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Impact of Climate Change on Crop Water Requirement in Kamala River Basin of Nepal

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Abstract

The future climate which has crucial role of any hydrological events that occurs within basin will have more uncertainty. Changing the climatic variables, the water balance of the basin will more unpredictable. Not only will climatic parameter changes but also adversely affected the water management within the basin. In this study, an attempt has been carried out to compare the future River flow of Kamala basin and future water demand of Kamala irrigation command area. The CROPWAT and AQUACROP model, based on climatic, soil and crop data, was used to estimate the future Crop Water Requirement (CWR), Irrigation Water Requirement (IWR) and Biomass yield. The hydrological station, because not exist within basin, was not possible to simulate the future river flow of the Kamala basin using any hydrological model. Therefore, the WECS method is simply used to forecast the future monthly flow of Kamala River. The two emission scenarios, ssp245 and ssp585 were conducted based on cropping intensity 170% and 300 % and IWD for each sub-scenario over 12 months was estimated. For the first sixth months, IWR is increased in the future period as maximum and minimum temperature increases and the IWR for monsoon season is less required due to increases in precipitation and again for the post-monsoon season, IWR is increased compared as historical IWR. The highest irrigation water requirement occurs in March month under ssp245 and ssp585 and CI 300%. Whereas, July and August months have the lowest irrigation water demand under ssp245 and ssp585 scenarios. Based on the finding, the production of crop with irrigation system has higher than rainfed system. For paddy, the rainfed system produced dry yield of 6.58 ton/ha whereas, dry yield of irrigated field has 7.05 ton/ha. The future river flow is insufficient to meet the irrigation water demand in first five months in near future under both ssp245 and ssp585 scenarios. The magnitude of deficiency in ssp585 is comparatively higher than in ssp245. As a result, all of these findings suggest that the crop water requirement of KIP is insufficient in the future to provide a year-round irrigation system.

Keywords : Crop Water Requirement, Irrigation Water Requirement, CROPWAT, AQUACROP, ssp245, ssp585

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1. Introduction

Climate change is a major environmental problem around the world. About two-thirds of Nepalese agriculture is strongly reliant on the monsoon, resulting in an excess of food production imbalance. Climate change has emerged as a significant worldwide issue that has sparked widespread concern at both the national and international levels (Khadka & Pathak, 2016). According to several studies, Climate change has been linked to a drop in crop yield (Chowdhury, Al-Zahrani and Abbas 2013; Gohari et al. 2013; Kang, Khan and Ma 2009). Climate change is having varying degrees of impact on river hydrology around the world. (Pandey et al., 2011; Wang & Chen, 2014). According to the report from Intergovernmental Panel on Climate Change (IPCC), Assessment Report Six (AR6) increases in monsoon precipitation attributable to warming from GHG emissions were offset by declines in monsoon precipitation due to cooling from human-caused aerosol emissions over the twentieth century in South Asia. Important climate conditions in Nepal have considerable seasonal and temporal variations. The temperature and precipitation are affected by the change in height. As a result, there is a wide range of climate variations from tropical in the south to alpine in the north in Nepal. (Shrestha & Aryal, 2011).

For the future projection of climate change, different sets of SSP/RCP scenarios for Phase 6 of Coupled Model Inter-comparison Project (CMIP6) have been defined by IPCC. (Riahi et al., 2017). Precipitation, like temperature, is a climatic component that changes in amount and pattern. Over the twentieth century, global land precipitation has increased by roughly 9 mm. (New et al., 2001). As per global circulation model (GCM) forecasts, the temperature across Nepal will rise between 0.5ºC and 2.0ºC with a multi-model mean of 1.4ºC, by the 2030s and between 3.0ºC and 6.3ºC by the 2090s, with a multi-model mean of 4.7 ºC. (UNDP, Nepal).

Throughout the century, both the minimum and maximum temperatures, both seasonal and yearly, will rise. The temperature rise in the mountains was found to be significantly higher than in the lowlands. CWR was estimated for four scenarios: current temperature and rainfall (S1), the temperature is 2050 and current state of rainfall (S2), rainfall in 2050 and current state of temperature (S3), and temperature and rainfall in 2050 and current state of temperature (S4) In Al-Jouf, Saudi Arabia a 1°C increase in temperature might raise the overall CWR by 2.9 percent. (Surendran et al., 2015) In the CROPWAT model, the ETo was calculated using the penman-monteith method, and its impact on other parameters such as sunshine hour, wind speed, maximum and minimum temperature, and rainfall humidity was found. (ROJAS, 12(36)). To address these issues, a study was conducted to specify the analysis of rainfall data to determine its contribution to agricultural water requirements

2. Database and Methods

2.1 Study area

The Kamala Basin, almost 2,100 km2 in area, is located in the southeast of Nepal, the southern tip of the catchment boundary being the international border with India. The Kamala River is a tributary of the Ganges, the major river of India. Geographically the Kamala Basin comprises 3 defined landscape types in Nepal: The Middle Mountains, Chure and Terai. The unstable, often steep slopes of the Chure (or Siwalik) region throughout southern Nepal present particular challenges. It has been the focus of special conservation and development requirements, though terrace agriculture is widely practiced. The Chure region covers almost two-thirds of the Kamala Basin. The gently sloping to flat Terai is where the population and agriculture are more concentrated, as is the economic activity of the Basin.

