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Impact of Climate Change on ROR Hydropower: A Case Study of Upper Trishuli 3A Hydropower Station, Nepal

by

Nabin Devkota

A THESIS

SUBMITTED TO THE DEPARTMENT OF APPLIED SCIENCE AND CHEMICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN CLIMATE CHANGE AND DEVELOPMENT

DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING

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……………………………..

Head of Department:
Prof. Dr. Sahira Joshi
Department of Applied Science and Chemical Engineering, Pulchowk Campus, Institute of Engineering
Pulchowk, Lalitpur,
Nepal

Tribhuvan University
Institute of Engineering
Pulchowk Campus
Department of
Applied Sciences and Chemical Engineering

TRIBHUVAN UNIVERSITY
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PULCHOWK CAMPUS
DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING

The thesis titled "Impacts of climate change on ROR Hydropower: A case study of Upper Trishuli 3A Hydropower Station, Nepal" prepared and submitted by Nabin Devkota in partial fulfilment of the requirements for the degree of Master of Science (M. Sc.) in Climate Change and Development has been examined by us and is accepted for the award of M. Sc. in Climate Change and Development by Tribhuvan University.

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis report entitled "Impacts of climate change on ROR Hydropower: A case study of Upper Trishuli 3A Hydropower Station, Nepal " submitted by Nabin Devkota in partial fulfillment of the requirements for the degree of Master in Climate Change and Development.

....

Supervisor: Er. Mukesh Regmi
Technical Chief
Devighat Hydropower Station, NEA

....

External Examiner: Prof. Dr. Tirtha Raj Adhikari
Professor Emeritus
Faculty of College of Applied Science-Nepal, Tribhuvan University, Nepal

....

Program Coordinator:
Prof. Dr. Rinita Rajbhandari
M.Sc. in Climate Change and Development
Department of Applied Science and Chemical Engineering, IOE, Pulchowk

....

Head of Department:
Prof. Dr. Sahira Joshi
Department of Applied Science and Chemical Engineering, IOE, Pulchowk

Date: May, 2025

DECLARATION

I hereby declare that this study titled "Impacts of climate change on ROR Hydropower: A case study of Upper Trishuli 3A Hydropower Station, Nepal " is based on my original research work. Related works on the topic by other researchers have been duly acknowledged. I owe all the liabilities relating to the accuracy and authenticity of the data and any other information included hereunder.

Nabin Devkota
079MSCCD008
MSc in Climate Change and Development
Date: 8th May, 2025

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Nabin Devkota
079MSCCD008
May, 2025

ABSTRACT

Nepal has huge hydropower potential with about 43,000 MW being technically and financially viable. Once the hydropower is constructed, the main variable that can fluctuates in hydroelectric generation is the available discharge which is dependent on climatic parameters such as temperature, precipitation, solar radiation, humidity, etc. Hence, the evaluation of climatic parameters is important but overlooked factor in hydropower scheme planning, construction and operation. This study evaluates the impact of climate change on hydrology and hydro-energy generation at Trishuli River Basin taking reference as UT3A hydropower station. Semi distributed hydrological model, SWAT model with spatial and meteorological data of watershed is used for the prediction. The SUFI-2 algorithm is applied to calibrate and validate the model. Five CMIP6 GCMs under two scenarios SSP245 and SSp585 with bias correction at hydrological and meteorological stations are obtained and put in calibrated and validated SWAT model to get the future discharge at the outlet. The average annual discharge is found to be increased by 8.84%, 11.59% and 15.43% in NF, MF and FF under scenario SSP245 and by 13.68%, 14.37% and 21.81% in NF, MF and FF under scenario SSP585. Similarly, there is variation in average annual hydroelectric energy generation from January to April in future period under both scenarios but the generation is not affected for remaining eight months due to availability of design discharge though there is change in future discharge. The variation in energy generation is from -3.69% in April to 19.13% in February in NF, -3.16% in January to 32.53% in March in MF and -8.78% in February to 10.72% in March in FF under scenario SSP245. Similarly, the variation in energy generation is from -11.76 in April to 27.47% in March in NF, -9.32% in April to 37.01% in MF and -7.3% in January to 41.97% in March in FF under scenario SSP585. The findings highlight the significant impacts of climate change on river discharge and correspondingly hydroelectric generation underlining the need to integrate climate risk assessment in hydropower planning and sustainable hydropower development.

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ABBREVIATIONS AND ACRONYMS

CC	Climate Change
CMIP	Coupled Model Intercomparison Project
DHM	Department of Hydrology and Meteorology
ESRI	Environmental Systems Research Institute, Inc.
FDC	Flow Duration Curve
FF	Far Future
FY	Fiscal Year
GCM	Global Circulation Model
GHG	Green House Gas
GWh	Gigawatt Hour
HPP	Hydro Power Project
HRU	Hydrological Response Unit
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
Km^2	Square Kilometers
KW	Kilowatt
m.a.s.l.	Meters above sea level
m3/s	Cubic meter per second
MCM	Million Cubic Meters
MF	Mid Future
MW	Mega Watt
MWh	Mega Watt Hour
NEA	Nepal Electricity Authority
NF	Near future
NSE	Nash Sutcliffe Efficiency
PoE	Percentage of Excedance
PP	Precipitation
Q	Discharge
QM	Quantile Mapping
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
ROR	Run of River
SD	Standard Deviations
SDSM	Statistical Downscaling Model

SOTER	Soil and Terrain
SRES	Special Report on Emission Scenario
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Program
T	Temperature
THPS	Trishuli Hydropower Station
UN	United Nations

1 INTRODUCTION

1.1 Background

“Steep gradient and southern mountainous topography make Nepal rich in hydropower resources” (Regmi et. al. 2022). An approximate theoretical power potential of 83,000 MW and the financially and technically viable capacity of 43,000 MW makes it one of the world's highest per capita hydropower potentials (Shrestha et. al., 2018). However, due to various reasons, it is able only to utilize 5 % of its possible hydropower potentials. At present hydro energy generation in the country is about 12072 GWh in 2022/23 and the total domestic consumption in FY 2023/24 is 10243 GWh (NEA Annual Report 2023/24). There are large seasonal fluctuations in electricity generation Nepal which is causes the variation in the river discharge and lower to very low level in dry season. It causes the energy generation lowers to about 16.66% of design level in dry period that makes power crisis reach to peak during these dry months (Sharma et. al., 2013). The variation in electricity generation is occurred because almost all except Kulekhani I hydropower in Nepal are run of river hydropower plant whose generation depends on real time discharge in the river.

Hydropower is a great asset to the country. Hence, its development is urge for economic progress and industrialization of a country. In 2008, government of Nepal had planned to generate 10,000 MW by 2020 and 25,000 MW by 2030 (WECS, 2013). For getting this, large number of hydroelectric projects are there under construction and many are in the pipeline. It is compulsion to tap out ultimate feasible hydropower capacity in order to support the national plan of graduating our country from least developed to a developing country by 2022 (NPC, 2013).

The main variable in the constructed hydropower is the discharge of the river flow which varies with the changing climate (Regmi et. al. 2022). Climate change has remarkable implications on hydropower generation, primarily through its influence on hydrological patterns, temperature, glacial melt, and river discharge. Earlier research shows that rising glacier retreat, change in river flow and increasing extreme weather events are increasing with rising global temperatures that impacts hydropower generation (Hock et al., 2019). Among the hydropower schemes, run-of-river (ROR) hydropower schemes are vulnerable to seasonal and long-term hydrological fluctuations due to their reliance on natural streamflow (Gaudard et al., 2014).

During the construction of hydropower in Nepal, only short term hydrological and metrological data were considered. The impacts of climate change is neglected on power generation and its operation in future. In the recent years, the studies regarding the climate change and the impacts on river discharge and power generation are conducted. The studies show the different behavior of climate change in Himalayan region. With the rise of global average temperature by 0.75 °C in the last century, it shows an increase of 0.15 °C to 0.16 °C in the last three decades (Shrestha et al., 2014).

Located in central region of Nepal, Trishuli River Basin (TRB) is pivotal for hydropower generation due to its steep gradients and perennial river flow. The hydrological characteristics of basin, rainfall and snow and glacier melting contributes in hydropower generation (IFC, 2020). The Trishuli River Basin (TRB), covering up to 13 percent of the Gandaki River Basin (one of the nine major river basins in Nepal), covers an area of about 32,000 square kilometers in the central part of a country. There are six operational hydropower projects (81 MW), seven under construction (286 MW) and about 23 in the planning stages with survey licenses being issued by the Department of Electricity Development (DoED 2018). The operating hydro power plants in Trishuli basin are a) Trishuli Hydropower Station-24 MW, b) Trishuli 3A Hydropower Station- 60 MW, c) Devighat Hydropower Station- 15 MW, d) Chilime Hydropower Station- 22 MW, e) Mailung Hydropower Project- 5MW, f) Rasuwagadhi Hydropower Project- 111 MW, g) Sanjen Hydropower Project 57 MW etc. and some are under construction phase such as a) Upper Trishuli 1, 216 MW, b) Trishuli 3B Hydropower Project 37 MW, c) Langtang Khola Hydropower Project 10 MW, d) Rasuwa Bhotekoshi Hydropower Project 120 MW etc. Thus, currently a total of 845 MW is generated with operation of commissioned hydropower plants and a significant amount of energy can be generated from the upcoming projects. However, the hydropower development authorities and other stakeholders are not concerned about necessity of assessment of the potential risks and impacts related to the climate change in Trishuli River. Thus, it is crucial to assess the potential impacts on hydropower due to the alteration in the Climatic parameters in the Trishuli Watershed and utilize the results for the development & operation of hydropower, climate related risk analysis and finally integrate the results in the national energy planning and implementation. This study is concentrated to investigate the probable effect of climate change on the hydroelectric energy production in Upper Trishuli 3A Hydropower Station by simulation of the hydrology of watershed using SWAT model.

1.2 Research Gaps and Problem Statement

The water resources in the Trishuli River Basin are important not only from view point of hydropower development, but they contribute to the national economy from various ways. Water from Trishuli river are used for irrigation, power generation, forestry and residential purposes.

According to (A.B. Shrestha & Aryal, 2011), Nepal is vulnerable to climate change caused by global warming. Future projections of metrological parameters indicate negative effects on the availability of water. The hydrological situation is highly impacted by the effects of climate change, which includes temperature rise, differential rainfall, and more intense weather events (Seneviratne et at., 2012). Till date many studies have been conducted on the impacts of climate change on hydrology in various River Basins in Nepal. But, very few studies are concerned with climate change and Trishuli river basin and there is no any study conducted on the impact of climate change on Upper Trishuli 3A Hydropower Plant which has significant importance in national economy. Hydropower As the life span of Hydropower Plants is longer i.e., about 50 to 100 years, they are are extremely vulnerable to effect of climate change in the end.

One of the major challenges in the Hindu Kush Himalayan Region of which Trishuli basin is a part, is the impact of climate change on water resources and hydrology of river basin. The spatial and temporal variation of weather parameters possess significant impacts on weather patterns components of the water balance in Nepal's river basin (A.R. Bajracharya et al., 2018). Hence, detail analysis is required to see the trend of stream flow and the availability of water for UT3A hydropower plant considering the negative effects of climate change. Upper

Trishuli 3A hydropower plant has started to generate electricity in 2019 AD. Being a ROR hydropower plant, it is directly affected by the effect on hydrology of river basin. Hence, this research is conducted to predict the effect of climate change on river flow and energy generation of UT3A hydropower plant.

1.3 Objectives

The general objective of this research included identification of possible impacts of the climate change in energy generation of UT3A hydropower plant.

The specific objectives of the research include:

- To predict trend of temperature and precipitation in Trishuli basin.
- To predict the potential impact of climate changes on the hydrology of Trishuli basin using SWAT model.
- To predict the effect of climate change on energy generation from UT3A Hydropower Plant.

1.4 Scope

The study specifically focuses on:

- Collecting and analyzing hydrological, metrological and spatial data of Trishuli River Basin.
- Predicting the trend of precipitation and temperature in future period.
- Application of hydrological model i.e., SWAT model, for watershed modeling of the basin.
- Predicting the probable effect of climate change on stream flow.
- Analyzing hydropower energy production trend in future period.

1.5 Limitations

Some limitations during the research period are:

- Short-term hydro-meteorological data.

- Very few number of meteorological and hydrological stations. The spatial distribution of stations was also poor throughout the selected catchment.
- The future projection of the model ensembles may not fully represent all the physiographical features of the site.
- Parameter values chosen in the SWAT model for calibration and validation may not necessarily have a desired physical reflection of the basin.
- Discharge data from DHM station no. 447 for period 1998 to 2016 is used and rating curve is not developed for getting intake discharge. Catchment area method is used to get observed river discharge at intake point.
- There are missing gaps in the hydrological data from DHM.
- The theoretical energy for trend analysis is calculated using the rated efficiency, design discharge and net head neglecting the losses from dam site intake to the power production unit. Hence, there may be some variation between calculated baseline energy and the exact energy generation from the power house.

2 LITERATURE REVIEW

This chapter discusses the fundamental theme of the work and of the various literatures that will define the scope of the study. Among the various literatures that have been collected and studied, few are studied in detail to get the broader idea about the topic, site area, climate change and its relation to the hydropower and the details of the UT3A hydropower plant.

2.1 Climate Change and Hydropower

Climate change is triggered by both natural and human activities by the increased emission of greenhouse gases from fossil fuel combustion, deforestation and industrialization. It leads to the prolonged changes in rainfall, temperature, and other atmospheric parameters on Earth (IPCC, 2021). Climate change generates serious issues by affecting natural system, biodiversity and altering water cycles. It causes food insecurity and health risks in human societies with susceptibility to various disasters and extreme events like rising global temperatures, shifts in rainfall pattern and sea level rise (Hansen et al., 2013).

IPCC in 2018 has published the alerts of a global temperature rise of 1.5 degree celsius over pre-industrial levels. As per the reports and publications, global average temperatures have already rised by around 1^0C than the pre-industrial period, with manmade warming contributing 0.2^0C per decade. It has predicted that if present human GHG emissions continue, global average warming would surely exceed 1.5^oC between 2030 and 2052 (IPCC, 2018).

Climate change is a complex occurrence that poses threat to long-term human progress. Hence, the scientific community is studying it closely (Bolisetti et al., 2017). Climate change impacts different sectors in multifaceted ways. If we are only concerned with hydrological cycle, changes in precipitation and temperature influence river flows, water availability and hydropower generation (Xu et al., 2019). On another part, if we shift our focus to specific issues like glacial retreat and shift in monsoon patterns in the Himalayas, we can see that it poses challenges for both water resource management and energy generation (Immerzeel et al., 2010).

Hence, climate change has substantial impacts on hydropower generation, due to its effect on precipitation patterns, temperature, glacial melt and river discharge. It is widely known fact that the changing climate conditions lead to variation in streamflow thus affecting hydropower production and its operational efficiency (Schaefli, 2021). The Himalayan region is particularly vulnerable due to its reliance on glacier-fed rivers and seasonal precipitation where many run-of-river (ROR) projects operate (Nepal et al., 2014). On contrary to short-term effect of glacial melting is increase in flow rates, long-term projections suggest reduced water availability posing challenges for hydropower sustainability especially during dry seasons, (Mukhopadhyay & Khan, 2015).

Climate changes has brought uncertainty on the future of hydrological conditions (Berga L. 2013). Though the future climate projection is far from being completely accurate, it is crucial for preliminary assessment due to the careful gathered data, ability to predict trends, and produce projections on hydropower generation.

Anghileri et. al. (2018), asserted the reduction in the availability of water in their findings and stimulated a decrease in hydroelectricity generation to -27% by the end of mid-21st Century.

Godbole, (2014), noted that the global climate is projected to show a warming signal whereby the European ensembles depict a likely increase of 1.5^{0} C and 2^{0} C in mean annual temperature. In the same way, there will be decreasing trends of precipitation in summer and rise by small portion in autumn and winter by the 2050's end.

Sharma & Shakya, (2006), had pointed out that there has been a significant drop in river flows of Nepal in the winter and summer season providing the risk of discharge variations that leads to the extreme events like unusual rainfall, floods and landslides.

