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Climate Change Impact due to Hydrological Alteration in Kaligandaki River Basin in Nepal

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Abstract
Climate changes, particularly those related to temperature and precipitation, can have a negative impact on the region's hydrological regime. In our study, we modeled how climate change might affect the hydrological regime and water balance of the snow-dominated Kaligandaki Basin.Based on SSP245 & SSP585 of the ensemble General Circulation Model (GCM) outputs from CMIP6, the HEC-HMS model was used to estimate changes in the hydrological regime of the Kaligandaki basin in the future. According to the study, climate change is causing a rise in the river's annual average discharge. Under both SSP245 and SSP585, seasonal variation in river flows is anticipated to decline solely during the post-monsoon season.However, under scenarios SSP245 and SSP585, monthly variation in river flows is anticipated to grow in most months and decrease in September, October, and November during the course of the NF, MF, and FF. In general, the rising trend of river discharge increases the likelihood of future natural disasters such floods, landslides, and soil erosion.Our findings are anticipated to contribute to a better understanding of the hydrological characteristics of the Kaligandaki River, future benefits associated with an increase in the river's average annual discharge, such as increased hydropower production and irrigation opportunities, as well as adaptation strategies that can lower risks associated with an increase in the river's hydrological flow.

Keywords
HEC-HMS, CMIP6, Climate Change,Kaligandaki River Basin

1. Introduction

Due to the threat it poses to long-term human growth, scientists are attentively investigating the complicated phenomenon known as climate change[1] . In the end, it has an impact on the availability of water resources, both in terms of quantity and quality, as well as on sectors that use water, such as agriculture, hydropower, environmental uses, etc. In addition to contributing to climate change, urbanization and land use increase the amount of non-pervious area within the watershed, which can then increase runoff from the watershed by lowering infiltration [2]. Therefore, understanding changes in hydrological characteristics with climate change is important for sustainable use and management of a country's water resources. For assessing how climate change influences hydrological characteristics, drought analysis, and hydropower generation, including multi-model efforts, analyses of climate model output are very helpful [3].

A difficult task is choosing a suitable Global Climate Model (GCM) or Regional Climate Model (RCM) for a region from a variety of GCMs/RCMs. An ensemble of numerous climate models been used to reduce uncertainty in the selection of climate models [4]. To better comprehend using a multi-model context, the Working Group on Coupled Modeling launched the Coupled Model Intercomparison Project (CMIP) inside the World Climate Research Program framework [5]. As the CMIP's sixth phase (CMIP6) has begun, climate models are refining a number of parameterization techniques for significant physical and biogeochemical climate system processes. A fresh collection of scenarios based on diverse socioeconomic hypotheses form the basis of the CMIP6 data [6]. Based on these presumptions, the Shared Socioeconomic Routes (SSPs) produce a number of socioeconomic scenarios and radiative forcing pathways to the end of the twenty-first century [7]. The SSP scenarios concentrate on adjustments to the risk and severity of droughts as well as adjustments to precipitation and hydrological runoff

[8]. To make climate model outputs suitable for local applications, the GCM/RCM model outputs subjected to bias correction using relevant methods, such as empirical quantile mapping [9]. Since the Himalayan, regions have complex hydrological systems with a wide range of flora, soils, topography, and regionally and temporally variable snowmelt patterns and snow cover, determining the hydrological effects of climate change is challenging [10]. One of the major challenges in the Hindu Kush Himalayan Region, which includes Kaligandaki basin, is the impact of climate change on water resources. Climate change has a significant impact on the temporal and spatial variance of weather patterns components of the water balance in Nepal's Kaligandaki basin [11]. Overall, certain change observed in this basin hydrology. So further detail and modern analysis is required to see the trend of stream flow and climates indicates as well as to find whether these changes are due to climate change.

This study address hydrological impact due to climate change in Kaligandaki basin using lastested version of GCM i.e. CMIP6. This study inc-operate individual consideration like precipitation, temperature, evapotranspiration which can be used to determine future hydrology. Previous research had only focused time based stream flow this research has used precipitation and temperature on different component of water balance in Kaligandaki River Basin.

