27.13	87.55	1029.29	Climatology
2	1405	Taplegung	Taplejung	27.35	87.66	1696.28	Synoptic
2	1406	Memeng Jagat	Taplejung	27.2	87.93	1979.72	Precipitation
3	1407	Illam Tea Estate	Illam	26.92	87.9	909.12	Agrometeorology
4	1408	Damak	Jhapa	26.67	87.7	134.6	Precipitation
5	1409	Anarmani Birta	Jhapa	26.63	87.98	121.87	Precipitation
6	1410	Himali Gaun	Illam	26.88	88.03	1742.06	Precipitation
7	1415	Sanischare	Jhapa	26.68	87.97	139.92	Precipitation
8	1416	Kanyam Tea Estate	Illam	26.87	88.07	1261.57	Climatology
9	1419	Phidim	Panchther	27.15	87.75	1065.2	Climatology
10	1421	Gaida	Jhapa	26.58	87.9	96.55	Agrometeorology
11	795	Mainchuli	Jhapa	26.68	87.86	125	Hydrology

CMIP6 database website. Along with the four future socioeconomic pathways, historical data set of temperature and precipitation were also available. Future datasets of temperature and precipitation from four different CMIP6 models- ACCESS-CM2 EC-EARTH3, MPI-ESM1-2HR, MRI-ESM2-0 -under two different scenarios SSP245 and SSP585 were downloaded from CMIP6 database to be used in our study [13]. The bias correction of coarse precipitation data was done using Empirical Robust Quantile Mapping Method and Linear Mapping was applied for temperature. The bias correction was performed using R Studio Interface and these data were used for the climate change analysis. The daily future precipitation and temperature (both maximum and minimum) data were available from 2015-2100. The daily historical datasets were available from 1975-2014 in MPI-ESM1-2HR while in MRI-ESM2-0 and ACCESS-CM2 the datasets were available from 1950-2014. The historical datasets for EC-Earth3 were available from 1980-2014. The historical datasets available were compared with the historical dataset of the study area for bias correction. The future bias corrected data were divided into three future periods, 2021-2045, 2046-2070, and 2071-2095 termed as near, mid and far future respectively for the future projection of climate in the Kankai-Mai.

3.4 Hydrological modeling

Hydrological analysis involves some chronological steps to be followed. Figure 5 describes the framework under which this study has been performed. A better understanding of effects of climate change on the river discharge can be gained through hydrological model [14]. A semi-distributed, physically based hydrological tool, Soil and Water Assessment Tool (SWAT) [15] was used for rainfall-runoff modeling in this study to assess future discharge in the basin. The key hydrological modeling procedure is represented by the water balance equation (1)[15]:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \tag{1}$$

Where

SW_t final soil water content (mm H_2O)

SW_0 initial soil water content on day i (mm H_2O)

t time (days)

R_{day} daily precipitation on day i (mm H_2O)

Q_{surf} amount of surface runoff on day i (mm H_2O)

E_a amount of evapotranspiration on day i (mm H_2O)

w_{seep} amount of water entering the vadose zone from the soil profile on day i (mm)

Q_{gw} amount of return flow on day i (mm H_2O).

The first step of modeling using SWAT is the discretization of a basin into number of sub-basins and Hydrological Response Units (HRUs). Each sub-watershed is associated through a stream channel and further discretized into Hydrologic Response Units (HRUs). HRU is the combination of unique land features, soil type, and slope classification within a sub-basin based upon user-defined thresholds. The outflow at the selected outlet is the accumulated flow at each subbasin and HRUs connected through stream channels. The whole study area was divided into twenty-three sub basins and further into 171 HRUs. Weather data required by SWAT are daily precipitation, maximum and minimum air temperature, solar radiation and relative humidity.