Sharma & Awal, (2013), stated that many river basins in Nepal like Koshi, Gandaki, and Bagmati were already been affected by climate change due to climate- induced disasters like floods, drought, landslides, erosion and sedimentation. It is projected that the summer and winter seasons will pose a serious threat to the availability of water which will ultimately impact hydro energy generation in lean season.

Bajracharya et. al. (2011), studied on the biggest river basin of Nepal and depicted that increments in temperature and changing patterns of rainfall drastically hampers hydroelectric production.

Nepal et al. (2014) emphasized that hydrological extremes like floods during wet seasons and water scarcity in dry seasons could increase due to climate-induced shifts in monsoon patterns, posing major challenges for hydropower operations.

It is quite obvious, from the literature review correlating hydropower plants with climate change effects, that climate change will be definitely affect the hydroelectric facilities of Nepal. Most of the river basins including the river's hydrological characteristics has been affected. The projections of future climate clearly depict extreme change in the weather parameters throughout various basins of Nepal. The climate projections show that future hydrological changes are substantial with corresponding erratic or increasing changes in climatic parameters. The future projections based on climate change factors are here fore done in order to analyze the hydropower plant operation.

2.2 Hydrological Modeling

Hydrological models have become an essential tool to analyze stream flows as it has potential to incorporate the physical dynamics underlying the basin (Harnett et. al. 2007). It fills holes in data series and forecast the proper modeling response to variations.

Due to hydrological models' ability to understand the physical processes taking place within the catchment, it has emerged as a crucial tool to help water resources management projects (Gautam, 2014).

According to Ghimire et al. (2019), hydrological models replicate natural processes by simulating flows under various conditions or scenarios that operate on the principles of the hydrological cycle.

The reliable forecasts of inflow and timely judgment methods can noticeably assist the functioning of basins and the processes of operation in handling climate change approaches (Yao and Georgakakos, 2001)

Many hydrological models have been developed to incorporate the complexity of accurately reflecting the rainfall-runoff process within the basin (Renji et. al. 2015). From the early 1960s, a number of model, typically a mixture of linear and non-linear functions, constructs is built and incorporated into the software. On the basis of usage of input data and definition of physical processes, all watershed models can be classified as black-box models (e.g. Unit Hydrograph and Empirical Regression Approaches), conceptual models (e.g. HYSIM, SWAT and HEC- HMS), and physically based models (e.g. IHDM and SHE). These models are entirely focused on observational data and on the calibrated input-output relationship without the individual process being defined. Conceptual models are models in which the processes in the basin (snowmelt, infiltration, evapotranspiration, etc.) are to some degree isolated, but their input-output algorithms are tuned. However, physically- based models are based on the mass and energy transfer equations of mathematical physics in the river basin and are intended to reduce the need for calibration using observable catchment features.

Most of the streamflow including rivers and rivulets of Nepal is unmonitored (Poudyal et. al. 2019). The ungauged, unmonitored or poorly gauged river flow is because of the absence of methodological and monetary support in collecting data, extremity, and complexity of the terrain, extreme climate scenario, etc. The hydrological modeling techniques are very helpful to monitor the streamflow because of their simplicity in application and precision in projection.

Usage of the models of theoretical or conceptual types for water flow simulation is preferred, particularly in areas where data is lacking and various physical parameters and processes within the site are unmonitored, because these models are appropriate and easy to function having few input data, also are suitable for real-time prediction (Hansen et. al. 2007). It is so because of the calibration parameters, often providing results like those provided in operational situations by physically based models.

The statistical performance of indicators and the threshold limit for which the modeling system is categorized: very good, good, satisfactory, and unsatisfactory (Moriasi, 2007), noted. The hydrological system is considered reliable, if PBIAS lies in the range of ±15% and NSE and R2 is greater than 0.75, for the simulation of the water flow.

Out of the given approaches to watershed models, the conceptual approach (semi-distributed SWAT) is adopted, as it gives a real-time prediction from the least available observational data for the watershed, for hydrologic modeling of Trishuli basin and achieve impact of climate change on hydropower generation of UT3A. SWAT is widely used for simulating the effects of climate variability on river basins, as it effectively integrates climatic, land-use, and hydrological data (Arnold et al., 2012). SWAT is particularly useful for evaluating hydropower potential under different climate scenarios by coupling it with climate models such as General Circulation Models (GCMs) and Regional Climate Models (RCMs) (Abbaspour et al., 2015).

2.3 GCM Selection

Climate models are computer coded models that allows us to understand the earth's system and to project future climate (Horton et. al. 2006). These models are used for various climate research around the world and are constantly updated to incorporate changing climatic scenarios like information about horizontal and vertical areas on Earth's surface and extremes of the hydrological incident both on a temporal and spatial scale. Meteorological and hydrological information from Global Climate Models is necessary for these models.

According to Turner et al. (2012), choosing an appropriate Global Climate Model (GCM) or Regional Climate Model (RCM) from a variety of GCMs and RCMs for a given location is a difficult task. For this reason, an ensemble or the average projection value of multiple climate models is normally implemented, to reduce the ambiguity associated with the future projection of the climate model. GCMs are computer programs that incorporates physical processes to simulate the operation of the global climate system as closely as possible. Mathematical equations used in GCM simulate the operation of global climate system in all three dimensions and across time (Gidden et al., 2019).

Coupled Model Inter-Comparison Project phase six (CMIP6) dataset is used to investigate the changes in precipitation and temperature over Trishuli basin as it has higher sensitivity towards greenhouse gas emission than CMIP5 in South Asian region (Almazroui et al., 2020). Power generation under a range of climate change scenarios can be anticipated by CMIP6 global circulation models, which are based on several socioeconomic assumptions known as Shared Socioeconomic Pathways (SSPs) (Hausfather et al. 2019). CMIP6 is a massive improvement over CMIP5. Its terms of modeling group participation, assessment of the projected future climate setups, and an amount of investigation conducted, all these components are enhanced immensely. It shows two different futures: low carbon, high renewables, and strong international cooperation, and high fossil fuel use, low renewable, and fragmented cooperation.

SSPs are a collection of scenarios for anticipated land use change and greenhouse gas emissions based on various assumptions about economic growth, climate mitigation efforts, and international governance that are used to generate various radiative forcing routes and accompanying warming out to the end of the twenty-first century (Cook et al., 2020).

The SWAT model was first simulated in this study, and then SWAT-CUP was used for calibration and validation. Future temperature and precipitation datasets from five distinct CMIP6 models as EC-EARTH3, MRI-ESM2, ACCESS CM2, MIROC6 and MPI-ESM1 are then used.

2.4 Calibration and Validation

Calibration involves adjusting model parameters to match observed data, while validation tests the model's predictive performance using an independent dataset (Moriasi et al., 2007). These are critical steps in hydrological modeling to ensure model accuracy and reliability. These processes are essential in applications such as hydrological simulations, climate impact studies, and hydropower assessments.

Effective calibration reduces uncertainty in predictions by improving the model's ability to simulate real-world processes, (Gupta et al., 1999). Validation secures that the model is not over fitted to calibration data, rendering it to perform well under different conditions (Refsgaard & Henriksen, 2004). Studies emphasize that effective calibration and validation enhance the credibility of hydrological models for decision-making in water resource management (Beven & Freer, 2001). SWAT-CUP, a tool used for model calibration and validation, should be used for automatic calibration, integrating uncertainty analysis (Arnold et al. 2012).

2.5 Bias Correction

Bias correction, the process of adjusting data or model outputs to reduce systematic errors or deviations from observed values, is an important step in improving the reliability of climate model outputs for hydrological and impact assessments. Linear scaling, the delta change method, monthly mean correction, general quantile mapping, gamma quantile mapping, and power transformation techniques are a few bias correction techniques. Because of their coarse geographic resolution, parameterization flaws, and limitations in capturing regional climatic variability, GCMs and RCMs frequently have systematic biases (Teutschbein & Seibert, 2012). A better simulation result depends on selecting the right bias correction technique because it significantly affects the stream flow simulation.

Linear scaling is the simplest method of bias correction of climate change RCM models which has been applied for adjusting the average value of the regional climate model (Shrestha et al. 2018). To obtain the fine bias-corrected climate data, the mean distinction between the averaged observed monthly data and averaged modeled data is used in the raw modeled data.

Quantile mapping, a comparatively complex technique of bias correction, is the process in which the simulated and observed data cumulative distribution functions (CDFs) of the GCMs are matched with each other. The quantile value of precipitation's observed cumulative distribution function is matched with that of GCM's simulated variable.

While comparing the outputs of linear scaling and quantile mapping, no significant difference is seen but both methods shows the identical performances (Shrestha et al. 2018). Thus, linear scaling method is sufficient for accessing the hydrological characteristics of Nepalese Basin.

An empirical linear scaling method was used in this work to adjust for bias in coarse data related to precipitation, whereas the delta change method was used to account for bias in temperature. A correction factor is used in this bias correction method which is nothing but the ratio of average value of observed data to the average value of the historical climate data. This ratio is the correction factor or the multiplication factor to be applied to all the future raw climate data of daily precipitation to get the corrected time series from the model matches that closely match the observed variable. Similarly, in the delta change method of bias correction, a correction change is used which is the difference between the observed data to the historical climate data. This difference is the correction change or the additional change to be applied to all the future daily raw maximum temperature and daily raw minimum temperature data to get the corrected temporal series so that the model matches as closely as possible with the observed minimum and maximum temperature data.

3 STUDY AREA AND DATA

3.1 Study Area

The study is carried on the Upper Trishuli 3A Hydropower Station that lies in the Trishuli River Basin (TRB). Located in the Bagmati Province of Nepal, Trishuli River Basin (TRB) covers an area of 32,000 square kilometers and makes up approximately 13 percent of the Gandaki River Basin. Trishuli River and its major tributaries contribute to 81 megawatts (MW) having six operational hydropower projects while seven hydropower projects (totaling 286 MW) are under construction. Not to mention that at least 23 hydropower projects are in the planning stage with survey licenses being issued by the Department of Electricity Development (DoED 2018). The latitude and longitude of UT3A Hydropower Station dam site is 28.064 °N and 85.207 °E respectively and that of power house is 28.025°N and 85.186° E respectively. It is located about 70 km north of the capital city Kathmandu with power house altitude 738 masl near simle village. More than 60 percent area of the catchment area lies in Tibet among which 9 percent is covered by snow and glaciers. About 85% of the catchment area lies above 3,000 metres out of which 11 percent lies above 6,000 metres. The elevation of the catchment area varies from 445 m to 7408 m above mean sea Level.

UT3A Hydropower Station is the Run of River (ROR) type hydropower Plant which is located at Simle village of Rasuwa district. The installed capacity of power plant is 60 MW and the annual generation is 427.1 GWh which is 62.66 GWh less than design generation. The plant was commissioned in 2019 AD. The plant has two 30 MW francis units. The cumulative generation till end of Fiscal year 2080/081 was 2035.5 GWh.

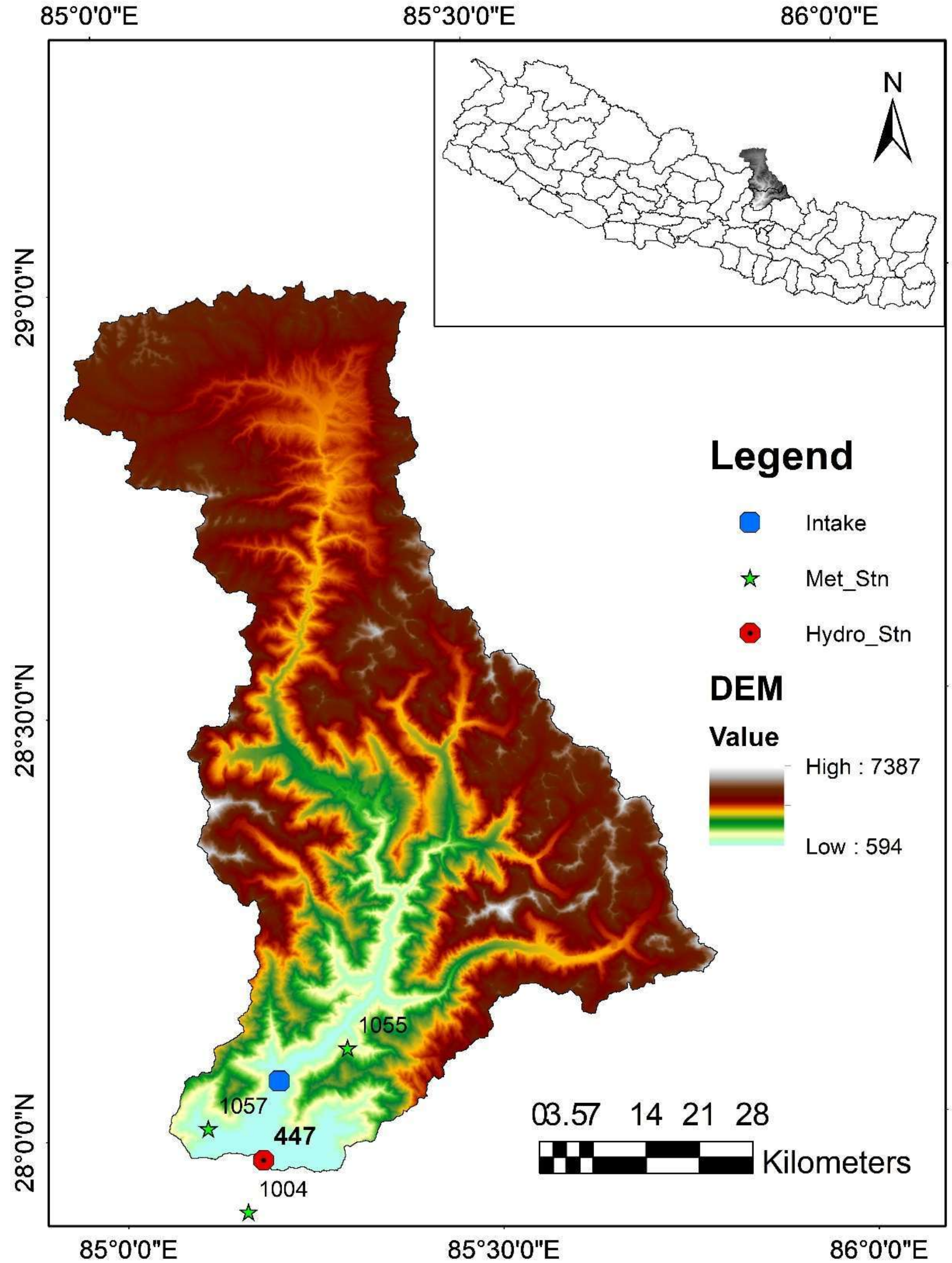

Figure 3-1: UT3A Catchment Area

Table 3-1: Salient Features of UT3A Hydropower Station

(NEA Generation Magazine, 13th issue, 2021)

Type	Run of river Hydro Power Station
Location	Simle village, Rasuwa District
Installed Capacity	60 MW
Rated Efficiency	92.24 %
Maximum Gross Head / Net head	143.57 m, 133.41 m
Catchment Area	4542 km^2
Design Discharge	51.0 m3/s
Average Annual Flow to Hydropower	48.2 m3/s
Turbine : Number and Type Rated discharge Rated output Rated speed	2, Vertical Francis 25.7 m^3/sec 31.2 MW 428.6 rpm
Generator Rated Capacity Rated voltage Rated frequency Power factor	3529 KVA 11 kV 50 Hz 0.85
Power transformer	36 MVA, 11/132 kV, 3-phase, 2 Nos.
Transmission line	132 kV, 45km (Power house – Matatirtha), Double circuit

Figure 3-2: Powerhouse entrance of UT3A Hydropower Station

3.2 Data

Different data are essential for research work. The data set includes geospatial DEM data set, metrological data, hydrological data and the projected future climate data ranging from historical period. These data are obtained from multiple sources and are processed to fit the basin.

Figure 3-3: UT3A Hydropower Intake

3.2.1 Topographic Data Set

Topographic data is a crucial geographical resource for SWAT model hydrological simulations. For topographic research, a 30m resolution Digital Elevation Model (DEM) available in Geo TIFF file format with latitude and longitude in geographic coordinates referenced to WGS 1984 was used, necessary for GIS and watershed model. The topographical information is derived from DEM for the basin. The DEM in GIS, helps define watershed, river network, drainage pattern, slope length, gradient, sub-basin and helped generate other information about the terrain. The Figure 3-4 shows the DEM data with altitude varies from 445 m to 7408 m above sea level.