2. Study Area

The Narayani Basin in Nepal, a significant tributary of the Ganges River Basin, includes the Kaligandaki Basin as a significant sub-basin. It lies between 27.8° N, 29.3° N, 82.86° E, and 83.6° E, with a catchment area of roughly 10,607 Km2.Basin under study lies in Manang, Mustang, Myagdi, Syangja district of province five in Nepal. The Kaligandaki Basin's elevation ranges from 320 to 8167 m, therefore substantial topographic differences are a feature. High heights, chilly temperatures, and some glacier coverage define the upper portion of the Kaligandaki Basin. The plains in the South have a subtropical climate with high precipitation, whereas the center section of the basin is largely hilly with high altitude topography. Major tributary of kaligandaki in the study region are Maygdi Khola, Mistri Khola, Raughat Khola, Modi, Aadhi khola. Climate information (temperature and precipitation) gathered at Department of Hydrology and Meteorology (DHM) sites across the basin from 1992 to 2017, which input into the HEC-HMS model. Discharge data of Kaligandaki River at Ansing station collected from the period of 1996 to 2010.

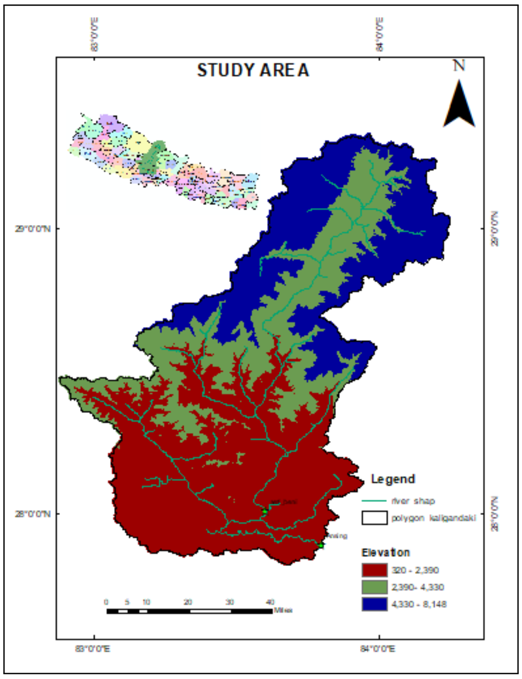

Figure 1: study area

3. Methodology and Data

Model based technique, used to examine the effect of climate change on Kaligandaki River Bain. Adopted technique for the research presented in flow chart as shown in figure (2) and sub-section follows the detail discussed below.

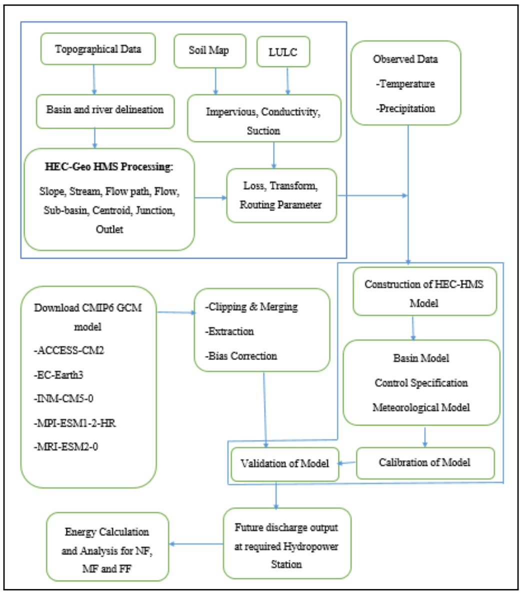

Figure 2: flow chart

Future climatic parameter (precipitation and temperature) forecasted using multiple CMIP6-GCM. For examine hydrological feature model developed by Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) was used. The Hydro-Meteorological data for baseline period (1992-2017) used and the predication for three different period near future (2023-2047), Mid-future (2048-2072), far future (2073-2100) was done.