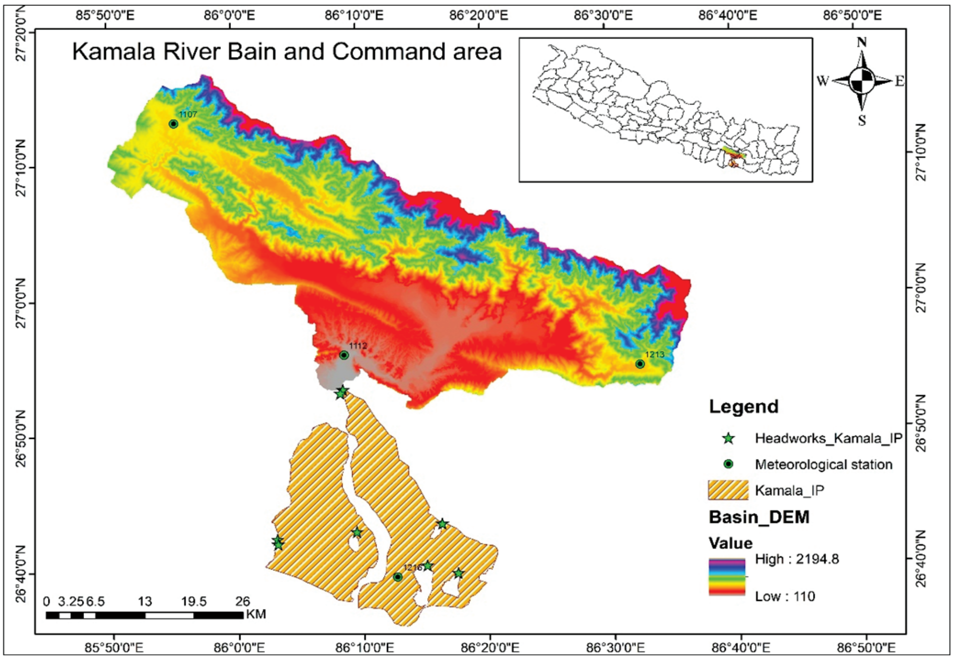

Figure 2:1: Location map of hydrological station and headworks of different irrigation projects.

2.2 Data collection

The various types of that required during this research will be collected from respective sources. The following topics elaborate the list of data required for the whole study.

Observed historical data like daily maximum temperature, minimum temperature, precipitation, humidity, sunshine hour, and wind speed for meteorological and climatology stations inside and near KIP are collected from the Department of Hydrology and Meteorology (DHM), Babarmahal for the period of 1985 to 2014. Among those stations, precipitation data for all 5 stations were collected but due to the unavailability of temperature data from all 5 stations data from only three stations and humidity, sunshine hour, and wind speed from only one station are taken.

Stations for Observed precipitation

Table 2.1: List of climate stations for precipitation used in this study.

S.N.	Index no.	Station name	Latitude (Deg)	Longitude (Deg)	Elevation (m)
1	1107	Sindhuli Madhi	85.92	27.21	556
2	1112	Chisapani Bazar	86.14	26.93	127
3	1213	Udaypur Gadhi	86.53	26.91	469
4	1216	Siraha	86.21	26.65	63

Stations for Observed maximum and minimum temperature

Table 2.2: List of climate stations for maximum and minimum temperature in this study.

S.N.	Index no.	Station name	Latitude (Deg)	Longitude (Deg)	Elevation (m)
1	1111	Janakpur Airport	85.92	26.71	76

2.3 Methodology:

(a) GCMs Selection for the Raw GCMs Collection

For the study of climate change in KIP using CMIP6 GCM models, we selected 10 GCM models that participated in Coupled Model Intercomparison Project Phase 6 (CMIP6) for the pool of raw GCMs. These models are selected based on the previous research performed on south Asian countries (Aadhar & Mishra, 2020a, 2020b; Almazroui et al., 2020; Timilsina, n.d.).