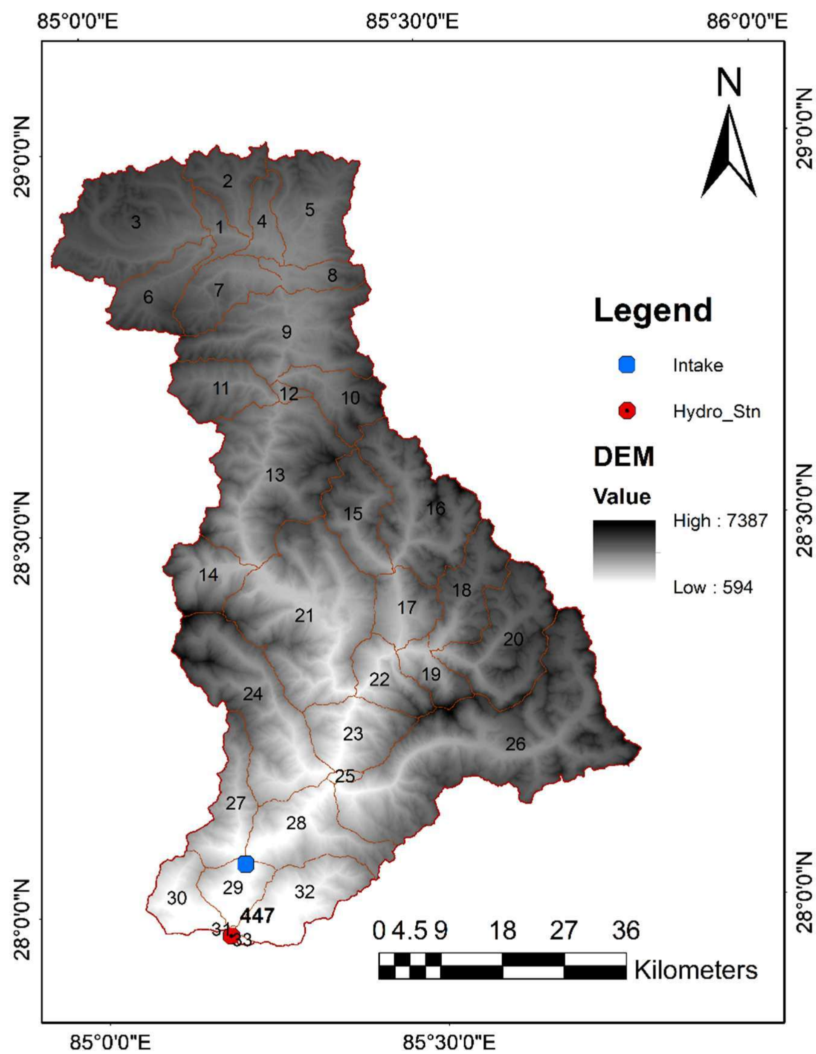

Figure 3-4: Digital Elevation Model of Betrawati Hydrological Station

3.2.2 Land Cover Map

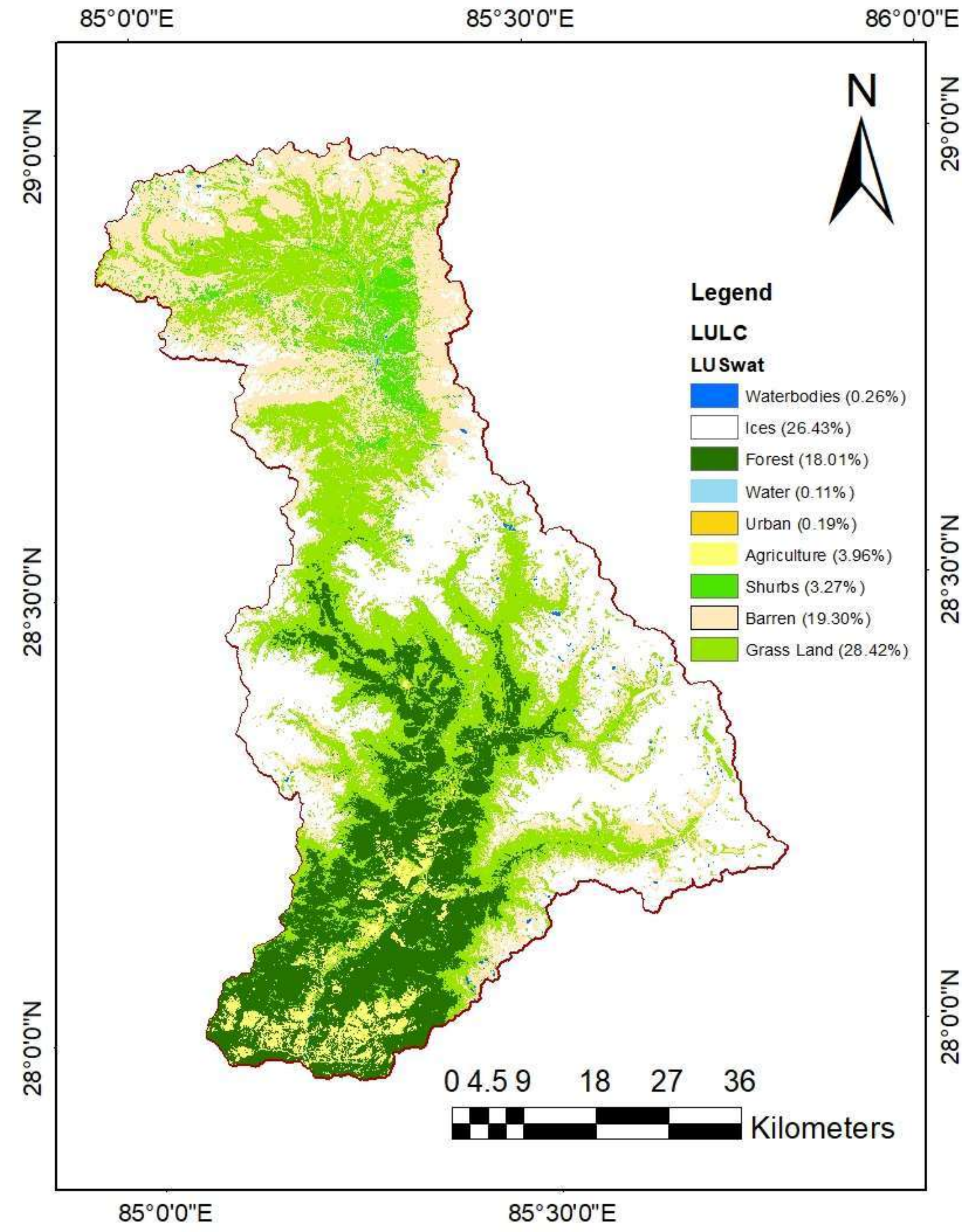

Figure 3-5: Land Use Map of Trishuli Catchment

Land cover is the major factor that influences the basin's runoff, evapotranspiration, and soil erosion attributes. International Center for Integrated Mountain Development (ICIMOD) and Department of Survey can be used to obtain land cover data/map at a 30 m resolution. Using GIS, the map was processed for catchment area of UT3A as shown in Figure 5. Nine different land use types were observed in the basin, with a maximum of 28.42 % occupied by grasslands followed by 26.43% occupied by ice and glacier. Barren land covers an intermediate area of 19.3 % followed by forest which covers 18.01% of total catchment area. Water Bodies and Buildup areas are significantly lesser as compared to other classes.

3.2.3 **Soil Map**

Soil and Terrain Database Program (SOTER) is used to download

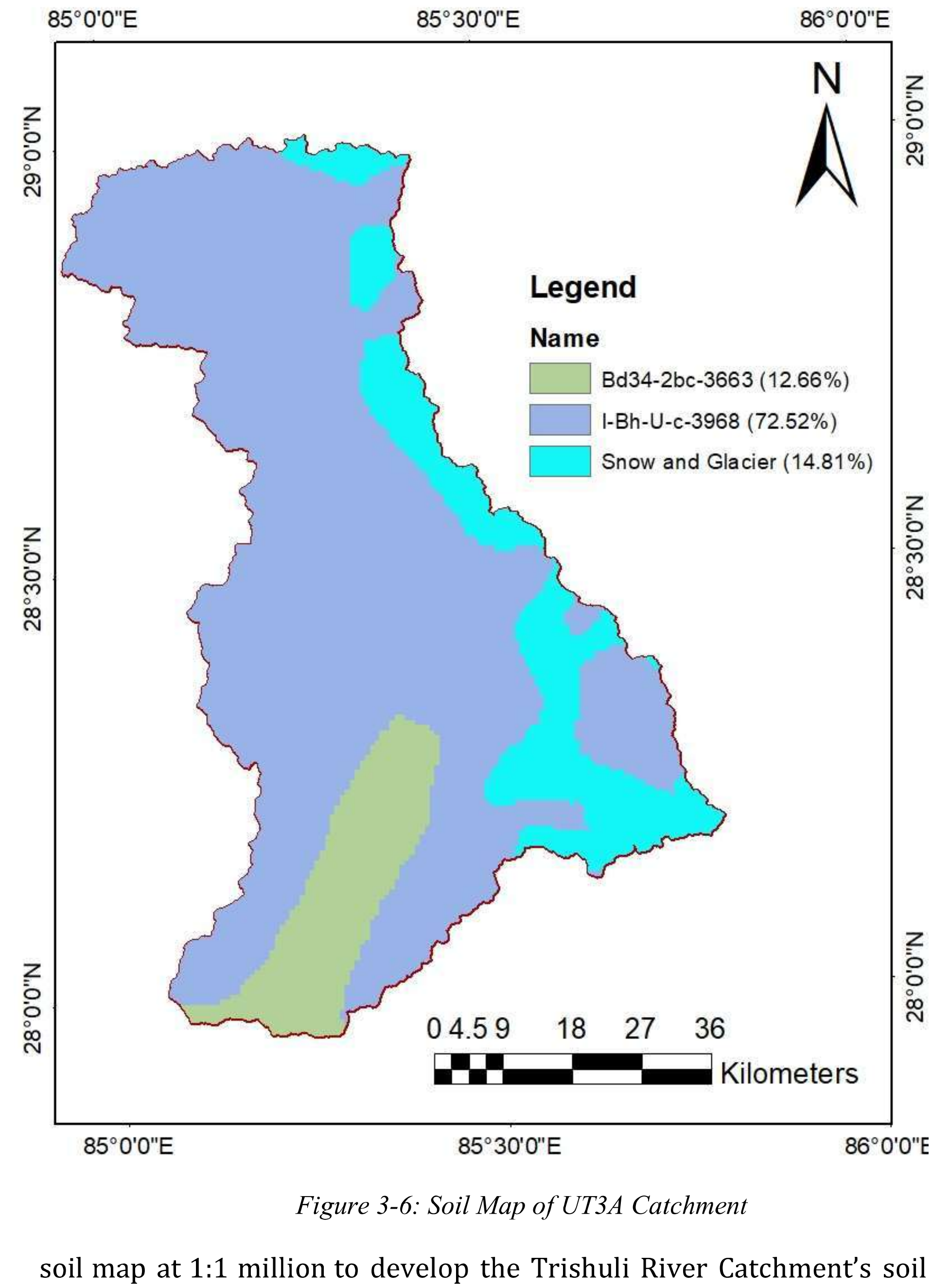

Figure 3-6: Soil Map of UT3A Catchment

soil map at 1:1 million to develop the Trishuli River Catchment's soil map as given in figure 3-6. Three types of soil were found as shown in the cathment map. The map was compiled by FAO and Nepal's Survey Department.

3.3 Baseline Climate Data

3.3.1 Meteorological Data

Among 282 meteorological stations claimed by Hydrological and Meteorological Department (DHM) of Nepal, only four stations lie at Trishuli River Basin which are Nuwakot (1004), Pansayakhola (1057), Thamachit (1054) and Dhunche (1055). Among four, Thamachit (1054) was not in operation. Hence, temperature and precipitation data from three metrological station were collected from DHM from year 1990 to 2019. Daily rainfall data, and daily maximum, as well as minimum temperature data, were the weather data used for the SWAT modeling purposes. For the model simulation purpose, we have taken weather data, temperature data & precipitation data set for the basin for 19 years from 1998-2016 in order to maintain uniformity in the study period. The descriptions of the meteorological stations are given in Table 3-2.

Table 3-2: Meteorological Stations in Trishuli river basin

S.N.	Station Name & No.	Latitude (N)	Longitude (E)	Elevation (masl)	Year	Available Data	Source	Remarks
1.	Nuwakot (1004)	27.91	85.16	1003	1990 - 2019	Climatology (Rainfall, Temperature)	DHM	Daily Data
2.	Pansayakhola 1057)	28.01	85.11	1240	1990 - 2019	Climatology (Rainfall, Temperature)	DHM	Daily Data
3.	Dhunche (1055)	28.1	85.3	1982	1990 - 2019	Climatology (Rainfall, Temperature)	DHM	Daily Data

3.3.2 Hydrological Data

Among 51 hydrological stations located throughout the country, the nearby hydrological station was Betrawati (Station no 447). The discharge hydrological data were used in the model for two purposes: to simulate existing conditions at the discharge point and to perform sensitivity analysis, calibration, and validation of the model. The observed data of the rainfall and temperature for the historical baseline period and future projection of bias-corrected GCM data were used as inputs to the ArcSWAT version 12.10.4 to estimate river discharge. These data were used for calibration from 2002 to 2011 and validation from 2012 to 2016. The details of the hydrological stations near the study site are shown in Table 3-3.

Table 3-3: Hydrological Stations in Trishuli river basin

S.N.	Station Name & No.	Latitude (N)	Longitude (E)	Elevation (masl)	Year	Data Available	Source	Remarks
1.	Betrawati (447)	27^0 58' 08"	85^0 11' 00"		1970-2015	Hydrology (Discharge)	DHM	Daily

3.3.3 Future Climate Data

The ensemble of five CMIP6 global climate model is used for future projections. These CMIP6 GCM models are accessible from databank (https://esgf-node.llnl.gov/search/cmip6/) under four shared socioeconomic pathways SSP126, SSP245, SSP370 and SSP585 from where we can get historical as well as future projected data set. The CMIP6 datasets of temperature and precipitation from five CMIP6 models EC-EARTH3, MRI-ESM2, ACCESS CM2, MIROC6 and MPI-ESM1 under two different scenarios SSP245 and SSP585 are used in the research work.

3.3.4 Data Processing

The first step to get reliable data for any hydro-meteorological modeling study is data Processing (Sattari et al., 2017). It is important to process hydro-meteorological data for watershed modeling and simulations because there may be data gaps in historical observed data. For the project to set up, both spatial and temporal data required are obtained from various sources.

The weather data required as input to the model are rainfall, maximum and minimum temperature, relative humidity, solar radiation, and wind speed. The processing of every data is very important because of the fact that incomplete data cannot be input into any hydrological model and the series of data to be fed into SWAT should be proper and complete. Hydro-meteorological series of data are often incomplete due to various factors such as geographical and technical limitations, instrument errors, instrument damage, data collector's inability in measuring daily data, data compiler's mistake in storing and compiling data, poor storage system, and so on. The quality of the study is highly affected by missing data. The data quality assessment involves checking each data and finding the total number of missing data for each station.

A large number of data was missing in the data series provided by the Department of Hydrology and Meteorology, Nepal even some cases of missing figures were to the extent that month-long gaps were noticed. Likewise, to obtain the best results from the modeling criteria input data series to be provided must remain consistent for which the quality and quantity of the figures should be continuously tested by various different techniques. Various ways applied to test the data quality in this research work were visual plotting graphs and data reading. Among several methods available for filling in missing data, the notable ones are the Normal Ratio Method, Long Term Average Method, Arithmetic Mean Method, etc. In the arithmetic mean method missing figures if any was calculated by computing the arithmetic mean of the data figure equivalent to the nearby hydro-meteorological weather stations. The Arithmetic mean method is not satisfactory in our country where rainfall gauges are not uniformly distributed over an area. Long term average filling method is a quite specialized filling method to be used when the rainfall in a region varies linearly over time. The normal Ratio method was used to fill the missing data for precipitation from surrounding stations and long- term average monthly values for temperature. The station was selected based on data quality and spatial distribution in the Trishuli River Basin.