3.1 Data and Sources

Observed historical daily precipitation data at the stations within the KRB collected from DHM (www.dhm.gov.np) for the baseline period of 1996 to 2017. Daily raw temperature and precipitation are obtained from DHM in excel format. For daily temperature and precipitation data, CMIP6-GCM model outputs gathered from the World Climate Research Program (WCRP) website at https://esgfnode.llnl.gov/search/cmip6/. CMIP6 dataset are available in different horizontal resolution, common grid with 1°×1° resolution. A Digital Elevation Model (DEM) with a 30m resolution based on the Shuttle Radar Topography Mission used for topographical research (SRTM). Data reading, single/double mass curves, and visual plotting of graphs were used to evaluate the quality of the data. The analysis excluded stations with a considerable amount of missing data. The Normal Ratio Method [12] was used to fill in the missing precipitation data, and the long-term average daily values were used to fill in the gaps in other meteorological variables. Using five CMIP6-GCMs and two scenarios (SSP245 & SSP585) derived from [13] future precipitation, maximum, and minimum temperature data were collected for the period 2021–2095. Based on an empirical quantile mapping method, biases in the GCM data were rectified. Empirical quantile method is selected based on study performed previously in Gandaki basin and basin near to Kaligandaki basin [14, 15].

3.2 Hydrological Modeling

A semi-distributed HEC-HMS model developed for KRB, which is capable for simulated hydrological process of the watershed to derive river discharge and water balance. Basin model represents physical characteristics of the watershed. The simulated runoff as production takes into account daily precipitation, long-term average monthly potential evapotranspiration, basin runoff flow (for calibration and validation), and geographic information about the basin. The HEC-HMS model is composed of a basin model, a meteorological model, control parameters, and input data (time series data) [16]. Thirteen reaches and 23 sub-basins in the basin depicted in Figure 3 developed while considering various hydroelectric and hydrological stations. Three hydrological station at Ansing (INDEX-419), Seti-Beni (INDEX-410) and Mangalghat (INDEX-405) used for calibration and validation. The Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2), and percentage bias used to assess the model's performance statistics (PBIAS).

Figure 3: Basin model showing different sub-basin and reaches.

3.3 Climate Change Impact Assessment

The effects of climate change examined using a calibrated and verified hydrological model. In order to simulate expected future hydrology under five CMIP6 GCMs with two scenarios, estimated future temperature and precipitation were supplied into the calibrated and verified model (SSP245 & SSP585). Climate change's impact on hydrological characteristics is provided as changes in expected future hydrological features relative to the baseline. Impact evaluation can aid in the understanding of climate change and its effects by enterprises and the general population.

4. Result and Discussion

4.1 Performance of Hydrological Model

Hydrological model is done using semi distributed model HEC-HMS (1992-2017). All the model parameter are set and output discharge from the model compared with observed discharge for given duration at known gauge station. When the parameters are changed, the hydrograph also changes, allowing the model to run and the parameters that effect high output discharge to be noted. Some of the various characteristics, including imperviousness (percent), lag time, conductivity, Base flow, Muskingum value (X, K), and maximum storage, were shown to be sensitive. Sensitive parameters are those that have a significant impact on the high output of simulation with a modest change in value. So, for a model to perform well, identification and fixation of sensible parameter has a major challenge. The parameters' sensitivity can be evaluated manually by adjusting the value within the range using various techniques, or automatically at a specific point utilizing tools for computational point management at known discharge locations.

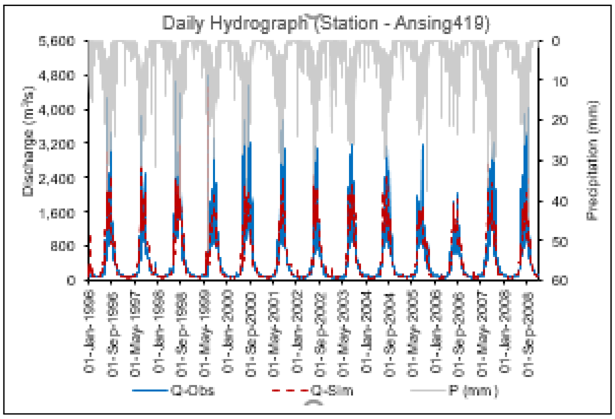

Figure 4: Observed Vs Simulated Daily Flow Hydrograph for (1996-2010) Ansing (419) with Precipitation.