(b) Downscaling and Extraction of GCMs data

The historical (1985-2014) precipitation, maximum, and minimum temperature data of each GCM model are downloaded from the CMIP6 database website (https://esgf-node.ilnl.gov/search/cmip6). The downloaded data were in netCDF format and of global scale. We merged the data from the year (1985-2014) into a single netCDF file format for each GCM model and each variable i.e., tmax, tmin, and pr. We downscaled the data for our study area from the merged file by providing a limit of latitude (22.56 °N to34.158°N) and longitude (75.965°E to 42.223°E). The merge and clip operation are performed using the climate data operator tool (CDO) available in the Linux operating system Ubuntu. Then we extracted the gridded data to point data from net CDF file format to comma delimited text (CSV) format for five stations of the study area for all variables using the python codes.

(c) Selection of Meteorological Stations and Filling missing data of observed climate data

The data from five meteorological stations inside the KIP command are taken, those stations are selected such that it covers the whole command area and represents the overall climatic condition of the study area.

The gap of fewer than 10 days in daily observed data obtained from the department of hydrology and meteorology (DHM) was filled using the missing data filling approach of linear interpolation from the nearby stations (Engineering Hydrology, n.d.).

The 'POWER Global Downloads NASA' widget which gives access to global Climatology 1/2 x 1/2-degree datasets, is used for filling the missing gaps more than 10 days in the observed climate data.

(d) Historical Raw GCMs Performance Evaluation

The performance metrics of historical raw GCMs were evaluated for each station and each variable using performance evaluation metrics Root Mean Square Error (RSR), Percentage Bias (PBIAS), and Nash-Sutcliff Efficiency (NSE) compared to the observed historical data (1985-2014). The ratings for each performance metric's value are listed in table 4. For each precipitation, maximum, and minimum temperature, the average rating for each GCM is determined.

Table 2.3: Performance Evaluation Criteria of Historical Raw GCMs (Moriasi et al., 2007)

Performance rating	NSE	RSR	PBIAS	Rating
Very good	0.75<NSE<=1.00	0.00<RSR<=0.50	PBIAS< 10	5
Good	0.55<NSE<=0.75	0.50<RSR<=0.6	10 <= PBIAS	4
Satisfactory	0.40<NSE<=0.55	0.60<RSR<=0.70	15 <= PBIAS <25	3
Unsatisfactory	0.25<NSE<=0.40	0.70<RSR<=0.80	25 <= PBIAS	2
Poor	NSE<=0.25	RSR>0.80	PBIAS>=35	1

(e) Bias Correction and Selection of the best method of correction

The bias correction method Quantile mapping (QM) with 13 statistical transformation functions available in the Qmap package in R for bias correction is used. The transformation functions are as follows:

- Bernoulli Exponential
- Bernoulli Gamma
- Bernoulli Weibull
- Bernoulli Log-normal
- Exponential Asymptote
- Exponential Asymptote x0
- Linear Transformation
- Power Transformation
- Power x0 Transformation
- Scale Transformation
- Non-parametric Quantile Mapping
- Non-parametric Robust Quantile Mapping
- Smoothing Spline

The bias-corrected daily precipitation, maximum and minimum temperature for the baseline period (1985-2014) from the selected GCMs are compared with the observed data obtained from the department of hydrology and meteorology (DHM) to evaluate the performance metrics RMSE, PBIAS, and NSE. The bias correction methods are rated based on the criteria as shown in table 5. The bias correction method with the highest rating is selected for each variable.

Table 2.4: Performance Evaluation Criteria of Bias Correction Methods.

Performance rating	NSE	RSR	PBIAS	Rating
Very good	$0.85<R^2<=1.00$	0.00<RSR<=0.25	PBIAS< 5	**8**
	$0.75<R^2<=0.85$	0.25<RSR<=0.50	5 <= PBIAS<10	**7**
Good	$0.70<R^2<=0.75$	0.55<RSR<=0.60	10 <= PBIAS <12.5	**6**
	$0.65<R^2<=0.70$	0.50<RSR<=0.55	12.5 <= PBIAS <15	**5**
Satisfactory	0.57<NSE<=0.65	0.65<RSR<=0.70	15 <= PBIAS<20	**4**
	0.50<NSE<=0.57	0.60<RSR<=0.65	20 <= PBIAS <25	**3**
Unsatisfactory	0.4<NSE<=0.5	0.70<RSR<=0.80	25 <= PBIAS <35	**2**
Poor	NSE<=0.4	RSR>0.80	PBIAS>=35	**1**

(f) Crop evapotranspiration (ETc)

ET0 is multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc),

ETc =Kc X ETo

(g) Crop Water Requirement (CWR)

Effective rainfall (Eff. rain) is subtracted is from ETc to get actual CWR.

