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Impact of Variation in Climatic Parameters on Hydropower Generation: A Case of Super Dordi Hydropower Project Kha in Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, thesis entitled **"Impact of Variation in Climatic Parameters on Hydropower Generation: A Case of Super Dordi Hydropower Project Kha in Nepal"** submitted by **Er. Raj Singh** in partial fulfillment of the requirements for the degree of Masters in Energy Systems Planning and Management.

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ABSTRACT

Nepal has substantial potential to generate electricity through hydropower projects. Most of the hydropower projects in Nepal are Run-off-River (ROR) types. Significant seasonal variation can be pronounced on its river basins resulting in higher streamflow & higher hydropower generation during the wet/summer season and just reverse scenario in case of the dry/winter season. Thus, ROR-type hydropower in Nepal is more susceptible to Climate Change.

This study assesses the impact of variation in climatic parameters on the power generation of Super Dordi Hydropower Project Kha and streamflow of Dordi River by implementing WEAP model using the meteorological and hydrological data from 1976 to 2004 under Reference & Climatic Scenarios.

Super Dordi Hydropower Project Kha is located in Lamjung District in the Western Development Region of Nepal. It is a Run-off-River type of project being developed by Peoples Hydropower Company Ltd. The Geographical coordinate of the project area lies between Longitudes 84°34’15” E and 84°31’00” E, Latitudes 28°18’50” N and 28°16’20” N.

Dordi River is one of the major tributaries of Marsyandi River in Lamjung district of Nepal, flowing from North to South and westward direction in Lamjung district of Western Development Region, Nepal.

The results reveal that the streamflow of Dordi River of Nepal is in increasing trends and can be more pronounced during April, May, June & July of the season under climatic scenarios. The generation of hydropower plant is likely to increase from 0.35% to 15.16%, 0.66% to 31.99% & 0.92 to 50.51% over the study period under climatic scenario-1, 2 & 3, respectively, as compared to baseline scenario and the increments are observed to be more prominent during April & May of the season which is very crucial finding in current context of Nepal as there is power deficit during the dry season.Therefore, detailed technical and policy level planning can enhance the power generating capability of the future hydropower projects that will be developed in this corridor. This will significantly impacts the national energy planning and implementation.

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LIST OF ABBREVIATIONS

CC	:	Climate Change
DoED	:	Department of Electricity Development
DHM	:	Department of Hydrology and Meteorology
DPR	:	Detail Project Report
FAO	:	Food and Agricultural Organization
GHG	:	Green House Gas
HPP	:	Hydropower Project
ICIMOD	:	International Centre for Integrated Mountain Development
IEE	:	Intial Environment Examination
IPCC	:	Intergovernmental Panel on Climate Change
LDC	:	Load Dispatch Centre
LEAP	:	Low Emission Analysis Platform
LULC	:	Land Use Land Cover
MOFE	:	Ministry of Forests and Environment
NAP	:	National Adaption Plan
NDC	:	Nationally Determined Contribution
NEA	:	Nepal Electricity Authority
NST	:	Nepalese Standard Time
PH	:	PowerHouse
PHCL	:	Peoples Hydropower Co. Ltd.
RCM	:	Regional Climate Model
RCP	:	Representative Concentration Pathway
RoR	:	Run off River
SEI	:	Stockholm Environment Institute
WEAP	:	Water Evaluation And Planning system

LIST OF MEASUREMENT UNITS

°C	:	Degree Celsius
’	:	Minute
’’	:	Second
Cumec	:	Cubic meter per sec
GJ	:	Giga Joule
GWhr	:	Gigawatt hour
km	:	Kilometer
kN	:	Kilo Newton
kPa	:	Kilo Pascal
kWhr	:	Kilowatt hour
M	:	Meter
m/s	:	Meter per second
masl	:	Meter above sea level
MJ/m^2day	:	Mega Joule Per sq. meter per day
mm	:	Millimeter
MW	:	Megawatt
N	:	North
Sq.km	:	Square Kilometer

CHAPTER ONE: INTRODUCTION

1.1 General Background

In the context of Nepal, the majority of the electricity generation is contributed through the hydropower sector. Nepal has tremendous potential to generate electricity through hydropower projects. The country's river basin has a theoretical potential of 83,290 MW, out of which 45,610 MW is technically viable & 42,133 MW is economically feasible (K.C et al., 2011). However, it hasn't been able to harness even 5 % of the hydropower potential mentioned above. The present hydropower generation capacity in the country is about 6052 GWhr, and the current peak demand is 1482 MW (Nepal Electricity Authority, 2021). On a positive note, the Nepal Government has planned to expand the power generation up to 15,000 MW by 2030, on which a significant contribution will be from the hydropower sector (Nationally Determined Contribution, 2020).Most of the hydropower in Nepal is Run-off-River (ROR) type. Thus, significant seasonal variation can be pronounced in the river basins resulting in higher hydropower generation during the wet/summer season while lower generation during the dry/winter season. This seasonal variation causes energy deficits during the dry season. In these conditions, the energy demands are met by importing the energy from the neighboring country (Nepal Electricity Authority, 2021).

Climate Change has been a serious challenge and matter of concern globally, regionally & nationally. Global warming is key factor of the climate change. It is quite evident that the temperatures have been increasing globally and causing serious climate-related risks for the human and natural systems. The IPCC Special Report on the impacts of global warming of 1.5°C stated that it is estimated to cause approximately 1.0°C of global warming above pre-industrial levels by human activities, with a possible global temperature rise in the range of 0.8°C to 1.2°C. Global warming will possibly approach 1.5°C between 2030 and 2052 if it continues to increase at the current trend (IPCC Special Report, 2019). Several efforts have been put together globally to respond to the serious threat of Climate Change. Many plans and policies have been formulated and implemented at the national level in the form of Nationally Determined Contribution (NDC) to suppress rising global temperature from the national level. The Paris Agreement sets the main goal to limit the global temperature rise this century well below 2°C above pre-industrial level central and to put efforts to keep temperature rises to 1.5°C. In addition to this, the agreement intends to improve the nation's capacity to deal with the effects of climate change and align the constant financial flows with low GHG emissions and a climate-resilient pathway.

The Ministry of Forests and Environment MOFE (2015) under the Nepal Government commenced the National Adaptation Plan (NAP) to access the Climate Change pattern in terms of medium and long. The study regarding the changes in precipitation and temperature shows that the average annual precipitation is projected to increase by 2 - 6% in medium term period and 8-12% in the long-term period. Similarly the annual mean temperature is projected to increase by 0.9 – 1.1°C in medium term period and 1.3 – 1.8°C in the long term period.

Climate Change has a greater impact on hydropower. Many studies can be found across the globe assessing the impact of Climate Change on hydropower projects. The gross hydropower potential is projected to increase up to 2.4% & 6.3% by 2080 under the RCP 2.6 & 8.5 scenario as compared to those between 1971 to 2080s with significant increments pronounced in Central Africa, Asia, India, and northern high latitudes (Vliet et al., 2016). Likewise, the annual streamflow in Florida, USA, is projected to increase by an average of 21% with distinct seasonal alterations leading to an increment in power generation by approx. 56% during winter, an average of 15% during autumn, and decrement by 14 % during summer, with an increase in the global mean temperature (Chilkoti et al., 2017). The study has revealed the different degrees of impacts on streamflow in the Colorado river basin and hydropower generation with varying predictions of temperature and precipitation (Shu et al., 2018; Nashand Gleick, 1993; Wolock and McCabe, 1999; Christensen et al., 2004; Christensen and Lettenmaier, 2007).

1.1. Problem Statement

Many hydropower projects in the Nepal have been developed and developing without sufficient and detail assessment for the potential climate risks and impacts. The majority of hydropower developers are not attentive to consider the possible impacts caused by the Climate Change during the development of hydropower projects due to the lack of i) right knowledge and awareness of Climate Change, its impact on entire parts of energy value chain; ii) detailed and clear provisions in the guidelines for study of hydropower projects (Department of Electricity Development, 2018) and requirement of their mandatory investigation and risk assessment due to the Climate Change during the development of hydropower.

Even when it is intended to assess the possible climatic risks and impact, it has been very difficult to carry out such research and detail investigation due to the lack of quality and reliable climatic datasets, availability of denser hydrological and meteorological network/stations, improved in-situ data, penetration of climate resilient funds, lack of proper coordination between the key authorities and actors associated during the hydropower development.

1.2. Objective

Main Objective:

To access the impact of variation in climatic parameters on streamflow of Dordi River and hydropower generation of Super Dordi Hydropower Project Kha

Specific objective:

- To quantify impact of variation in climatic parameters on streamflow of Dordi River & power generation of Super Dordi HPP Kha on difference scenario

i) Reference scenario

ii) Climatic Scenarios

1.3. Limitation

a) This modeling approach excludes the impacts of extreme weather events, which may increase under CC conditions leading infrastructural damage, potential loss in energy and other indirect effects, such as interruption in business & other latent effects. Exploring these potential effects would be fruitful area for further work.

b) The model doesn’t consider the impact of CC on transmission and distribution of electricity network while they appear to be significant components.

c) The model doesn’t consider the effect of the snowmelt in the study area.

In spite of these limitations, this research work will render a methodological framework for Climate Change impact assessment on the hydropower generation and motivate to introduce potential resilience measures in order to maintain the entire parts of the electrical energy value chain of hydropower projects.

CHAPTER TWO: LITERATURE REVIEW

2.1 Review on Climate Change and Hydropower

Climate Change has been matter of serious global concern. Its impact can be observed in different sectors and hydropower is one of them. Several studies had been conducted in the hydropower systems located in the low altitude area lesser than 1000 ft, California, to investigate the effect of climate change. The study revealed that the hydropower generation from water supply reservoirs has increased in the wetter scenario due to the increase in the availability of the water, while the hydropower production has decreased in the drier scenario due to the low availability of the water (Yao and Georgakakos, 2001; VanRheenen et al., 2004; Tanaka et al., 2006). Variations in runoff can be observed across the different parts of the world due to Climate Change. The runoff is likely to increase in the high northern latitudes, Southeast Asia, East Africa, northeastern Europe, India, and parts of, Austria, China, Hungary, Norway, Sweden, the northwest Balkans, and Sahel under 2°C of global warming scenario as observed from the study (Schleussner et al., 2016; Donnelly et al., 2017; Döll et al., 2018; Zhai et al., 2018). However, studies in the Mediterranean region, southern Australia, Central America, and central and southern South America found decrement in the runoff these areas.

A study was conducted by Oti et al. (2020) in the Densu River Basin. The study showed that the temperature would increase by 8.23%, and rainfall would be decreased by 17% in that area due to the impact of climate change. An investigation of Olabanju et al. (2020) revealed that under RCP 4.5 & 8.5 scenarios, the temperature is likely to increase in the range of 1°C - 4°C & there will be decrease in the precipitation in the range of 5% - 30% as compared to baseline scenario.

It has been observed that global warming has a greater impact on runoff of river basins across the different continents - Upper Amazon, Darling, Ganges, Lena, Upper Mississippi, Upper Niger, Rhine and Tagus, where the runoff is found to increase in Lena, decrease in Rhine, and Tagus and unclear effects on remaining parts due to the impact of global warming of 1°C, 2°C and 3°C above pre-industrial levels (Gosling et al., 2016).

Liu et al. (2017) have researched the impacts of Climate change in the river basins of China. The results of study in the Yiluo River, northern part of China, demonstrated that the mean annual runoff is likely to decrease by 22% & 21% under 1.5°C & 2°C temperature increment scenarios, respectively, while it is projected to increase by less than 1% & less than 3% under 1.5°C & 2°C scenarios in the Beijing River, southern part of China as compared to the baseline scenario. Similarly, another research in the Upper Yangtze River basin of China was conducted by Chen et al. (2017) and observed a slight increase and decrease in the river's annual discharge under 1.5°C & 2°C scenarios, respectively.

2.2 Studies related to Climate Change & its impact on hydropower in Nepal

Nepal has been experiencing the visible impact of Climate change over the past few decades. It can be observed that the temperature in Nepal is increasing trend. The annual maximum temperature has been increasing at the rate of 0.056 °C/year between 1975 & 2014. Likewise, the minimum temperature increases at the rate of 0.02°C/year, mainly pronounced during monsoon season (Department of Hydrology and Meteorology). It is found to have increasing trend in temperature in the Eastern Koshi river basin & Karnali (Shrestha et al. 2016; Khatiwada et al., 2016).

Similarly, it can be observed that there is variation in the precipitation due to the impact of Climate Change. The rainfalls are observed to have a decreasing trends during pre-monsoon and post-monsoon, while rainfalls are in increasing trends during monsoon in the Gandaki river basin (Panthi et al., 2015). The precipitations in various stations of the Karnali river basin is found to show both increasing and decreasing trends. However, the average precipitation is found to have a decreasing trend in most of the stations (Khatiwada et al., 2016).

The government agency in Nepal has carried out research to assess the patterns of changing Climate in the future periods. It has been projected in the study that average annual precipitation is expected to increase by 8-12% in the long-term and 2-6% in the medium-term period. Likewise, the avg. annual mean temperature is expected to increase by 0.9–1.1℃ in the medium-term and 1.3–1.8℃in the long-term (Ministry of Forests and Environment, 2019).

A study has been carried out in the Marsyandi River, Lamjung district of Nepal, regarding the variation of Climatic parameters -temperature & precipitation and projections in future periods in a different scenario. The investigation has revealed that the temperature is likely to increase by 0.47℃ from maximum temperature & 0.84℃ from minimum temperature, 0.96℃ from maximum temperature & 1.33℃ from minimum temperature & 1.18℃ from maximum temperature and 1.49℃ from minimum by 2030s, 2060s & 2090s respectively and precipitation by 6%, 12% & 17% by 2030s, 2060s & 2090s respectively with respect to the value of temperature and precipitation recorded at Khudi Bazar Station, Lamjung under baseline scenario (Khadka and Pathak, 2016).

It can be observed from the above studies and research that the climatic pattern – temperature and precipitation has been dynamically changing in most parts of Nepal. Since most of the hydropower projects in Nepal are Run-off-River (ROR) types with significant seasonal variations, the hydropower projects in Nepal are susceptible to Climate Change.

A study has carried out in the Gandaki river basin of Nepal and observed that the variations in climatic parameters had impacted the generation of the Trishuli Hydropower Project located in the basin (bajracharya et. al., 2011). Likewise, a study was carried out by Sahukhal & Bajracharya, (2015) at the Kaligandaki gorge HPP, Myagdi district of Nepal to assess the impact on the hydropower plant due to climatic parameter variation. The study showed there is variation in precipitation patterns in the vicinity of project area with no any change in the temperature trend. However, the discharge of the Kaligandaki river is found to have adecreasing trend. The investigation in the Kaligandaki river revealed that there is a decrease in full capacity power generation of the Kaligandaki Gorge Hydropower Project. Similarly, the study in the Kaligandaki river basin area revealed that the hydropower potential in that basin has been influenced by the impact of climate change (Bagale, 2017).

Two unprecedented flood cases have been closely observed and analyzed its impacts for the Super Dordi Hydropower Project Kha under this study. These two flood events were occurred in the Dordi River, Dordi Corridor, Lamjung, Nepal within 3 years – one on July 24, 2019 and another on June 15, 2021. The 1st flood event was flash flood in which maximum flood flow lasted for 2 hours and exceeded the 1000 years of flood level and Maximum flow of 2nd flood event lasted for 7 hours which also exceeded the 1000 years of flood level. These floods had caused the different level of impacts on the several hydropower projects and other infrastructures in the Dordi Corridor including the Super Dordi Hydropower Project Kha. The details case study of these two flood events occurred is summarized as below:

CASE I: FLOOD EVENT OF JUNE 15, 2022 OF SUPER DORDI HPP

Team of Peoples Hydropower Co. Ltd., the developer & Clean Energy Consultant Pvt. Ltd. had visited the project site immediately after the occurrence of flood for collecting the firsthand information and assessed the consequences of the flood to the project.

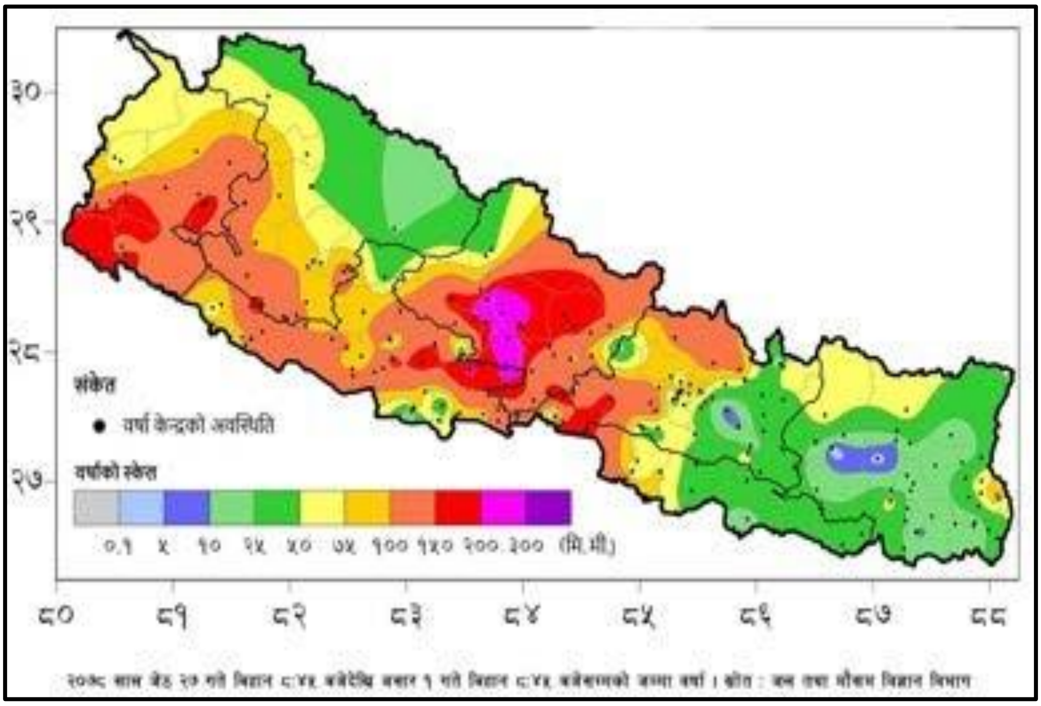


Figure 2-1: Graphical Presentation for the Rainfall across different part of Nepal from June 10 to 15, 2021, Source DHM

A severe flood was encountered by the project on **June 15, 2021.** The following is the summary of the event:

<u>Summary of the event</u>

Flood date : June 15, 2021 - Tuesday

Flood Duration : June 15 – 16,2021, 10 P.M. (NST)

Maximum flow : Lasted for about 7 Hours (3 PM – 10PM)

Flood discharge estimate : Exceeding 1000 yrs. Flood,

Estimated flood of June 15, 2021 : 1,090 m3/sec (>> Shrawan 8, 076 flood)

Estimated 1000 years flood @ Intake: 411m3/ sec

Estimated 1000 years flood @ PH : 496 m3/sec

100 Years Design flood @Intake : 300 m3/sec 100

Years Design flood @ PH : 362 m3/sec

Design discharge : 9.9 m3/sec

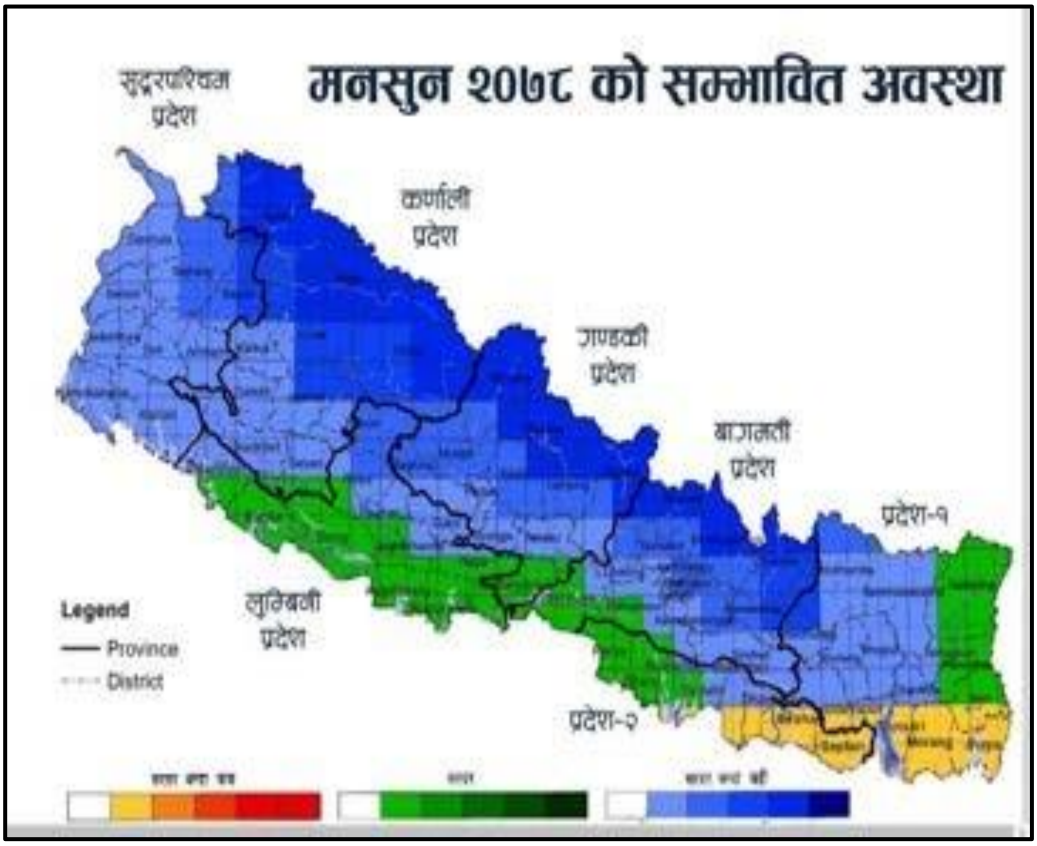


Figure 2-2: Monsoon Prediction – 2078, Province wise, DHM

Impacts Area:

The flood event had generated large volume of losses to project components, which is depicted as hereunder:

Human Casualties

There was no human casualty. Total 15 persons trapped inside the HRT face about 700m inside tunnel face and rescued after 5 Hours (0:00 – 5:00 AM Asar 1, 2078).

Physical Losses to Project Components

- Damage to Dordi and Purmu Headworks,
- Damage of contractor's equipment,
- Damage on desander inlet access road,
- Damage to intake flood wall
- Damage to Intake upstream
- Damage to Diversion Inlet and inside
- Damage to Connecting Tunnel
- Damage to Gravel trap cross regulator
- Damage to Dordi Desander and Purmu Desander

- Damage to Headrace Tunnel access and Headrace Tunnel
- Damage to Purmu Adit
- Powerhoue & Tailrace area
- Damage to Construction power, Transmission Line & NEA interconnection substation at Kirtipur and Kirtipur-Udipur Line
- Damage to Project Acesss Road
- Damage to Hydromechanical Works
- Impact on Project Cost and Time

CASE II: FLASH FLOOD OCCURRED IN SUPER DORDI HPP

Team of Peoples Hydropower Co. Ltd and Clean Energy Consultant P. Ltd. had made an investigation after occurrence of unprecedented flood on July 24, 2019 in Dordi River. It is reported that the flood was flood was triggered by damming of river and sudden breach of the dam considering the sudden and short nature of the flood wave with lots of debris. It is estimated to be exceeding more than 1000 years flood. This had caused different level of impact to many hydropower projects and other infrastructures in the Dordi Corridor including the Super Dordi Hydropower Project Kha.