Weather generator is prepared to account for the missing data of precipitation and temperature. Weather definition tool allows to load weather station locations into the current project and assign weather data to sub-basins. Each sub-watershed is linked to one gauge for each type of weather data. The period of simulation was set specifying the starting date as 1/1/1990 and the ending date 12/31/2005 and two years of warm-up period was taken. Once a model is setup using input data, the model requires the set of parameters and such ranges of those parameters that can replicate the observed flow. So, an additional interface by SWAT, SWAT-CUP is used for calibration and validation of model. SWAT- CUP links to SWAT through five optimization programs viz. SUFI-2, PSO, GLUE, ParaSol, and MCMC all of which enable sensitivity analysis of parameters, calibration, validation, and uncertainty analysis of SWAT model. In this study SUFI-2 algorithm has been used to calibrate and validate the model in SWAT-CUP. The future climatic data from the referenced stations for all the four GCMs and also under both socio-economic pathways were to be fed into the calibrated and validated SWAT. The SWAT model after feeding the future climatic data was run from future period 2021-2095 to obtain the projection of future discharge. Thus, obtained discharge for four GCMs under two scenarios were also divided into three future periods. The combined average of SSP245 of all four GCMs and that of SSP585 were calculated to obtained two sets of data for three future periods. The discharge was used for the analysis of water availability in the future.

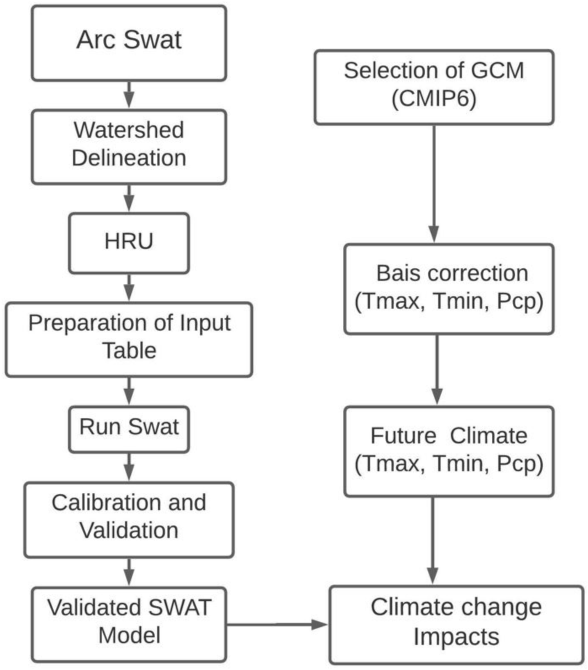


Figure 5: Framework of the methodology of Study

3.5 Model Calibration and Validation

SWAT-CUP (SWAT Calibration and Uncertainty Program) is such a computer program consisting of coded algorithms, called upon to help adjust the parameters in such a way to best represent a basin. A set of parameters and their ranges are set either manually or between each auto-iterations. Parameterization is an important phase during calibration performed after the necessary information collected through review of similar works carried out in literature [16] [17] [18]. Another chief aspect of calibration is the parameter sensitivity meaning which parameter among the set of parameters chosen has the most responsive effect on the basin. A large number of parameters were taken initially and only few of them were used for further calibration after performing sensitivity analysis. Sensitivity analysis can be done through Global sensitivity analysis (all at a time) and Local Sensitivity analysis (one at a time). Though both the methods have pros and cons, as in local sensitivity analysis the dependency of one variable to another cannot identified as only one parameter value at a time is changed to see the sensitivity of that particular parameter but in real picture the other parameter might be affecting the sensitivity that particular parameter. Besides, the local sensitivity analysis is fast and can be done with few simulations. The inter-dependencies can be identified in global sensitivity analysis but it takes longer simulation time. Global sensitivity analysis was performed in SUFI-2 and only most sensitive parameters were considered for further calibration. The sensitivity of a parameter is identified based on the p-value and t-stat. The parameter having least p-value (close to 0) and highest absolute t-stat value is considered to be the most sensitive parameter. Several iterations were performed with the new set of parameter ranges as recommended by SUFI-2 until the best parameter range was obtained. There is large uncertainty in parameters' range as the unrealistic range could be misleading. Thus, it is important to understand the actual physical knowledge of the basin before setting the parameters' range. To assess the performance of the model predictability of representing the hydrological simulation of the reality of the basin, three basic statistical hydrological model performance check was used- NSE (Nash Sutcliffe efficiency), R2 (Coefficient of Determination) and PBIAS (Percentage Bias) [19]