CWR= ETc-Eff. Rain

(h) Estimation of IWR and CWR

The Crop Water Requirement (CWR) is the total quantity of water required for the plant

throughout the life period. It is the compensate water to the crop which loss by plant through evapotranspiration. There are various methods by which plant get compensation such as water from the soil which is storage as the moisture, rainfall, irrigation etc. The CWR can said a crop evapotranspiration (ETc). It can be calculating by equation;

$ETc = Kc \times ETo$

Where

ETc = Crop evapotranspiration

ETo = Reference evapotranspiration

Kc= Crop coefficient

The value of Kc varies mainly on the specific crop type and somehow depends on the soil evaporation and climate condition. The value of Kc also varies with in the life period of the plant. There is different value in growing period, maturity period and harvesting period. It converts the reference evapotranspiration to the crop evapotranspiration. Kc approach is accepted universally. Scheme water requirement was calculating by using CROPWAT8.0. For that the first step is to calculate the ETo. As describe in the equation 4.1, ETo can calculate by the CROPWAT model. There are different methods to calculate ETo but Penman-Monteith method was used in this study. After that the effective rainfall was calculated. Effective rainfall (P_{eff}) was calculated by the USDA soil conservation method where effective rainfall was calculated as per following equations

$P_{eff} = (P^* (125-0.2^*3^*P))/125$ for P<=250/3

$P_{eff} = 125/3+0.1^*P$ for P> 250/3

The next step is to define the cropping pattern. The cropping pattern of the study area was collected from the past report and field visit. Both cases collecting data from the field or district level office. Some data were taken from the literature. The software calculates the CWR of each crop. Then after deduction the effective rainfall from the CWR, irrigation water requirement was obtained for each crop. Finally, after summing up the all-water requirement in corresponding time period, total scheme water requirement can be obtained. After applying efficiency-coefficient in scheme water requirement, total water required in source can be obtained. For this study, he cropping pattern was obtained from the field data. All climatic data were obtained from DHM, Nepal. Figure 5.1 shows the steps to calculate the irrigation water demand. The cropping pattern and the corresponding cultivated area were taken from the field during field survey. The scheme water requirement or water required in the source was calculated by using the scheme efficiency 30%. The present water requirement will be calculated by using the present cropping system and current climate scenario where as the future crop water requirement will be calculated by using the future cropping pattern.

The study assumes that the climatic parameters, such as wind speed, sunshine hour and humidity, are assumed to be the same in the future under different analysis scenarios. In case of Kamala irrigation project, there is no meteorological stations inside the command area so the nearby Janakpur Airport stations data are used.

The crop water requirement in present and future condition has calculated by using the Penman equation. The evapotranspiration was calculated by using the Penman Monith equation. The meteorological data from the Janakpur Airport stations was used to calculate the crop water requirement in the present condition. The sunshine hour, wind speed and relative humidity was also taken from the nearby Biratnagar station. The proposed (future) cropping pattern was used to calculate the crop water requirement during present and future condition.

The present cropping pattern is shown in the Table 4.4, in which traditional paddy remains the main monsoon crop, with supplementary irrigation to increase yields. Other major seasonal crops are the wheat, maize, pulses, oilseed, potato, seasonal vegetables etc. The choices of crops are made analyzing the land use capability, water availability and preference made by the farming communities and also taking account of market opportunities.

The cropping intensity under the proposed plan is as high as 170 to 300%.

After confirmed the present and future cropping pattern, the irrigation water requirement is calculated. By taking the thirty percent of the scheme efficiency, scheme water for the project is calculated.