Flood Event July 24, 2019

A brief information on the Dordi Flood of **July 24, 2019** is as follows:

Flood date	: July 24, 2019
Flood Duration	: 2:30 PM – 4:30 PM (2 Hrs)
Maximum flow	: Lasted for about 30 minutes
Estimated flood of July 24, 2019	: >1200 cumec
Estimated 1000 years flood @ Intake	: 411 cumec
Estimated 1000 years flood @ PH	: 496 cumec
100 Years Design flood @ Intake	: 300 cumec
100 Years Design flood @ PH	: 362 cumec
Design discharge	: 9.9 cumec

Impact Areas:

- Weir site/DS Apron area
- Access to Connecting Tunnel
- Desander basins Flushing Portal

- Gravel Trap
- Access road to Flushing Tunnel including the a part of main access to Headworks area
- Scouring more than 3-6m depth in the headwork area
- Site establishment area/ Portal Facilities/ site offices of Contractor located in
- the headwork area (Diversion inlet, main intake & undersluice, Diversion outlet and Diversion Tunnel)
- Contractor’s equipment was swept away by the flood.
- Powerhouse Area, Tailrace tunnel including portal area;Site establishment area
- Contractor’s portal facilities, equipment: Contractor’s crusher plant.

2.3 Identification of Gaps on past study

Several studies have been conducted by hydropower developers, government authorities and other stakeholders in the Dordi Basin, Lamjung prior to the project development, during the project design period & during construction period which is reflected in the Pre-feasibility Report, Feasibility Report, Due Diligent Report, Detail Project Report and other forms. These studies have incorporated geo-technical analysis, optimum design, financial analysis, economic analysis, sensitivity analysis, sediment analysis, seismic designs and so on. However, the project authorities in the Dordi Corridor hasn’t considered the potential risks related to the Climate Change.

Currently, on the Dordi Corridor locating in the Lamjung district, Nepal, there are several projects that are under construction phases and some are even in the verse of completion, namely - Dordi Khola Hydroelectric Project -27 MW, Dordi-I Hydroelectric Project -10.3 MW, Upper Dordi-A Hydroelectric Project -25 MW & Super Dordi Hydroelectric Project -54MW. Thus, significant amount of electricity cumulatively 116.3 MW, is going to tap into the national electricity grid when all these projects come in operation in full swing. However, there has been no any necessary assessment in the Corridor conducted by hydropower developers, project authorities and other stakeholders to consider the potential risks and impacts related to the climate that can be arisen in the future due to the Climate Change. Thus, it is very important to assess the potential impacts on hydropower due to the variation in the Climatic parameters in the corridor and possibly utilize the results for the hydropower development & operation, climate-related risk analysis and ultimately integrate the results into the national energy planning and implementation.

2.4 Description of Study Area

Super Dordi Hydropower Project HPP-Kha is situated in Lamjung District in the Western Development Region of Nepal. It is a Run-off-River type being developed by Peoples Hydropower Company Ltd. The Geographical coordinate of the project area lies between Longitudes 84o34’15” E and 84o31’00” E, Latitudes 28o18’50” N and 28o16’20” N as shown in Fig. 2-3 & 2-4 (Peoples Hydropower Company Ltd., 2015; 2017)

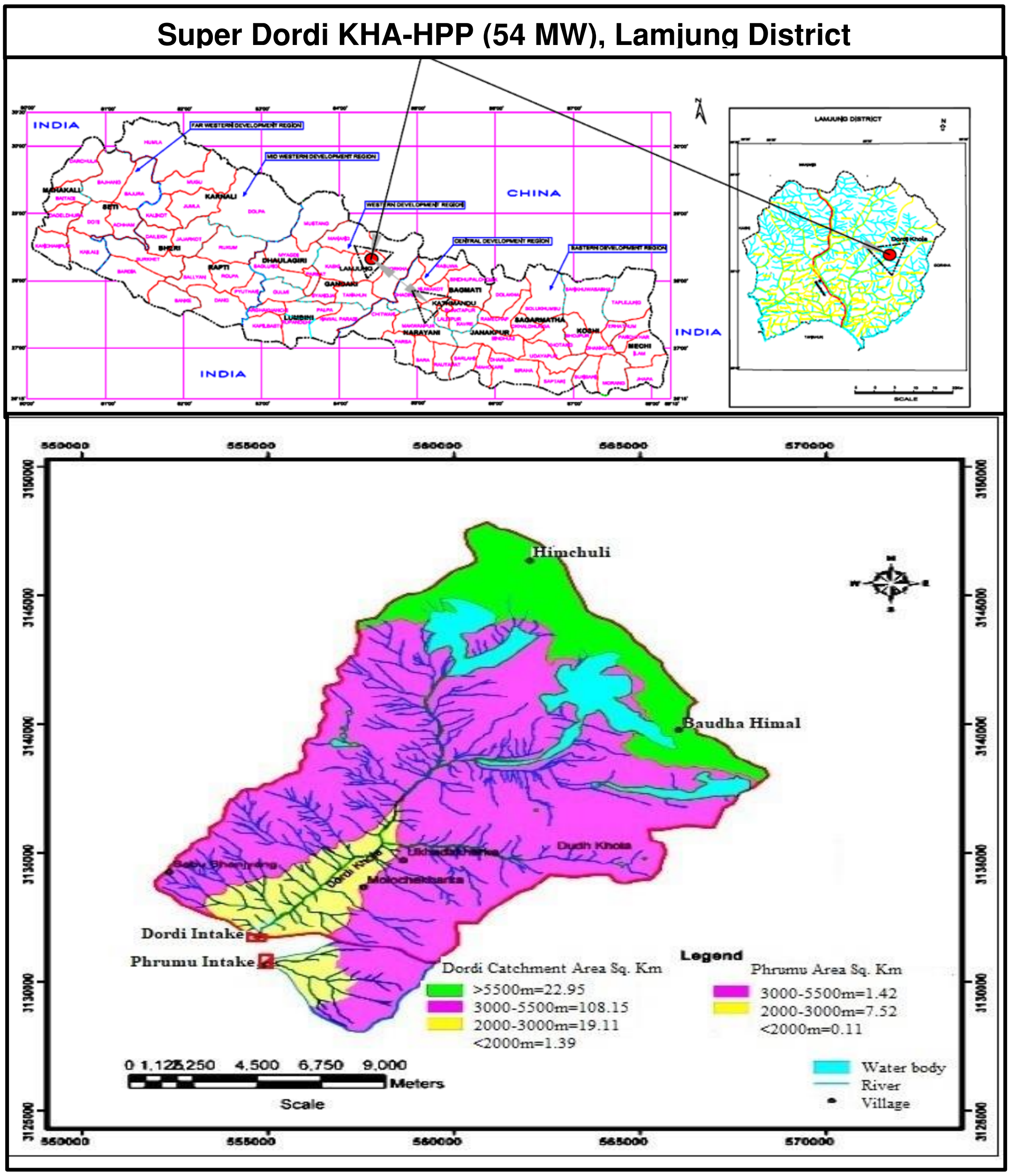


Figure 2-3: Project Location Map & Dordi – Phrumu Intake Catchment(PHCL, 2017)

Dordi River is one of the major tributaries of Marsyandi Khola in Lamjung district of Nepal, flowing from North to South and west direction. The river originates from the southern and eastern slope of Himal Chuli (7893m) and the western slope of Baudha

Himal (6672m). Dordi River meets the Marsyandi Khola in the vicinity of Bhoteodar Lamjung, downstream side of Madya Marsyandi HPP’s headwork, and Marsyandi River meets Trishuli River at Mugling. Dordi River comprises several sub-tributaries like Dudh Khola, Phrumu Khola, etc.

The maximum length of Dordi River up to intake is about 18 km. The width of Dordi River’s catchment above intake varies from 8.3 km-12 km. The total catchment area of the project is 151.6 sq. km of which 22.95 sq. km lies above 5500 masl altitude, 108.15 sq. km lies between 3000-5500 masl, and 19.11 sq. km between 2000-3000 masl & 1.39 sq. km lies below 2000 masl. as shown in Fig 2-3 & 2-4.

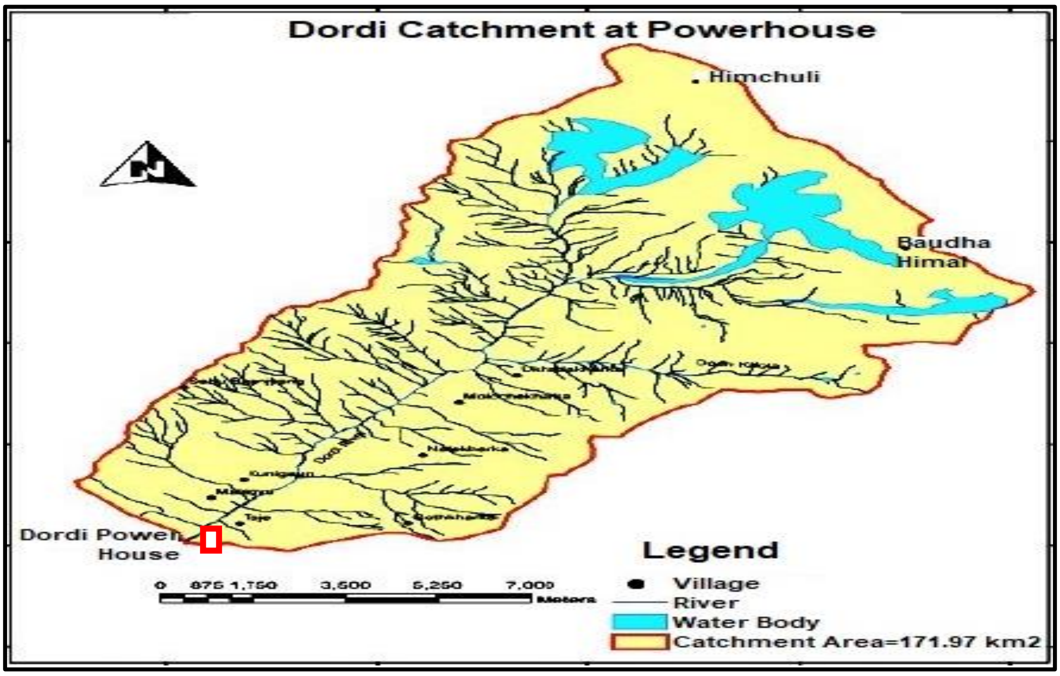


Figure 2-4: Catchment of Super Dordi HPP Kha, Powerhouse Area (PHCL, 2017)

The climate of this region is significantly affected by the region’s topography. The mean annual rainfall in the Dordi Khola basin is estimated to be 2535mm. The monsoon begins in late June and continues until late September, followed by a dry period. The winter begins in November and continues until February. The climate becomes progressively warmer in February/March and is characterized by hot and dry weather followed by a transitional pre-monsoon period with thundershowers and frequently strong winds until the beginning of the monsoon. The mean annual temperature of the Gandaki basin is 15.4 °C which increases from North to South. In the lower part of the project area, the sub-tropical climate can be experienced during the dry and rainy seasons. However, the upper part of the Dordi River is cold. The area’s temperature ranges from 8°C (in January) to 23°C (in July). The most mixed dense forest can be found in the Dordi River banks in the vicinity of intake river banks of Dordi near intake are mostly mixed dense forest. There is no settlement at the upstream side of the Dordi intake. A tributary named Prumu River also consists of a dense mixed forest catchment. In the cultivated basin area, the general type of the agricultural soil is found which varies from sandy loam to loamy sand and soil depth ranges from 0.15m to 1.83m. The riverside valley on the bottom and the plains tend to be more fertile than the soil on the hill slopes. Barley, wheat, maize, millet, etc., are major crops in this area that are suitable for agriculture. The pasture land also can be found in some of the areas inside the catchment.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Approach

This study used the WEAP to model the nexus of water, energy, and climate in the electricity sector of Dordi River.

The WEAP, developed by SEI, is a hydrological model which is widely used to study the hydrological processes and cycle (Rochdande et al., 2012; Leong and Lai, 2017) and assess the impact of climate change (Alemayehu et al., 2010; Rosenzweig et al., 2004; Purkey et al., 2007; Mehta et al., 2013; Santikayasa et al., 2015). The WEAP model includes five methods for modeling the catchment processes – Irrigation Demand Only (Simplified Coefficient Method), Rainfall Runoff (Simplified Coefficient Method), MABIA (FAO 56, dual KC, daily), Rainfall Runoff (Soil Moisture Method) & Plant Growth (daily; CO_2, water and temperature stress effects). The major reason to use this Soil Moisture method among the above other methods is due to the availability of the relevant data for the modeling of Dordi River via this method and assess its hydrological response to the changing climatic parameters and it also fits with purpose of the present study. Furthermore, this method accounts the impact of land use and soil types on these process.

3.1.1 Soil Moisture Method

In this method, the catchment is partitioned into layers of soil – the upper soil layer called shallow water capacity & low soil layer called deep-water capacity. This method implements empirical functions that divide the water system into ET, surface runoff, sub-surface runoff (i.e., interflow), and deep percolation as shown in Figure 3-1 (SEI, 2021). It permits for the characterization the impact of land use land type on these processes. The Dordi catchment will be sub-divided into several sub-catchments representing different land use land type aggregating the catchment area to 100% in order to observe the effect of hydrologic response in the catchment, the values of land use land cover from the individual fractional area with the catchment are summed. The surface runoff, sub-surface runoff, and base-flow are connected to the river feature, and Evapotranspiration will be lost from the system in this process.

A water balance is calculated for each fractional area, j of N, assuming there will be similar climate over each sub-catchment. When the appropriate link is made between the catchment unit node and a groundwater node, the deep percolation within the catchment unit can be transmitted to a surface water body as base flow or directly to groundwater storage. The expression of the water balance is presented as (SEI, 2021):

$$Rd_j \frac{dZ_{1,j}}{dt} = P_e(t) - ET_0(t)K_{c,j}(t)\left(\frac{5Z_{1,j} - 2Z^2{}_{1,j}}{3}\right) - P_e(t)Z^{RRF}{}_{1,j} - f_j k_{s,j} Z^2{}_{1,j} - \left(1 - f_j\right)k_{s,j}Z^2{}_{1,j} \quad \text{Equation 3.1}$$

where $Z_{1,j}$ = [1,0] is the relative storage given as a fraction of the total effective storage of the root zone, Rd_j (mm) for land cover fraction, j; P_e(mm) is effective precipitation, $ET_0(t)$ is reference evapotranspiration in mm/day, $K_{c,j}$ is the crop coeff. for each fractional land cover, RRFj is the Runoff Resistance Factor of the land cover, $P_e(t)Z^{RRF}{}_{1,j}$ is the surface runoff, $f_j k_{s,j} Z^2{}_{1,j}$ represents interflow from the upper layer of land use, f_j is partitioning coeff. relating to the land cover type, soil, and topography for the area which partitions flow into horizontal f_j and vertical $\left(1 - f_j\right)$ & $k_{s,j}$is the estimate value of the root zone saturated conductivity in mm/time. Thus, total surface and interflow runoff, RT, from each sub-catchment at time t is given as,

$$RT(t) = \sum_{j=0}^{N} A_j \left(P_e(t)Z^{RRF}{}_{1,j} - f_j k_{s,j} Z^2{}_{1,j}\right) \quad \text{Equation 3.2}$$

The base flow emanating from the second bucket where no return flow link is created from a catchment to a groundwater node. It will be calculated as below:

$$S_{max}\frac{dz_2}{dt} = \left(\sum_{j=1}^{N}\left(1 - f_j\right)k_{s,j}Z^2{}_{1,j}\right) - k_{s2}Z^2{}_2 \quad \text{Equation 3.3}$$

Where S_{max} represents the deep percolation from the upper storage, and k_{s2} is the saturated conductivity of the lower storage in mm/time.

Actual evapotranspiration (ET) is also estimated using reference ET, crop coefficient (K_c), and soil water level in the modeling unit root zone given by

$$ET = ET_0 * K_c \frac{(5Z_1 - 2Z_{12})}{3} \quad \text{Equation 3.4}$$

ET_0 is the water from the surface of land which would be lost to the atmosphere when water is adequate to meet the demand for the atmospheric evaporation from the reference surface. ET_0 estimation implements the standard climatological records of humidity, sunshine, air temperature, and wind speed. The Penman-Monteith method to compute $ET_0$is presented as below:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \text{Equation 3.5}$$

Where, ET_0 represents the reference evapotranspiration in mm/day, R_n represents net radiation at the crop surface in MJ/m^{2}day, G indicates soil heat flux density in MJ/m^{2}day, T is mean daily air temperature at 2 m height in °C, u_2 represent the wind speed at 2 m height (m/s), e_s is the actual vapor pressure (kPa), $e_s - e_a$ is saturation vapor pressure deficit (kPa), Δ is slope vapor pressure curve (kPa/°C), and γ is the psychrometric constant (kPa/°C).

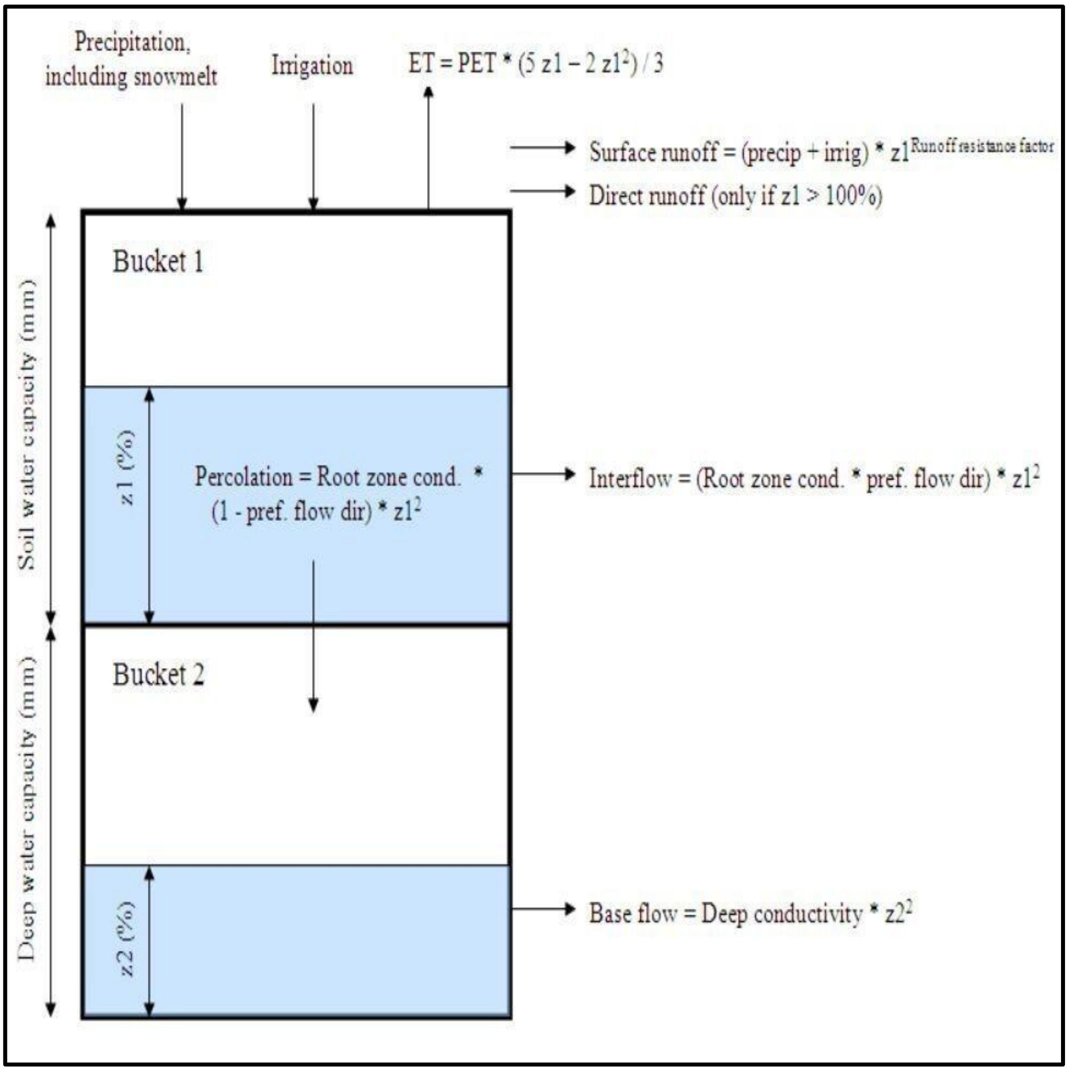


Figure 3-1: Conceptual diagram in Soil Moisture model (Sieber and Purkey, 2015)

3.1.2 WEAP River Nodes (SEI, 2021)

In WEAP, the rivers and diversions are composed from river nodes which are linked by river reaches. Other rivers may flow in from tributaries or flow out of river (diversions). In WEAP, river nodes are categorized as follow:

- **Reservoir** nodes: On a river, they represent reservoir sites. Water can be directly released to demand sites or for use downstream via river reservoir node. For the simulation of hydropower production, river nodes can be also used.

- **Run-of-river** hydropower nodes: In the WEAP model they indicate points on which ROR type hydropower stations are located. These hydropower stations produce power based on changing streamflows but a fixed water head.

- **Flow requirement** nodes: They maintain the minimum incoming stream flow that are required at a point on a river or diversion to meet requirement of water quality, Aquatic & wildlife, navigation, recreation, downstream or other any requirements.

- **Withdrawal** nodes: They indicate points where any number of demand sites receive water directly from a river.

- **Diversion** nodes: The function of these nodes in WEAP is to divert water from a river or other diversion into a canal or pipeline called a diversion.

3.1.3 WEAP Algorithms for Hydropower Generation (SEI, 2021)

Run-of-River Hydropower Flows

The flow releasing is the sum of the flow in from upstream, demand site (*DS*) and treatment plant (*TP*) return flows that come in at that point.

$$DownstreamOutflow_{ROR} = UpstreamInflow_{ROR} + DSReturnFlow_{DS,ROR} + TPReturnFlow_{TP,ROR} \quad \text{Equation 3.6}$$

Hydropower generation is calculated from the amount of water flows through the turbine, based on the reservoir release or run-of-river streamflow, which is constrained by the maximum flow capacity of turbine.

In case of river reservoirs, all water towards downstream is flow through the turbines,

$Release_H = DownstreamOutflow_H$ Equation 3.7

In case of local reservoirs,

$Release_H = TransLinkInflow_{H,DS} + ExtraOutflowForHydropowerRequirement$

Equation 3.8

In case of ROR hydropower nodes, the "release" is equal to the downstream outflow from the node.

$Release_H = DownstreamOutflow_H$ Equation 3.9

The water volume flowing through the turbines is limited by the maximum flow of turbine. Even if there is excess of water, then it is assumed to be released through spillways which don’t contribute to produce electricity.