4. Results and Discussion

4.1 Performance of SWAT model

The SWAT model was calibrated and validated using SWAT-CUP after proper parameterization and sensitivity analysis. During parameterization 24 parameters were selected and 16 parameters were found out to be most sensitive parameters for our basin after sensitivity analysis. Ground water parameter GW-DELAY was identified to be the most sensitive parameter. Similarly, other ground water parameters Groundwater ”revap” coefficient (GW-REVAP), GWQMN were found to have more dominant effect in the Kankai-Mai basin. The list of parameters based on their sensitivities from 1-16, 1 being the most sensitive are shown in Table 3

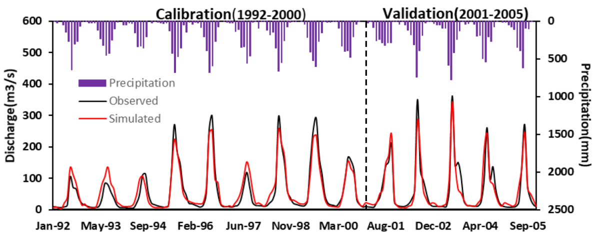


Figure 6: Observed and simulated monthly discharge hydrograph at hydrological station Mainachuli for calibration and validation

Table 2: Model Performance during monthly calibration and validation

Timeline	Period	NSE	R^2	PBIAS
Calibration	1992-2000	0.88	0.89	-4.32
Validation	2001-2005	0.87	0.90	-6.65

The calibration and validation were performed at Mainachuli station(795); the observed and simulated monthly hydrograph is shown in Figure 6. The observed discharge at the outlet station was found to be in consistent with the simulated discharge from the model. The performance of SWAT model in terms of statistics of three performance indicators is presented in Table 2 . According to [19], the range of statistics for a good model for monthly simulation for PBIAS value within ±15% and NSE and R2 is above 0.75. The result shows that the NSE value is 0.88, Coefficient of Determination R2 is 0.89 and PBIAS.is -4.32%. The positive PBIAS indicated that simulated discharges are underestimated. The validation result shows NSE of 0.87 and R2 of 0.90 and PBIAS -6.65. While the NSE and R2 values show better results, overestimation of discharge by model is increased during validation since the percentage bias negative value was increased. The overall statistics shows reliable output by the model. Hence, it shows that SWAT reliable and accurate result from the model in further analysis can be assured.

4.2 Water Budget during the Calibration and Validation Periods

The model was re-run for the years 1990-2005 by using the calibrated parameters to see water balance during the calibration and validation periods as well as till the end of century obtained from four different GCMs under SSP245 and SSP585 scenarios. Table 4 shows the water budget reported by SWAT and it can be seen that the model maintains mass balance.

4.3 Climate change analysis

Bias corrected climate data on the Kankai Basin were used for an analysis of projected precipitation and temperature. The future timeline was categorized into three periods: from 2021-2045, 2046-2070 and 2071-2095 termed as near, mid and far-future respectively. Each timeline having 25 years of data are compared with the reference period (1990-2005). The analysis is performed under averaged projections from four CMIP6 models under two scenarios SSP245 and SSP585 each.