The normal ratio has been the most widely used method for estimating missing rainfall values, due to its simplicity and efficiency (Murhanuddin et al., 2017). The normal ratio method is used for the annual precipitation exceeding 10% of the considered gauge compared to the surrounding gauges, in which nearby stations were used to estimate missing data. This weighs the effect of each surrounding station. Normal precipitation used in calculations is taken as a fundamental for comparison. Rainfall averaged at a date taking thirty years of data is normal precipitation.

The technique of arithmetic mean is used for the case whereby the 10% threshold of normal annual precipitation at station x is not crossed by various station's normal annual precipitation, then estimate P_x is given by equation 1.

$$P(x) = \frac{1}{m}\sum_{i=1}^{m} Pi: P(x) = \frac{P1+P2+P3+\cdots+PM}{M} \quad \text{.....Equation (1)}$$

(Walpole et. al., 2012)

Where,

- P_x = Rainfall at missing station
- P_1, P_2, P_3, ... P_m = Annual precipitation values at stations 1, 2, 3, …m respectively
- M = Total number of stations

The weightage averages of each surrounding station are summed up to estimate the missing series of data of the station. If the normal precipitations show a large gap, Px is estimated by the normal ratio method which is calculated by weighted average method given in equation 2.

$$P(x) = \frac{1}{m}\sum_{i=1}^{m} \frac{Nx}{Ni} Pi \quad \text{……….Equation (2)}$$

(Walpole et. al., 2012)

Where,

- N1, N2, N3, ..., Nm = Normal annual precipitations at each 1, 2, 3, …, m stations
- Nx = Normal precipitation at station x

In this study, rainfall data were filled using the Normal-ratio method and the temperature data was filled using the long-term average method. The period of usable data for both rainfall and temperature was set for 1998-2016. All these corrected data from selected gauge stations lying in the vicinity or inside the basin are fed into the SWAT for continuous event simulations.

3.3.5 Data Bias Correction

The appropriate choice of bias correction is important to adjust GCM outputs to match delineate with observed climatic conditions and for a better future projection of climate data. The method suitable and sufficient for hydrological analysis at monthly resolution in the river basins of Nepal is linear scaling method. (Shrestha et al., 2018). Based on this proposition linear scaling method is applied to compensate for biases in future precipitation data. The monthly mean bias of precipitation is corrected using the correction factor which is the ratio of the monthly mean of observed and historical precipitation given by equation 3.

$$P'(F) = P(F)\frac{\mu(Po)}{\mu(Ph)} \qquad \ldots\ldots\ldots\ldots\ldots \text{Equation (3)}$$

(Wilby et. al., 2010)

Where, P'(F)= Corrected Future Precipitation at station x

- P(F) = Coarse Future Precipitation at station x
- μ(Po)= Mean Monthly Observed Precipitation at station x
- μ(Ph)= Mean Monthly Historical Precipitation at station x

The delta approach is used to correct GCM data for bias in temperature given by equation 4.

$$T'(F) = T(F) + [\mu(To) - \mu(Th)] \qquad \ldots\ldots\ldots\ldots\text{Equation (4)}$$

(Wilby et. al., 2010)

Where, T '(F)= Corrected Future Temperature at station x

- T (F) = Coarse Future Precipitation at station x
- μ(To)= Mean Monthly Observed Temperature at station x

  μ(Th)= Mean Monthly Historical Temperature at station x

4 RESEARCH METHODOLOGY

The methodology flow diagram implemented for this study is detailed and depicted in Figure 4-1.

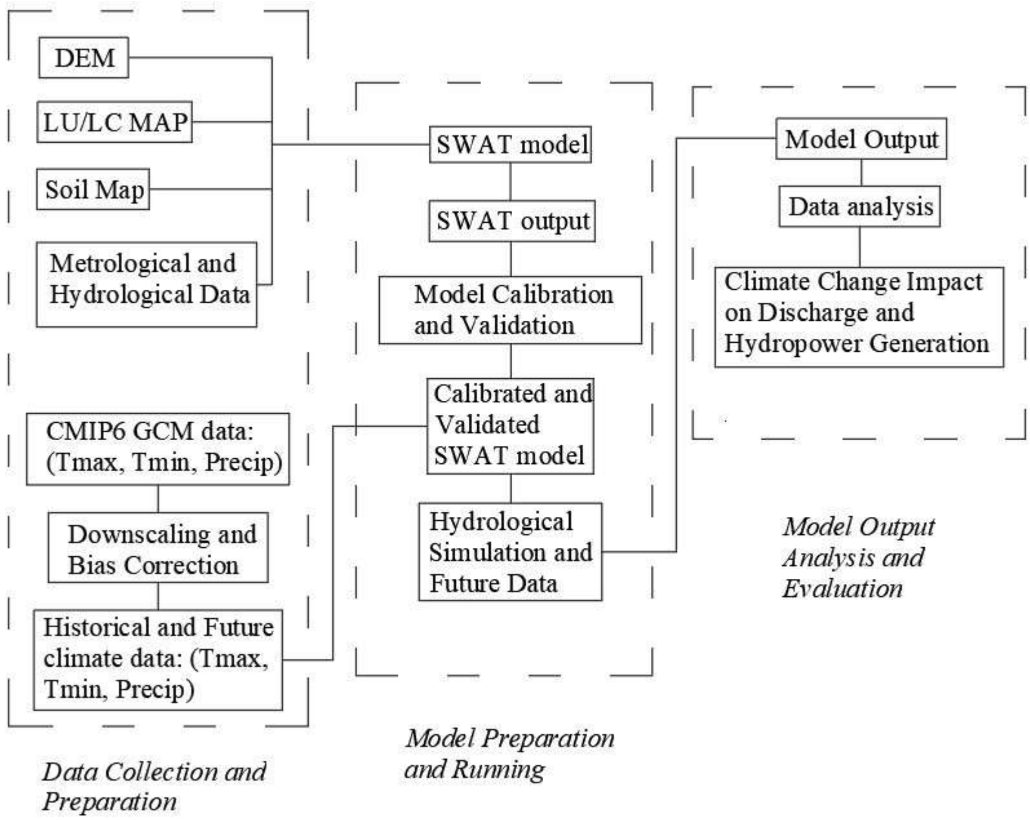

Figure 4-1: Research Methodology Flow Dragram

4.1 Hydrological Model

Hydrological analysis with hydrological modeling – selected based on the complexity and availability of resources - is necessary for the proper assessment of climate impacts on hydropower projects (Bajracharya, et al., 2018). The model plays a crucial role in assessing the impact of climate change on water resources.

The Soil and Water Assessment Tool (SWAT) is widely used for simulating the effects of climate variability on river basins, as it effectively integrates climatic, land-use, and hydrological data (Arnold et al., 2012). SWAT is particularly useful for evaluating hydropower potential under different climate scenarios by coupling it with climate models such as General Circulation Models (GCMs) and Regional Climate Models (RCMs) (Abbaspour et al., 2015).

In this research, SWAT model in ArcGIS platform is used to analyze the impact of climate change in Trishuli river basin and ultimately to the UT3A hydropower plant. A SWAT model is developed using soil, land use, land cover, topographic and DHM data. The important factor is the water balance for using SWAT model. The basin is divisioned into land and water routing phase of hydrological cycle for making simulation easy. In land phase, simulation in each sub-basin for the discharge of water, sediments and nutrients is done. Similarly, the movement of water, nutrients and sediment to the outlet is simulated in water routing phase.

The water balance equation of SWAT for hydrological cycle in SWAT is provided in equation 5:

$$SW(t) = SW(o) + \sum(R(i) - \boldsymbol{Q}(si) - E(i) - W(i) - \boldsymbol{Q}(gi)) \quad \text{.........Equation (5)}$$

(Thornthwaite & Mather, 1955; Dingman, 2015)

Where

- SW(t) is the final soil water content on day t (mm),
- SW(o) is the initial soil water content (mm),
- R(i) is the amount of precipitation on the day i (mm),
- Q(si) is the amount of surface runoff on the day i (mm),
- E(i) is the amount of evapotranspiration on the day i (mm),
- W(i) is the amount of water entering the vadose zone from the soil profile on the day i (mm), &
- Q(gi) is the amount of return flow on the day i (mm).

Total run off of the catchment area is calculated predicting the streamflow of each HRUs. Daily observed climate data are used by the model as the inputs for running. Each sub basin weather data is generated by the model.

4.1.1 SWAT Model Setup

DEM data, Land use/ Land cover data, Soil data and climate data shall be ensured before using SWAT model. Initially, watershed is delineated, to divide the catchment area into number of sub-basins based on the elevation where the model performs the simulation in each sub-basin to get the result at the final outlet of the basin, using DEM for setting up SWAT model. The works includes filling sinks, determining flow direction, flow accumulation and finally finalizing watershed delineation creating sub- basins.

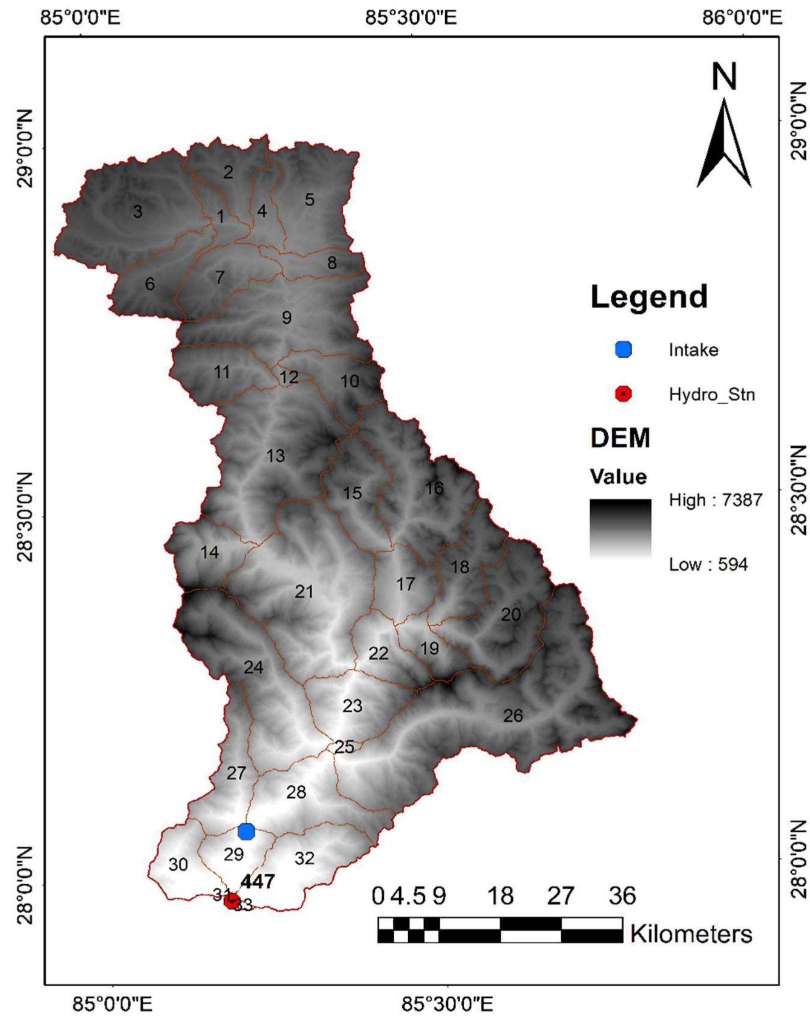

Figure 4-2: Watershed Delineation with Sub Basin

The outlet point was added manually to the watershed at the intake of UT3A intake gate manually. Once the watershed is delineated, the sub-basin parameter was determined for each of the sub- basins. 33 sub-basins were created in our study area, as shown in figure 8.

The delineated sub-basins are further divided in Hydrologic Response Units (HRUs). An HRU is the basic element of the model which has a unique mixture of soil type, slope classifications, land use, and land cover within a study watershed based upon user-defined limits. HRUs are created using GIS layer maps such as land use/ land cover map and soil map. SWAT model allows multiple HRUs per sub-basin where all land use, soil and slope combinations are represented. Defining of Soil, land use and slope classes separately is necessary for defining HRU.

In the watershed boundary the projected Raster GRID file of land use was loaded and clipped that provides raw land use. This raw land use was reclassified using lookup tables for land use map, soil map and slope. Five slope classes are defined as 0-25%, 25-45%, 45-65%, 65-85% and above 85% for doing slope reclassification. Then these maps were overlaid to create HRU feature classes. After that 193 HRUs were created in 33 sub-basins and obtained the details of each HRU. After HRU is created, SWAT requires data humidity for further calculations as weather data like daily rainfall, maximum and minimum temperatures, solar radiation and relative. Missing data regarding precipitation and temperature is taken into account by the weather generator which uses the observed data near the location to determine the likelihood of daily precipitation and uses random numbers to generate weather variables based on daily probability and statistical methods.

One gauge is connected to each sub-basin for all weather data kinds. Daily data for precipitation, maximum temperature, minimum temperature was created in .txt file format and the station data were loaded from input tables. Precise formatting input files are required for SWAT model. The collected data was processed to create bus-basins and HRUs to convert them into SWAT readable format. SWAT model was run and output is created using SWAT formatted input files.

4.1.2 SWAT Model Run

While running SWAT model, there are certain things that needs to be considered after SWAT formatted input files are written to be fed.

The first thing is time period division for running the model. The time shall be break into historical period, calibration period, validation period and future period. Among the historical period having observed data, calibration and validation of the model is done. Another one is choosing suitable rainfall distribution used in precipitation generator, and the time step for writing the output. SWAT model simulation is done after finalizing the parameters.

The starting date for simulation was 1998 ending on 2016 in which warm up period is four years from 1998 to 2001, calibration period is 10 years from 2002 to 2011 and validation period is from 2012 to 2016. Weather generator was selected for simple skewed distribution of rainfall. 64-bit version of SWAT and monthly step for writing output was selected. After that, the model was run for the UT3A catchment area in Trishuli river basin. The output from the successfully run model simulation is the discharge data at the main outlet which is the intake of UT3A hydropower station.

4.1.3 Calibration and Validation in SWAT-CUP

Calibration and validation are the techniques of aligning the model parameters towards the station data and making the platform for predicting the future data in a realistic form. After running the model, we can obtain the txtinout file which is the input file for the calibration. In the automated model calibration, the ambiguous parameters of the model are reformed then the model is run again to obtain the essential output files. The set of those parameters are required to replicate the observed flow.

SWAT-CUP (SWAT Calibration and Uncertainty Program) interface - helps to adjust the parameters in such a way that it represents a basin to its close proximity -is used for calibration and validation. In the research, SUFI-2 algorithm is used for calibration and validation of the model.

Parameterization is of utmost importance during calibration phase. The parameters are set to their threshold ranges either manually or between each auto-iteration for performing calibration. Also, the parameter sensitivities among the available parameters is another important factor. Among the parameters, the set which shows most responsive effects on the basin is chosen. As given by SUFI-2, these new parameters are employed for a number of iterations until the optimal parameter range is achieved. To get the reliable result, many iterations are performed reducing the range of parameters in each iteration. After obtaining the satisfactory result, the model was run to validation period for validation.

4.1.4 Model Evaluation

The performance of SWAT model is evaluated by comparing the output with the statistical performance indicators. (Moriasi et al., 1998) had given the statistical rating parameters for evaluating the output of the models which is shown in Table 4-1.