$VolumeThroughTurbine_H = Min(Release_H , MaxTurbineFlow_H)$ Equation 3.10

The Energy production in a month,gigajoules (GJ),

$EnergyFullMonthGJ_H = VolumeThroughTurbine_H \; x \; HydroGenerationFactor_H$

Equation 3.11

$HydroGenerationFactor_H = 1000 \; (kg / m^3) * DropElevation_H \; x \; PlantFactor_H \; x \; PlantEfficiency_H * 9.806 / (1{,}000{,}000{,}000 \; J / GJ)$ Equation 3.12

In case of reservoirs, Drop in elevation is calculated from the difference in the elevation attained at the starting of the month and the tailwater’s elevation

$DropElevation_H = BeginMonthElevation_H - TailwaterElevation_H$ Equation 3.13

In case of ROR hydropower nodes, the drop in elevation is

$DropElevation_H = FixedHead_H$ Equation 3.14

$SupplyRequirement_H = EnergyDemandFullMonthGJ_H / HydroGenerationFactor_H$

Equation 3.15

3.2 Data Collection and WEAP Model Input

The meteorological, hydrological, land use land cover, soil & geographic latitude data are required to model the Dordi River. Twenty-Nine years (1976 – 2004) of monthly temperature, precipitation, and relative humidity data are obtained from the DHM, Government of Nepal, for the Khudi Bazar Station (Station ID 802) located at Lamjung District of Nepal.

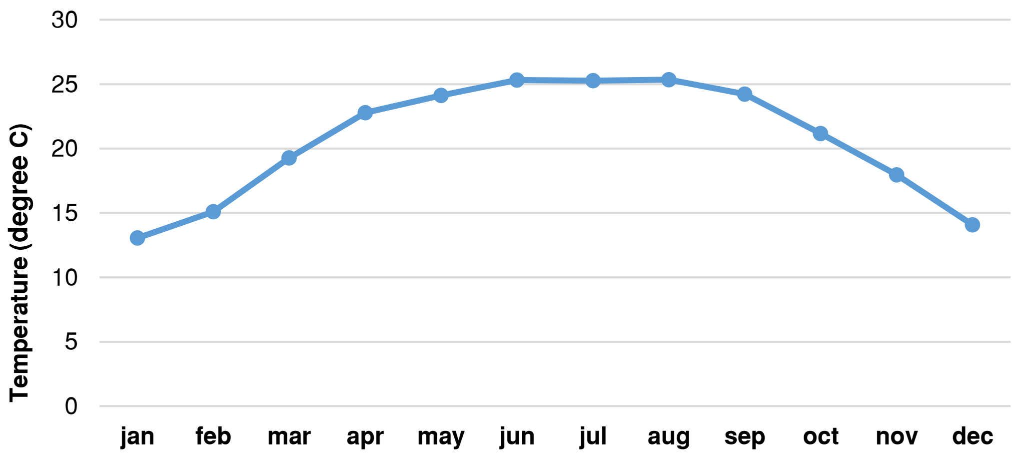


Figure 3-2: Mean Monthly Temperature Pattern

The monthly discharge of Dordi River from 1976 – 2004 is obtained from Detail Project Report, DPR, 2015, which was recorded by the Peoples Hydropower Co. Ltd & Clean Energy Consultant P. Ltd (developer & design consultant of the Super Dordi Hydropower Project Kha) during the time of project development. And all the missing data are filled by the of linear interpolation technique. The temperature, discharge, relative humidity & precipitation pattern from the years 1976 to 2004 is present in Figure: 3-2, 3-3, 3-4 & 3-5 respectively.

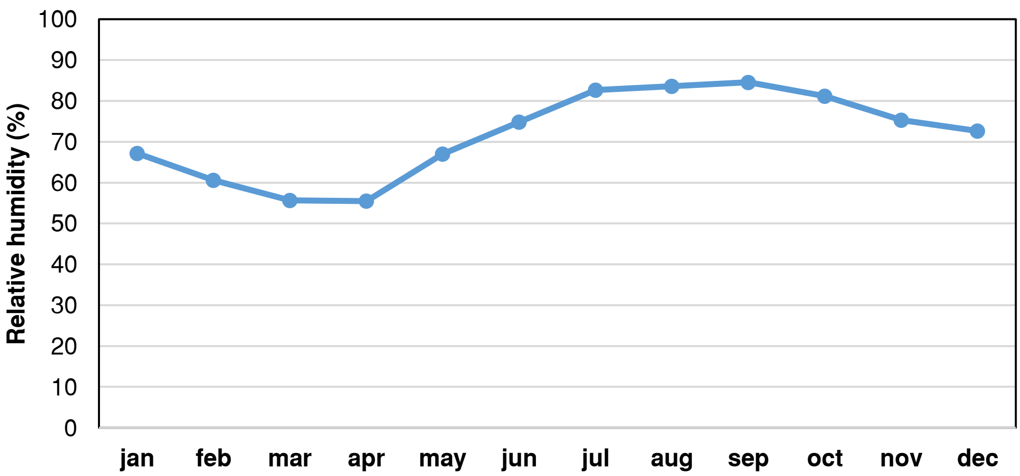


Figure 3-3: Mean Monthly Relative Humidit

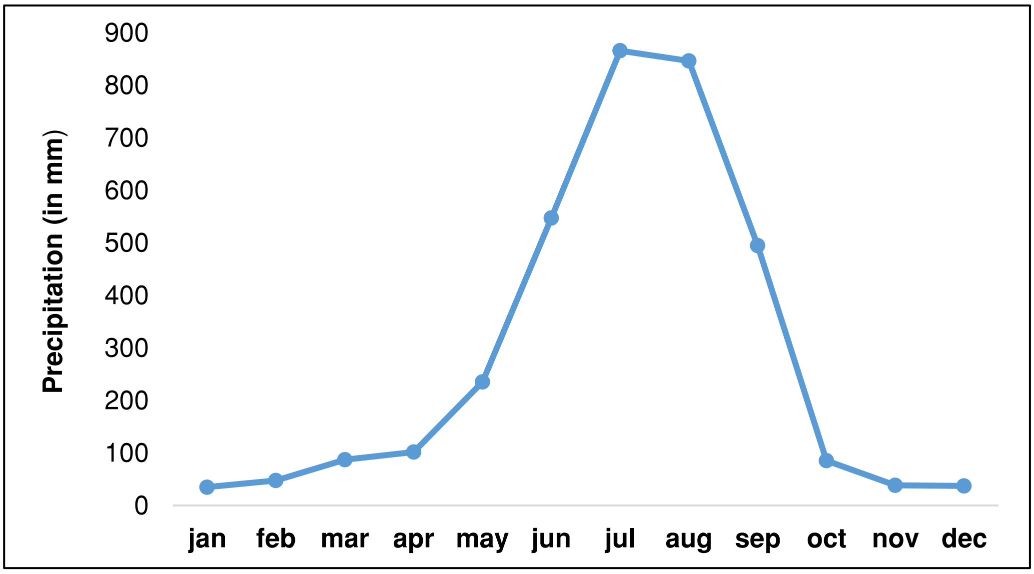


Figure 3-4: Monthly Average Precipitation pattern

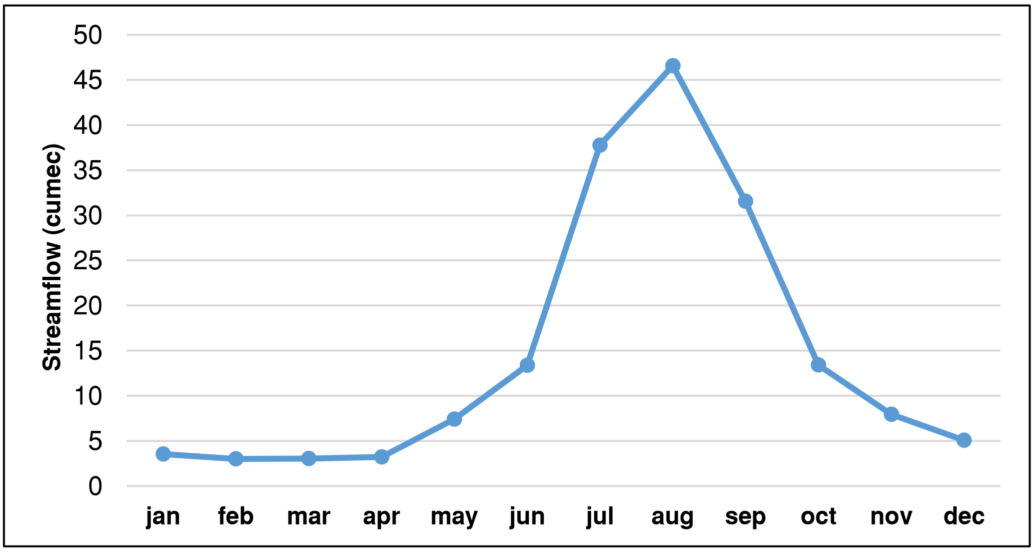


Figure 3-5: Mean Monthly Observed Streamflow pattern of Dordi River

In addition to the Climatic data parameters, the land use and land cover (LULC) are required for the modeling of the Dordi River. The data of the project catchment area: 151.6 Sq. km is fetched from the report produced by Project developer. Further, the LULC map are developed by the tool facilitated by the ICIMOD – land type and their coverage are presented in Figure 3-6. The Land use pattern of Lamjung District is presented in Table 3-1.

A similar study has carried out by Khadka and Pathak, (2016) in the Marsyandi river basin located in Lamjung district of Nepal, located between 27°50'42" N to 28°54'11" N Latitudes and 83°47'24" E to 84°48'04" E Longitudes. It implemented the Second Generation Canadian Earth System (CanESM2) for the Climate Change projection for

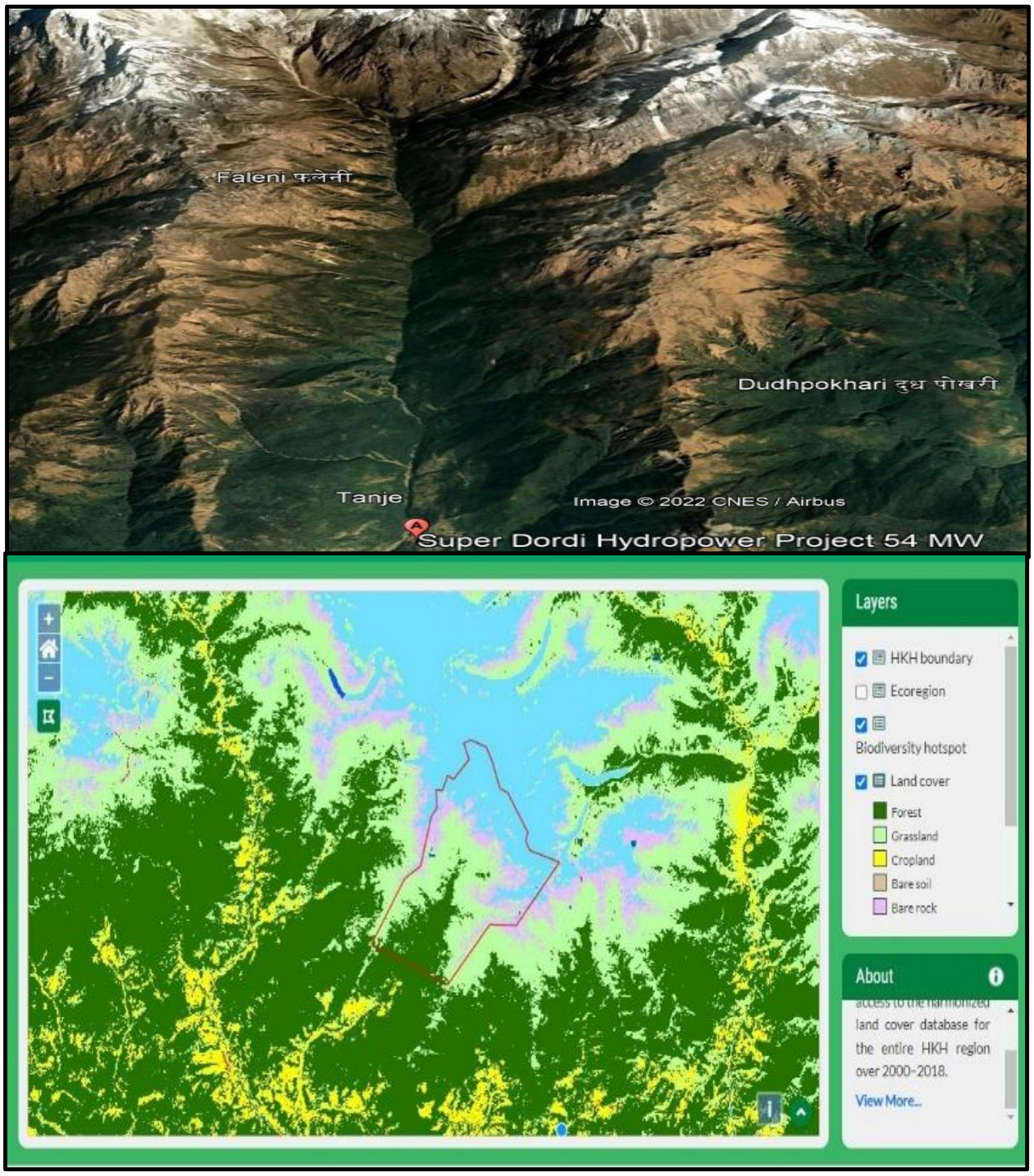


Figure 3-6: LULC map of Dordi basin (demarcated by red color polyline)

Table 3-1: Land Use Pattern of Lamjung District (IEE Report, 2018)

S.N	Type of Land Use	Lamjung Land Use
1	Agricultural Land	26.45%
2	Forest Land	47.37%
3	Grazing/Pasture Land	13.77%
4	Snow Covered Aarea	2.64%
5	Barren land	6.41%
6	Water covered area	3.30%
7	Other	0.06%

the future, performed within framework of CMIP5 which contributes to 5th assessment report of IPCC. The Projection for the temperature and precipitation in the future under RCP 4.5 is summarized and presented in the table 3-2.

Table 3-2: Projected Change in Temperature & Precipitation compared to Baselin

Station		Baseline		RCP4.5			Reference
				2030s	2060s	2090s	
Khudi Bazar	**Temperature**						*Khadka and Pathak, 2019*
	Maximum	26.64 °C	Projected Change, °C	0.47 °C	0.96 °C	1.18 °C	
	Minimum	14.68 °C		0.84 °C	1.33 °C	1.49 °C	
	Annual Precipitation in Baseline period, mm	3362mm	% change in Precipitation compared to the Baseline	6%	12%	17%	

Therefore, the present study takes the basis of above climatic results drawn from khudi Bazar Station, Lamjung, Nepal investigated by the khadka and Pathak, implementing CanESM2 dataset with CMIP5 model under RCP 4.5 for the projection of Climatic Parameters (Temperature & Precipitation) for the future periods.

It can be observed from the table 1 that under the RCP 4.5, the temperature is likely to increase by 0.47°C from maximum temperature and 0.84°C from minimum temperature (with an average of 0.655°C), 0.96°C from maximum temperature & 1.33°C from maximum temperature (with an average of 1.145°C) & 1.18°C from maximum temperature & 1.49°C from maximum temperature (with an average of 1.335°C) by 2030s, 2060s & 2090s respectively and precipitation by 6%, 12% & 17% by 2030s, 2060s & 2090s respectively with respect to the value of temperature and precipitation recorded at Khudi Bazar Station, Lamjung under baseline scenario.

Therefore, for projecting the climatic parameters (temperature & precipitation) for future and inputting these projected temperature and precipitation in WEAP model, three **Climatic Scenarios**: **Climatic Scenario-1, 2 & 3** are developed for this study on the basis of above study, which is presented in the table 2. In the **Climatic Scenario-1,** temperature & precipitation is **increased by 0.5°C & 5 %** respectively, by **1°C & 10 %** in **Climatic Scenario -2** & **1.5°C & 15%** in **Climatic Scenario -3** with respect to the value of mean temperature and precipitation at Reference Scenario.

Furthermore, in order to assess the uncertainties in the Climatic Scenarios, the Scenario analysis have performed for this study using Monte Carlo Simulation – Probabilistic Approach which is presented in the Table 3-3 & **APPENDIX-F**.

Table 3-3: Calculation for 95% Confidence Interval

For Climatic Scenario-1

S.N	**Temperature in °C (x)**		**S.N**	**Precipitation Change wrt baseline in % (x)**
1	0.47		1	1
2	0.5		2	2
3	0.6		3	3
4	0.7		4	4
5	0.84		5	5
			6	6
n	5		n	6
Mean, $\bar{x}$	0.622		Mean, $\bar{x}$	3.5
Standard Deviation, σ	0.136		Standard Deviation, σ	1.708

Calculation for 95% Confidence Interval, Temperature			**Calculation for 95% Confidence Interval, Precipitation**		
If n<30	Confidence Interval, $CI = \bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks	If n<30	Confidence Interval, $CI = \bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks
dF = n-1	4	(t value for 95% CI from t-table)	dF = n-1	5	(t value for 95% CI from t-table)
$t_{\alpha/2}$	2.78		$t_{\alpha/2}$	2.57	
$\sigma/\sqrt{n}$	0.06		$\sigma/\sqrt{n}$	0.70	
95% CI			**95% CI**		
Upper Value	**0.79**	°C	**Upper Value**	**5.29**	%
Lower Value	**0.45**	°C	**Lower Value**	**1.71**	%

For Climatic Scenario-2

S.N	**Temperature in °C (x)**		**S.N**	**Precipitation Change wrt baseline in % (x)**
1	0.96		1	7
2	1		2	8
3	1.03		3	9
4	1.13		4	10

5	1.23		5	11
6	1.33		6	12
n	6		n	6
Mean, $\bar{x}$	1.113		Mean, $\bar{x}$	9.5
Standard Deviation,	σ 0.132		Standard Deviation	1.707

Calculation for 95% Confidence Interval, Temperature			**Calculation for 95% Confidence Interval, Precipitation**		
If n<30	Confidence Interval, CI = $\bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks	If n<30	Confidence Interval, CI = $\bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks
dF = n-1	5	(t value for 95% CI from t-table)	dF = n-1	5	(t value for 95% CI from t-table)
$t_{\alpha/2}$	2.57		$t_{\alpha/2}$	2.57	
$\sigma/\sqrt{n}$	0.05		$\sigma/\sqrt{n}$	0.70	
95% CI			**95% CI**		
Upper Value	**1.25**	℃	**Upper Value**	**11.29**	%
Lower Value	**0.98**	℃	**Lower Value**	**7.71**	%

For Climatic Scenario-3

S.N	**Temperature in ℃ (x)**		**S.N**	**Precipitation Change wrt baseline in % (x)**
1	1.18		1	13
2	1.29		2	14
3	1.39		3	15
4	1.49		4	16
5	1.5		5	17
n	5		n	5
Mean, $\bar{x}$	1.37		Mean, $\bar{x}$	15
Standard Deviation, σ	0.122		Standard Deviation σ	1.414

Calculation for 95% Confidence Interval, Temperature			**Calculation for 95% Confidence Interval, Precipitation**		
If n<30	Confidence Interval, CI = $\bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks	If n<30	Confidence Interval, CI = $\bar{x} \pm t_{\alpha/2}(\sigma/\sqrt{n})$	Remarks
dF = n-1	4	(t value for 95% CI from t-table)	dF = n-1	4	(t value for 95% CI from t-table)
$t_{\alpha/2}$	2.78		$t_{\alpha/2}$	2.78	
$\sigma/\sqrt{n}$	0.05		$\sigma/\sqrt{n}$	0.63	
95% CI			**95% CI**		
Upper Value	**1.52**	℃	**Upper Value**	**16.76**	%
Lower Value	**1.22**	℃	**Lower Value**	**13.24**	%

From the Calculation of 95% Confidence Interval in the normal distribution presented in the Table 3-3 & **APPENDIX-F** for different Scenarios, it has been observed following results under Climatic Scenarios.

1. Under Climatic Scenario-1, the 95% Confidence Interval for temperature is 0.45℃ to 0.79℃ and that for change in precipitation is 1.71% to 5.29%. Therefore, we are well known from this fact that this 95% confidence Interval contains 0.5℃ temperature and 5% change in Precipitation for Climatic Scenario-1.
2. Under Climatic Scenario-2, the 95% Confidence Interval for temperature is 0.98℃ to 1.25℃ and that for change in precipitation is 7.71% to 11.29%. Therefore, we are well known from this fact that this 95% confidence Interval contains 1℃ temperature and 10% change in Precipitation for Climatic Scenario-2.
3. Under Climatic Scenario-3, the 95% Confidence Interval for temperature is 1.22℃ to 1.52℃ and that for change in precipitation is 13.24% to 16.76%. Therefore, we are well known from this fact that this 95% confidence Interval contains 1.5℃ temperature and 15% change in Precipitation for Climatic Scenario-3.

Table 3-4: Summary-Scenario Analysis Result

Scenarios	**95% Confidence Interval**			
	Temperature(in ℃)		**Change in Precipitation (in %)**	
	Upper Limit	**Lower Limit**	**Upper Limit**	**Lower Limit**
Climatic Scenario-1	0.79	0.45	5.29	1.71
Climatic Scenario-2	1.25	0.98	11.29	7.71
Climatic Scenario-3	1.52	1.22	16.76	13.24

Table 3-5: Projected change in temperature and precipitation for present study

Station	Climatic Parameters	Baseline	Projected Change	RCP4.5			Remarks
				2030s	2060s	2090s	
				Climatic Scenario-1	Climatic Scenario-2	Climatic Scenario-3	
Khudi Bazar	**Temperature**	Reference Scenario	Projected Change, °C	0.5 °C	1°C	1.5 °C	Climatic Scenarios for Present Study
	Precipitation	Reference Scenario	% change in Precipitation compared to the Baseline	5%	10%	15%	

3.3 Model Setup

This study focuses on the development of a hydrological model of the Dordi River via WEAP to assess the hydrological behavior at the Dordi River. The study involves the simulation of the Dordi river through WEAP, the setup of which is shown in Figure 3-8, and evaluate the impact on the generation of the hydro plant due to the variation in the Climatic parameters under different scenarios – Reference scenario & Climatic Scenario-1, 2 &3 as mentioned above. Figure 3-7 represents the flow chart for the input, output, and modeling process of the WEAP hydrological model.

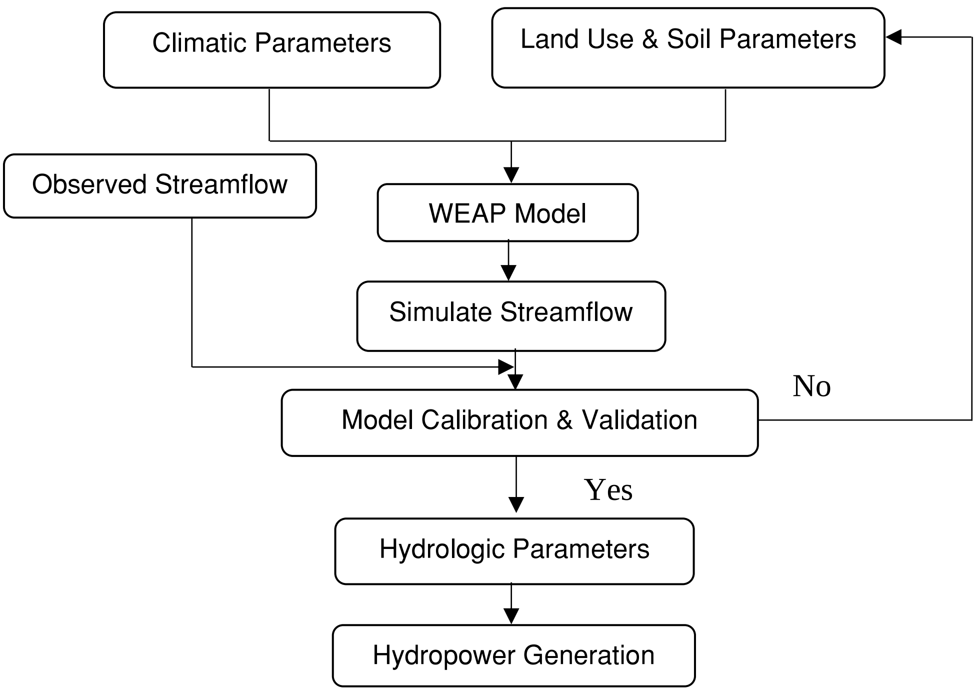


Figure 3-7: Flow Chart for WEAP Hydrologic model

The River model is created in the Schematic View of WEAP for the Super Dordi Hydropower Project Kha. The Major Components used in the Schematic River models are: River, Catchment, Transmission Link, Run of River Hydro, and Streamflow Gauge which is represented in the Figure 3-8.