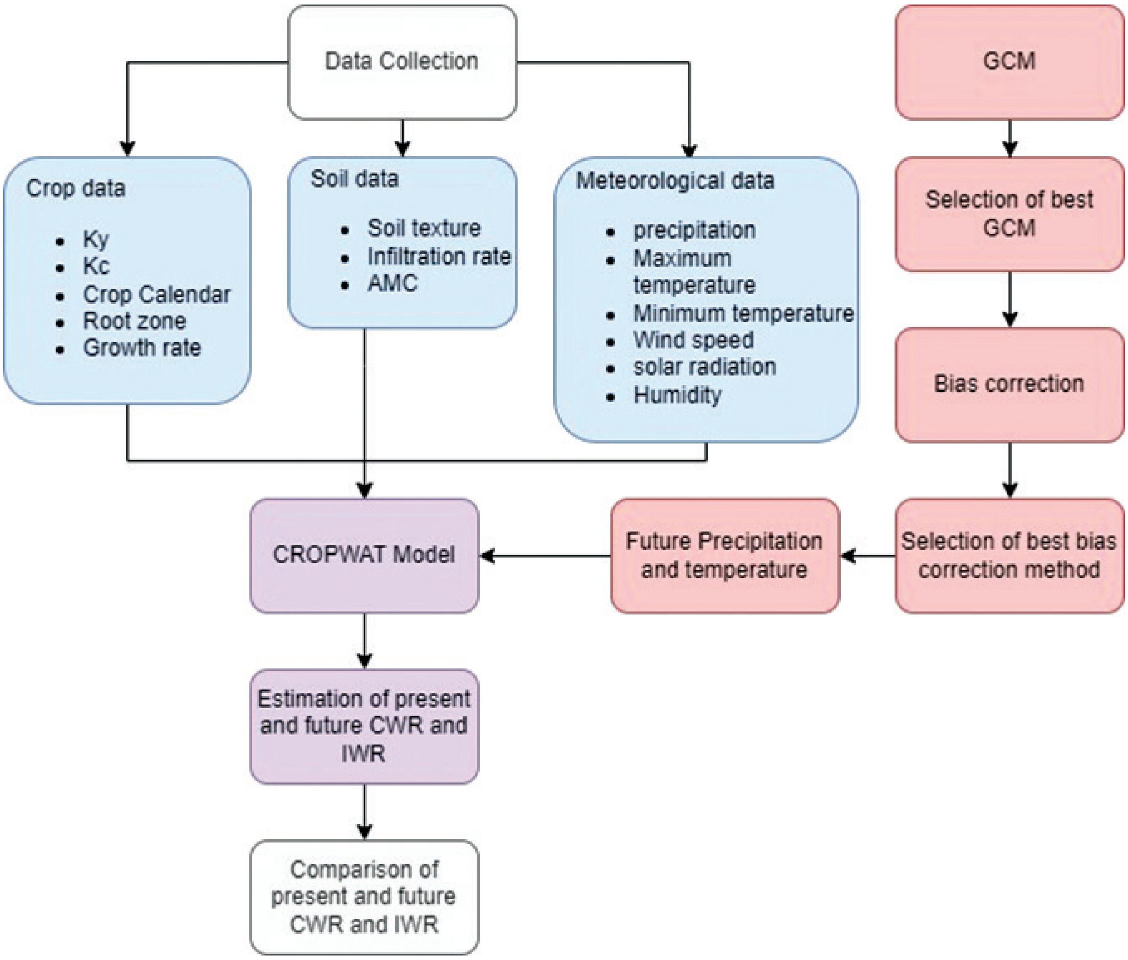

Figure 2:2: Methodological flow chart

3. Result and discussion

Bias corrected daily projection of maximum/minimum temperatures for one station (1111) and precipitation for four stations (1107, 1112, 1213, and 1216) are developed from the latest CMIP6-GCMs for KIP. The time series plot is available for the observed historical (1985-2014) and future (2015-2100) periods under ssp245 and ssp585 scenarios. The time series plot is done for the four best performing GCMs and one Multi-model Ensemble (MME).

3.1 Precipitation

The latest CMIP6-GCMs have been used to create daily bias-corrected projections of precipitation for five meteorological stations for KIP. The projections are accessible for the past (1985-2014) as well as the future (2015-2100). Precipitation is projected for four GCMs and one multi-model ensemble under two scenarios, ssp245 and ssp585. The long-term annual Precipitation of all five stations is presented below. The annual precipitation series of the projected precipitation doesn't show any significant change in the annual precipitation. The annual projected precipitation is in the range of 1000mm to 2000mm under both ssp245 and ssp585 scenarios. The annual projected precipitation under the ssp585 scenario is found to be slightly greater than that of the ssp245 scenario. Plots that contain the MME ssp245 and ssp585 long-term annual precipitation for all stations can be found in the appendix.