The observed and simulated flow at output station (Ansing 419) is shown in figure below for both calibration and validation period. All the figure shown below has shown that the model has simulated the flow very well and hydrograph of the simulated flow shows good agreement with the rainfall pattern during both calibration and validation period.

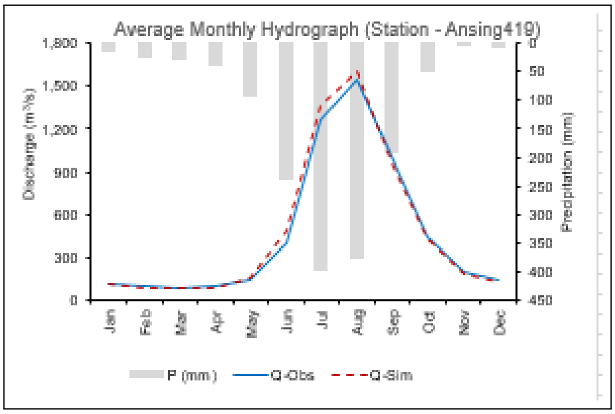

Figure 5: Monthly Average for Observed and Simulated Discharge for (1996-2010) Ansing (419)

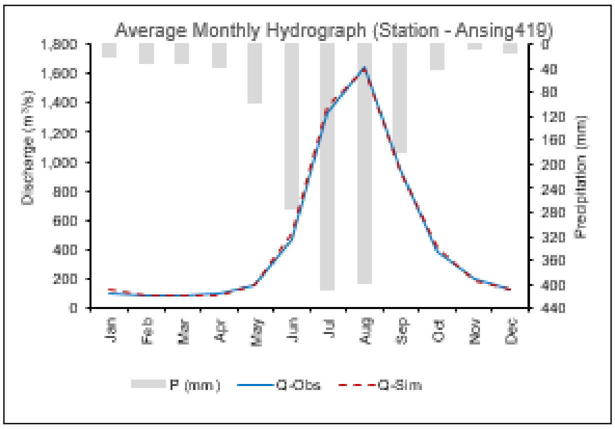

Figure 6: Monthly average Hydrograph Observed Vs Simulation for calibration period 1996-2004 at Ansing (419)

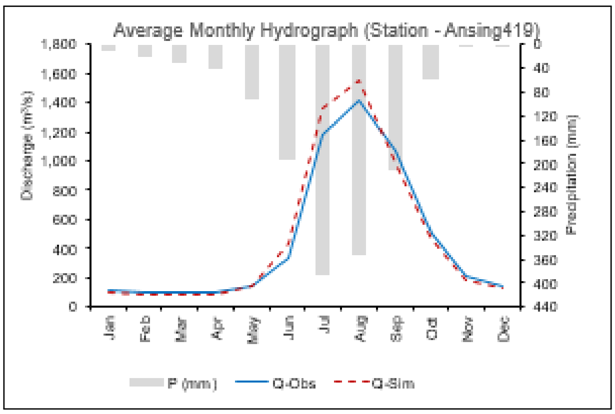

Figure 7: Monthly average Hydrograph Observed Vs Simulation for Validation period 2005-2010 at Ansing (419)

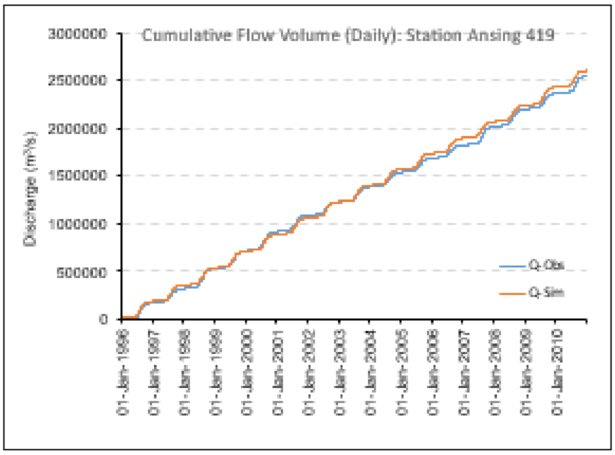

Figure 8: Observed Vs Simulated daily flow volume at Ansing (419)