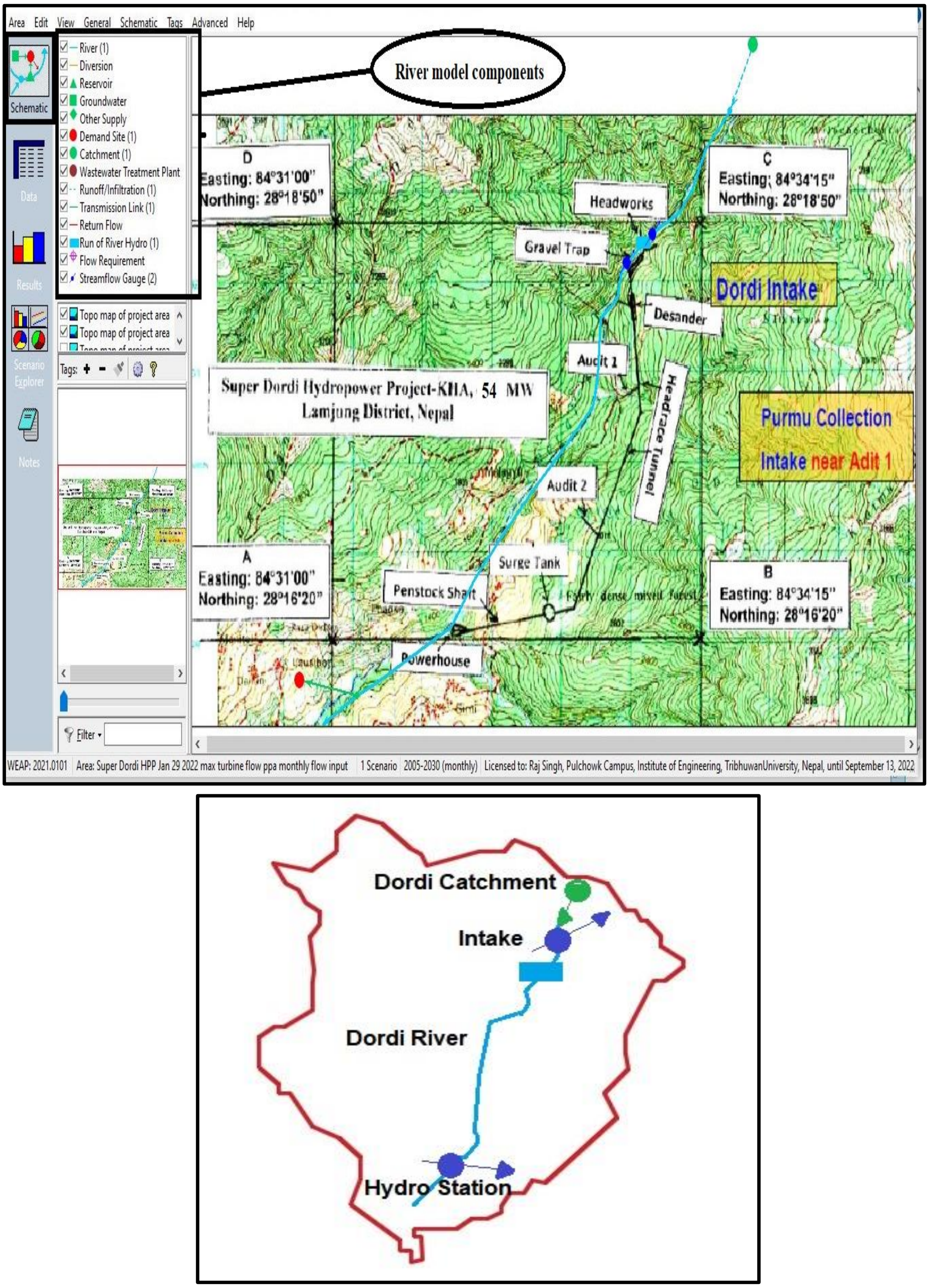


Figure 3-8: WEAP River model of Super Dordi HPP Kha

3.4 Calibration & Validation of Dordi River WEAP Model

The Climatic data that includes precipitation, avg. temperature, relative humidity, wind speed; land use, and soil parameters, are used for simulation of streamflow outputs. The simulated and observed streamflow outputs of the Dordi River from 1976 to 2004 are presented in Figure 3-9.

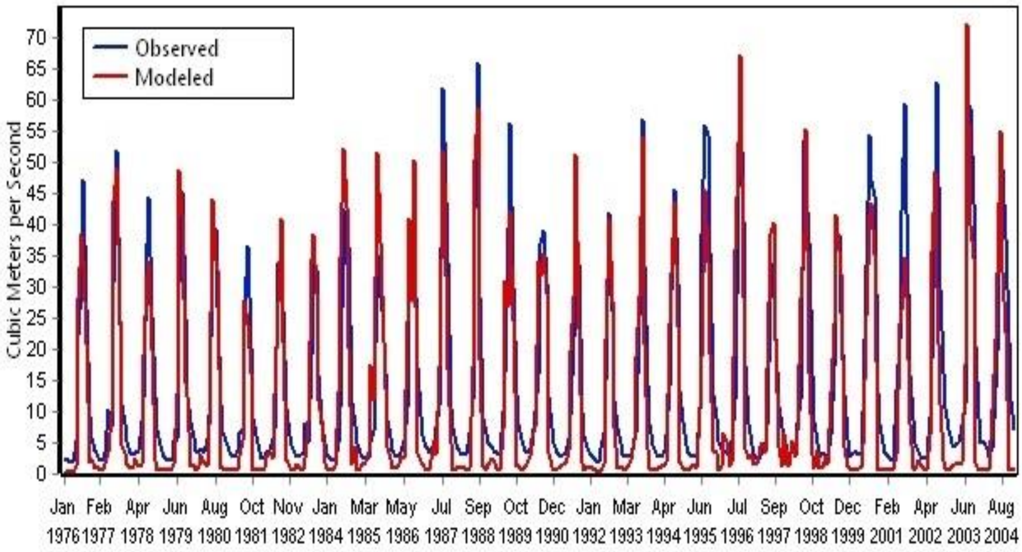


Figure 3-9: Simulated and Observed Streamflow WEAP results of Dordi River from 1976 to 2004

The model was calibrated to estimate the LULC parameter using the manual method. The values of land and soil parameters are selected in such a way it will give a good agreement between the observed and model streamflow & best performance statistics results for the WEAP model (Abdi and Ayenew, 2021).

3.5 WEAP model performance evaluation measures

The efficiency of WEAP model performance was assessed by comparing the observed streamflow versus the simulated streamflow using performance evaluation statistics – Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE) & Root Mean Square Error – observations Standard deviation Ratio (RSR).

Coefficient of Determination (R^2) measures the degree of collinearity between observed and simulated values. The Value of R^2 ranges from 0 to 1. The formula for determining the value of R^2 is given below:

$$R^2 = \frac{\sum_{i=1}^{n}(Y_i^{sim} - X^{sim})\ ((Y_i^{obs} - X^{obs})}{\sqrt{\sum_{i=1}^{n}(Y_i^{sim} - X^{sim})^2\ \sum_{i=1}^{n}(Y_i^{obs} - X^{obs})^2}} \qquad \text{Equation 3.16}$$

Where, Y_i^{sim} is the simulated streamflow, Y_i^{obs} is the observed streamflow, X^{sim} is the mean of simulated streamflow, and X^{obs} is the mean of observed streamflow.

The values of R^2 that are higher than 0.5 are acceptable (Santhi et al., 2001; Van et al., 2007). The higher values, the lesser the error variance.

The Nash-Sutcliffe Efficiency (NSE) evaluates the hydrological model's predictive capability. The Value of NSE ranges between - ∞ and 1, where NSE=1 shows the perfect fitness between the simulated and observed streamflow, NSE=0 shows that the model predictions are as accurate as the mean of the observed data & NSE<0 shows that the observed mean is a better predictor than model (Van et al., 2007). The formula for determining the value is presented below:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\ (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}\ (Y_i^{obs} - X^{obs})^2} \qquad \text{Equation 3.17}$$

Where, Y_i^{sim} is the simulated streamflow, Y_i^{obs} is the observed streamflow & X^{obs} is the mean of observed streamflow.

RSR is the ratio of Root Mean Square Error to Standard deviation. The formula for determining the RSR is given below:

$$RSR = \frac{\sum_{i=1}^{n}\ (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}\ (Y_i^{obs} - X^{sim})^2} \qquad \text{Equation 3.18}$$

Where, Y_i^{sim} is the simulated streamflow, Y_i^{obs} is the observed streamflow & X^{sim} is the mean of simulated streamflow.

CHAPTER FOUR: RESULT & DISCUSSION

4.1 Result and discussion

This section assesses 1) model performance of Dordi river using performance evaluation measures - R^2, NSE & RSR 2) the impacts on streamflow and hydropower generation due to the variation in the climatic parameters. The model performance of Dordi River has shown Goodness of fit measure as **Good** and **Very Good.** Similarly, after performing the WEAP modeling of the Dordi River, it has been observed that there will be an overall increment in the streamflow of the Dordi river and hydropower generation of Super Dordi HPP under Climatic Scenario -1, 2 & 3.

4.1.1 WEAP model performance evaluation

In this study, the monthly observed streamflow data of the Dordi River from 1989 to 1999 was used to calibrate the WEAP model, and the observed streamflow data from 2000 to 2004 was used to validate the model. Such calibrated and validated WEAP results are shown in Fig. 4-1 a), b), c) & d)

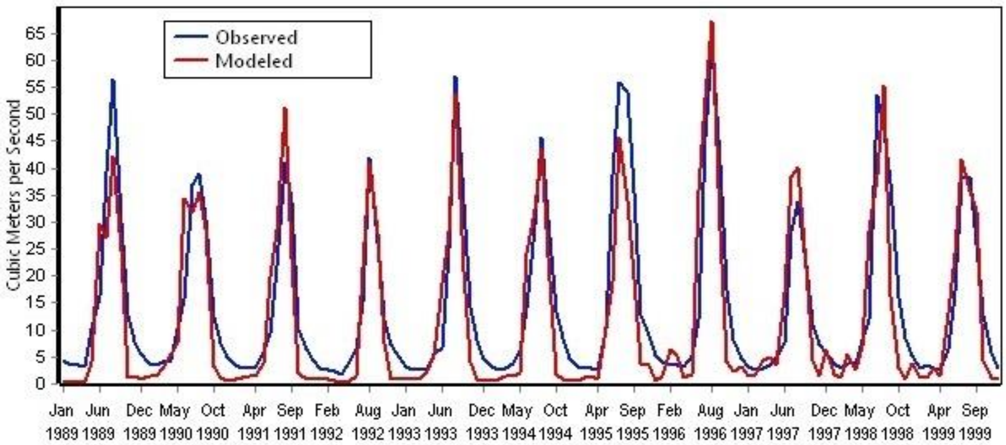


Figure 4-1 a): Observed & Simulated Monthly Streamflow for Calibration Period

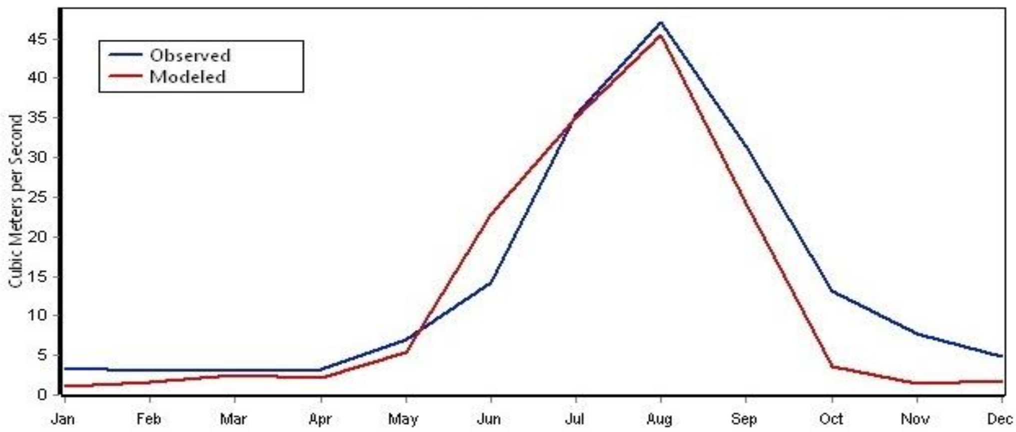


Figure 4-1 b): Observed & Simulated Mean Monthly Streamflow for Calibration Period

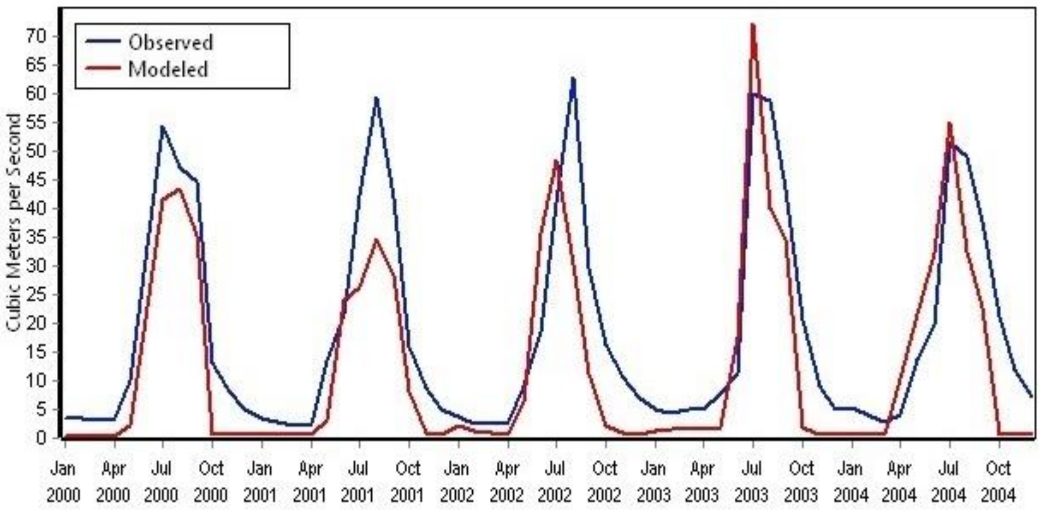


Figure 4-1 c): Observed & Simulated Monthly Streamflow for Validation Period

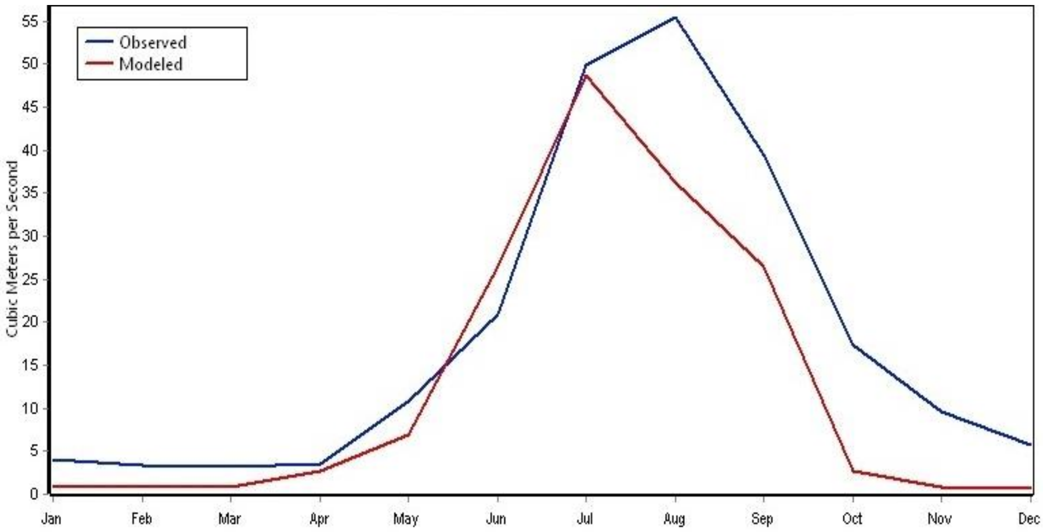


Figure 4-1 d): Observed & Simulated Mean Monthly Streamflow for validation period

For the monthly data, the values between

0.75 < NSE ≤ 1 and 0 ≤ RSR ≤ 0.5, is rated as **very good**

0.65 < NSE ≤ 0.75 and 0.5 ≤ RSR ≤ 0.6, is rated as **good**

0.5 < NSE ≤ 0.65 and 0.6 ≤ RSR ≤ 0.7, is rated as **satisfactory**

NSE ≤ 0.5 and RSR > 0.7, is rated **unsatisfactory** (Moriasi et al., 2007)

The model performance of Dordi River was performed to simulate the mean monthly streamflow with R^2, NSE & RSR values of 0.91, 0.87 & 0.34 respectively for the calibration period of 1989 to 1999. Similarly, monthly streamflow with R^2, NSE & RSR values of 0.81, 0.75 & 0.5 respectively for the same calibration period. Thus, by the above expression, this result has indicated a very good agreement between the mean monthly observed and simulated streamflow in the Dordi River. Likewise, the result has indicated a good agreement between monthly observed and simulated streamflow. For the validation period from 2000 to 2004, the model performance of the Dordi River was conducted to simulate the mean monthly streamflow with R^2, NSE & RSR values of 0.9, 0.82 & 0.4, respectively. Similarly, the model performance was conducted to simulate the monthly streamflow R^2, NSE & RSR values of 0.78, 0.7 & 0.54, respectively, for the same validation period. Thus, the result has shown a very good and good agreement. The Performance Statistics of the Dordi river model for measured and simulated monthly and mean monthly streamflow are summarized and presented in Table 4-1.

Similar studies have been conducted across different river basins of the world. The study in the Central Rift Valley basin of Ethiopia revealed the WEAP hydrological model to achieve the R^2 & NSE 0.82, 0.8; 0.91 & 0.91 for the monthly calibration and validation periods between observed and simulated streamflow, respectively (Abdi and Ayenew, 2021) . Another study in the USA had developed the WEAP hydrological model to achieve the R^2 & NSE 0.92, 0.91; 0.83 & 0.78 for the monthly calibration and validation periods between observed and simulated streamflow respectively (Mehta et al., 2013). The R^2 & NSE 0.85, 0.86; 0.89 & 0.87 were attained between observed and simulated streamflow in the Central Indus basin (Asghar et al., 2019).

Table 4-1: Model Performance Statistics Summary for measured and modeled Dordi River – Monthly and Mean Monthly Streamflow

Statistics	Monthly	Mean Monthly
Calibration Period	**1989-1999**	
Coefficient of Determination (R^2)	0.81	0.91
Nash-Sutchliffe Coefficient (NSE)	0.75	0.87
RMSE-observations Standard Deviation Ratio (RSR)	0.5	0.34
Validation Period	**2000-2004**	
Coefficient of Determination (R^2)	0.78	0.9
Nash-Sutchliffe Coefficient (NSE)	0.7	0.82
RMSE-observations Standard Deviation Ratio (RSR)	0.54	0.4

4.1.2 Streamflow

The streamflow of the Dordi river is observed to increase from 0.35% to 15.16%, 0.66% to 31.99% & 0.92 to 50.51% over the modeling period under i) Climatic Scenario -1: when the temperature & precipitation is increased by 0.5°C & 5 %, ii) Climatic Scenario -2: when the temperature & precipitation is increased by 1°C & 10 % & iii) Climatic Scenario -3: when the temperature & precipitation is increased by 1.5°C & 15 %, respectively, as compared to the simulated values of streamflow under Reference Scenario which is represented by Figure 4-2 a) & c).

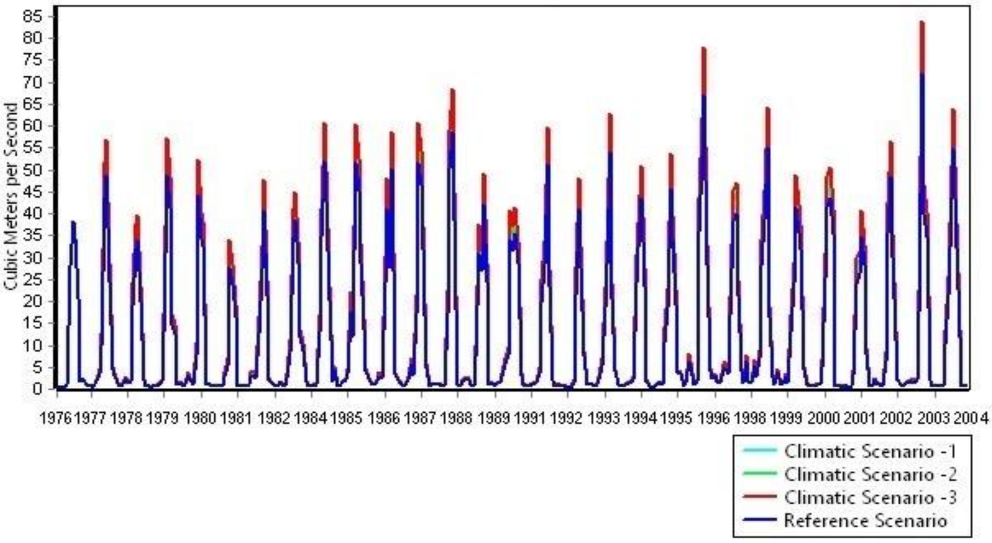


Figure 4-2 a): Results for Simulated Streamflow of Dordi River from 1976 to 2004 under Reference & Climatic Scenarios

Moreover, the results of the study under these scenarios revealed a more prominent increase in the streamflow of the Dordi River during the April, May, June & July months of the season due to the increment of climatic parameters under the above mentioned Scenarios which is represented by Figure 4-2 b) and Table 4-2.