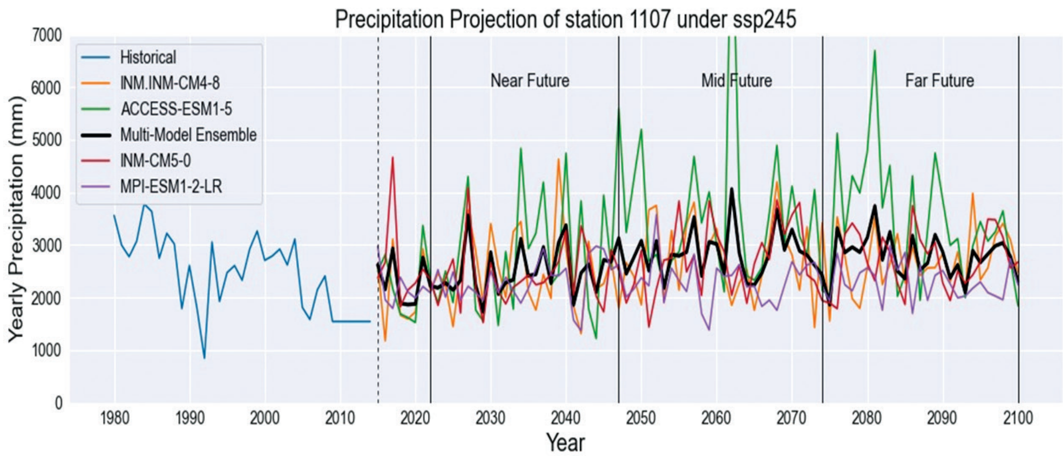

Figure 3:1: Projected annual precipitation under ssp245 at station 1107

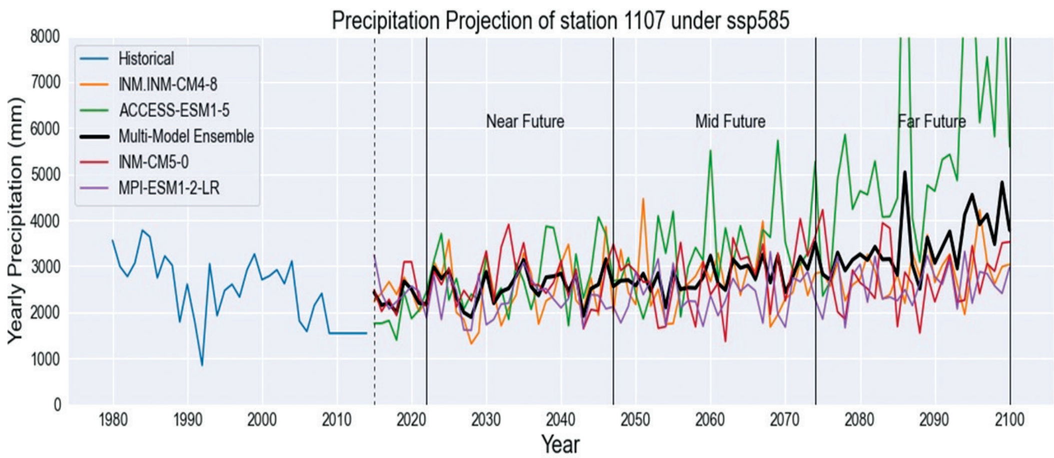

Figure 3:2: Projected annual precipitation under ssp585 at station 1107

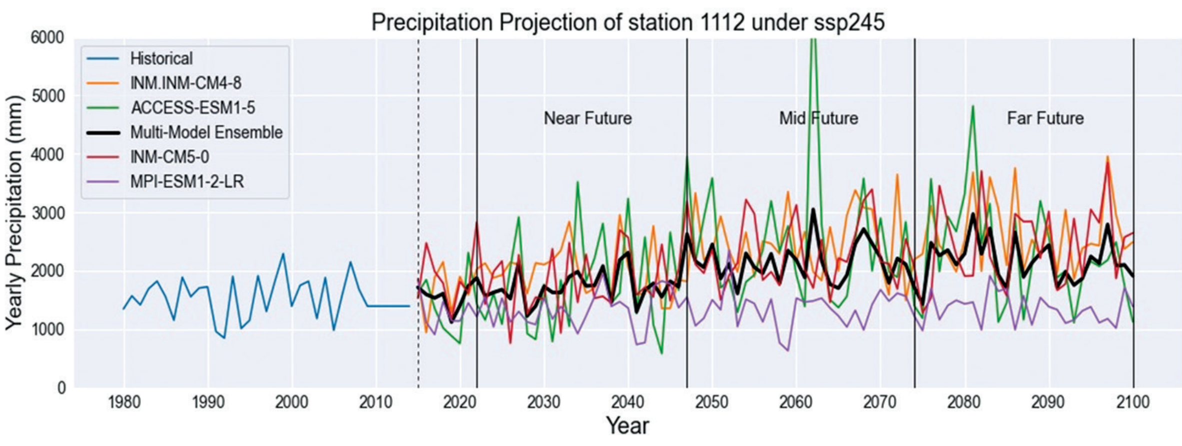

Figure 3:3: Projected annual precipitation under ssp245 at station 1112

3.2 Comparison of future river flow and IWD

The climate change has significant impact on hydrological processes of basin. The change in precipitation pattern and variation of temperature within the basin directly affected the hydrological phenomenon of basin. The future river flow, which changes as the time passes, has very important for designing and planning of water resources projects. In this study, an effort has been carried out to estimate the future river flow and irrigation water demand in Kamala River basin and identified the irrigation water deficit months.

Since, the Kamala basin has no hydrological data measurement stations. Therefore, empirical method is carried out to predict the future flow of River. The projected precipitation has been used for prediction of future flow. The future flow is based on WECS/Department of Hydrology and Meteorology (DHM) method developed by The Department of Hydrology and Meteorology, Nepal. The projected river flow in near future including both scenarios is represented in Table 3.1.

Here, river flow and irrigation water demand are estimated under two scenarios namely: ssp245 (Middle Road approach) and ssp585 (High emission scenarios). The future hydrology is unpredictable and IWD is also changes as the climatic variable's changes. Therefore, two scenarios, one middle approach and other high emission scenarios was taken to estimate the future river flow and IWD.