4.3.1 Projected Temperature

The change in projected monthly temperatures (both minimum and maximum) for three future periods- Near Future (NF), Mid-Future- (MF) and Far-Future- (FF) under SSP245 and SSP585 on comparison with the baseline monthly temperature were taken as average from two reference stations Illam tea State (1407) and Kanyam tea state 1416. The projection by combined future data of four GCMs in the SSP245 scenario shows that there is continual increase in temperatures. The increase in minimum temperature is found to be highest during far future where it will be increased by 3.1°C in the month of May. In the SSP245 combined scenario the minimum temperature has increased with maximum rate for the summer period of May, June, July and August. The maximum increase is seen in the far end future period

Table 3: Parameters rank based on their sensitivity

SN	Parameter	Description	Fitted Value	Min Value	Max value
1	V__GW_DELAY.gw	Groundwater delay [days]	350	148.76	450
2	V__GW_REVAP.gw	Groundwater "revap" coefficient	0.015	0.01	0.03
3	V__LAT_TTIME.hru	Lateral flow travel time [days]	49.94	22.2	66.6
4	V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur [mm]	109.3	0	342.1
5	V__CN2.mgt	SCS runoff curve number for moisture condition	98	81	98
6	V__CH_K1.sub	Effective hydraulic conductivity in tributary channel [mm/hr]	3.53	0	35
7	V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur [mm]	408.13	245.3	487.3
8	V__CH_K2.rte	Effective hydraulic conductivity [mm/hr]	243.34	165.12	312.7
9	V__ESCO.bsn	soil evaporation compensation factor	0.21	0.16	0.25
10	V__CANMX.hru	Maximum canopy storage [mm]	2.94	2.14	15.13
11	V__CH_N2.rte	Manning's n value for main channel	0.13	0.11	0.19
12	V__ALPHA_BNK.rte	Baseflow alpha factor for bank storage [days]	0.61	0.5	0.74
13	V__PLAPS.sub	Precipitation lapse rate [mm/km]	-145	-212.3	5.43
14	V__ALPHA_BF.gw	Baseflow alpha factor [days]	0.51	0.44	0.71
15	V__TLAPS.sub	Temperature lapse rate [°C/km]	-6.32	-7.53	-2.21
16	R__HRU_SLP.hru	Average slope stepness [m/m]	0.22	0.1	0.27

2071-2095.Also there is the increasing trend of minimum temperature for all the near future, mid future and far end future especially in summer season. The combined future analysis of four models in the SSP 585 scenario shows highest increase in the minimum temperature by 4.24°C for the month of the May in the far end future period of 2071-2095.Overall there is trend of rise in minimum temperature especially more pronounced in the summer period but the temperature has slightly decreased in the near future for the month of October in contrast to SSP245.

Similarly for the Maximum temperature, the combined future scenario analysis for all four GCMs was performed and it was found that there is the overall increase in maximum temperature for all future periods in general with the maximum increase being more pronounced in the months of summer like in SSP245. The temperature rise is more profound between January to July compared to other months for SSP245. However, there is a slight decrease in temperatures from August to November in near future period. And for the Combined SSP585 there is significant increase in maximum temperature for the month of the January with increase in temperature of 4.18 °C from the base line period. The temperature has risen high for the far-future period. Thus, there is overall rise in the temperature on average for all the months especially for the summer months for all future periods for both the scenarios. The percentage changes in monthly minimum and maximum temperature compared with baseline temperature (value) are presented for both the scenarios in Tables 5 and 6.

4.3.2 Projected Precipitation

The CMIP models show a more or less same amount of annual precipitation for both the SSP245 and SSP585 scenarios for all time periods falling within ± 2.5% range with the exception in increase of 23.2% of annual precipitation for far future period of SSP 585 scenario. Although the annual precipitation figures are more or less similar, erratic nature of future precipitation on the monthly basis presented in Figure 7 present the range of uncertainties. Heavy decrease in precipitation can be observed during the months of March-June while significant increase in rainfall can

Table 4: Average annual basin values of water balance components in the Kankai River Basin during the calibration -validation periods and the for the future Scenarios of four GCMs