Table 4-1: Statistical Rating of Model (Moriasi et. al., 1998)

Rating of Model	Coefficient of Determination (R^2)	Nash Sutcliffe Efficiency (NSE)	ntage of BIAS (PBIAS)
Very good	$0.75 \leq R^2 < 1$	0.75 ≤ NSE < 1	PBIAS ≤ ± 10%
Good	$0.65 \leq R^2 < 0.75$	0.65 ≤ NSE < 0.75	10% < PBIAS ≤ ± 15%
Satisfactory	$0.5 \leq R^2 < 0.65$	0.5 ≤ NSE < 0.65	15% < PBIAS ≤ ± 25%
Unsatisfactory	$R^2 < 0.5$	NSE < 0.5	PBIAS ⍰ ± 25%
Ideal Value	$R^2 = 1$	NSE = 1	PBIAS = 0%

To analyze the functioning of the simulated model representation compared to the basin reality, above three statistical performance indicator NSE (Nash Sutcliffe efficiency), R^2 (Coefficient of Determination) and PBIAS (Percentage Bias) are computed.
The coefficient of determination (R^2) is used to find the variance proportion in the measured data as described by the simulated SWAT model. The coefficient of determination (R^2) value ranges from -1 to 1 if the model is valid and fits the data within the range of the horizontal fit line. The model is considered satisfactory if the value of coefficient of determination (R^2) is greater than 0.5 though the optimal value is 1.

Likewise, Nash Sutcliffe Efficiency (NSE) is used to fix the noise, relative degree of the residual variance, in the model by comparing it with the measured data variance, and is also used to know how exactly the plot of simulated and observed data is fitting the 1:1 Line. The range of Nash Sutcliffe Efficiency (NSE) value is from -∞ to 1 with the ideal value of 1. For the model statistical performance, the Nash Sutcliffe Efficiency (NSE) value higher than 0.5 is considered to be satisfactory.

Lastly, to confirm the average tendency of the simulated data of the SWAT model to be larger or smaller than their observed counterpart, a statistical performance parameter known as the percentage of bias (PBIAS) is used. Based on the positive and negative percentage of the bias value of the model the underestimation and overestimation bias in the model are depicted. The best value of percentage of bias (PBIAS) is the least value of ± 0% but for the model to be satisfactory, it can be in the range of ± 25%.

The performance of the model was again checked by drawing scatter plot between observed and simulated value and drawing flow duration curve to check the alignment of simulated value with observed value. Again, the performance of the model is confirmed by checking water balance components such as ratio of evapotranspiration to precipitation and ground water flow and lateral flow to surface runoff.

4.2 Climate Change Impact on River Discharge

The river discharge value obtained in the baseline period is used for predicting the impact of climate change on river discharge. The river discharge is obtained at intake point and the change in the average monthly discharge value is obtained by obtaining the deviation from the baseline value and the deviations are analyzed to know the climate change impact on Trishuli River Discharge at intake point.

4.3 Climate Change Impact on Hydroelectric Energy Generation

The capacity of hydropower plant is calculated using the formula given in equation 6 which is the function of head and discharge.

Plant capacity $P = \eta * \gamma * Q * h$ ……Equation (6)

(Paish, 2002)

Where P = Capacity of plant

η = Overall efficiency of the plant

γ = Unit weight of water

Q = Design discharge

H = Net head

For any hydropower plant, overall efficiency, unit weight of water and head is almost constant. The factor that fluctuates the power generation is available discharge. The discharge is affected by the climate change which ultimately affects the energy generation by hydropower.

For UT3A hydropower plant, overall efficiency is 0.88, unit weight of water is 9.81 KN/m3, net head is 133.41 m, the design discharge is 51 m3/s and the design capacity is 60 MW. The average monthly energy generation will be calculated using equation 7 for future time using the predicted future discharge values for each scenario (SSP245 and SSP585) and the result will be compared among each scenario to know the impact of climate change in future energy generation in UT3A RoR hydropower plant.

$E = P*t$ …….Equation (7)

(Serway & Jewett, 2014)

Where,

E= Energy generated

P = Power capacity of Hydropower

t = time of generation

5 RESULTS AND DISCUSSION

5.1 Hydrological Model Performance

The hydrological model performance is checked in historical calibration and validation period by analyzing performance statistical indicators as per Moriasi Table, Flow duration curve, Scatter plot and water balance components. Total 19 years is taken for preparation of SWAT model in which 4 years from 1998 to 2001 is taken as warm up period, 2002 to 2011 is used for calibration and 2012 to 2016 is used for validation.

5.1.1 Evaluation of Statistical Performance Indicators

The simulated value of the three statistical performance indicators Coefficient of determination (R^2); Nash Sutcliffe efficiency (NSE); and percentage of bias (PBIAS) shows acceptable hydrological performance of the model. Figure 5-1 displays a hydrograph of the observed and simulated flow for the calibration and validation periods. The hydrograph demonstrates that the observed discharge and the simulated discharge were consistent for the majority of the periods for both periods.

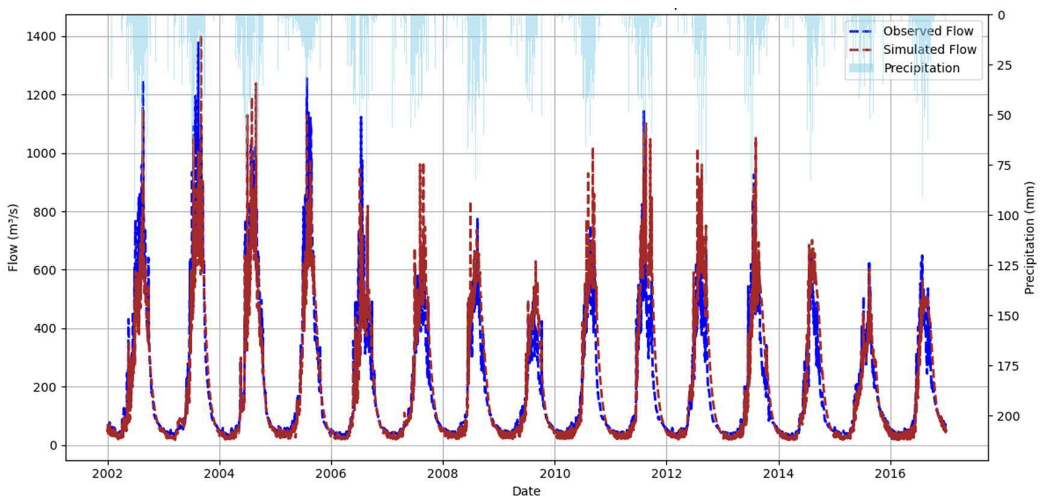

Figure 5-1: Observed Vs. Simulated Monthly Discharge Hydrograph for Calibration & Validation Period

The value of statistical performance indicators are given in Table 5-1. In our model, the value of (R^2) obtained in calibration and validation period are 0.75 and 0.72 respectively which shows the performance of model is good. Similarly, the model provides the value of NSE as 0.74 and 0.73 respectively which mean the performance of model is good as per table 4. Again, table 5 depicts the statistical rating of a model in terms of PBIAS as good as the value of PBIAS is 11.62% in calibration and 14.23% in validation period.

Table 5-1: Statistical Performance of Model during Calibration and Validation

S.N.	Period	Timeline	Performance Indicators		
			R2	NSE	PBIAS
1	Calibration Period	2002-2011	0.75	0.74	11.62%
2	Validation Period	2012-2016	0.72	0.73	14.23%

5.1.2 Scatter plot and flow duration curve plot

The scatter plot between observed and simulated flow is shown in Figure 5-2 and Figure 5-3 for calibration and validation period respectively. The plot shows that the density is high near the 45^0 line in both calibration and validation period which shows that the simulated discharge is correlated with observed discharge and hence depicts good performance of the model.

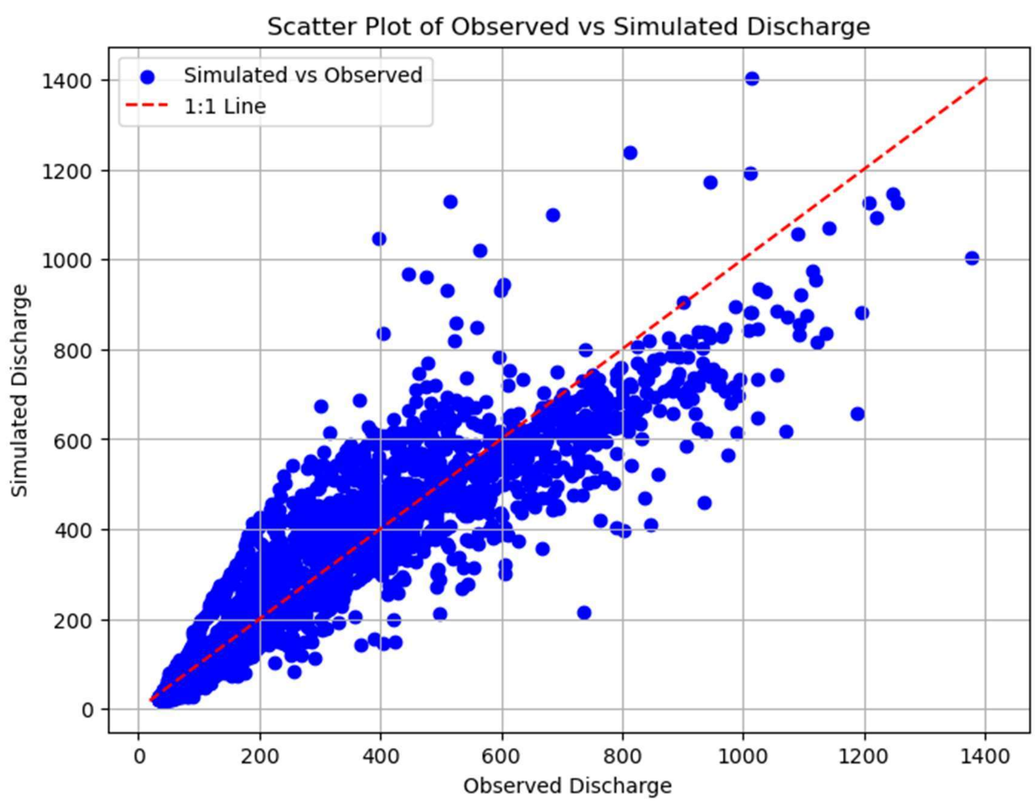

Figure 5-2: Scatter Plot of Calibration

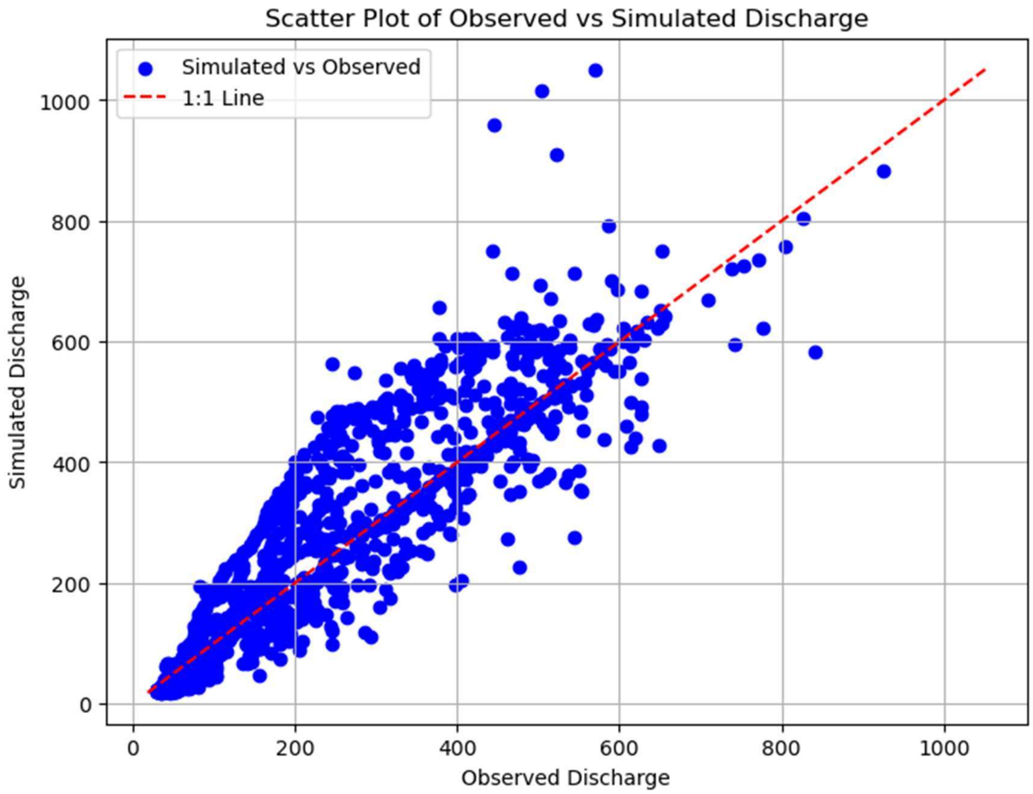

Figure 5-3: Scatter Plot of Validation

5.1.3 Flow duration curve

Figure 5-4 and 5-5 shows flow duration curve of both observed and simulated flow for calibration and validation period respectively. In calibration period, observed and simulated curves are moving overlapingly. But in validation curve, simulated flow is seen above the observed curve around 400 m^3/s discharge but the difference is very small. The trend of observed and simulated curves are in correlation which shows the model is performing well.

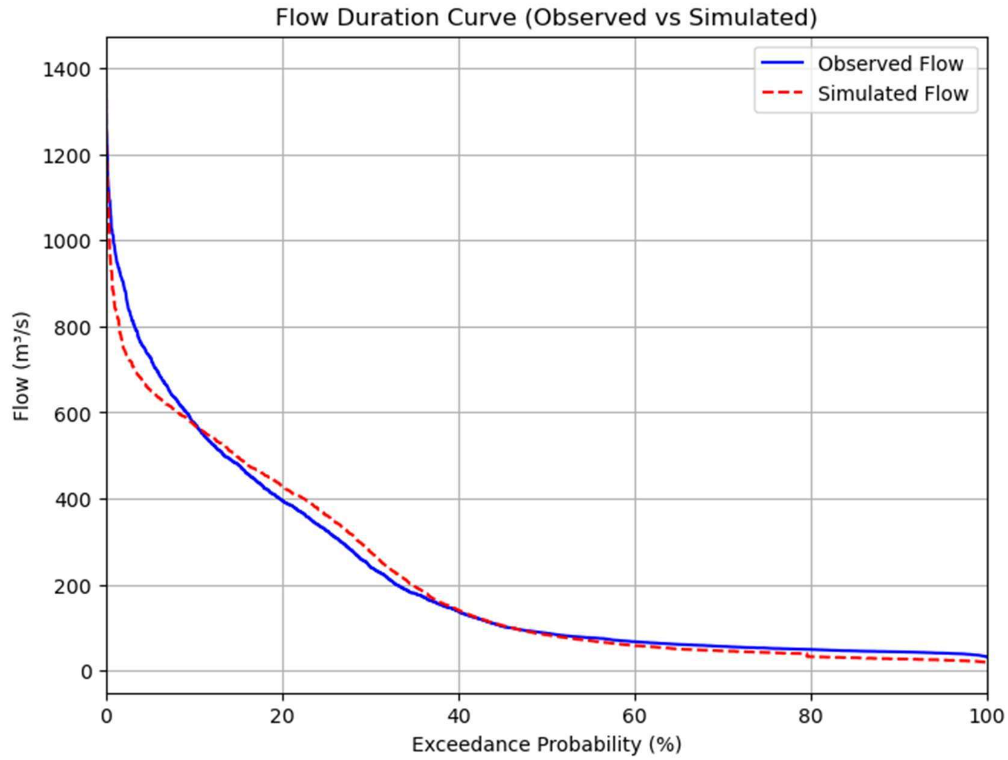

Figure 5-4: Flow Duration Curve Calibration

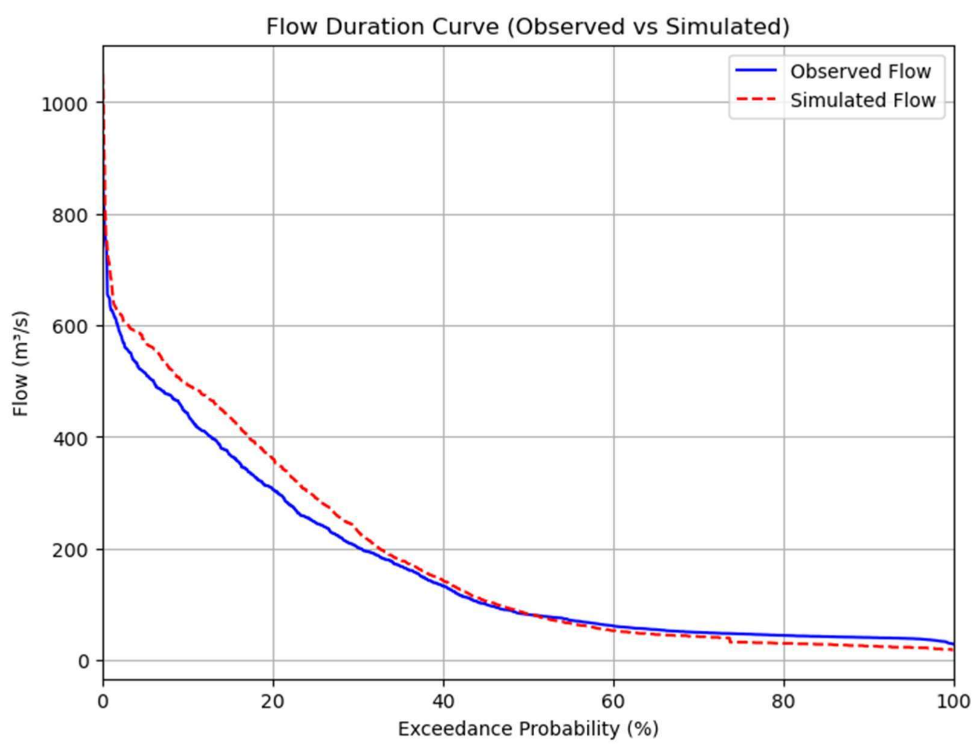

Figure 5-5: Flow Duration Curve Validation

5.1.4 Water balance components

The output of water balance components in baseline simulation of SWAT model is obtained as in Table 5-2.