The Figure 3:6 depicts the future river flow in near future and irrigation water demand including different sub-scenarios. From the analysis, the irrigation deficit is occurring in first five months in near future under ssp245 and the magnitude of deficiency is increased as the cropping intensity is increased. The available river flow is insufficient to meet the irrigation demand of Kamala irrigation system in five months from January to May in near future under ssp245 scenarios.

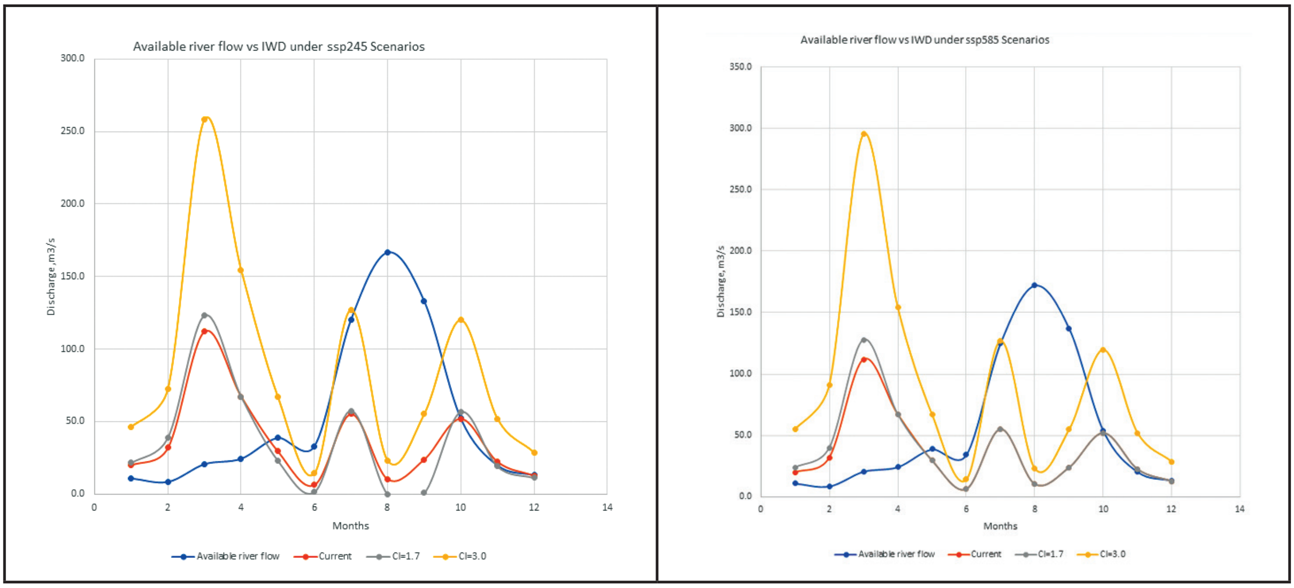

Figure 3:6: Comparison of future river flow and future IWD under ssp245 scenario.

The Figure 3:6 depicts the future river flow in near future and irrigation water demand including different sub-scenarios. From the analysis, the irrigation deficit is occurring in first five months in near future under ssp585 and the magnitude of deficiency is increased as the cropping intensity is increased. The available river flow is insufficient to meet the irrigation demand of Kamala irrigation system in five months from January to May in near future under ssp585 scenarios. The magnitude of water deficit under ssp585 is much higher than under ssp245 scenario.

Table 3.1: Future river flow and IWD under both ssp245 and ssp585 scenarios.

Months	Near future river flow m3/s	Irrigation water demand, m3/s				
		Current	ssp245		ssp585	
			CI=1.7	CI=3.0	CI=1.7	CI=3.0
January	11.2	20.0	21.6	46.4	24.0	55.2
February	8.7	32.0	39.2	72.8	40.0	91.2
March	20.7	112.0	123.2	258.4	128.0	295.2
April	24.5	67.2	67.2	154.4	67.2	154.4
May	38.8	29.6	23.2	67.2	29.6	67.2
June	34.3	6.4	1.6	14.4	6.4	14.4
July	125.1	55.2	57.6	127.2	55.2	127.2
August	172.0	10.4	0.0	23.2	10.4	23.2
September	137.2	24.0	0.8	55.2	24.0	55.2
October	53.7	52.0	56.8	120.0	52.0	120.0
November	20.4	22.4	19.2	52.0	22.4	52.0
December	13.4	12.8	11.2	28.8	12.8	28.8

3.3 Estimation of productivity with respect to water (Rain and irrigation water)

The production of biomass and dry yield is estimated using Aquacrop. All the climatic variables (Wind speed, humidity, maximum temperature, minimum temperature, solar radiation and rainfall) are imported to the model and simulation were done. There are two scenarios are setup: first one is the production of dry yield without irrigation water i.e., rainfed and second is the production of dry yield with irrigation facilities.