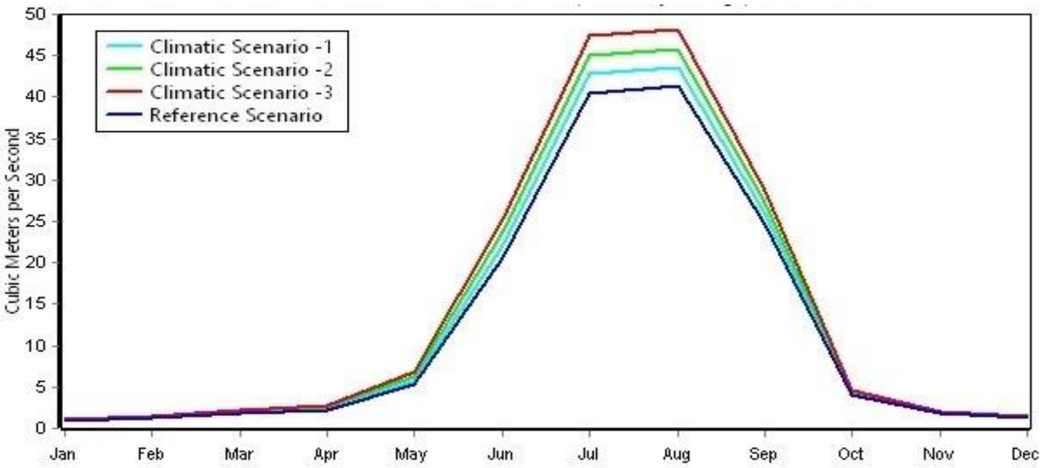


Figure 4-2 b): Results for Monthly Average Streamflow under Reference & Climatic Scenarios

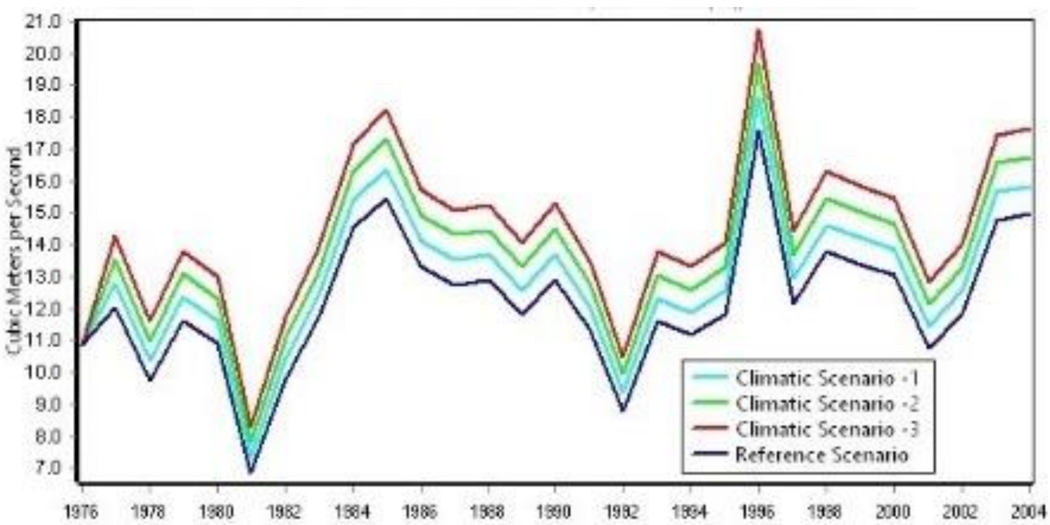


Figure 4-2 c): Results for Annual Total Streamflow from 1976 – 2004 under Reference & Climatic Scenarios

4.1.3 Hydropower Generation

Likewise, the power generation of the plant is found to be increased over the modeling period from 0.35% to 15.16%, 0.66% to 31.99% & 0.93% to 50.51% under Climatic Scenario -1, 2 & 3, respectively, as compared to the simulated values of the hydropower generation under Reference Scenario which is represent by Figure 4-3 a) & c).

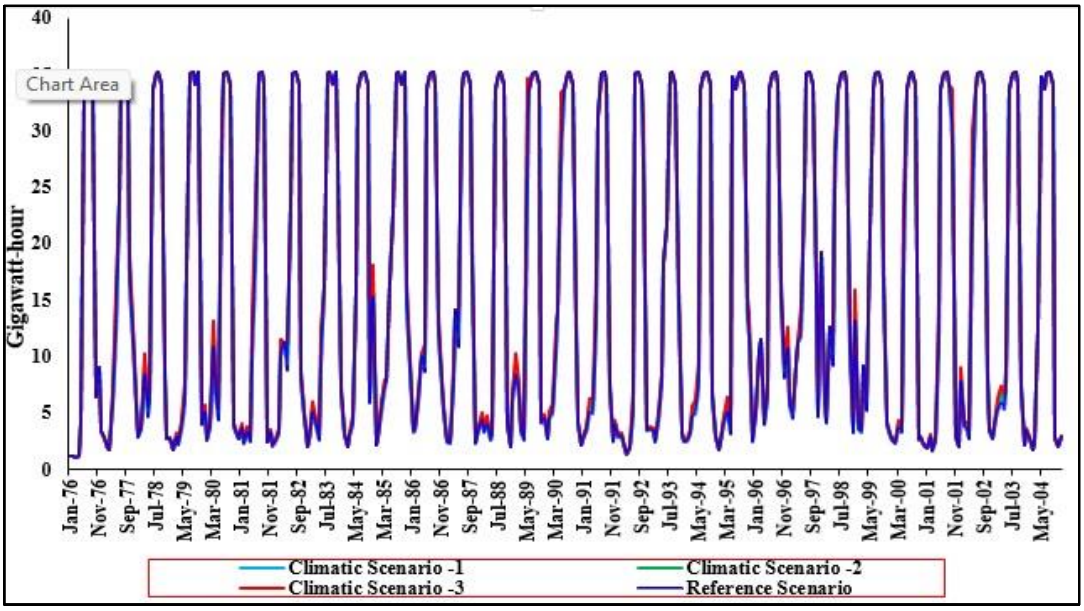


Figure 4-3 a): Results for Monthly Generation from 1976-2004 under Ref & Climatic Scenarios

After a detailed assessment of the study's results, it has been found that there is an increment in hydropower generation of the plant during dry seasons & this increment can be mainly pronounced during April & May of the season. However, there are no impacts on the generation of power plants, mainly during June, July, August &

September of the wet season when temperature & precipitation both are increased simultaneously under Scenario -1, 2 & 3 which is represented by Figure 4-3 b) & Table 4-3.

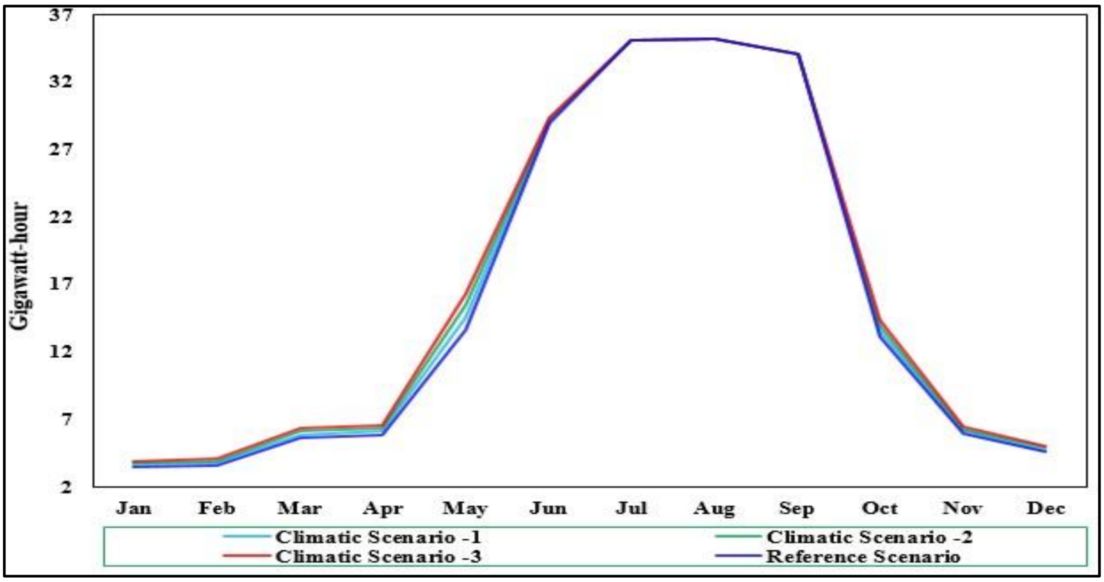


Figure 4-3 b): Results for Monthly Average Generation under Ref. & Climatic Scenarios

This is because the streamflow at Reference Scenario during the dry seasons is low as compared to the plant's design discharge. Thus, the increment of the streamflow under the Climatic Scenario during the dry season results in the increment of the hydropower generation of plants under Climatic Scenario during dry seasons.

On the Contrary, the streamflow during the wet season at the Reference Scenario is already higher than plant design discharge in major cases. Therefore, the increment of the streamflow under the Climatic Scenario has no significant impact on hydropower generation during the wet season.

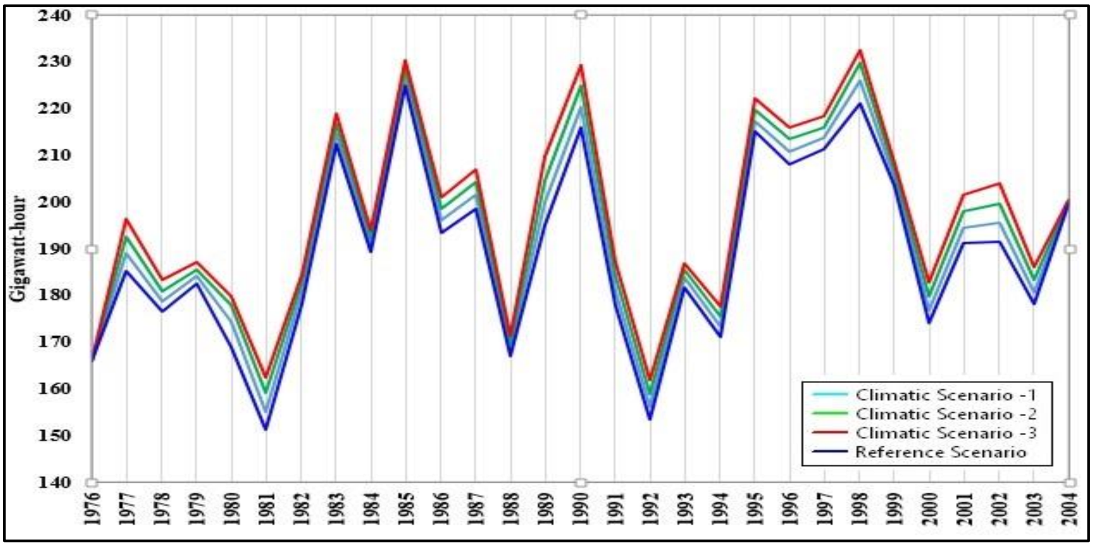


Figure 4-3 c): Results for Total Annual Generation from 1976-2004 under Ref & Climatic Scenarios

Table 4-2: Monthly Average Discharge (Cumec)
WEAP Model Streamflow results for the Dordi River
Under Reference Scenario & Climatic Scenario

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed	3.53	3.00	3.05	3.20	7.41	12.68	35.99	44.89	30.23	12.66	7.53	4.83
Reference Scenario	0.84	1.01	1.40	1.72	5.35	22.34	42.41	43.08	25.00	3.90	1.61	1.16
Climatic Scenario-1	0.87	1.06	1.50	1.88	5.89	24.02	44.78	45.39	26.35	4.09	1.68	1.21
Climatic Scenario-2	0.90	1.11	1.61	2.05	6.44	25.68	47.15	47.69	27.71	4.28	1.74	1.26
Climatic Scenario-3	0.93	1.17	1.72	2.22	7.00	27.34	49.50	49.99	29.06	4.47	1.81	1.31

Table 4-3: Monthly Average Power Generation (Gigawatt-Hour)
WEAP Model Power Generation results for the Super Dordi HPP Kha
Under Reference Scenario & Climatic Scenario

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference Scenario	2.97	3.03	4.62	5.08	13.49	28.08	33.58	33.58	32.49	12.70	5.41	4.08
Climatic Scenario-1	3.08	3.14	4.85	5.32	14.41	28.12	33.58	33.58	32.49	13.11	5.58	4.21
Climatic Scenario-2	3.18	3.25	5.10	5.56	15.33	28.15	33.58	33.58	32.49	13.52	5.75	4.33
Climatic Scenario-3	3.29	3.36	5.35	5.77	16.19	28.19	33.58	33.58	32.49	13.93	5.92	4.45

CHAPTER FIVE: CONCLUSION & RECOMMENDATION

5.1 Conclusion

In this research, the WEAP hydrological model that was calibrated & validated by historical data was implemented to model the Dordi river between 1976 to 2004. This study concludes that there are prominent impacts on the streamflow of the Dordi river and hydropower generations due to the variation of climatic parameters. Base on the study findings, following conclusions can be drawn:

a) The streamflow of the Dordi river is observed to increase from 0.35% to 15.16%, 0.66% to 31.99% & 0.92 to 50.51% over the modeling period under Climatic Scenario -1, 2 & 3, respectively, as compared to the simulated values of streamflow under Reference Scenario. These increments are more prominent during the April, May, June & July months of the season.

b) The power generation of Super Dordi HPP is projected to increase from 0.35% to 15.16%, 0.66% to 31.99% & 0.92 to 50.51%, under climatic scenario-1, 2 & 3, respectively, as compared to baseline scenario and the increments can be mainly pronounced during April & May of the season.The hydropower generation increment results during April & May (Dry season period) drawn from this study under Climatic Scenarios is very crucial in context of Nepal as currently there is power deficit during the dry season.Therefore proper and detailed technical planning to enhance the power generating capability of the hydropower plant during or prior to the development of future hydropower projects in this corridor significantly impacts the national energy planning and implementation.

   However, there are no impacts on the generation of power plants, mainly during June, July, August & September of wet season under Climatic Scenarios -1, 2 & 3.

This type of site-specific research will certainly assist in better analysis of the collective assessment of climate change's impact on hydropower.

5.2 Recommendation

a) As it can be observed from the above results, the streamflow is dynamically changing with the variation of the climatic conditions; therefore, it is necessary to analyze the varying hydrological conditions of the Dordi River with the constant provision of the monitoring system. The rainfall gauging in the climatic station & discharge measurements in the Dordi River shall be conducted from time to time for more updated and accurate data for analysis.

b) Thus, the hydrological curve of the turbine shall be designed and selected considering the possible dynamics of streamflow in the Dordi river due to the variation of climatic parameters in the future for upcoming projects in the Corridor to obtain the optimum outcome. The revision of the design discharge of the plant shall be carried out in the future in accordance with the projected discharge.

c) Similarly, the efficiency curve and power capability curve of the plant's generator shall be designed and selected considering the potential increment of generation in a hydropower plant in the future due to climatic variation.

d) Moreover, the results of this study revealed that the generation of the power plant is likely to increase due to the variation of climatic parameters during the dry season which will have significant impacts on the energy development, planning, and implementation in the context of Nepal. Thus, proper technical actions shall be taken prior to or during the development of hydropower project to enhance the power generating capability of the hydropower plant.

e) The unit commitment and scheduling of the hydropower plant shall be done in accordance with increment patterns of streamflow and hydropower generation due to the variation in climatic parameters under climatic scenarios.

REFERENCES

[1] Abdi DA and Ayenew T. Evaluation of the WEAP model in simulating subbasin hydrology in the Central Rift Valley basin, Ethiopia. Ecological processes 2021; 10: 41.

[2] Alemayehu T, McCartney M and Kebede S. The water resource implications of planned development in the Lake Tana catchment, Ethiopia. Ecohydrol. Hydrobiol. 2010; 10: 211-222

[3] Allen RG, Pereira LS, Raes D and Smith M. Crop evapotranspiration: guidelines for computing crop water requirements. FAO irrigation and drainage 1998: 56.

[4] Asghar A, Iqbal J, Amin A and Ribbe L. Integrated hydrological modeling for assessment of water demand and supply under socio-economic and IPCC climate change scenarios using WEAP in Central Indus Basin. Journal of Water Supply: Research and Technology 2019; 68:136–148.

[5] Bagale LN. Impacts of Climate change on Hydropower Potential in Kaligandaki River Basin -A Case Study of Kaligandaki Gorge Hydropower Project, North of Nepal. Fish & Ocean Opj. 2017; 4: 555629

[6] Bajracharya TR, Acharya S and Ale BB. Changing climatic parameters and its possible impacts in hydropower generation in Nepal (a case study on Gandaki river basin). Journal of the Institute of Engineering 2011; 8: 160–173

[7] Chen J, Gao C, Zeng X, et al. Assessing changes of river discharge under global warming of 1.5°C and 2°C in the upper reaches of the Yangtze River Basin: Approach by using multiple- GCMs and hydrological models. Quaternary International 2017; 453: 1040-6182.

[8] Chilkoti V, Bolisetti T, and Balachandar R. Climate change impact assessment on hydropower generation using multi-model climate ensemble. Renewable Energy 2017; 109: 510–517.

[9] Christensen NS, Wood AW, Voisin N, et al. The effects of Climate Change on the hydrology and water resources of the Colorado River Basin. Climatic Change 2004; 62:337-363

[10] Christensen NS and Lettenmaier DP. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. Hydrology & Earth System Sciences 2007; 11:1417-1434

[11] DHM (Department of Hydrology and Meteorology). Observed Climate Trend Analysis in the Districts and Physiographic Zones of Nepal (1971-2014), https://www.dhm.gov.np/uploads/climatic/ 467608975Observed %20Climate%20Trend%20Analysis%20Report_2017_Final.pdf(2017, accessed 5 March 2021)

[12] Doll P, Trautmann T, Gerten D, et al. Risks for the global freshwater system at 1.5°C and 2°C global warming. Environmental Research Letters 2018; 13: 044038.

[13] Donnelly C, Greuell W, Andersson J, et al. Impacts of climate change on European hydrology at 1.5, 2 and 3 degrees mean global warming above preindustrial level. Climatic Change 2017; 143: 13–26.

[14] Gosling SN, Zaherpour JJ, Mount NJ, et al. A comparison of changes in river runoff from multiple global and catchment-scale hydrological models under global warming scenarios of 1°C, 2°C and 3°C. Climatic Change 2016; 141: 577–595.

[15] IPCC (Intergovernmental Panel on Climate Change). An IPCC Special Report on impacts of Global Warming of 1.5°C, https://www.ipcc.ch /site/assets/uploads/sites/2/2019/06/SR15_Full_Report_ High_Res.pdf

[16] K.C Surendra, Khanal SK, Shrestha P, et al. Current Status of Renewable Energy in Nepal: Opportunities and Challenges. Renewable and Sustainable Energy Reviews 2011; 15: 4107–4117.

[17] Khadka D and Pathak D. Climate Change projection for the marsyangdi river basin, Nepal using statistical downscaling of GCM and its implications in geodisasters. Geoenvironmental Disasters 2016; 3:15

[18] Khatiwada KR, Panthi, J, Shrestha ML & Nepal S. Hydro-Climatic Variability in the Karnali River Basin of Nepal Himalaya. Climate 2016; 4: 17.

[19] Leong WK and Lai S. Application of water evaluation and planning model for integrated water resources management: case study of langat river basin, Malaysia. In: IOP Conference Series on Materials Science and Engineering, 2017, vol. 210. IOP Publishing.

[20] Liu L, Xu H, Wang Y and Jiang T. Impacts of 1.5 and 2°C global warming on water availability and extreme hydrological events in Yiluo and Beijiang River catchments in China. Climatic Change 2017; 145: 145–158.

[21] Mehta VK, Haden VR, Joyce BA, et al. Irrigation demand and supply, given projections of climate and land-use change, in Yolo County, California. Agricultural Water Management 2013; 117:70-82

[22] MOFE (Ministry of Forests and Environment). Climate Change Scenarios for Nepal, http://mofe.gov.np/downloadfile/MOFE_2019_Climate%20change%20scenarios%20for%20Nepal_NAP_1562647620.pdf (2019, accessed 5 March 2021)

[23] Moriasi DN, Arnold JG, Van Liew MW, et al. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 2007; 50:885–900.

[24] Nash JE and Sutcliffe JV. River flow forecasting through conceptual models part I– A discussion of Principles. Journal of Hydrology 1970; 10: 282–290.

[25] Nash LL and Gleick P. The Colorado River Basin and Climate Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation, EPA, Policy, Planning and Evaluation. EPA 1993; 230:93-009.

[26] NDC (Nationally Determined Contribution). Second Nationally Determined Contribution, https://climate.mohp.gov.np/30-manuals/167-second-nationally-determined-contribution-ndc-gon-2020 (2020,accessed 5 March 2021)

[27] NEA (Nepal Electricity Authority). Annual Report 2020/2021, https://www.nea.org.np/annual_report (2021, accessed 5 March 2021)

[28] Olabanji MF, Ndarana T, Davis N and Archer E. Climate change impact on water availability in the olifants catchment (South Africa) with potential adaptation strategies. Physcis and Chemistry of the Earth 2020: 1474-7065

[29] Oti JO, Kabo-bah AT and Ofosu E. Hydrologic response to climate change in the Densu River Basin in Ghana. Heliyon 2020; 6: 2405-8440

[30] Panthi J, Dahal, P, Shrestha M, et al. Spatial and Temporal Variability of Rainfall in the Gandaki River Basin of Nepal Himalaya. Climate 2015; 3: 210–226.

[31] Peoples Hydropower Co. Ltd. Updated Feasibility Study Report of Super Dordi Hydropower Project-kha. Report for the Department of Electricity Development, Ministry of Energy, Government of Nepal. Vol-1: Main Report, April 2017.

[32] Peoples Hydropower Co. Ltd. Detailed Project Report of Super Dordi Hydropower Project-kha. Report for the Government of Nepal. Volume I: Main Report, September 2015.

[33] Peoples Hydropower Co. Ltd. Intial Environment Examination (IEE) of 132 kV Transmission Line Project for Super Dordi Hydropower Project. Report for the Department of Electricity Development, Ministry of Energy, Government of Nepal. October, 2018.

[34] Purkey DR, Huber-Lee A, Yates DN, et al. Integrating a climate change assessment tool into stakeholder-driven water management decision-making processes in California. Water Resources Management 2007; 21:315-329.

[35] Rochdane S, Reichert B, Messouli M, et al. Climate change impacts on water supply and demand in Rheraya Watershed (Morocco), with potential adaptation strategies. Water 2012; 4: 28–44.

[36] Rosenzweig C, Strzepek KM, Major DC, et al. Water resources for agriculture in a changing climate: international case studies. Global Environmental Change 2004; 14: 345-360.

[37] Sahukhal R and Bajracharya TR. Integration of Climate Change Impact Parameters in Hydropower Planning in Nepal: A Case Study of Kaligandaki Gorge HP. In: Proceedings of IOE Graduate Conference, Nepal, 2015, pp. 211-217.

[38] Santhi C, Arnold JG, Williams JR, et al. Validation of the SWAT model on a large river basin with point and nonpoint sources. Journal of the American Water Resources Association 2001; 37:1169–1188.

[39] Santikayasa IP, Babel MS and Shrestha S. Assessment of the impact of climate change on water availability in the Citarum river basin, Indonesia: The use of statistical downscaling and water planning tools. Managing water Resources under climate uncertainty 2015: 45-64.

[40] Schleussner C-F, Lissner TK, Fischer EM, et al. Differential climate impacts for policy-relevant limits to global warming: The case of 1.5°C and 2°C. Earth System Dynamics 2016b; 7: 327–351.

[41] SEI (Stockholm Environment Institute). WEAP: Water Evaluation and Planning System-User Guide, 2021.

[42] Seiber J and Purkey D. WEAP—Water Evaluation and Planning System User Guide for WEAP 2015. Stockholm Environment Institute: Stockholm, Sweden. 2015.

[43] Shrestha AB, Bajracharya SR, Sharma AR, et al. Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975–2010. Int. J. Climatol 2016; 37: 1066–1083.

[44] Shu J, Qu JJ, Motha R, et al. Impact of climate change on hydropower development and sustainability: a review. In: Conference Series – Earth and Environmental Science, 2018; 163:012126

[45] Tanaka SK, Zhu T, Lund JR, et al. Climate warming and water management adaptation for California. Climatic Change 2006; 76:361-87.

[46] Van Liew MW, Veith TL, Bosch DD and Arnold JG. Suitability of SWAT for the conservation effects assessment project: comparison on USDA agricultural research service watersheds. Journal of Hydrological Engineering 2007; 12:173–189.