Water Balance Component	Volume(mm)								
	Calibrated validated	SSP245				SSP585			
		ACCESS -CM2	EC -Earth3	MPI	MRI	ACCESS-CM2	EC -Earth3	MPI	MRI
Precipitation	1750.4	1992.6	2135	1778.1	1646.3	1975.6	2322.4	1954.8	1879.3
Snowfall	0	0	0	0	0	0	0	0	0
Snow melt	0	0	0	0	0	0	0	0	0
Sublimation	0	0	0	0	0	0	0	0	0
Surface Runoff, Surf Q	330.53	231.24	348.92	216.88	276.06	254.37	625.49	270.08	265.01
Lateral Soil, Lat Q	816.77	1120.58	1166.61	990.58	774.31	1095.67	1335.28	1083.7	1038.61
Ground water (Shallow AQ)	207.22	96.2	108.38	78	160.4	89.26	134.23	93.56	82.76
Ground water (Deep AQ)	19.13	26.44	28.82	22.61	10.25	25.2	34.22	25.72	23.91
Revap (Shal AQ=> soil/plants)	12.36	33.11	32.75	32.61	34.3	34.18	33.64	32.46	34.29
Deep AQ recharge	12.28	26.47	28.91	22.65	10.25	25.29	34.39	25.79	23.99
Total AQ recharge	245.59	155.82	170.19	133.32	204.98	148.92	202.47	151.83	141.22
Total water yield	1366.89	1474.46	1652.73	1308.08	1221.02	1464.5	2129.22	1473.1	1410.28
Percolation out of soil	245.47	156.12	172.41	134	205.01	151.01	207.44	153.15	143.14
Actual evapotranspiration	357.8	484.7	447	436.6	390.8	474.5	454.2	447.8	432.6
Potential evapotranspiration	1305.4	1655.6	1637.6	1630.3	1715	1708.9	1681.08	1623.2	1714.3

Table 5: Change in average minimum temperature under SSP245 and SSP585 scenarios for three future periods compared with baseline temperature

Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BaseTmin(°C)	6.5	8.1	11.3	14.4	16.0	17.9	18.5	18.4	17.5	15.0	11.4	8.0
SSP245 NF	1.42	0.77	0.34	0.35	1.84	1.33	0.70	0.55	0.52	0.04	0.30	0.80
SSP245 MF	2.13	1.36	0.87	1.08	2.43	1.98	1.32	1.05	0.97	0.64	1.00	1.57
SSP245 FF	2.57	1.90	1.46	1.69	3.10	2.51	1.71	1.43	1.28	0.90	1.38	1.93
SSP585 NF	1.43	0.80	0.18	0.55	1.76	1.35	0.81	0.64	0.51	-0.04	0.13	0.72
SSP585 MF	2.62	1.79	1.37	1.64	2.90	2.36	1.76	1.49	1.34	1.14	1.46	1.98
SSP585 FF	4.19	3.58	3.00	3.11	4.24	3.56	2.78	2.49	2.48	2.53	2.96	3.54

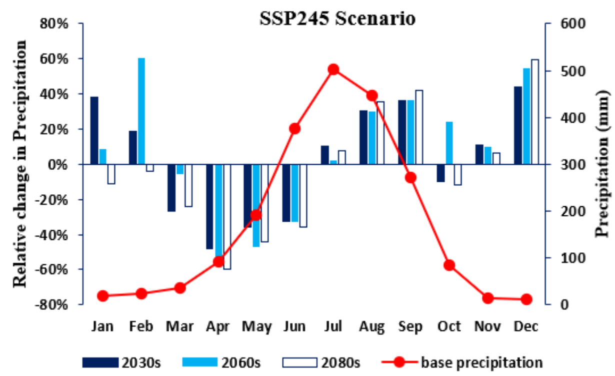
Table 6: Change in average maximum temperature under SSP245 and SSP585 scenarios for three future periods compared with baseline temperature

Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base Tmax(°C)	15.3	16.9	20.9	23.9	24.5	24.7	24.2	24.6	24.3	23.2	20.5	17.3
SSP245 NF	1.41	1.40	0.97	0.90	1.80	1.41	0.26	-0.64	-0.73	-1.17	-0.77	0.04
SSP245 MF	2.30	2.10	1.56	1.74	2.52	2.09	1.01	-0.10	-0.19	-0.65	-0.18	0.79
SSP245 FF	2.79	2.95	2.31	2.52	3.24	2.72	1.37	0.20	0.06	-0.24	0.22	1.24
SSP585 NF	1.52	1.43	0.76	1.14	1.86	1.44	0.36	-0.58	-0.69	-1.13	-0.80	0.11
SSP585 MF	2.74	2.69	2.03	2.08	2.90	2.44	1.25	0.13	0.15	-0.26	0.26	1.19
SSP585 FF	4.18	4.11	3.30	3.47	4.17	3.40	2.22	1.05	1.09	0.82	1.67	2.52

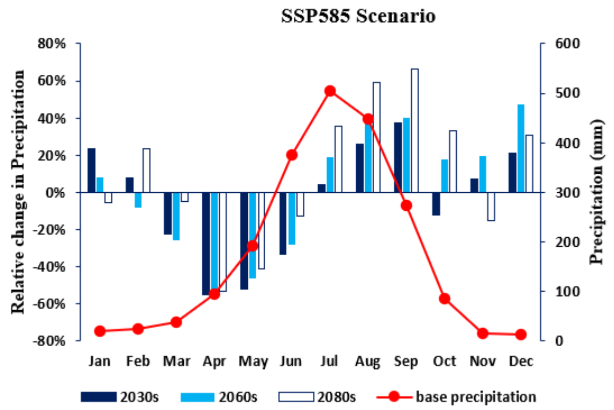
be observed in the months from July-September under both SSP 245 and SSP 585 scenarios with the maximum decrease in the month of June. Baseline peaks in the month of July has been shifted to the month of August. 78% of baseline total yearly rainfall that occurs between June to September will significantly increase to about 85% of annual precipitation in both scenarios in the months of June to September. The projections of heavy rainfall hint huge inundation and landslides.

4.3.3 Impact on discharge

In order to assess the impact of changing temperature and precipitation on river flows, the baseline scenario of discharge developed from calibrated and validated SWAT model was compared with the discharge projected by the model after feeding future climate data to the model. The future projection of discharge is the combined simulated discharge from four CMIP6 models. Table 7 depicts the comparison of average monthly baseline discharge with average monthly discharges of near, mid and far future time periods for both scenarios SSP245 and SSP585. The average annual discharge at the outlet of the basin in baseline period was 62.1 m3/s. The annual discharge is projected to increase by 2.3% in near future and decrease by 0.3% and 2.9% in mid and far future under SSP245 scenario. Under SSP585 the average



(a) Change in average precipitation for SSP245



(b) Change in average precipitation for SSP585

Figure 7: Impact of Climate Change on Precipitation for three different future periods compared with base under SSP245 and SSP585 scenarios.

annual discharge is projected to decrease slightly by 0.2% in Near future period while increase by 4.1% and 8.6% respectively under mid and far future. In both scenarios there is a trend of peaks between the months of June to September. However, the peaks have been shifted to the month of August contrary to the peaks that used to be achieved during the month of July in baseline period. The decrease in discharge in the months of April to May where the decrease varies from -9.6% to -34.6% in all the future periods while increase in discharge from December to March was projected to vary from 0.7% to 11.1%. The discharge in August and September are projected to increase from 3% to 18% while decrease in July vary from -0.1 to 8.7%. The October and November months' discharge are projected to decrease and they vary from -6.8 to -14%. SSP 245 shows the decrease in low flow discharges from near to far future periods. On seasonal basis the increase in discharge was projected during winter and monsoon while the decrease in discharge was projected during post monsoon and pre-monsoon in all the future periods. The increase or decrease was found to be more profound in far future period under SSP585.

4.3.4 Flow Duration Curve

Flow-duration curve was prepared for baseline period and average discharges modeled over three future periods each of 25 years interval for both the scenarios SSP245 and SSP585. Figure 8 show the comparison between the flow duration curve during the baseline period and the three future periods under SSP 245 and SSP585 scenarios respectively. The water availability or the probability of occurrence of flow could be lower in the Kankai River Basin.