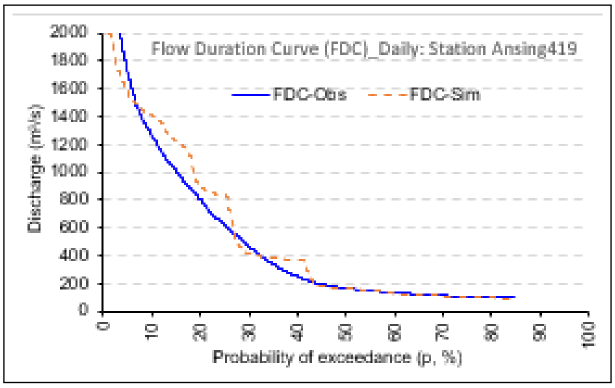

Figure 9: Observed Vs Simulated daily flow duration curve at Ansing (419)

Statistical performance parameter is use to check the efficiency of simulated value with the observed value, for calibration coefficient of determination (R^2=0.78), Nash Sutcliffe efficiency (NSE=0.77), Percentage bias during calibration (-5.54). For validation coefficient of determination (R^2=0.79), Nash Sutcliffe efficiency (NSE=0.79), Percentage bias during validation (-5.29). Which shows that obtained model has high prediction capabilities. The calibration and validation periods reveal that the data used for the calibration and validation are different since the model predicts the same R^2 and NSE performance statistics parameter but there is a distinct volume differential between the observed and simulated flow at the station.

Statistical performance parameter is use to check the efficiency of simulated value with the observed value, for calibration coefficient of determination (R^2=0.88), Nash Sutcliffe efficiency (NSE=0.85), Percentage Bias during calibration (9.68). For validation coefficient of determination (R^2=0.88), Nash Sutcliffe efficiency (NSE=0.84), Percentage bias during validation (10.38). Which shows that obtained model has high prediction capabilities.

Daily Performance (ANSING 419)

Parameter	Calibration	Validation	Entire Period
R2	0.78	0.78	0.78
NSE	0.77	0.77	0.77
PBIAS	-5.54	-5.29	-5.44

Monthly Performance (ANSING 419)

Parameter	Calibration	Validation	Entire Period
R2	0.94	0.91	0.93
NSE	0.94	0.91	0.93
PBIAS	2.12	2.49	2.27

Figure 10: Performance Stastics Parameter at Ansing (419)

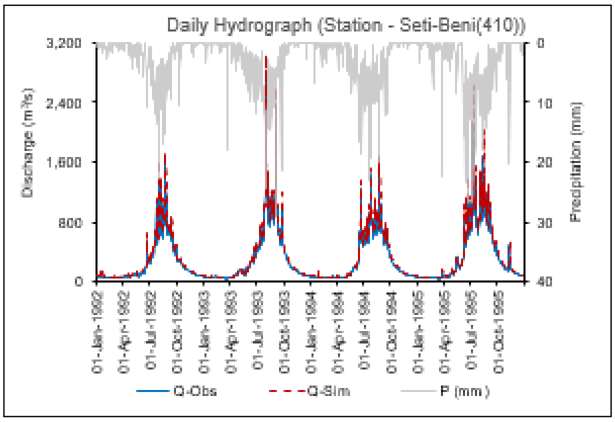

Figure 11: Observed Vs Simulated Daily Flow Hydrograph for (1992-1995) Seti-Beni (410) with Precipitation