[47] VanRheenen NT, Wood AW, Palmer RN and Lettenmaier DP. Potential implications of PCM climate change scenarios for Sacramento–San Joaquin River Basin hydrology and water resources. Climatic change 2004; 62:257-81.

[48] Vliet Van MTH, Beek Van LPH, Eisner S, et al. Multi-model assessment of global hydropower and cooling water discharge potential under climate change. Global Environmental Change 2016; 40: 156–170.

[49] Wolock DM and McCabe GJ. Estimates of runoff using water –balance and atmospheric general circulation models. Journal of the American Water Resources Association 1999; 35:1341-1350.

[50] Yao H andGeorgakakos A. Assessment of Folsom Lake response to historical and potential future climate scenarios: 2. Reservoir management. Journal of Hydrology 2001; 249:176-96

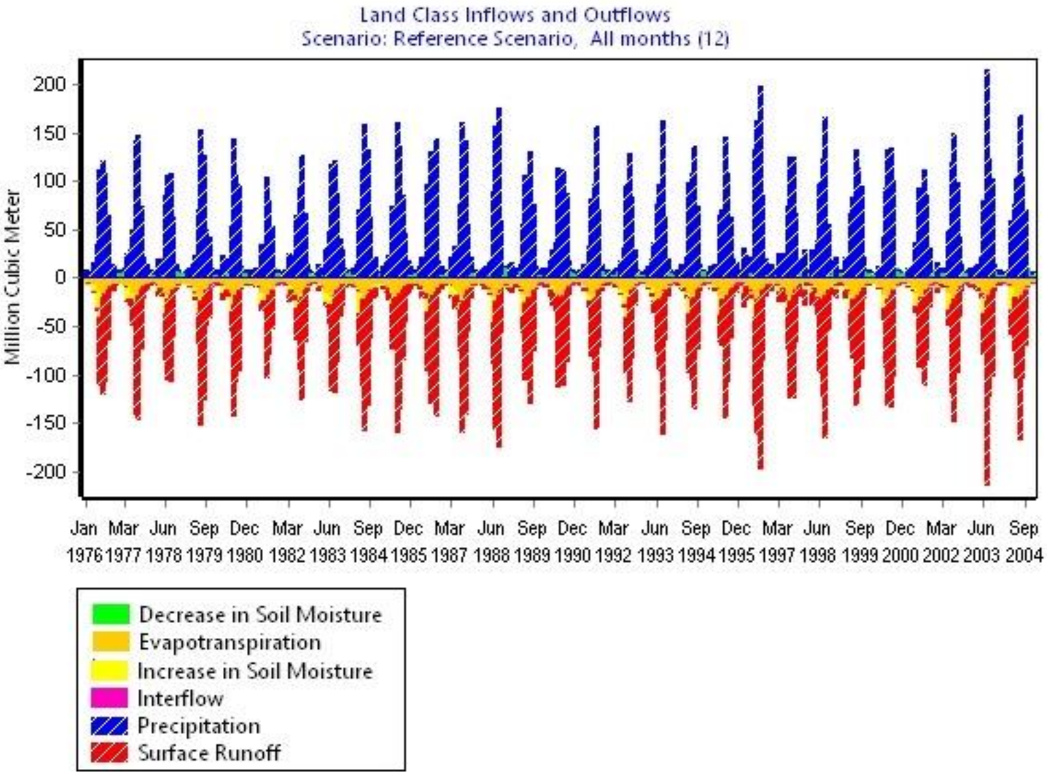
[51] Zhai R, Tao F and Xu Z. Spatial-temporal changes in runoff and terrestrial ecosystem water retention under 1.5 and 2°C warming scenarios across China. Earth System Dynamics 2018; 9: 717–738.

APPENDIX A: KEY PARAMETERS

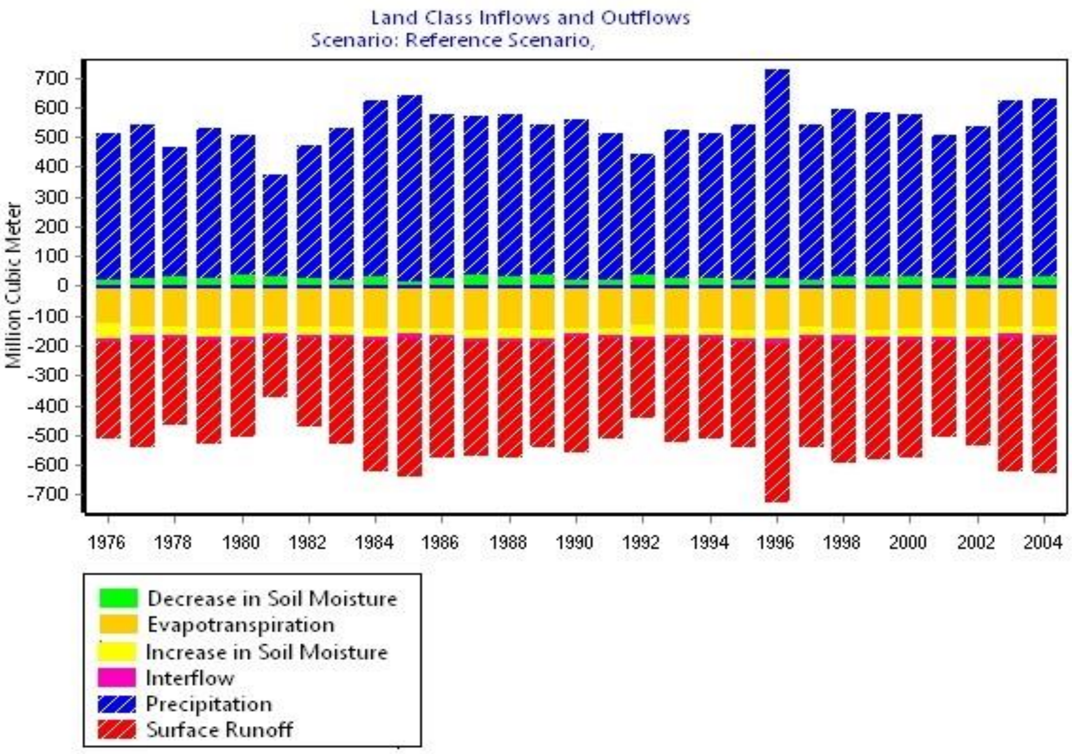
Characteristics	Dordi
Study Area	Super Dordi HPP kha, Lamjung
Catchment Area	151.6 km^2
Elevation(masl)	
< 2000	1.39 km^2
2000 to 3000	19.11 km^2
3000 to 5500	108.15 km^2
> 5500	22.95 km^2
Climatic station	Khudi Bazar Station (ID 802)
River flow gauging station	Dordi Khola
Hydropower plants in Dordi Corridor	
Under construction	4 Nos. (116.3 MW)
Power plant- study site	
- **Geographical coordinates**	$84^0$34’15” E & $28^0$18’50” N
- **Installed Capacity**	54 MW
- **Design Discharge**	9.9 cumec at Q40%
- **Net Head**	628.30 m
- **Turbine Design Efficiency**	92%
- **Generator Design Efficiency**	98%

APPENDIX B: WATER BALANCE RESULTS

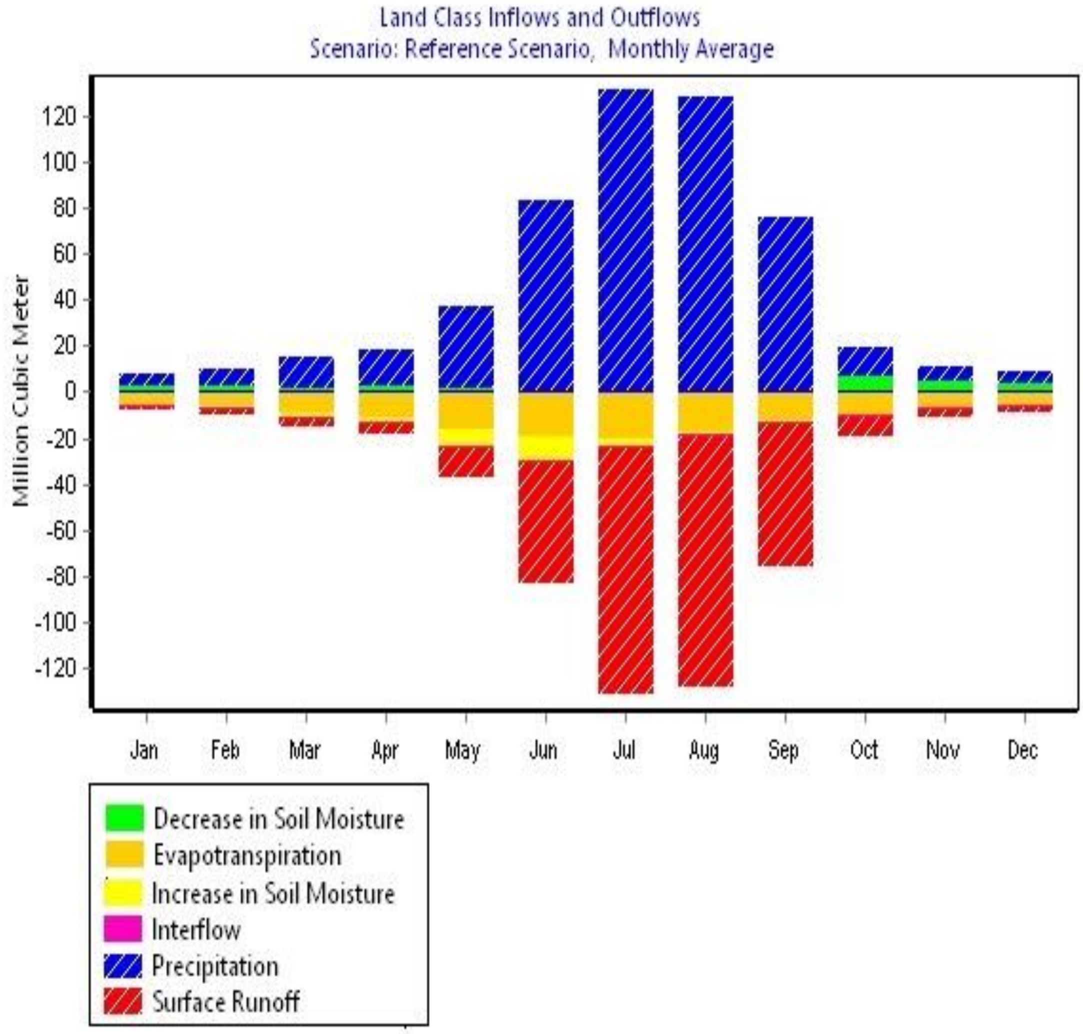
a) Land Class Inflows and Outflows from Jan 1976 to 2004



b) Annual Land Class Inflows and Outflows from 1976 to 2004

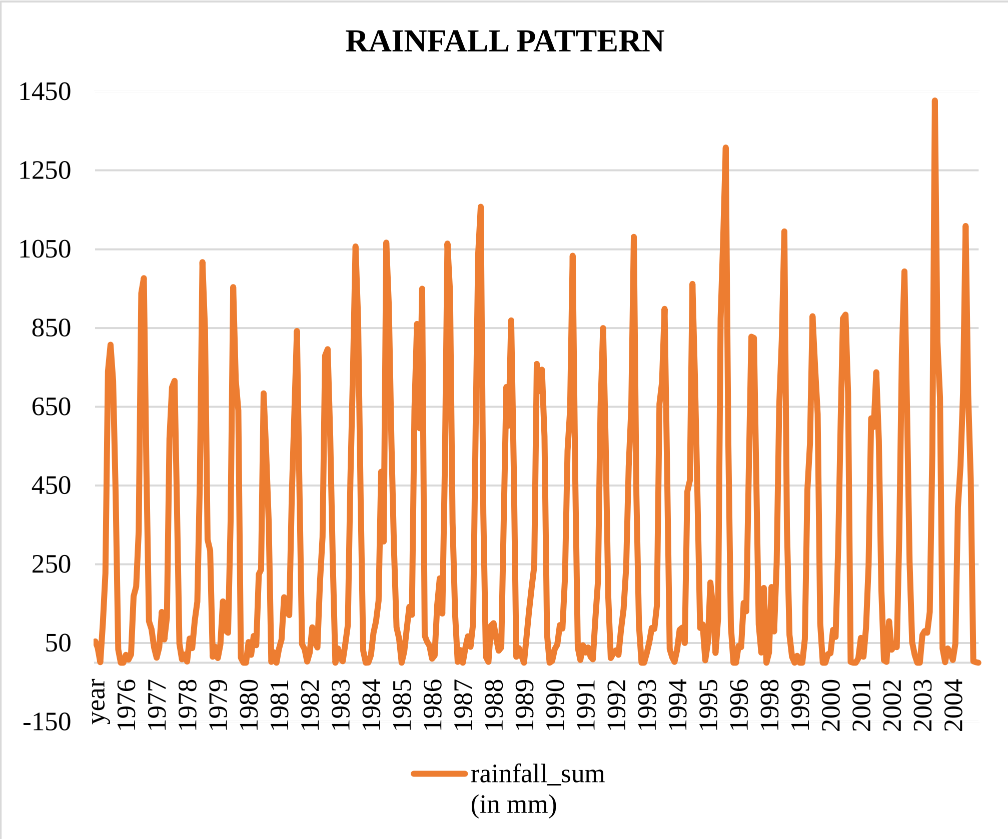


c) Monthly Average Land Class Inflows and Outflows



APPENDIX C: RAINFALL PATTERN

The Rainfall pattern of the Lamjung Khudi Bazar Station with ID 802 from 1976 to 2004 is shown as below:



APPENDIX D: WEAP RESULT FOR STREAMFLOW AND HYDROPOWER GENERATION UNDER REFERENCE AND CLIMATIC SCENARIOS

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jan-76	2.48	0.35	1.24	0.35	1.24	0.35	1.24	0.35	1.24
Feb-76	2.15	0.39	1.25	0.39	1.25	0.39	1.25	0.39	1.25
Mar-76	1.73	0.32	1.11	0.32	1.11	0.32	1.11	0.32	1.11
Apr-76	1.84	0.37	1.25	0.37	1.25	0.37	1.25	0.37	1.25
May-76	5.27	1.20	4.23	1.20	4.23	1.20	4.23	1.20	4.23
Jun-76	22.05	27.99	33.72	27.99	33.72	27.99	33.72	27.99	33.72
Jul-76	30.48	38.46	35.07	38.46	35.07	38.46	35.07	38.46	35.07
Aug-76	47.07	34.42	35.17	34.42	35.17	34.42	35.17	34.42	35.17
Sep-76	26.63	20.79	34.05	20.79	34.05	20.79	34.05	20.79	34.05
Oct-76	9.52	1.79	6.38	1.79	6.38	1.79	6.38	1.79	6.38
Nov-76	5.84	2.62	8.97	2.62	8.97	2.62	8.97	2.62	8.97
Dec-76	3.79	0.99	3.44	0.99	3.44	0.99	3.44	0.99	3.44
Jan-77	2.68	0.79	2.76	0.80	2.81	0.81	2.86	0.83	2.90
Feb-77	2.22	0.59	1.87	0.59	1.88	0.60	1.90	0.60	1.91
Mar-77	2.21	0.50	1.75	0.50	1.76	0.51	1.78	0.51	1.80
Apr-77	3.37	1.63	5.55	1.77	6.01	1.91	6.50	2.06	7.02
May-77	10.26	3.36	11.82	3.75	13.19	4.17	14.64	4.60	16.15

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jun-77	7.35	9.75	24.04	10.74	24.04	11.74	24.04	12.75	24.04
Jul-77	30.60	43.69	35.07	46.40	35.07	49.08	35.07	51.75	35.07
Aug-77	51.88	48.89	35.17	51.58	35.17	54.26	35.17	56.95	35.17
Sep-77	24.14	24.62	34.05	25.98	34.05	27.35	34.05	28.71	34.05
Oct-77	11.09	4.65	16.53	4.89	17.37	5.12	18.21	5.36	19.05
Nov-77	8.12	3.28	11.23	3.46	11.83	3.63	12.44	3.81	13.05
Dec-77	5.18	1.57	5.46	1.64	5.71	1.71	5.96	1.78	6.21
Jan-78	3.57	0.79	2.77	0.81	2.84	0.83	2.91	0.85	2.98
Feb-78	3.05	1.11	3.52	1.15	3.66	1.20	3.80	1.24	3.94
Mar-78	3.50	2.37	8.32	2.55	8.97	2.74	9.64	2.94	10.33
Apr-78	3.61	1.38	4.68	1.48	5.02	1.58	5.37	1.68	5.72
May-78	8.41	1.65	5.81	1.80	6.34	1.96	6.89	2.12	7.46
Jun-78	12.29	19.14	33.72	20.89	33.72	22.64	33.72	24.39	33.72
Jul-78	36.79	32.00	35.07	33.92	35.07	35.83	35.07	37.74	35.07
Aug-78	44.35	33.92	35.17	35.87	35.17	37.82	35.17	39.76	35.17
Sep-78	25.27	20.12	34.05	21.27	34.05	22.42	34.05	23.57	34.05
Oct-78	12.49	2.28	8.10	2.38	8.45	2.47	8.79	2.57	9.14
Nov-78	7.13	0.77	2.64	0.78	2.69	0.80	2.73	0.81	2.77
Dec-78	4.66	0.77	2.69	0.79	2.75	0.81	2.81	0.82	2.87

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jan-79	2.88	0.48	1.69	0.49	1.71	0.49	1.72	0.49	1.73
Feb-79	2.64	0.91	2.89	0.95	3.00	0.98	3.11	1.01	3.22
Mar-79	2.16	0.63	2.21	0.65	2.29	0.68	2.38	0.70	2.47
Apr-79	2.36	1.03	3.52	1.12	3.79	1.20	4.09	1.29	4.40
May-79	5.25	1.61	5.67	1.81	6.34	2.01	7.07	2.24	7.86
Jun-79	5.58	12.96	18.02	14.42	18.02	15.90	18.02	17.38	18.02
Jul-79	30.72	48.71	35.07	51.62	35.07	54.51	35.07	57.38	35.07
Aug-79	45.22	41.57	35.17	43.88	35.17	46.19	35.17	48.50	35.17
Sep-79	24.93	14.65	34.05	15.47	34.05	16.30	34.05	17.13	34.05
Oct-79	12.43	12.60	35.20	13.36	35.20	14.12	35.20	14.88	35.20
Nov-79	8.32	1.16	3.98	1.20	4.10	1.23	4.21	1.26	4.32
Dec-79	5.88	1.46	5.08	1.51	5.28	1.57	5.48	1.63	5.68
Jan-80	3.90	0.73	2.56	0.75	2.62	0.76	2.67	0.78	2.73
Feb-80	3.35	1.17	3.70	1.22	3.86	1.26	4.01	1.31	4.17
Mar-80	4.03	3.07	10.78	3.32	11.68	3.59	12.61	3.87	13.14
Apr-80	3.36	1.99	6.75	2.15	7.30	2.32	7.87	2.49	8.45
May-80	5.59	1.23	4.31	1.32	4.64	1.42	4.98	1.52	5.34
Jun-80	9.39	7.84	26.71	8.76	29.84	9.70	30.99	10.66	30.99
Jul-80	34.75	44.14	35.07	46.96	35.07	49.73	35.07	52.49	35.07

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Aug-80	39.48	34.42	35.17	36.36	35.17	38.31	35.17	40.25	35.17
Sep-80	26.74	32.74	34.05	34.56	34.05	36.39	34.05	38.21	34.05
Oct-80	11.25	1.09	3.86	1.11	3.95	1.14	4.04	1.16	4.13
Nov-80	6.87	0.99	3.38	1.01	3.45	1.03	3.53	1.05	3.60
Dec-80	5.19	0.76	2.65	0.78	2.71	0.79	2.76	0.81	2.81
Jan-81	3.80	1.04	3.66	1.08	3.80	1.12	3.94	1.16	4.09
Feb-81	3.26	0.71	2.26	0.73	2.32	0.75	2.39	0.77	2.45
Mar-81	2.80	0.93	3.26	0.98	3.44	1.03	3.63	1.09	3.82
Apr-81	3.77	0.71	2.42	0.75	2.55	0.79	2.68	0.83	2.82
May-81	6.65	2.74	9.64	3.08	10.84	3.45	12.11	3.84	13.47
Jun-81	7.10	5.21	17.75	5.84	19.90	6.49	22.11	7.15	23.19
Jul-81	27.00	27.89	35.07	29.97	35.07	32.02	35.07	34.04	35.07
Aug-81	36.40	24.04	35.17	25.47	35.17	26.89	35.17	28.31	35.17
Sep-81	20.17	16.38	34.05	17.35	34.05	18.33	34.05	19.30	34.05
Oct-81	9.01	0.68	2.41	0.69	2.44	0.69	2.46	0.70	2.48
Nov-81	6.11	0.97	3.31	0.99	3.40	1.02	3.49	1.04	3.58
Dec-81	3.72	0.59	2.07	0.60	2.11	0.61	2.14	0.62	2.17
Jan-82	2.47	0.71	2.49	0.73	2.56	0.75	2.64	0.77	2.71
Feb-82	2.56	0.99	3.15	1.04	3.30	1.09	3.46	1.14	3.62

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Mar-82	3.55	2.85	10.01	3.13	10.99	3.42	11.45	3.73	11.45
Apr-82	3.61	3.30	11.21	3.62	11.29	3.96	11.29	4.31	11.29
May-82	5.55	2.50	8.77	2.73	9.59	2.97	10.42	3.21	11.26
Jun-82	7.23	12.79	23.64	14.03	23.64	15.27	23.64	16.50	23.64
Jul-82	33.73	27.50	35.07	29.29	35.07	31.06	35.07	32.81	35.07
Aug-82	34.24	40.83	35.17	43.16	35.17	45.48	35.17	47.80	35.17
Sep-82	26.35	21.32	34.05	22.52	34.05	23.73	34.05	24.93	34.05
Oct-82	10.47	2.23	7.94	2.33	8.28	2.42	8.62	2.52	8.95
Nov-82	6.39	1.36	4.65	1.41	4.82	1.46	5.00	1.51	5.17
Dec-82	4.72	0.57	1.98	0.57	2.01	0.58	2.03	0.59	2.05
Jan-83	3.44	0.73	2.56	0.75	2.63	0.77	2.69	0.78	2.76
Feb-83	2.96	1.61	5.10	1.70	5.40	1.80	5.72	1.91	6.05
Mar-83	2.98	1.08	3.79	1.15	4.03	1.22	4.28	1.29	4.53
Apr-83	3.03	0.76	2.59	0.80	2.73	0.85	2.87	0.89	3.02
May-83	8.05	2.59	9.11	2.90	10.18	3.22	11.31	3.56	12.52
Jun-83	5.04	8.28	16.18	9.22	16.18	10.17	16.18	11.11	16.18
Jul-83	19.14	34.42	35.07	36.71	35.07	38.98	35.07	41.22	35.07
Aug-83	34.11	38.48	35.17	40.66	35.17	42.84	35.17	45.01	35.17
Sep-83	32.86	28.89	34.05	30.51	34.05	32.13	34.05	33.74	34.05