Table 5-2: Water Balance Components simulated value

MON	RAIN (mm)	SNOWMELT (mm)	SNOWFALL (mm)	SURF Q (mm)	LAT Q (mm)	GWQ (mm)	WATER YIELD (mm)	ET (mm)
1	26.24	6.66	22.98	0.00	1.35	0.00	15.05	19.52
2	40.42	11.01	34.74	0.08	1.25	0.03	8.09	26.05
3	36.49	9.45	26.91	0.08	2.75	0.07	7.14	55.84
4	53.13	14.14	31.20	0.91	6.82	0.34	13.88	89.27
5	72.84	18.65	30.09	5.37	13.95	3.22	28.67	117.27
6	223.58	61.01	67.95	59.66	36.05	31.91	82.76	129.41
7	464.96	131.03	130.91	197.59	102.88	121.00	250.71	135.15
8	450.68	123.22	130.43	176.51	135.08	95.49	341.89	129.52
9	256.65	68.53	91.45	60.16	108.18	35.78	285.29	110.45
10	39.96	10.93	20.35	1.40	48.70	1.61	152.20	84.21
11	4.86	1.21	3.27	0.00	13.36	0.00	62.47	46.12
12	7.68	2.05	6.08	0.00	3.72	0.00	29.94	27.58
Total	**1677.49**	**457.89**	**596.36**	**501.76**	**474.09**	**289.45**	**1278.09**	**970.39**

The ratios of water balance components are checked and found satisfactory as in Table 5-3.

Table 5-3: Water Balance Components Ratios

Total precipitation=	**2273.85**	**mm**
Component	**Value (mm)**	**% of Precipitation**
Surface Runoff (SURQ)	502.08	22.08%
Lateral Flow (LATQ)	474.34	20.86%
Groundwater Flow (GWQ)	289.47	12.73%
Water Yield (WYLD)	1278.62	56.23%
Evapotranspiration (ET)	970.50	42.68%
Component	**Value (mm)**	**% of Water Yield**
Surface Runoff (SURQ)	502.08	39.27%
Lateral Flow (LATQ)	474.34	37.10%
Groundwater Flow (GWQ)	289.47	22.64%

5.2 Baseline hydrological characteristics

The discharge data at Betrawati Hydrological Station for the period 1998 to 2016 was obtained from DHM. The average annual discharge is 198.28 m^3/s for baseline period at Betrawati Hydrological Station. The maximum discharge for the period obtained was 1399 m^3/s in 2002 and minimum discharge was in 2014 i.e., 29 m^3/s. The average seasonal discharge on winter (DJF) was 44.13 m^3/s, on pre-monsoon (MAM) was 52.21 m^3/s, on monsoon (JJAS) was 437.63 m^3/s and post-monsoon (ON) was 175.84 m^3/s. As there is no any hydrological station at intake point of UT3A HPS, the discharge value of Betrawati was modified by catchment area ratio method to get observed discharge at intake point. The ratio of catchment area of intake point of UT3A to catchment area of Betrawati Hydrological Station is 0.935. The observed discharge at hydrological station was multiplied by the factor 0.935 and obtained the observed discharge at UT3A HPS. By applying catchment area ratio factor, the average annual discharge obtained at intake point is 167.48 m^3/s.

5.3 Future climate prediction

The ensemble of 5 GCMs was used for the future climate projection. Bias correction of the GCM data was done using the observed data of three metrological stations such as Nuwakot, Dhunche and Pansayakhola and the trend of temperature and precipitation was obtained. The future time frame was divided into three periods such as Near Future (NF 2025 to 2050 AD), Mid Future (MF 2051 to 2075 AD) and Far Future (FF from 2076 to 2100 AD) and the analysis was done accordingly.

5.3.1 Future temperature prediction

Temperature is the most sensitive parameter in climate change. The change in temperature affects directly and indirectly to other factors of climate change. To get the trend of temperature in future period, the bias corrected daily temperature values are obtained and analyzed for different future time periods for both scenarios SSP 245 and SSP 585.

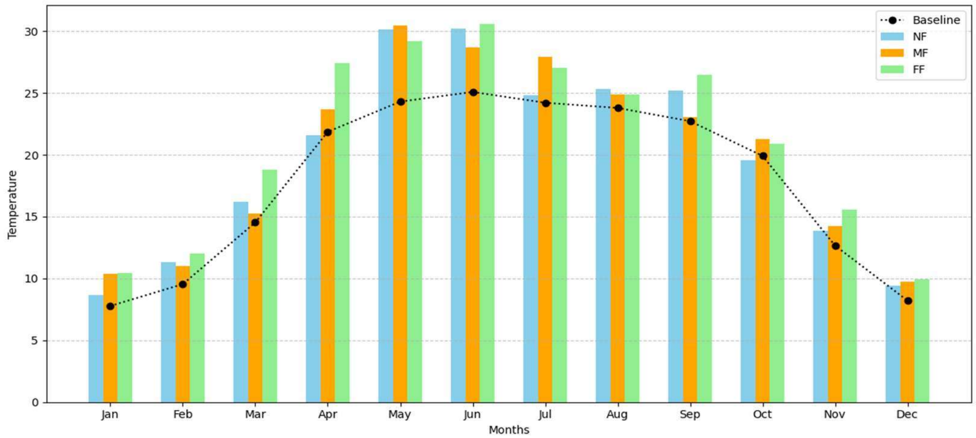

Figure 5-6: Projected monthly average temperature (^0C) in Nuwakot Station(ID: 1004) under scenario SSP 245

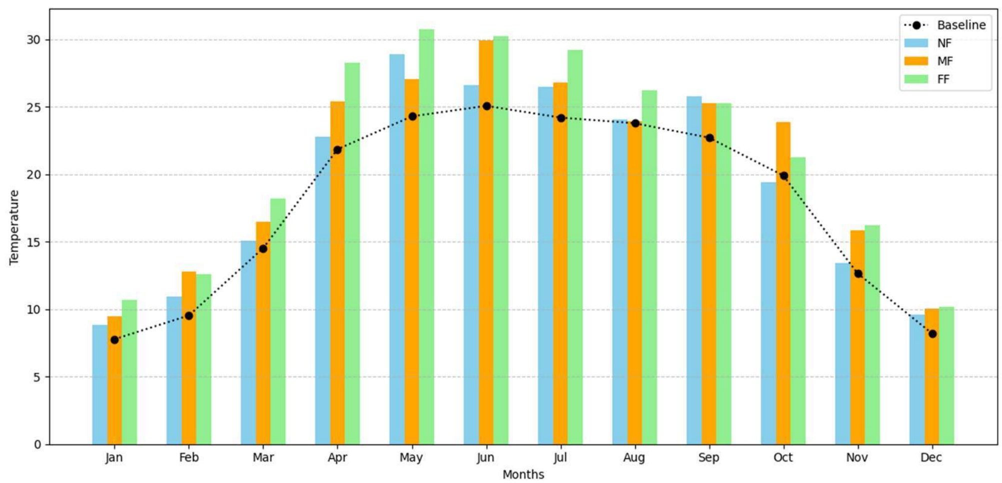

Figure 5-7: Projected monthly average temperature (^0C) in Nuwakot Station(ID: 1004) under scenario SSP 585

The temperature forecast under scenario SSP 245 and SSP 585 at Nuwakot station shows that there is an increase in average monthly value of temperature for most of the months. There is decrease of temperature by 1.37 % and 1.63% in months April and October respectively in NF under scenario SSP 245. Similarly, the decrease in temperature can be seen in October under SSP 585 in NF period. The maximum increase is seen in May (24%), January (33.05 %) and January (34.38%) in scenario SSP 245 for NF, MF and FF respectively. Similarly, the maximum increase is seen in May (19%), February (34.37%) and January (37.74 %) in scenario SSP 585 at Nuwakot Station.

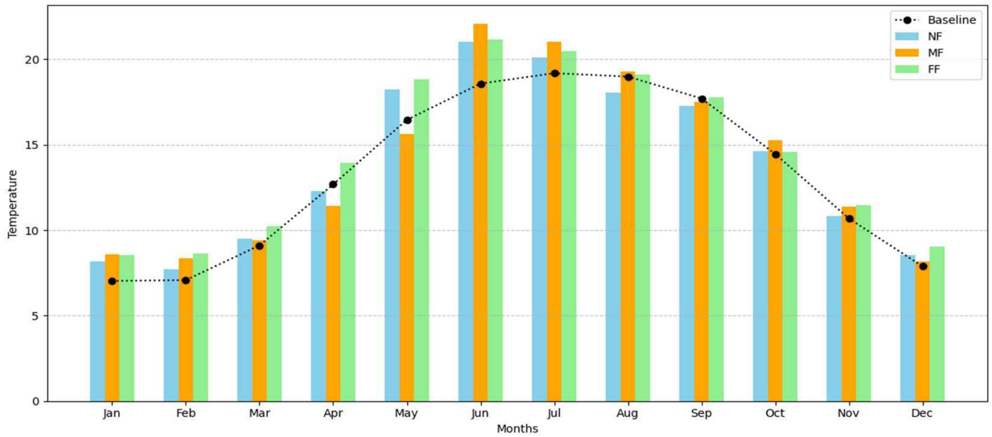

Figure 5-8: Projected monthly average temperature (^0C) in Pansayakhola Station(ID: 1055) under scenario SSP 245

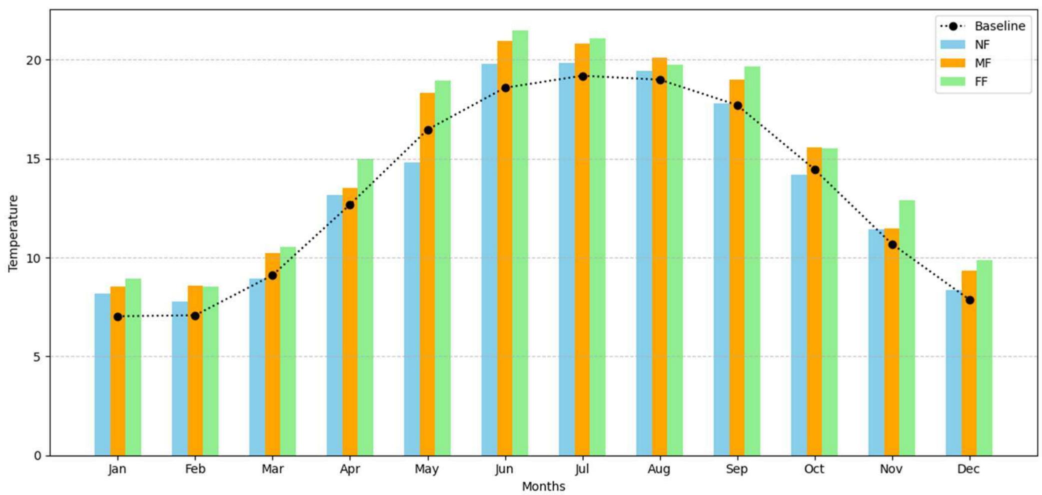

Figure 5-9: Projected monthly average temperature (^0C) in Pansayakhola Station(ID: 1055) under scenario SSP 585

The temperature forecast under scenario SSP 245 and SSP 585 at Pansayakhola station shows that there is an increase in average monthly value of temperature for majority of the months. There is decrease of temperature by 5 % in August, 2.52 % in September in NF period and by 10% in April, 5% in May and 1.2 % in September MF period under SSP 245 in Pansayakhola station. Similarly, the decrease in temperature can be seen in March (1.83%), May (10%) and October (1.84%) under SSP 585 in NF period. The maximum increase is seen in January (15.96 %), January (22.29 %) and February (21.91%) in scenario SSP 245 for NF, MF and FF respectively. Similarly, the maximum increase is seen in January in all three time frames under scenario SSP 585 at Pansayakhola Station.

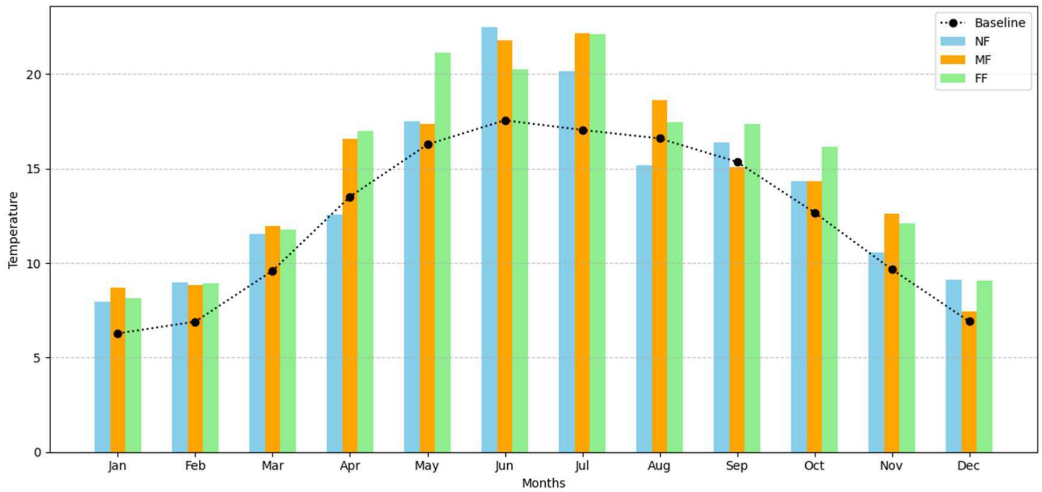

Figure 5-10: Projected monthly average temperature (^{0}C) in Dhunche Station(ID: 1057) under scenario SSP 245

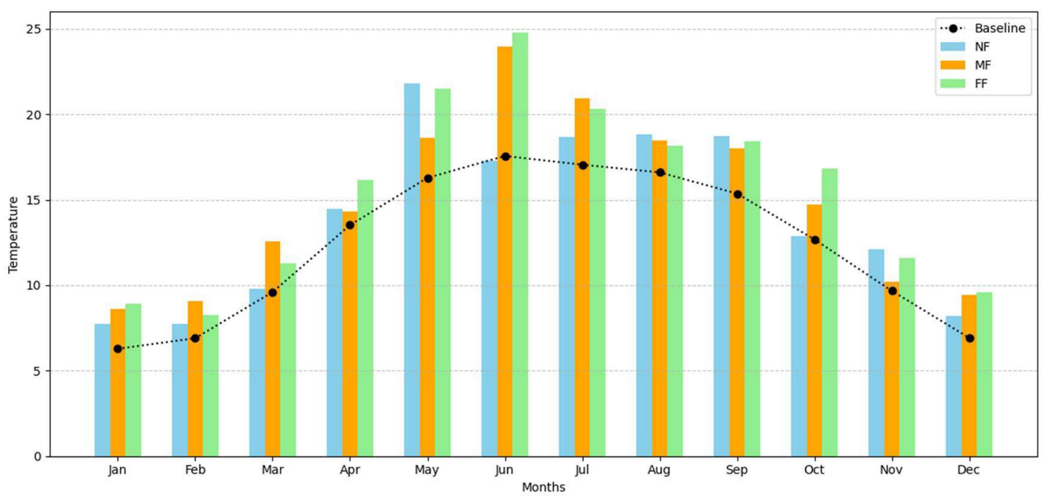

Figure 5-11: Projected monthly average temperature (^{0}C) in Dhunche Station(ID: 1057) under scenario SSP 585

As similar to the Nuwakot and Pansayakhola station, there is increase in temperature in Dhunche station as well though some decrease condition is seen in months April, August in NF and September in MF period in Dhunche station under scenario SSP 245. Under 585 scenarios, all the conditions are increase in temperature condition except for months June where the decrease in baseline temperature by 1.54% can be seen.