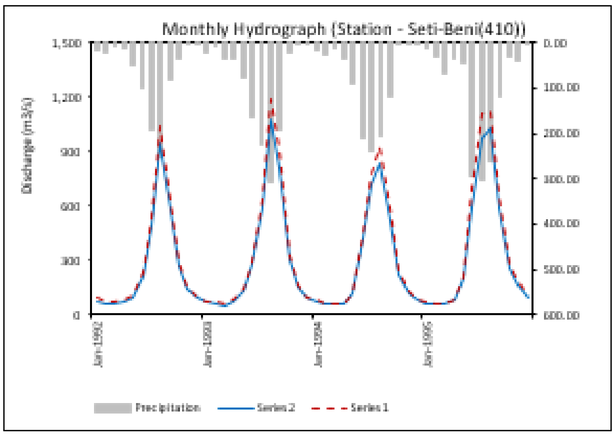

Figure 12: Monthly average observed vs Simulation at Seti-beni (410) with Precipitation

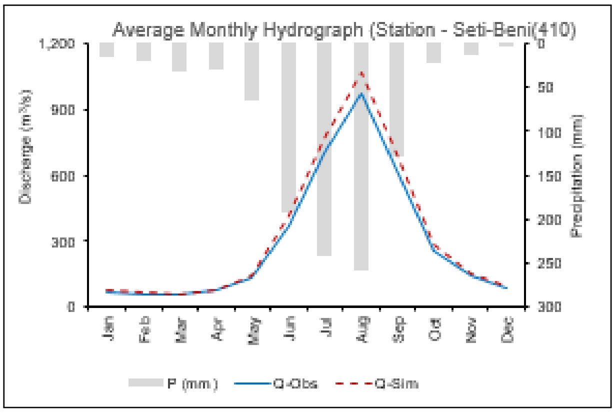

Figure 13: Monthly Average Observed Vs Simulation for calibration period 1992-1993 at Seti-Beni

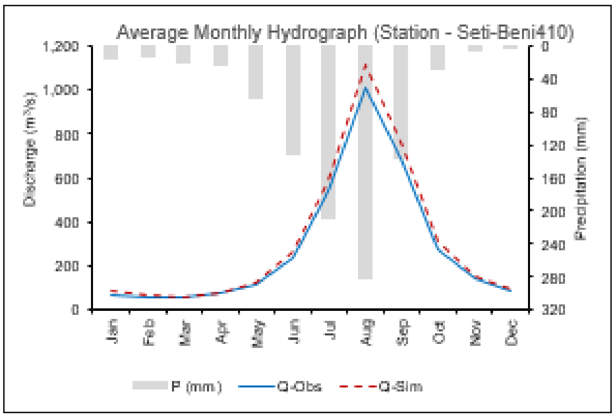

Figure 14: Monthly average Observed Vs Simulation for Validation period 1994-1995 at Seti-Beni (410)

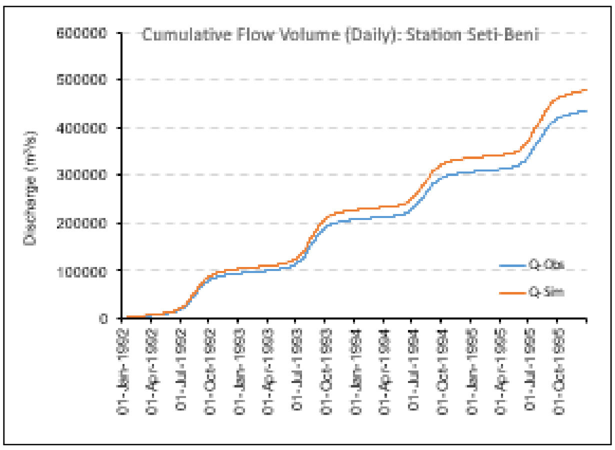

Figure 15: Observed Vs Simulated Daily Cumulative Flow Volume at Seti-Beni (410)

Performance daily			
	Calibration	Validation	Entire Period
R2	0.88	0.88	0.88
NSE	0.85	0.84	0.84
PBIAS	9.68	10.38	10.04
Performance monthly			
	Calibration	Validation	Entire Period
R2	1.00	1.00	1.00
NSE	0.98	0.98	0.98
PBIAS	9.67	10.38	10.05

Figure 16: Performance stastics Parameter for Seti-Beni (410)

4.2 Baseline Hydrological characteristics

Precipitation and temperature data are analyzed from 1992-2017 and hydrological data is used from 1996-2010. While analyzing hydrological data from the above mentioned period long term average discharge is found to be 422.70m^3/s and average annual volume is estimated to be 169771.64 MCM/year. The average least monthly flow in our study basin at the outlet within our study period is estimated to be 82.03 m^3/s in March and maximum flow is estimated to be in August 1404.067 m^3/s. Average seasonal discharge in winter (DJF) is 97.80 m^3/s, on pre monsoon season is (MAM) 103.553 m^3/s, on monsoon season is (JJAS) 962.488 m^3/s and on post monsoon period is (ON) 284.39 m^3/s. The 90 percentile of flow available in the river is 79.1 m^3/s.