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Oct-83	15.79	11.82	35.20	12.49	35.20	13.15	35.20	13.81	35.20
Nov-83	8.19	8.82	27.04	9.34	27.04	9.86	27.04	10.38	27.04
Dec-83	4.87	1.87	6.51	1.95	6.79	2.03	7.07	2.11	7.35
Jan-84	3.19	0.86	3.01	0.88	3.08	0.90	3.15	0.92	3.22
Feb-84	2.44	0.63	1.99	0.63	2.01	0.64	2.03	0.65	2.05
Mar-84	2.12	0.83	2.91	0.85	3.00	0.88	3.09	0.91	3.18
Apr-84	2.03	1.16	3.95	1.24	4.20	1.31	4.46	1.39	4.72
May-84	4.86	13.03	16.05	14.32	16.05	15.63	16.05	16.95	16.05
Jun-84	10.75	34.77	33.72	36.92	33.72	39.06	33.72	41.18	33.72
Jul-84	42.37	52.14	35.07	55.05	35.07	57.96	35.07	60.87	35.07
Aug-84	33.62	42.88	35.17	45.26	35.17	47.64	35.17	50.02	35.17
Sep-84	36.60	20.20	34.05	21.34	34.05	22.48	34.05	23.62	34.05
Oct-84	11.70	1.64	5.84	1.70	6.06	1.76	6.27	1.82	6.48
Nov-84	7.92	4.45	15.25	4.73	16.19	5.01	17.14	5.29	18.10
Dec-84	5.12	0.61	2.11	0.61	2.13	0.62	2.15	0.62	2.17
Jan-85	3.35	0.79	2.79	0.82	2.87	0.84	2.95	0.86	3.03
Feb-85	2.79	1.60	5.07	1.69	5.37	1.79	5.67	1.89	5.98
Mar-85	2.54	2.01	7.08	2.18	7.65	2.35	7.90	2.52	7.90
Apr-85	2.58	3.44	7.78	3.78	7.78	4.14	7.78	4.50	7.78

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	**Cumec**	**GWhr**	**Cumec**	**GWhr**	**Cumec**	**GWhr**	**Cumec**	**GWhr**
May-85	5.04	17.61	16.69	19.08	16.69	20.54	16.69	21.99	16.69
Jun-85	6.98	11.99	22.78	12.78	22.78	13.56	22.78	14.33	22.78
Jul-85	35.17	51.46	35.07	54.47	35.07	57.47	35.07	60.46	35.07
Aug-85	30.17	45.17	35.17	47.65	35.17	50.13	35.17	52.61	35.17
Sep-85	26.18	28.73	34.05	30.31	34.05	31.90	34.05	33.49	34.05
Oct-85	16.12	13.87	35.20	14.64	35.20	15.41	35.20	16.18	35.20
Nov-85	8.85	4.22	14.46	4.44	15.19	4.65	15.93	4.87	16.67
Dec-85	5.90	2.50	8.72	2.62	9.15	2.75	9.58	2.87	10.02
Jan-86	3.65	0.94	3.29	0.96	3.38	0.99	3.47	1.01	3.56
Feb-86	2.70	1.07	3.38	1.10	3.49	1.14	3.60	1.17	3.71
Mar-86	2.85	1.65	5.81	1.75	6.16	1.85	6.51	1.96	6.87
Apr-86	3.30	2.96	10.07	3.22	10.23	3.49	10.23	3.78	10.23
May-86	5.26	2.46	8.65	2.69	9.45	2.92	10.27	3.16	11.11
Jun-86	10.56	24.36	33.72	26.33	33.72	28.26	33.72	30.21	33.72
Jul-86	31.92	40.97	35.07	43.34	35.07	45.70	35.07	48.06	35.07
Aug-86	40.65	27.69	35.17	29.28	35.17	30.88	35.17	32.47	35.17
Sep-86	39.49	50.35	34.05	53.10	34.05	55.85	34.05	58.60	34.05
Oct-86	17.19	3.37	11.98	3.52	12.50	3.66	13.02	3.81	13.53
Nov-86	9.51	2.10	7.20	2.19	7.50	2.28	7.81	2.37	8.11

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Dec-86	6.40	1.46	5.09	1.52	5.30	1.58	5.52	1.65	5.74
Jan-87	4.25	0.69	2.41	0.70	2.46	0.71	2.51	0.73	2.56
Feb-87	3.50	0.71	2.27	0.73	2.32	0.75	2.37	0.76	2.42
Mar-87	3.98	2.12	7.43	2.29	8.03	2.46	8.65	2.65	9.31
Apr-87	4.43	5.45	14.07	6.01	14.07	6.59	14.07	7.19	14.07
May-87	7.43	3.07	10.77	3.33	11.71	3.60	12.65	3.87	13.59
Jun-87	10.87	17.11	33.72	18.58	33.72	20.05	33.72	21.51	33.72
Jul-87	61.81	51.69	35.07	54.68	35.07	57.66	35.07	60.63	35.07
Aug-87	53.33	46.81	35.17	49.39	35.17	51.98	35.17	54.56	35.17
Sep-87	33.91	16.90	34.05	17.85	34.05	18.81	34.05	19.76	34.05
Oct-87	10.53	5.00	17.79	5.28	18.77	5.56	19.76	5.84	20.75
Nov-87	7.59	0.68	2.32	0.68	2.34	0.69	2.36	0.70	2.39
Dec-87	5.05	1.02	3.55	1.05	3.67	1.09	3.79	1.12	3.90
Jan-88	3.98	1.24	4.37	1.30	4.58	1.36	4.79	1.42	5.00
Feb-88	3.25	1.03	3.28	1.08	3.43	1.13	3.59	1.18	3.75
Mar-88	3.47	1.12	3.94	1.19	4.19	1.27	4.46	1.35	4.73
Apr-88	3.19	0.74	2.50	0.78	2.64	0.82	2.78	0.86	2.92
May-88	6.56	0.84	2.97	0.91	3.21	0.99	3.46	1.06	3.73
Jun-88	11.80	17.13	33.72	18.93	33.72	20.75	33.72	22.57	33.72

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jul-88	42.37	50.32	35.07	53.24	35.07	56.15	35.07	59.04	35.07
Aug-88	66.01	58.81	35.17	62.01	35.17	65.22	35.17	68.41	35.17
Sep-88	28.33	18.33	34.05	19.35	34.05	20.37	34.05	21.39	34.05
Oct-88	9.07	1.09	3.89	1.12	3.99	1.15	4.10	1.18	4.20
Nov-88	6.41	0.58	2.00	0.59	2.02	0.59	2.03	0.60	2.04
Dec-88	4.95	1.70	5.93	1.79	6.23	1.88	6.54	1.97	6.86
Jan-89	4.31	2.37	8.33	2.55	8.95	2.73	9.60	2.92	10.26
Feb-89	3.44	1.99	6.31	2.13	6.77	2.28	7.24	2.43	7.72
Mar-89	3.35	0.93	3.28	0.98	3.46	1.03	3.63	1.09	3.81
Apr-89	3.11	0.74	2.53	0.78	2.65	0.82	2.78	0.86	2.91
May-89	10.06	7.22	25.36	8.08	28.38	8.97	31.50	9.88	34.69
Jun-89	16.37	31.07	33.72	33.23	33.72	35.36	33.72	37.47	33.72
Jul-89	39.37	26.90	35.07	28.50	35.07	30.10	35.07	31.70	35.07
Aug-89	56.32	42.11	35.17	44.51	35.17	46.91	35.17	49.31	35.17
Sep-89	30.03	24.68	34.05	26.07	34.05	27.46	34.05	28.84	34.05
Oct-89	12.88	1.15	4.08	1.18	4.18	1.21	4.29	1.24	4.40
Nov-89	7.99	1.30	4.47	1.35	4.62	1.39	4.76	1.43	4.91
Dec-89	5.49	0.76	2.66	0.78	2.72	0.80	2.78	0.82	2.84
Jan-90	3.68	1.30	4.55	1.36	4.78	1.43	5.01	1.49	5.25

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Feb-90	3.41	1.53	4.86	1.63	5.17	1.73	5.50	1.84	5.84
Mar-90	4.05	2.83	9.94	3.09	10.85	3.36	11.79	3.64	12.78
Apr-90	4.43	5.55	14.07	6.09	14.07	6.64	14.07	7.19	14.07
May-90	10.06	7.58	26.63	8.23	28.90	8.87	31.16	9.51	33.41
Jun-90	15.81	34.19	33.72	36.43	33.72	38.66	33.72	40.88	33.72
Jul-90	36.97	31.69	35.07	33.54	35.07	35.39	35.07	37.24	35.07
Aug-90	38.93	35.37	35.17	37.40	35.17	39.43	35.17	41.46	35.17
Sep-90	30.48	28.91	34.05	30.54	34.05	32.17	34.05	33.79	34.05
Oct-90	12.37	3.31	11.76	3.46	12.30	3.61	12.85	3.77	13.39
Nov-90	7.59	1.17	3.99	1.20	4.11	1.24	4.23	1.27	4.35
Dec-90	4.90	0.61	2.13	0.62	2.15	0.62	2.18	0.63	2.20
Jan-91	3.59	0.87	3.06	0.90	3.15	0.92	3.24	0.95	3.34
Feb-91	2.83	1.01	3.21	1.05	3.34	1.10	3.48	1.14	3.61
Mar-91	2.97	1.45	5.08	1.55	5.45	1.66	5.83	1.77	6.22
Apr-91	3.18	1.45	4.92	1.57	5.34	1.70	5.78	1.84	6.24
May-91	5.74	3.64	12.77	4.07	14.29	4.52	15.88	4.99	17.54
Jun-91	9.45	19.79	31.20	21.50	31.20	23.20	31.20	24.87	31.20
Jul-91	21.90	28.41	35.07	30.16	35.07	31.91	35.07	33.64	35.07
Aug-91	41.08	51.28	35.17	54.15	35.17	57.02	35.17	59.89	35.17

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Sep-91	33.82	23.37	34.05	24.68	34.05	25.98	34.05	27.29	34.05
Oct-91	10.13	1.95	6.94	2.03	7.21	2.11	7.49	2.18	7.76
Nov-91	6.30	0.73	2.49	0.74	2.53	0.75	2.56	0.76	2.59
Dec-91	4.31	1.14	3.99	1.18	4.13	1.22	4.27	1.26	4.41
Jan-92	3.03	0.80	2.81	0.83	2.90	0.85	2.99	0.88	3.08
Feb-92	2.73	0.92	2.91	0.95	3.03	0.99	3.14	1.03	3.26
Mar-92	2.29	0.51	1.80	0.53	1.84	0.54	1.89	0.55	1.93
Apr-92	1.79	0.38	1.30	0.39	1.32	0.39	1.34	0.40	1.36
May-92	4.19	0.52	1.82	0.55	1.92	0.58	2.03	0.61	2.14
Jun-92	6.49	1.41	4.79	1.61	5.47	1.83	6.22	2.07	7.05
Jul-92	15.00	21.56	35.07	23.67	35.07	25.78	35.07	27.85	35.07
Aug-92	41.83	40.99	35.17	43.36	35.17	45.71	35.17	48.05	35.17
Sep-92	26.18	27.91	34.05	29.48	34.05	31.04	34.05	32.61	34.05
Oct-92	11.98	7.55	26.85	7.96	28.31	8.38	29.78	8.79	31.25
Nov-92	7.39	1.00	3.41	1.02	3.50	1.05	3.58	1.07	3.67
Dec-92	4.89	0.99	3.47	1.02	3.57	1.05	3.67	1.08	3.78
Jan-93	3.27	0.96	3.37	0.99	3.49	1.02	3.60	1.06	3.72
Feb-93	2.70	0.76	2.42	0.78	2.48	0.80	2.55	0.82	2.62
Mar-93	2.75	1.22	4.28	1.29	4.54	1.37	4.81	1.45	5.08

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Apr-93	2.79	2.19	7.45	2.40	8.16	2.62	8.50	2.86	8.50
May-93	5.48	5.23	18.23	5.82	18.23	6.42	18.23	7.05	18.23
Jun-93	6.61	18.76	21.52	20.29	21.52	21.82	21.52	23.31	21.52
Jul-93	25.14	28.30	35.07	30.06	35.07	31.81	35.07	33.56	35.07
Aug-93	56.94	53.95	35.17	56.96	35.17	59.97	35.17	62.97	35.17
Sep-93	33.37	20.84	34.05	22.01	34.05	23.17	34.05	24.34	34.05
Oct-93	14.28	4.09	14.54	4.30	15.29	4.51	16.04	4.72	16.79
Nov-93	8.19	0.92	3.15	0.94	3.23	0.97	3.30	0.99	3.38
Dec-93	4.70	0.71	2.47	0.72	2.52	0.74	2.57	0.75	2.62
Jan-94	3.30	0.71	2.49	0.73	2.55	0.74	2.61	0.76	2.67
Feb-94	2.75	0.99	3.14	1.03	3.27	1.07	3.41	1.12	3.54
Mar-94	2.87	1.32	4.63	1.41	4.96	1.51	5.30	1.61	5.66
Apr-94	3.77	1.42	4.84	1.55	5.26	1.68	5.70	1.81	6.16
May-94	6.16	2.02	7.10	2.24	7.88	2.48	8.71	2.73	9.58
Jun-94	14.08	24.18	33.72	26.27	33.72	28.32	33.72	30.39	33.72
Jul-94	29.46	32.30	35.07	34.23	35.07	36.16	35.07	38.08	35.07
Aug-94	45.53	43.65	35.17	46.12	35.17	48.59	35.17	51.07	35.17
Sep-94	30.48	23.69	34.05	25.03	34.05	26.37	34.05	27.71	34.05
Oct-94	13.52	1.79	6.35	1.85	6.59	1.92	6.83	1.99	7.08

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Nov-94	8.55	0.83	2.84	0.85	2.90	0.86	2.96	0.88	3.01
Dec-94	4.70	0.51	1.77	0.51	1.78	0.51	1.79	0.52	1.80
Jan-95	3.32	0.69	2.41	0.70	2.47	0.72	2.52	0.73	2.57
Feb-95	2.80	1.29	4.11	1.37	4.33	1.44	4.57	1.52	4.81
Mar-95	2.99	1.45	5.11	1.57	5.51	1.69	5.94	1.82	6.38
Apr-95	2.69	0.93	3.16	0.99	3.38	1.06	3.61	1.13	3.85
May-95	10.16	10.56	34.78	11.71	34.78	12.91	34.78	14.12	34.78
Jun-95	38.55	18.79	33.72	20.14	33.72	21.48	33.72	22.80	33.72
Jul-95	55.93	45.62	35.07	48.29	35.07	50.96	35.07	53.62	35.07
Aug-95	54.22	34.04	35.17	35.97	35.17	37.91	35.17	39.85	35.17
Sep-95	35.58	19.45	34.05	20.57	34.05	21.70	34.05	22.82	34.05
Oct-95	12.77	3.71	13.18	3.90	13.86	4.09	14.55	4.28	15.23
Nov-95	8.91	3.42	11.72	3.62	12.41	3.83	13.10	4.03	13.80
Dec-95	5.27	0.71	2.49	0.73	2.54	0.74	2.59	0.76	2.64
Jan-96	3.99	1.35	4.76	1.42	4.99	1.49	5.23	1.56	5.47
Feb-96	3.56	6.44	10.38	6.98	10.38	7.53	10.38	8.09	10.38
Mar-96	3.57	5.22	11.52	5.62	11.52	6.01	11.52	6.40	11.52
Apr-96	3.11	1.14	3.88	1.19	4.05	1.24	4.22	1.29	4.38
May-96	5.16	1.74	6.12	1.86	6.55	1.99	6.98	2.11	7.42

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jun-96	11.92	35.77	33.72	38.39	33.72	41.00	33.72	43.61	33.72
Jul-96	45.79	52.95	35.07	55.91	35.07	58.86	35.07	61.81	35.07
Aug-96	62.92	67.14	35.17	70.77	35.17	74.40	35.17	78.02	35.17
Sep-96	40.68	28.45	34.05	30.01	34.05	31.58	34.05	33.15	34.05
Oct-96	17.47	4.14	14.73	4.35	15.46	4.55	16.19	4.76	16.92
Nov-96	8.25	2.35	8.05	2.47	8.44	2.58	8.83	2.70	9.23
Dec-96	4.67	3.06	10.66	3.25	11.32	3.44	11.99	3.63	12.68
Jan-97	3.17	1.59	5.57	1.67	5.87	1.76	6.18	1.85	6.48
Feb-97	2.48	1.43	4.54	1.51	4.78	1.58	5.01	1.66	5.25
Mar-97	2.94	4.36	9.31	4.73	9.31	5.10	9.31	5.49	9.31
Apr-97	3.60	5.01	11.25	5.43	11.25	5.84	11.25	6.26	11.25
May-97	5.07	3.37	11.83	3.63	12.75	3.89	13.66	4.15	14.58
Jun-97	7.66	16.99	25.10	18.40	25.10	19.80	25.10	21.20	25.10
Jul-97	28.08	38.37	35.07	40.67	35.07	42.96	35.07	45.24	35.07
Aug-97	33.68	40.14	35.17	42.40	35.17	44.65	35.17	46.91	35.17
Sep-97	21.98	21.40	34.05	22.61	34.05	23.82	34.05	25.02	34.05
Oct-97	10.97	4.32	15.36	4.54	16.15	4.76	16.94	4.99	17.72
Nov-97	7.39	1.36	4.66	1.41	4.83	1.46	4.99	1.51	5.16
Dec-97	5.82	6.48	19.29	6.93	19.29	7.38	19.29	7.83	19.29

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Jan-98	3.66	1.61	5.67	1.69	5.94	1.77	6.20	1.84	6.47
Feb-98	3.01	1.28	4.05	1.33	4.21	1.38	4.36	1.42	4.52
Mar-98	3.89	5.44	12.65	5.87	12.65	6.30	12.65	6.73	12.65
Apr-98	3.89	2.72	9.23	2.90	9.87	3.09	10.51	3.28	11.16
May-98	8.27	7.00	24.61	7.60	26.70	8.20	28.03	8.81	28.03
Jun-98	11.80	28.13	33.72	30.07	33.72	32.00	33.72	33.91	33.72
Jul-98	53.47	38.56	35.07	40.80	35.07	43.04	35.07	45.27	35.07
Aug-98	47.15	55.24	35.17	58.28	35.17	61.31	35.17	64.34	35.17
Sep-98	37.11	16.35	34.05	17.26	34.05	18.17	34.05	19.09	34.05
Oct-98	15.90	2.97	10.55	3.11	11.07	3.26	11.60	3.41	12.12
Nov-98	8.32	0.94	3.23	0.97	3.31	0.99	3.39	1.01	3.47
Dec-98	5.15	3.78	13.18	4.04	14.09	4.30	15.01	4.57	15.95
Jan-99	2.78	1.02	3.59	1.06	3.73	1.10	3.88	1.15	4.03
Feb-99	3.36	1.05	3.32	1.09	3.45	1.13	3.59	1.17	3.72
Mar-99	2.91	2.83	9.20	3.07	9.20	3.31	9.20	3.56	9.20
Apr-99	2.60	1.52	5.15	1.63	5.53	1.74	5.92	1.86	6.32
May-99	6.34	13.07	21.25	14.30	21.25	15.54	21.25	16.79	21.25
Jun-99	17.17	24.09	33.72	25.69	33.72	27.27	33.72	28.84	33.72
Jul-99	38.23	41.50	35.07	43.92	35.07	46.34	35.07	48.75	35.07

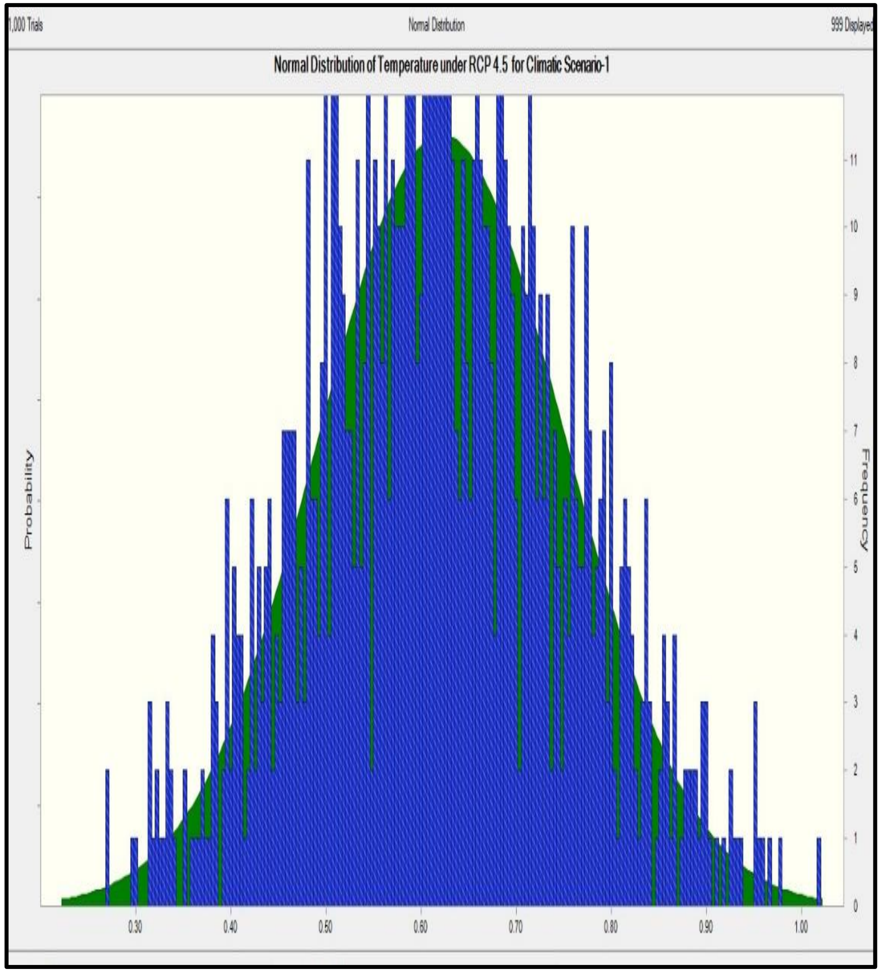
Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	**Cumec**	**GWhr**	**Cumec**	**GWhr**	**Cumec**	**GWhr**	**Cumec**	**GWhr**
Aug-99	38.49	35.91	35.17	37.94	35.17	39.98	35.17	42.02	35.17
Sep-99	26.01	32.05	34.05	33.84	34.05	35.63	34.05	37.43	34.05
Oct-99	12.71	4.50	15.98	4.72	16.77	4.94	17.56	5.16	18.35
Nov-99	5.76	1.15	3.93	1.18	4.05	1.22	4.16	1.25	4.28
Dec-99	2.90	0.84	2.93	0.86	3.00	0.88	3.07	0.90	3.14
Jan-00	3.43	0.74	2.61	0.76	2.68	0.78	2.74	0.80	2.80
Feb-00	3.29	0.72	2.29	0.74	2.35	0.76	2.41	0.78	2.46
Mar-00	3.19	1.06	3.73	1.12	3.94	1.18	4.16	1.25	4.39
Apr-00	3.30	0.94	3.20	1.00	3.41	1.07	3.64	1.14	3.88
May-00	9.96	4.78	16.79	5.38	18.91	6.02	21.14	6.68	23.47
Jun-00	33.36	25.18	33.72	27.15	33.72	29.10	33.72	31.02	33.72
Jul-00	54.31	41.42	35.07	43.82	35.07	46.22	35.07	48.61	35.07
Aug-00	47.15	43.46	35.17	45.89	35.17	48.31	35.17	50.74	35.17
Sep-00	44.65	35.32	34.05	37.26	34.05	39.21	34.05	41.15	34.05
Oct-00	13.16	0.74	2.61	0.74	2.63	0.75	2.65	0.75	2.67
Nov-00	8.05	0.82	2.80	0.83	2.84	0.84	2.88	0.85	2.92
Dec-00	5.07	0.60	2.11	0.61	2.13	0.62	2.15	0.62	2.17
Jan-01	3.42	0.53	1.84	0.53	1.86	0.53	1.88	0.54	1.89
Feb-01	2.79	0.89	2.82	0.92	2.92	0.95	3.01	0.98	3.11