Based on the finding, the production of crop with irrigation system has higher than rainfed system. For paddy, the rainfed system produced dry yield of 6.58 ton/ha whereas, dry yield of irrigated field has 7.05 ton/ha.

4. Conclusion and recommendation

The research was conducted to determine the impact of climate change on the Kamala irrigation system's future crop water requirement. Under ssp245 and ssp585 scenarios, the impact of climate change on future water requirements and irrigation water requirements of KIP was quantified. The following is a summary of the key findings.

1. The precipitation and temperature projections of the Kamala irrigation project area using the latest model CMIP6 are projected with bias-corrected monthly and annually (2015-2100) for two scenarios ssp585 and ssp245. This trend analysis was done for the near (2022-2046), mid (2047-2073), and far (2074-2100) future.

2. According to the findings, GCM models INM-CM4-8, NorESM2-MM, INM-CM5-0 showed a higher rating for maximum and minimum temperature, and ACCESS-ESM1-5, MPI-ESM1-2-LR, INM.INM-CM4-8 and INM-CM5-0 showed a higher rating for precipitation. These are the models useful for assessing future minimum temperature 0f Kamala irrigation project.

3. Based on the average of combined ratings of all metrics at all selected stations using 13 bias correction methods, the best performing bias correction method for precipitation was as Power x0 Transformation

method. Likewise, the maximum temperature and minimum temperature were bias-corrected by nine methods, and selection of the best bias correction method was done by using the performance rating of past data. Based on the average of combined ratings of all metrics at all selected stations using 9 bias correction methods, the best performing bias correction method for maximum temperature was Linear transformation and same for minimum temperature.

4. The magnitude of mean annual trend is 0.011°C per year in NF, 0.021°C year per in MF, and 0.025°C per year in FF for maximum temperature under ssp245. Similarly, 0.0127°C per year in NF, 0.072°C per year in MF, and 0.049°C per year in FF are obtained under ssp585 for maximum temperature. Also, the magnitude of mean annual trend is 0.045°C per year in NF, 0.04°C per year in MF, and 0.039°C per year in FF for minimum temperature under ssp245. Similarly, 0.0588°C per year in NF, 0.076°C per year in MF, and 0.05°C per year-1 in FF are obtained under ssp585 for minimum temperature. Similarly for precipitation, the %change of mean annual trend and monthly percentage change was done under ssp245 and ssp585 scenarios. The analysis above result obtained mean annual data of temperature (maximum and minimum indicated that there is a significant increasing trend for a future period.

5. According to the scenarios ssp245 and ssp585, the analysis revealed that both maximum and minimum temperatures will rise significantly in the future. The rise in future temperature with ssp585 was substantially bigger than with ssp245, in both the maximum and minimum temperature cases. According to the findings, both ssp585 and ssp245 are expected to increase both seasonal and annual precipitation. The projected increase for ssp585 was somewhat higher than for ssp245.

6. Based on the findings and analysis, it is predicted that precipitation will increase in the study area for a certain period and then decreased, while mean minimum and maximum temperatures will rise in the future. As a result, the requirement for crop water is expected to rise in the future.

7. The crop water requirement toward the future period is increased for all months except for October and November. The percentage change in crop water requirement is highly increased for the first three months (January, February, and March) as compared to other months because the percentage increase in maximum and minimum temperature of KIP is higher during those months.

8. The irrigation water requirement is decreased toward future period under ssp585 and ssp245 scenario in five months namely; May, June, August, November, and December months. But crop water requirement is increased in May, June, and August months towards different future periods. The increase in crop water requirement is fully met by increased precipitation. Whereas, irrigation water demand is increased in six months namely; January, February, March, April, July, and September months.

9. ssp 245 and ssp585 were conducted based on cropping intensity 170% and 300 % and IWD for each sub-scenario over 12 months was estimated. for the first sixth months, IWR is increased in the future period as maximum and minimum temperature increases and the IWR for monsoon season is less required due to increases in precipitation and again for the post-monsoon season, IWR is increased compared as historical IWR.

10. The highest irrigation water requirement occurs in March month under ssp245 and ssp585 and CI 300%. Whereas, July and August months have the lowest irrigation water demand under ssp245 and ssp585 scenarios.

11. Based on the finding, the production of crop with irrigation system has higher than rainfed system. For paddy, the rainfed system produced dry yield of 6.58 ton/ha whereas, dry yield of irrigated field has 7.05 ton/ha.

12. The future river flow is insufficient to meet the irrigation water demand in first five months in near future under both ssp245 and ssp585 scenarios. The magnitude of deficiency in ssp585 is comparatively higher than in ssp245. As a result, all of these findings suggest that the crop water requirement of KIP is insufficient in the future to provide a year-round irrigation system.

Conflict of interest

Not declared by the author(s).

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