4.3 Projected Change in Hydrological characteristics

The final calibrated and validated HEC-HMS model is provided with Multi-Model Ensemble future rainfall and temperature time series data. MME consists of five GCM's with two different scenario (245 & 585). To understand the change in river flow under the expected future climate, changes in hydrological features over the exit of the basin are analyzed. HEC-HMS model is run for the required future period and future discharge under different scenario is obtained and compared with the baseline discharge of the basin at the outlet.

As mentioned earlier the average annual discharge over the baseline period is 464.7 m^3/s which is projected to be increased by 9.7 percentage in near future (NF), 13.3 percentage in mid future (MF), and 13.7 percentage in far future (FF) under scenario SSP245. Similarly under the scenario SSP 585 the discharge at the basin outlet of the basin are projected to be increased by 10 percentage in near future (NF), 13.1 percentage in mid future (MF) and 17.2 percentage in far future (FF). Annual variation of discharge varies with future period and scenario. Projected change in discharge for different period and scenario are flow varies from -10.1 percentage in November to 27.7 percentage in March during near future (NF) of scenario SSP245. Similarly during mid-future (MF) flow at the outlet of the basin decreases to -5.1 percentage in November to maximum 33.2 percentage in March. Similar trend is the case for Far future (FF) where decrease in discharge is seen in November to -6.4 percentage. For scenario SSP585 flow at the outlet increases in most of the case except in September, October and November, flow decreases by -5.9 percentage in near future

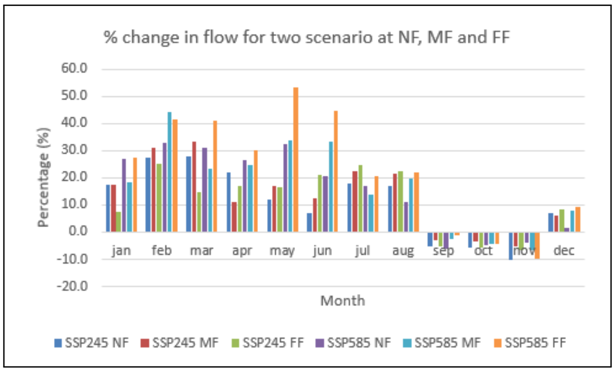

Figure 17: Percentage Change in Discharge at Ansing in NF, MF amp FF for SSP245 amp SSP585

5. Conclusion

One of the major issues in the Hindu Kush Himalayan Region is the impact of climate change on water resources. The temporal and spatial variance of water balance components in Nepal's Kaligandaki watershed is significantly impacted by climate change. To evaluate the effects of climate change on hydrological parameters in the Kaligandaki River Basin in Nepal, a well-calibrated and tested HEC-HMS hydrological model was created. An ensemble of chosen GCMs was used to estimate changes in future hydrological parameters for five consensus situations. For the calibrated/validated HEC-HMS model to simulate expected future hydrology, projected future precipitation and temperature were fed. The baseline period's average annual discharge was 422.70 m3/s, and the baseline period's average annual volume is expected to be 169771.64 MCM/year. Both projections indicate that both of these values will rise with time. Whereas monthly variation of discharge is expected to increase in all the month except September, October and November in all the period of both the scenario. This study will be important for development of project like hydropower, irrigation, water supply in future and adopt the measure that can reduce risk associate with increase or decrease in hydrological flow in the river. This study also helps to fix design discharge of the project which would be constructed or study in this study area. Most important part of this study prediction of climate variability of the basin and its impact in the future can be assessed through this study.

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