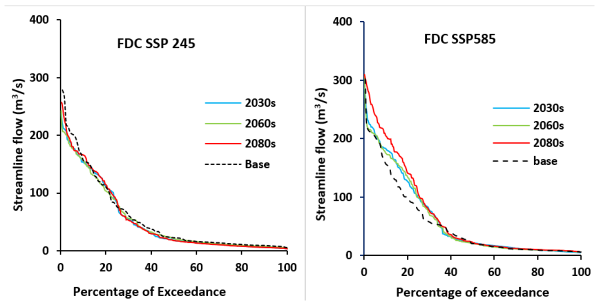


Figure 8: Flow duration curve for three future periods compared with base period under SSP245 and SSP585 Scenarios.

5. Conclusion

Acknowledging the effect of climate change on water resources as one of the key challenges in the Mid hills, hydrological modelling using Soil and Water Assessment Tool (SWAT) was performed. Future projected climate variables (precipitation and temperature) were used based on the ensemble of CMIP6 GCM models; bias corrected using robust empirical quantile method in R-studio interface. The bias corrected climate data were forced into calibrated and validated SWAT model to study the impact of projected climate change on the hydrological regime of the Kankai basin and to achieve the preset objectives of the research. The following are the conclusions drawn out from the hydrological modeling. The extreme projection of a Combined SSP585 scenario in the basin shows stronger warming signal that the average monthly temperature of the basin is expected to increase by 4.24°C. The projection also shows the continual increase in temperature in the future periods with minimum temperature increase rate faster than the maximum

Table 7: Impact of climate change on the average monthly discharge at the outlet of the Kankai basin at three future time periods under SSP245 and SSP585 scenarios of four combined CMIP6 Models

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Base(m3/s)	13.9	12.8	9.9	12.6	20.5	70.0	186.1	176.0	135.0	65.1	26.9	16.1	62.1
SSP245-NF	6.1	3.3	2.3	-26.2	-9.6	-8.9	-1.1	15.9	9.6	-14.0	-13.9	6.2	2.3
SSP245-MF	1.2	15.7	9.2	-27.8	-20.3	-6.5	-8.1	10.8	6.7	-10.9	-3.3	12.4	-0.3
SSP245-FF	0.7	-3.8	0.3	-21.3	-11.9	-5.7	-8.7	4.0	3.0	-9.4	-8.8	8.6	-2.9
SSP585-NF	6.9	4.5	0.4	-27.6	-34.6	-14.3	-2.2	10.8	7.4	-6.8	-14.2	5.5	-0.2
SSP585-MF	1.1	7.9	3.8	-33.3	-23.4	-9.6	-0.1	12.5	14.8	4.7	-7.1	11.1	4.1
SSP585-FF	-3.8	24.2	14.7	-25.4	-17.1	-4.7	7.5	14.8	18.5	9.0	-10.4	12.4	8.6

temperature. The average annual precipitation in the basin is projected to increase by as much as 23.15% which is contributed by share of more than 85% of annual precipitation during June to September but the decrease in precipitation in dry months resulted the considerable decrease in discharge in dry months insinuating the water scarcity during the late century under the combined SSP585 scenario. Seasonally the decrease in pre-monsoon and post-monsoon season while increase in winter and much pronounced increase in monsoon season was projected. The monthly projection of discharge under baseline period showed the decrease in inflow during April, May, October and November. The increase in discharges in other months were found to be increase. The seasonal impact of precipitation was reflected in discharges with increase in winter and monsoon while decrease in pre-monsoon and monsoon seasons.

References

[1] Daniel Viviroli, Hans H Dürr, Bruno Messerli, Michel Meybeck, and Rolf Weingartner. Mountains of the world, water towers for humanity: Typology, mapping, and global significance. *Water resources research*, 43(7), 2007.