5.3.2 Future precipitation prediction

The average of five CMIP6 models were used to predict the future value of precipitation under the scenarios SSP 245 and SSP 585. Severe fluctuation in the value of precipitation is seen in the future period. The chart showing the average monthly future predicted value of precipitation under time frames NF, MF and FF are shown in Figure 5-12 to Figure 17.

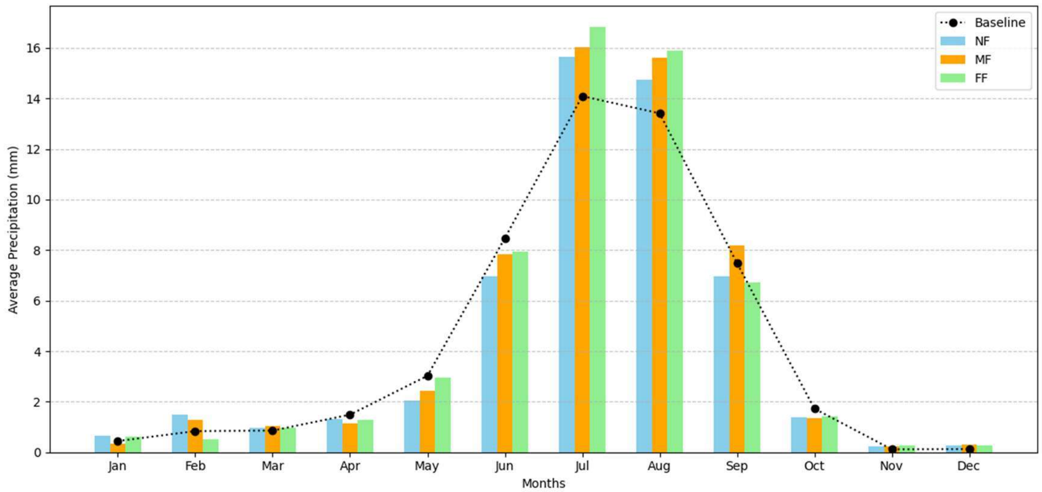

Figure 5-12: Projected monthly average precipitation in mm in Nuwakot Station(ID: 1004) under scenario SSP 245

scenario SSP 245.

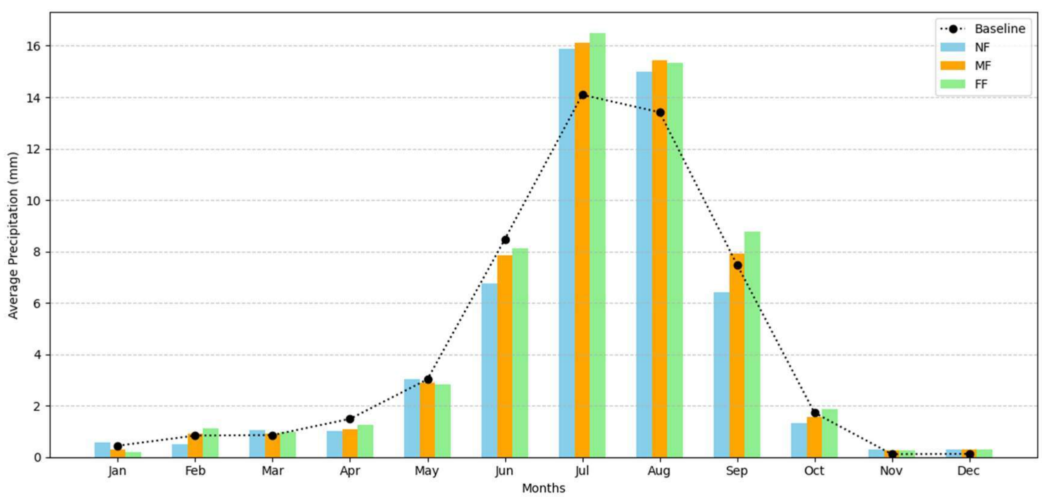

Figure 5-13: Projected monthly average precipitation in mm in Nuwakot Station(ID: 1004) under scenario SSP 585

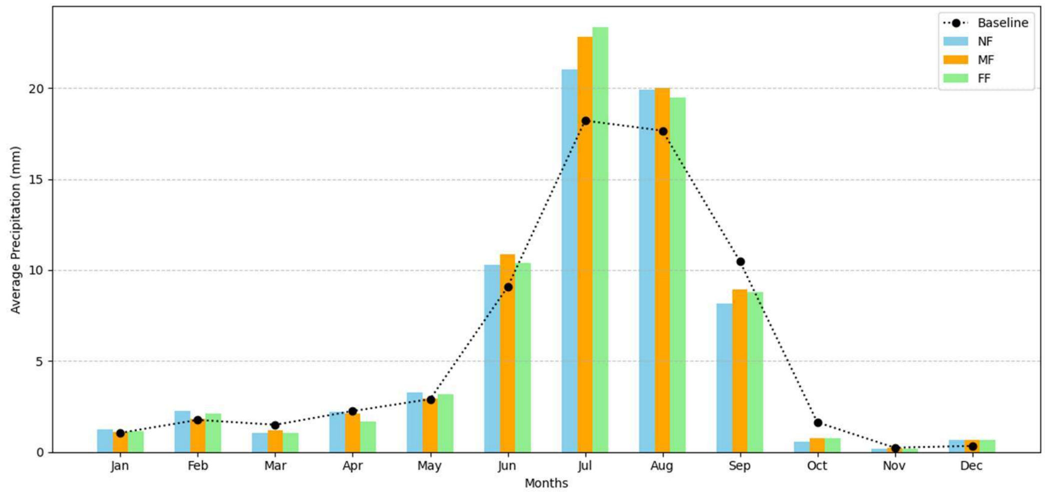

Figure 5-14: Projected monthly average precipitation in mm in Pansayakhola Station(ID: 1055) under scenario SSP 245

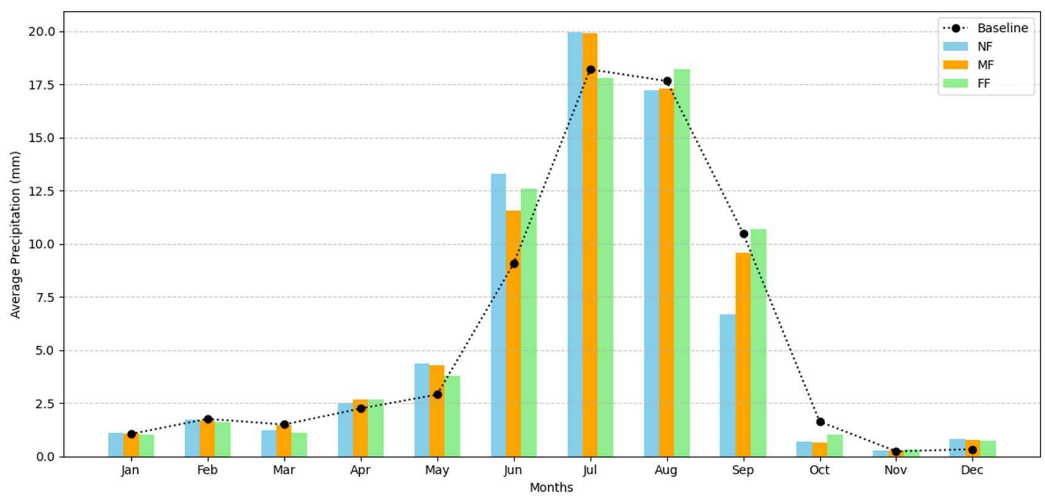

Figure 5-15: Projected monthly average precipitation in mm in Pansayakhola Station(ID: 1055) under scenario SSP 585

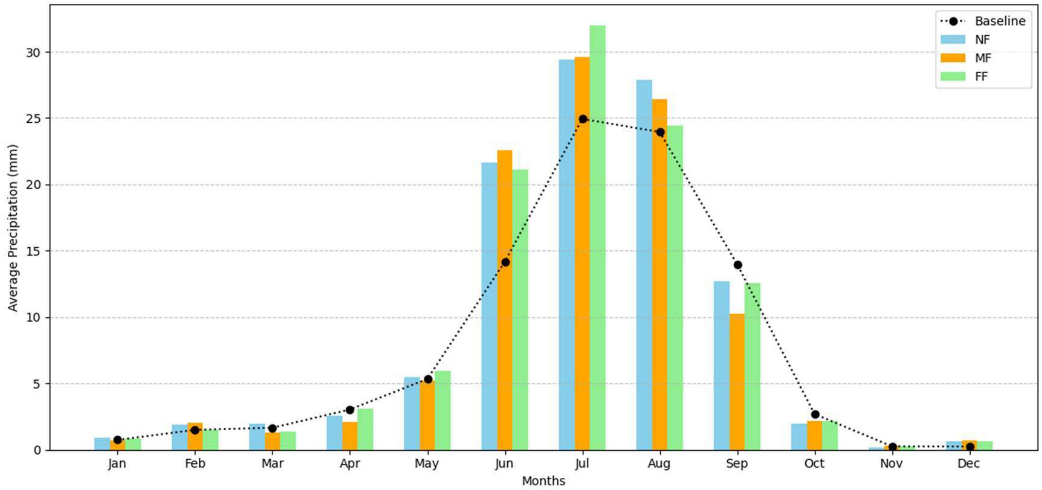

Figure 5-16: Projected monthly average precipitation in mm in Dhunche Station(ID: 1057) under scenario SSP 245

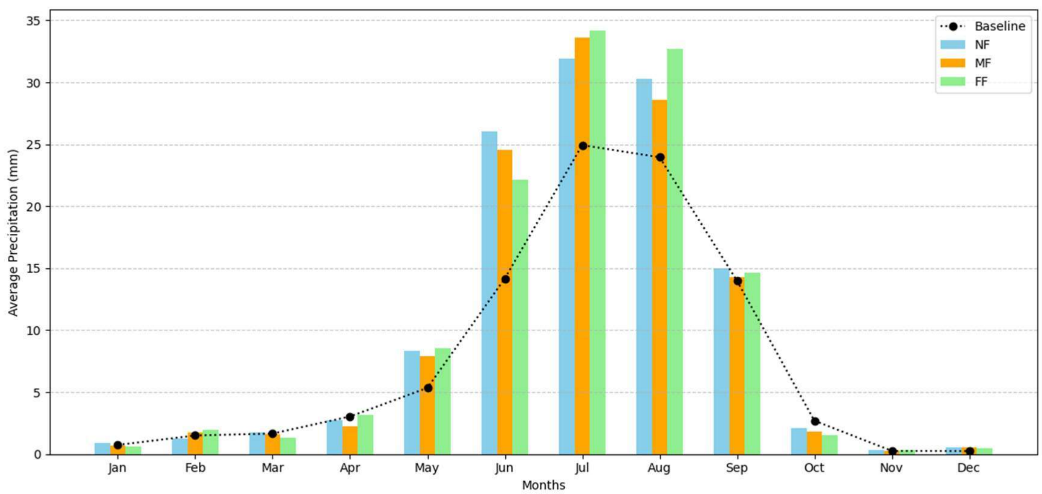

Figure 5-17: Projected monthly average precipitation in mm in Dhunche Station(ID: 1057) under scenario SSP 585

The chart from Figure 5-12 to Figure 5-17 shows that there is both increase and decrease trend of precipitation at all three stations under both scenariosSSP 245 and SSP 585. At Nuwakot station, the decrease in precipitation is seen in April, May, June, September and October in NF where the maximum decrease in percentage is seen in May by 32.57 % under SSP 245. On the other hand, the maximum increase is seen in November by 91.57%. In MF, the change in precipitation is seen from -23.29 in January to 108.99% in November. In FF of SSP245, the change is from -39.08% in February to 126.41 in November in Nuwakot station. Under SSP585, the change is from -37.89% in February to

152.53% in November in NF, from -34.57% in January to 147.08 in December and from -52.62 in January to 142.32 in December in Nuwakot Station.

Slight different trend in future precipitation is seen in Pansayakhola station. There is increase in precipitation in June, July and August under SSP245. The decrease of in precipitation is seen in September and October and the slight change and decrease is seen in remaining months. Under SSP 585 scenario, similar trend as SSP245 is seen with variation in degree of increase in July and August. The percentage of increase in precipitation in August is less in July and August than in SSP 245.

The future prediction of precipitation in Dhunche station shows that the change in NF is seen from -26.18% in October to 26.25% in February under SSP245. Similaryly, in MF the change is from -29.83% in April to 182.09% in December and in FF is from -19.88% in October to 157.56% in December. Under SSP585, the change is from -21.36 to 112.59 % in NF, from -31.38 in October to 116.68 in December and from -43.62 in FF to 108.5% in FF at Dhunche station. Overall, the precipitation is seen to be increased in July and August months. The percentage change in precipitation is more in December.

5.4 Climate change impact on discharge

The calibrated and validated SWAT model was used for analyzing the hydrological characteristics to understand the effect of climate change using the ensemble of five CMIP6 GCMs for two scenarios i.e. SSP 245 and SSP 585. The simulated discharge is obtained at the outlet of the basin for different time frame and is compared with the baseline discharge to obtain the change in hydrological characteristics due to climate change. The time frame is divided into baseline period and future time in which again future time is divided into NF (Near Future), MF (Mid Future) and FF (Far Future) for periods 2026-2050, 2051-2075 and 2076-2100 respectively for making analysis comparable.

The average annual discharge over the baseline period at the intake point is 167.48 m^3/s. While analyzing SWAT model output data, flow is found to be increased by 8.84 percentage in NF, 11.59 percentage in MF, and 15.43 percentage in FF under scenario SSP245. Similarly, under the scenario SSP 585, base flow discharge is increased by 13.68 percentage in NF, 14.37 percentage in MF and 21.81 percentage in FF. When observing the seasonal data, we found that the flow is high in monsoon season i.e., JJAS and low in dry season i.e., ON. Also, there is increase in flow from dry season i.e., DJF to pre monsoon period i.e., MAM which is due to the melting of snow and glacier. The comparison of long term simulated average monthly flow data shows that the flow varies from -15.93% in May to 27.72% in March in NF, -17.13% in May to 32.53% in March in MF and -23.46% in November to 35.48% in April in FF for scenario SSP 245. Similarly, the flow varies from -14.26% in May to 27.47% in March in NF, -21.16% in May to 37.01% in March in MF and -23.24% in October to 44.12% in April in FF for scenario SSP585.