[2] Immerzeel. Rising river flows throughout the twenty-first century in two himalayan glacierized watersheds. *Water resources research*, 43(7), 2007.

[3] AF Lutz, WW Immerzeel, AB Shrestha, and MFP Bierkens. Consistent increase in high asia's runoff due to increasing glacier melt and precipitation. *Nature Climate Change*, 4(7):587–592, 2014.

[4] Sangam Shrestha, Medha Khatiwada, Mukand S Babel, and Kshitij Parajuli. Impact of climate change on river flow and hydropower production in kulekhani hydropower project of nepal. *Environmental Processes*, 1(3):231–250, 2014.

[5] Raj Hari Sharma and Narendra Man Shakya. Hydrological changes and its impact on water resources of bagmati watershed, nepal. *Journal of Hydrology*, 327(3-4):315–322, 2006.

[6] Mansour Almazroui, Sajjad Saeed, Fahad Saeed, M Nazrul Islam, and Muhammad Ismail. Projections of precipitation and temperature over the south asian countries in cmip6. *Earth Systems and Environment*, 4(2):297–320, 2020.

[7] Mahesh Pathak. Climate change: uncertainty for hydropower development in nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, 6:31–34, 2010.

[8] Ram Chandra Paudel, Keshav Basnet, and Bikash Sherchan. Application of hec-hms model for runoff simulation: A case study of marshyangdi river basin in nepal. In *Proceedings of IOE Graduate Conference*, 2019.

[9] Luna Bharati, Pabitra Gurung, and Priyantha Jayakody. Hydrologic characterization of the koshi basin and the impact of climate change. *Hydro Nepal: Journal of Water, Energy and Environment*, pages 18–22, 2012.

[10] IRENE Palazzoli, S Maskey, S Uhlenbrook, ESTER Nana, and DANIELE Bocchiola. Impact of prospective climate change on water resources and crop yields in the indrawati basin, nepal. *Agricultural Systems*, 133:143–157, 2015.

[11] Vaskar Dahal, Narendra Man Shakya, and Rabin Bhattarai. Estimating the impact of climate change on water availability in bagmati basin, nepal. *Environmental Processes*, 3(1):1–17, 2016.

[12] Champak Babu Silwal, Dinesh Pathak, Drona Adhikari, and Tirtha Raj Adhikari. Climate change and its possible impact in groundwater resource of the kankai river basin, east nepal himalaya. *Climate*, 8(11):137, 2020.

[13] Tetiana Svystun. Modeling the potential impact of climate change on the distribution of western corn rootworm in europe. *Student thesis series INES*, 2015.

[14] Sarah Praskievicz and Heejun Chang. A review of hydrological modelling of basin-scale climate change and urban development impacts. *Progress in Physical Geography*, 33(5):650–671, 2009.

[15] Jeffrey G Arnold, Raghavan Srinivasan, Ranjan S Muttiah, and Jimmy R Williams. Large area hydrologic modeling and assessment part i: model development 1. *JAWRA Journal of the American Water Resources Association*, 34(1):73–89, 1998.

[16] Yogendra Mishra, Mukand Singh Babel, Tai Nakamura, and Bhogendra Mishra. Impacts of climate change on irrigation water management in the babai river basin, nepal. *Hydrology*, 8(2):85, 2021.

[17] Birsingh Dhami, Sushil Kumar Himanshu, Ashish Pandey, and Amar Kant Gautam. Evaluation of the swat model for water balance study of a mountainous snowfed river basin of nepal. *Environmental Earth Sciences*, 77(1):1–20, 2018.

[18] Yogendra Mishra, Tai Nakamura, Mukand Singh Babel, Sarawut Ninsawat, and Shiro Ochi. Impact of climate change on water resources of the bheri river basin, nepal. *Water*, 10(2):220, 2018.

[19] Daniel N Moriasi, Jeffrey G Arnold, Michael W Van Liew, Ronald L Bingner, R Daren Harmel, and Tamie L Veith. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, 50(3):885–900, 2007.