Table 5-4: Baseline Annual Average Discharge and Flow Trend under Scenarios SSP245 and SSP585

Months		Jan	Feb	Mar	Apr	May	Jun
Baseline Discharge (m^3/s)		38.44	33.05	32.80	41.57	70.97	180.27
% change in SSP245	NF	14.02	20.33	27.72	-3.7	-15.93	-12
	MF	-4.15	8.53	32.53	6.43	-17.13	13.95
	FF	2.87	-6.61	10.72	35.48	25.52	21.06
% change in SSP 585	NF	0.43	-8.78	27.47	-11.76	-14.26	15.02
	MF	-3.16	6.35	37.01	-9.32	-21.16	13.95
	FF	-7.3	20.33	41.98	44.12	-9.35	39.86
Months		Jul	Aug	Sept	Oct	Nov	Dec
Baseline Discharge (m^3/s)		440.72	559.84	454.05	230.73	98.16	52.52
% change in SSP245	NF	15.23	12.83	11.04	9.72	-0.03	-5.62
	MF	11.13	8.46	18.52	18.68	10.02	-3.38
	FF	27.92	16.03	19.72	13.74	-23.46	-12.51
% change in SSP 585	NF	22.94	13.3	13.61	-2.39	-7.06	-3.48
	MF	17.5	15.97	24.7	14.63	-9.03	-6.43
	FF	36.45	29.53	27.51	-23.24	-9.56	-12.14

5.5 Climate change impact on energy generation

For any constructed hydropower plant, overall efficiency, unit weight of water and head is almost constant. The factor that fluctuates the power generation is available discharge. For UT3A hydropower plant, rated efficiency is 0.9224, unit weight of water is 9.81 KN/m^3, net head is 133.41 m, the design discharge is 51 m^3/s and the design capacity is 60 MW.

The average monthly energy productions are calculated for future time frame using the predicted future discharge values for each scenario (SSP245 and SSP585) and the results are compared with baseline energy production to know the impact of climate change in future in UT3A RoR hydropower plant. The energy generated from power plant for full design discharge availability is 44328.12 MWh. Also, as per the prevailing Environmental law, 10% flow shall be released in river for aquatic water right. The baseline energy and change in energy generated in different months in future time frames NF, MF and FF with the availability of discharge are given in Table 5-4.

Table 5-5: Baseline Annual Average Energy and Generation Trend under Scenarios SSP245 and SSP585

Months		Jan	Feb	Mar	Apr	May	Jun
Baseline average energy available (MWh)		31067.06	24134.2	26513.43	32515.98	45805.73	44328.12
% change in SSP245	NF	14.02	20.33	27.72	-3.7	0	0
	MF	-4.15	8.53	32.53	6.43	0	0
	FF	2.87	-6.61	10.72	35.48	0	0
% change in SSP 585	NF	0.43	-8.78	27.47	-11.76	0	0
	MF	-3.16	6.35	37.01	-9.32	-1.26	0
	FF	-7.3	20.33	41.98	0	0	0
Months		Jul	Aug	Sep	Oct	Nov	Dec
Baseline average energy available (MWh)		45805.73	45805.73	44328.12	45805.73	44328.12	45805.73
% change in SSP245	NF	0	0	0	0	0	-5.62
	MF	0	0	0	0	0	-3.38
	FF	0	0	0	0	0	-12.51
% change in SSP 585	NF	0	0	0	0	0	-3.48
	MF	0	0	0	0	0	-6.43
	FF	0	0	0	0	0	-12.14

The Table 5-5 shows that though the effect of climate change on river discharge is pronounced, the effect on hydroelectric energy generation was seen only on five months i.e., January, February, March, April and December under both SSP245 and SSP585 scenario. Generation on remaining months is not affected due to the availability of design discharge in these months. Under SSP245, mostly positive change is seen in NF and MF period though -3.7 % decrease in generation is seen in April in NF, -4.15% in January in MF, 6.61% decrease in February in FF and decrease by 5.62, 3.38 and 12.51 % in NF, MF and FF under SSP245 in December. More fluctuation is seen under SSP585 in months January, February, March, April and January. The change is from -11.76% in April to 27.47% in March in NF, from -9.32% in April to 37.01% in March in MF and -12.14% in December to 41.98% in March in FF. The maximum increase in percentage of energy generation is seen in March of FF under SSP585 and maximum decrease in percentage is seen in -12.51% in December under SSP245 FF.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The future prediction of temperature shows that there is increase in average monthly temperature in future time period under both scenarios SSP 245 and SSP 585. In Nuwakot Station, 34.38% increment is seen in January in FF period under SSP245 and the decrease by 1.63% is seen in October month in NF period. Similarly, under SSP 585 scenario, maximum increase is by 37.74% in January in FF period and maximum decrease is by 2.6% in October in NF period. In Dhunche Station, 22.29% increment is seen in January in MF period under SSP245 and the decrease by 10% is seen in April month in NF period. Similarly, under SSP 585 scenario, maximum increase is by 27.26% in January in FF period and maximum decrease is by 10% in May in NF period. In Pansayakhola Station, 39.3% increment is seen in January in MF period under SSP245 and the decrease by 8.48% is seen in August month in NF period. Similarly, under SSP 585 scenario, maximum increase is by 41.78% in January in FF period and maximum decrease is by 1.54% in June in NF period.

The plot of average monthly precipitation shows that the precipitation increment is seen more pronounced by value in months July and August and decrement is seen in April and June. However, the percentage change is seen maximum in dry months. In Nuwakot Station, 131.14% increment is seen in December in MF period under SSP245 and the decrease by 39.08% is seen in February month in FF period. Similarly, under SSP 585 scenario, maximum increase is seen by 152.53% in November in FF period and maximum decrease is by 52.62% in January in FF period. In Dhunche Station, 93.23% increment is seen in December in MF period under SSP245 and the decrease by 64.55% is seen in October month in NF period. Similarly, under SSP 585 scenario, maximum increase is by 137.82% in December in NF period and maximum decrease is by 60.88% in October in MF period. In Pansayakhola Station, 182.09% increment is seen in December in MF period under SSP245 and the decrease by 29.83% is seen in April month in MF period. Similarly, under SSP 585 scenario, maximum increase is by 116.68% in December in MF period and maximum decrease is by 43.62% in October in FF period.

The watershed model developed for Trishuli river basin shows that there is positive variation in average annual discharge in Trishuli River in NF, MF and FF periods. The base flow in the river is predicted to be increased by 8.84 percentage in NF, 11.59 percentage in MF and 15.43 percentage in FF under scenario SSP245. Similarly, under the scenario SSP 585, base flow discharge is increased by 13.68 percentage in NF, 14.37 percentage in MF and 21.81 percentage in FF.

The energy calculation using SWAT output flow shows major variation in January, February, March, April and January months. The months May to November are not affected for power generation due to the availability of design discharge. There is 14.02% increase in generation in January under SSP 245 in NF period. The change is more pronounced in month March and December. There is increase in baseline energy production in range from 10.72 % to 41.97 % in different time periods. And in December, the decrease is seen from -3.38% to –12.51% from baseline energy generation. April shows negative trend in NF and MF period which indicates that there is less snow melt or less availability of discharge in river. The dramatic increase in March and negative trend in April shows that there is effect of climate change in energy generation in Upper Trishuli 3A Hydropower Plant.

6.2 Recommendations

The average discharge in MF and FF period is predicted to increase. Hence, to tackle with the sudden increase in flow, the power plant has to plan for the adaptation measures by constructing river training structures, river bank protection structures and arranging adequate spill of river flow. Early warning system shall be arranged for flash floods to protect the riparian area. Watershed conservation programs shall be launched routinely to protect the area from flash flood, flood and landslide. Watershed conservation programs shall be launched routinely to protect the area from flash flood, flood and landslide. Adequate installation of meteorological and hydrological stations shall be installed to enhance resolution of forecast and modelling. It is necessary to implement glacier and snow melt monitoring program to increase accuracy of runoff. While planning and designing the new projects, climate resilient design shall have to be followed. Explore small scale upstream storage or pondage schemes to regulate flow and buffer dry season variability.

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7 APPENDICES

APPENDIX A: % change of temperature in near future, mid future and far future

Nuwakot Station (1004)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline average Temperature		10.78	12.54	17.53	24.86	27.30	28.08	27.21	26.79	25.72	22.91	15.66	11.21
% change in SSP245	NF	11.04	18.76	11.69	-1.37	24.13	20.55	2.45	6.57	10.86	-1.63	9.40	15.11
	MF	33.05	15.25	5.13	8.27	25.25	14.29	15.34	4.67	1.53	6.78	12.71	18.65
	FF	34.38	25.84	29.30	25.51	20.01	21.83	11.77	4.63	16.55	4.81	22.85	20.95
% change in SSP 585	NF	13.55	14.92	3.73	4.42	19.00	6.13	9.49	1.13	13.42	-2.60	6.17	17.20
	MF	21.68	34.37	13.65	16.33	11.37	19.47	10.71	0.55	11.27	19.84	25.35	22.63
	FF	37.74	31.76	25.48	29.44	26.47	20.52	20.63	10.27	11.26	6.81	28.46	24.35

Pansayakhola Station (1055)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline average Temperature		9.28	9.90	12.60	16.52	19.28	20.56	20.05	19.60	18.36	15.68	12.67	9.92
% change in SSP245	NF	26.61	30.26	20.22	-7.16	7.61	27.97	18.16	-8.48	6.76	13.00	9.42	31.64
	MF	38.30	27.90	24.55	22.69	6.76	24.06	30.06	12.10	-1.89	13.15	30.67	7.34
	FF	29.48	29.38	22.51	25.69	29.90	15.32	29.71	5.25	13.10	27.33	25.11	31.24
% change in SSP 585	NF	23.33	11.97	2.21	7.12	33.87	-1.54	9.55	13.52	21.97	1.70	24.89	18.44
	MF	37.17	31.77	31.10	5.94	14.24	36.36	22.87	11.32	17.15	16.26	5.66	36.44
	FF	41.78	19.24	17.73	19.53	31.94	41.00	19.18	9.28	19.91	32.71	20.08	38.78

Dhunche Station (1057)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline average Temperature		10.03	10.08	12.11	15.68	19.46	21.58	22.19	21.99	20.71	17.46	13.69	10.88
% change in SSP245	NF	15.96	8.81	4.54	-3.00	10.83	13.09	4.78	-5.00	-2.52	1.25	1.41	8.56
	MF	22.29	18.04	3.23	-10.00	-5.00	18.72	9.65	1.58	-1.20	5.53	6.38	3.94
	FF	21.56	21.91	12.51	9.76	14.31	13.91	6.69	0.65	0.52	0.87	7.33	14.58
% change in SSP 585	NF	16.39	9.95	-1.83	3.70	-10.00	6.47	3.30	2.45	0.55	-1.84	6.69	5.76
	MF	21.30	21.19	12.15	6.53	11.44	12.85	8.43	5.77	7.30	7.73	7.48	18.27
	FF	27.26	20.79	15.84	18.03	15.04	15.52	9.95	4.01	10.91	7.31	20.44	25.51

APPENDIX B: % change of precipitation in near future, mid future and far future

Nuwakot Station (1004)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline precipitation		13.74	23.44	26.59	44.63	93.78	254.19	436.91	415.9	224.6	51.81	3.45	3.89
% change in SSP245	NF	51.16	76.78	11.93	-11.95	-32.57	-17.62	11.04	9.94	-7.17	-19.51	91.57	123.17
	MF	-23.29	54.09	18.92	-23.38	-19.68	-7.35	13.81	16.28	9.26	-21.83	108.99	131.14
	FF	39.88	-39.08	10.76	-14.64	-2.16	-6.41	19.34	18.44	-10.11	-17.20	126.41	115.20
% change in SSP 585	NF	26.35	-37.89	21.25	-31.44	0.49	-20.45	12.60	11.66	-14.11	-22.99	152.53	139.11
	MF	-34.57	8.70	8.43	-28.08	-4.47	-7.35	14.45	15.01	5.65	-10.25	126.41	147.08
	FF	-52.62	34.98	14.26	-15.31	-6.46	-4.17	16.93	14.19	17.27	8.86	123.12	142.32

Pansayakhola Station (1055)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline precipitation		32.67	49.4	46.4	67.49	90.06	271.81	564.37	547.35	314.53	49.08	7.1	10.43
% change in SSP245	NF	19.55	28.67	-28.52	-0.87	13.25	13.35	15.41	12.82	-22.07	-64.55	-15.46	87.25
	MF	6.26	4.30	-20.50	-7.10	1.20	19.97	25.40	13.22	-14.64	-52.32	-7.00	93.23
	FF	7.21	20.17	-29.85	-25.77	9.81	14.68	28.09	10.21	-16.35	-52.93	-19.69	90.26
% change in SSP 585	NF	5.32	-1.37	-19.17	11.57	50.08	46.69	9.47	-2.42	-36.19	-58.43	22.59	137.82
	MF	1.52	-4.77	-0.46	18.24	46.98	27.81	9.36	-1.96	-8.53	-60.88	18.36	134.85
	FF	-4.17	-8.17	-27.18	18.24	30.12	38.85	-2.12	3.08	2.06	-38.26	26.81	119.98

Dhunche Station (1057)													
Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline precipitation		23.06	42.14	51.56	91.06	165.75	425.19	772.98	742.65	419.74	80.88	7.87	7.58
% change in SSP245	NF	23.68	26.25	18.44	-14.67	1.93	52.97	17.95	16.38	-9.16	-26.18	-19.92	165.74
	MF	-8.58	34.22	-22.44	-29.83	-2.74	59.46	18.79	10.24	-26.67	-18.77	6.78	182.09
	FF	16.96	1.66	-17.03	2.46	11.47	49.09	28.17	1.98	-10.23	-19.88	-12.29	157.56
% change in SSP 585	NF	18.30	-16.28	5.22	-10.39	55.99	83.59	28.13	26.44	6.99	-21.36	33.47	112.59
	MF	-7.24	18.28	-4.40	-25.87	47.76	73.43	34.87	19.26	1.99	-31.38	10.59	116.68
	FF	-16.65	29.57	-19.43	5.42	59.54	56.14	36.96	36.33	4.49	-43.62	14.41	108.50

APPENDIX C: Average annual energy generation in MWh in future periods under SSP 245 and SSP 585 scenarios.

Year	Energy (MWh)		
	Baseline period	SSP 245	SSP 585
2002	496681.47		
2003	472049.56		
2004	472331.54		
2005	488222.30		
2006	453577.56		
2007	475787.82		
2008	487125.12		
2009	485137.96		
2010	485369.52		
2011	472948.21		
2012	463579.47		
2013	463566.78		
2014	443874.48		
2015	467207.31		
2016	477533.13		
2026		468782.96	435284.8
2027		466931.60	451173.39
2028		464454.44	463133.29
2029		462629.17	457101.19
2030		473615.59	458439.73
2031		469434.84	462446.64
2032		471712.09	462968.15
2033		477535.59	460916.89
2034		477744.19	465349.7
2035		478874.12	457683.54
2036		466879.45	458813.47
2037		478813.28	456831.75
2038		484332.57	457622.7
2039		482255.23	465532.23
2040		485019.22	474232.71
2041		462255.42	464454.44
2042		482107.47	468313.6
2043		478404.77	475275.72
2044		469061.09	461212.41
2045		474345.70	467114.13
2046		482785.43	470686.46
2047		491790.12	473789.43
2048		487044.40	476596.87
2049		475658.16	472103.22
2050		481751.11	482820.2
2051		461777.37	456327.62

2052		462611.79	456405.85
2053		461203.72	455284.61
2054		456788.29	450582.35
2055		458865.62	452659.69
2056		469261.00	463698.26
2057		462994.22	457596.62
2058		464211.07	458300.66
2059		470469.16	465245.4
2060		464671.74	458822.17
2061		464428.37	459491.43
2062		467679.10	462455.33
2063		473172.31	468600.43
2064		483263.48	479082.73
2065		487226.93	483254.78
2066		484897.53	480934.08
2067		481698.95	477735.5
2068		483532.92	479569.47
2069		483889.29	479917.14
2070		481472.97	477500.82
2071		483011.41	479039.27
2072		489990.92	486027.47
2073		492146.49	488174.34
2074		490208.22	486236.07
2075		494015.22	490043.07
2076		457414.10	478196.16
2077		462238.04	476509.96
2078		474197.94	474006.72
2079		468157.15	474267.47
2080		469504.37	482559.44
2081		473511.29	478821.97
2082		474032.80	481481.66
2083		471972.84	486149.15
2084		476127.52	487018.33
2085		468739.50	487270.39
2086		469878.12	488973.98
2087		467905.09	488000.5
2088		468696.04	492085.64
2089		476605.57	490277.75
2090		484306.49	492537.62
2091		475519.09	495327.68
2092		479386.94	490425.51
2093		484697.62	486114.38
2094		472285.75	478639.44
2095		478187.47	483524.23
2096		481698.95	491355.53
2097		484132.66	499125.99

2098		485705.87	494041.3
2099		483002.72	484263.03
2100		492172.56	491103.47

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