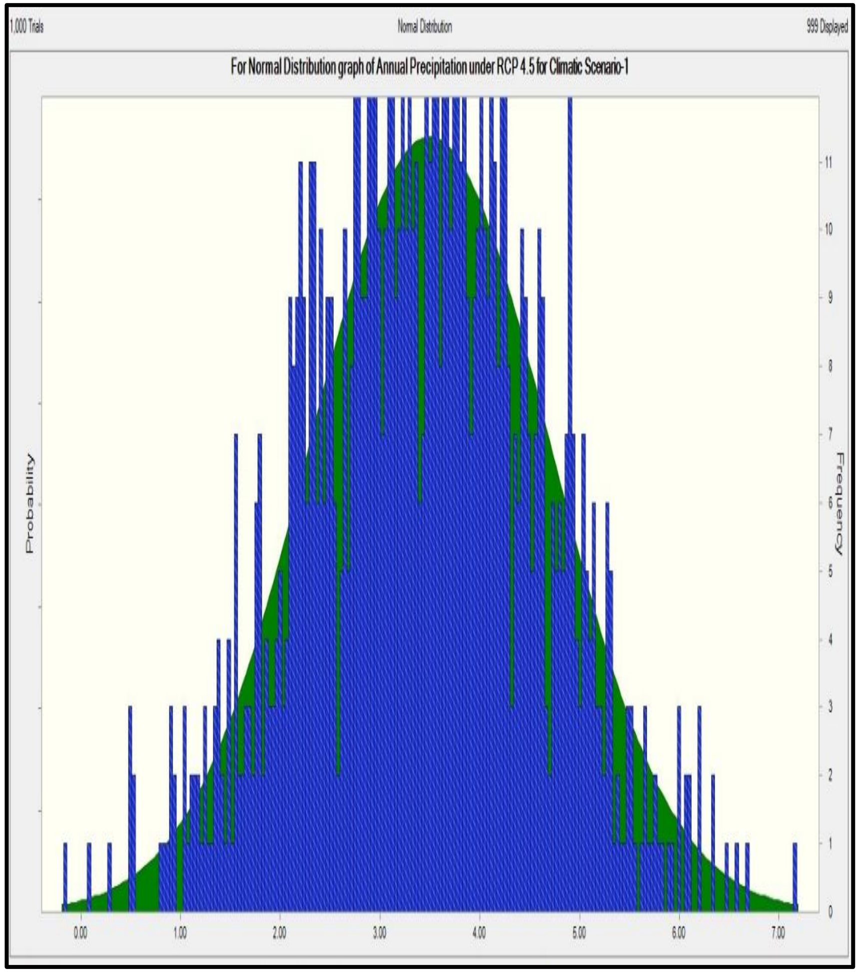
Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Mar-01	2.16	0.47	1.67	0.48	1.70	0.49	1.73	0.50	1.77
Apr-01	2.38	0.73	2.48	0.77	2.62	0.81	2.77	0.86	2.93
May-01	13.32	3.00	10.53	3.40	11.93	3.83	13.44	4.29	15.06
Jun-01	21.68	23.95	33.72	25.97	33.72	27.99	33.72	29.99	33.72
Jul-01	42.19	26.37	35.07	27.97	35.07	29.57	35.07	31.17	35.07
Aug-01	59.34	34.66	35.17	36.68	35.17	38.70	35.17	40.72	35.17
Sep-01	41.76	28.34	34.05	29.94	34.05	31.53	34.05	33.13	34.05
Oct-01	15.79	8.14	28.95	8.59	30.54	9.04	32.13	9.49	33.72
Nov-01	8.85	0.83	2.84	0.84	2.89	0.86	2.94	0.87	2.99
Dec-01	4.89	0.57	2.00	0.58	2.01	0.58	2.02	0.58	2.03
Jan-02	3.66	2.21	7.75	2.33	8.19	2.46	8.65	2.59	9.11
Feb-02	2.47	1.19	3.77	1.25	3.95	1.31	4.14	1.37	4.34
Mar-02	2.55	0.98	3.45	1.03	3.63	1.09	3.82	1.14	4.01
Apr-02	2.77	0.78	2.64	0.81	2.77	0.85	2.90	0.90	3.04
May-02	9.14	6.30	22.14	7.04	24.71	7.80	27.39	8.58	30.15
Jun-02	18.47	35.47	33.72	37.90	33.72	40.30	33.72	42.68	33.72
Jul-02	40.97	48.51	35.07	51.23	35.07	53.96	35.07	56.68	35.07
Aug-02	62.92	30.31	35.17	32.04	35.17	33.77	35.17	35.50	35.17
Sep-02	29.52	11.24	34.05	11.90	34.05	12.56	34.05	13.22	34.05

Modeling period	Observed Streamflow	Modeled Streamflow @ (Reference Scenario)	Hydrpower Generation @ (Reference Scenario)	Modeled Streamflow @ (Climatic Scenario -1)	Hydrpower Generation @ (Climatic Scenario -1)	Modeled Streamflow @ (Climatic Scenario -2)	Hydrpower Generation @ (Climatic Scenario -2)	Modeled Streamflow @ (Climatic Scenario -3)	Hydrpower Generation @ (Climatic Scenario -3)
	Cumec	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr	Cumec	GWhr
Oct-02	16.18	2.15	7.66	2.26	8.03	2.36	8.40	2.47	8.77
Nov-02	10.56	0.97	3.32	1.00	3.43	1.03	3.53	1.06	3.63
Dec-02	7.06	0.76	2.64	0.78	2.71	0.80	2.79	0.82	2.86
Jan-03	4.90	1.28	4.48	1.35	4.73	1.42	4.97	1.49	5.23
Feb-03	4.24	1.62	5.14	1.73	5.50	1.85	5.87	1.97	6.25
Mar-03	5.15	1.68	5.89	1.81	6.37	1.96	6.87	2.10	7.39
Apr-03	5.06	1.57	5.33	1.70	5.78	1.84	6.25	1.98	6.74
May-03	7.66	1.94	6.81	2.14	7.51	2.34	8.23	2.56	8.99
Jun-03	11.24	17.57	33.72	19.23	33.72	20.89	33.72	22.54	33.72
Jul-03	60.00	72.06	35.07	76.09	35.07	80.10	35.07	84.10	35.07
Aug-03	58.79	40.05	35.17	42.26	35.17	44.48	35.17	46.69	35.17
Sep-03	43.46	34.64	34.05	36.56	34.05	38.47	34.05	40.39	34.05
Oct-03	20.49	1.94	6.90	2.01	7.15	2.08	7.41	2.15	7.66
Nov-03	8.98	0.62	2.12	0.62	2.13	0.63	2.14	0.63	2.15
Dec-03	4.89	0.97	3.40	1.00	3.49	1.03	3.59	1.05	3.68
Jan-04	5.17	0.75	2.65	0.77	2.72	0.80	2.79	0.82	2.86
Feb-04	4.20	0.54	1.72	0.55	1.74	0.56	1.76	0.56	1.78
Mar-04	2.89	0.66	2.30	0.68	2.38	0.70	2.47	0.73	2.55
Apr-04	3.99	10.31	12.58	11.37	12.58	12.45	12.58	13.51	12.58
May-04	13.81	21.42	34.78	22.85	34.78	24.26	34.78	25.66	34.78

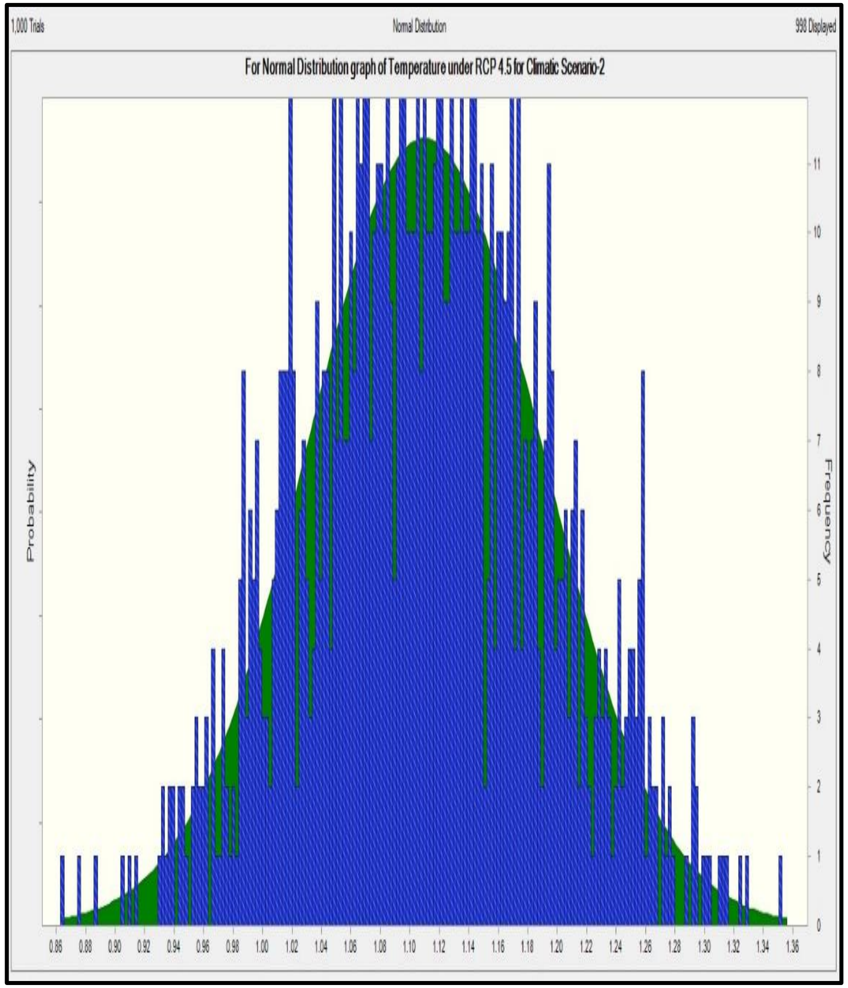
APPENDIX E: NORMAL DISTRIBUTION GRAPHS FROM MONTE CARLO SIMULATION

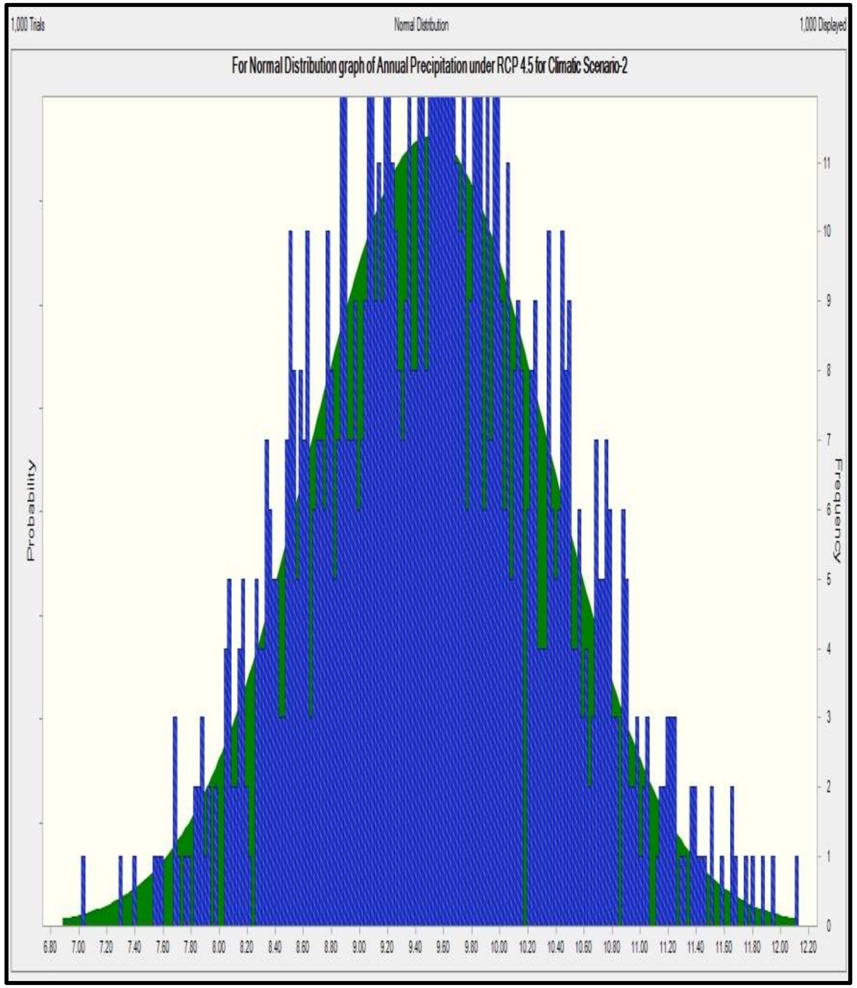
For Climatic Scenario-1



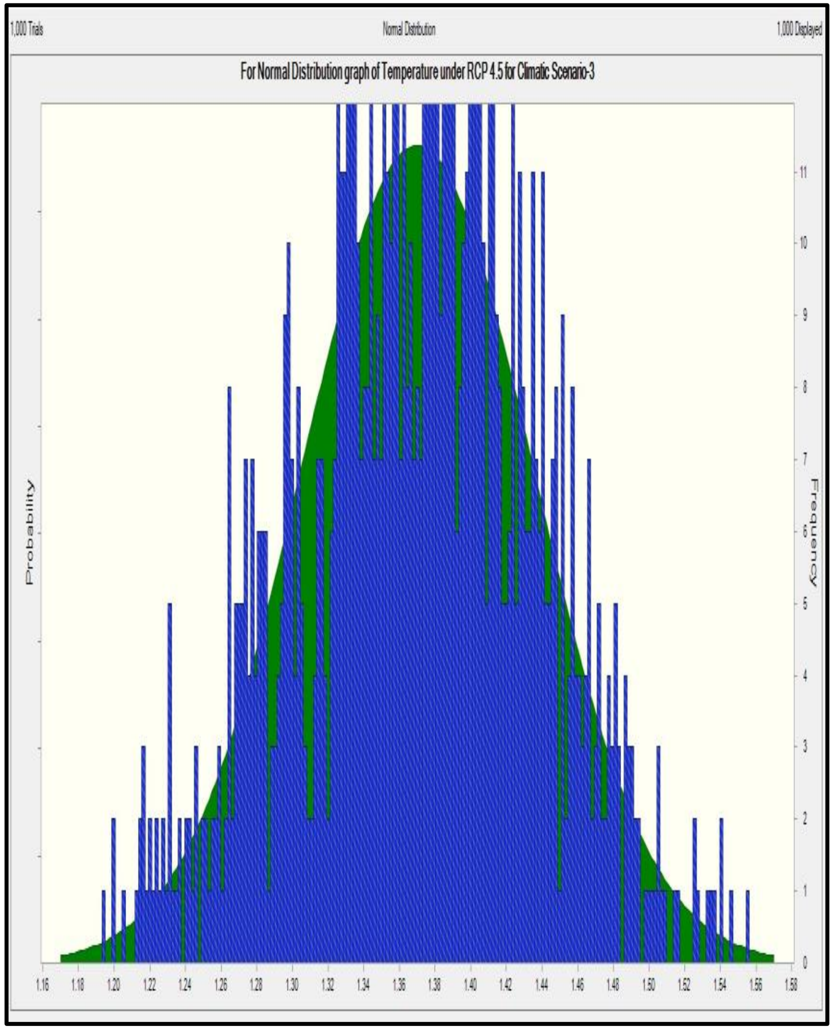


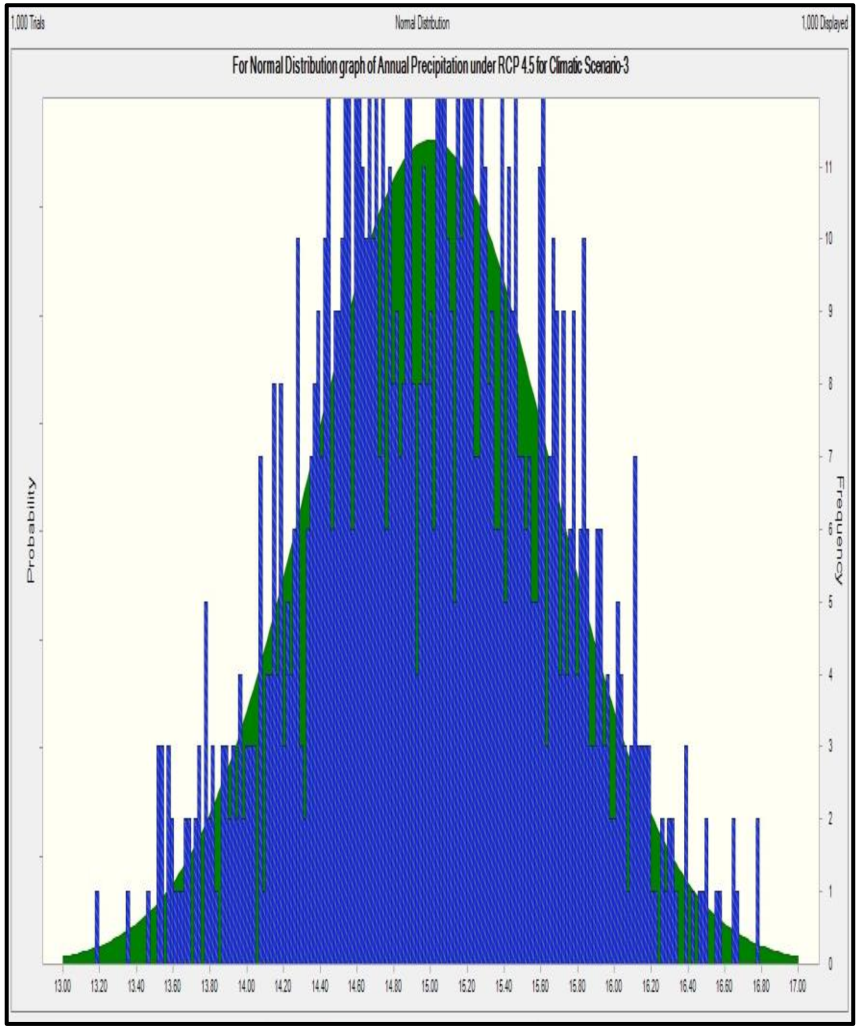
For Climatic Scenario-2





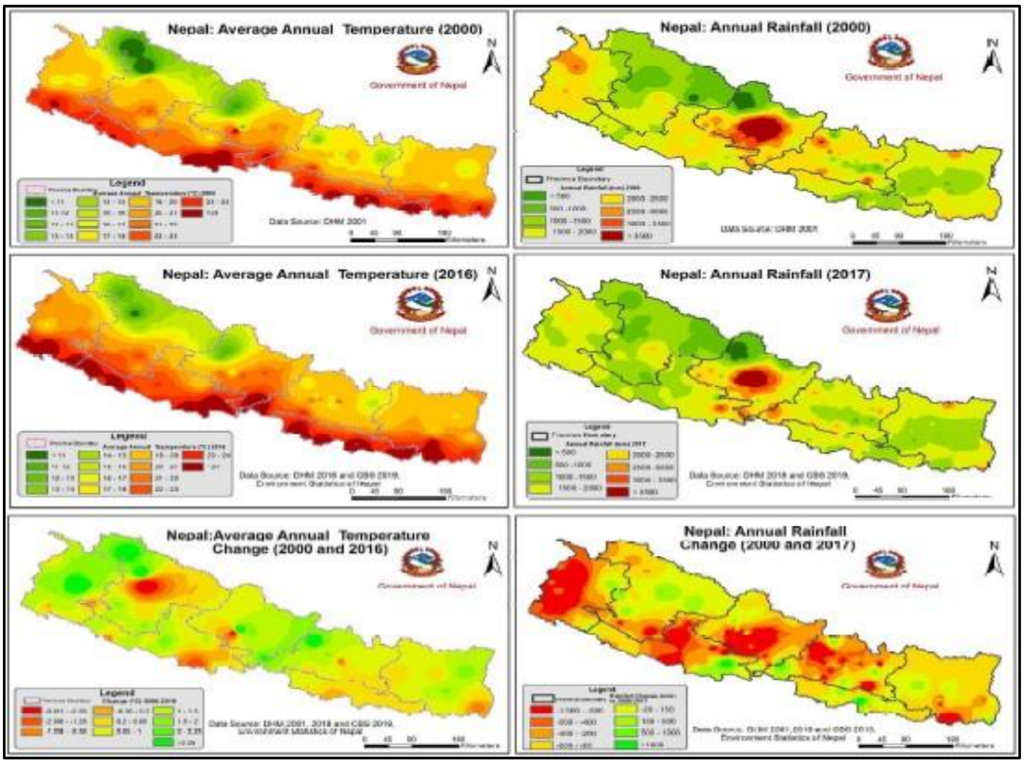
For Climatic Scenario-3



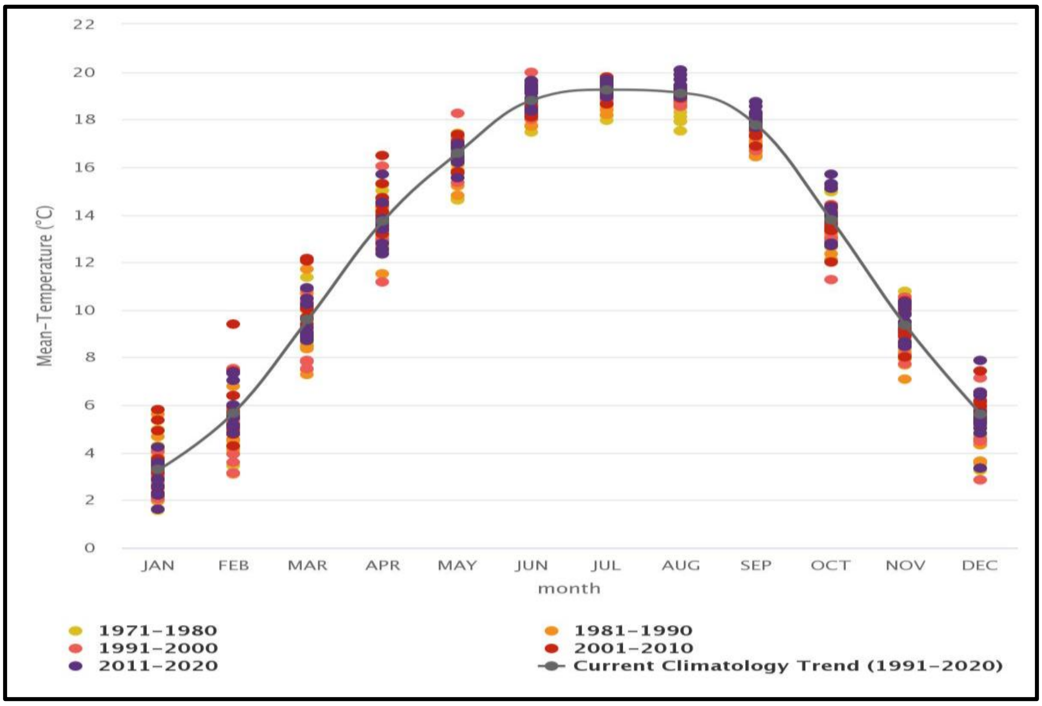


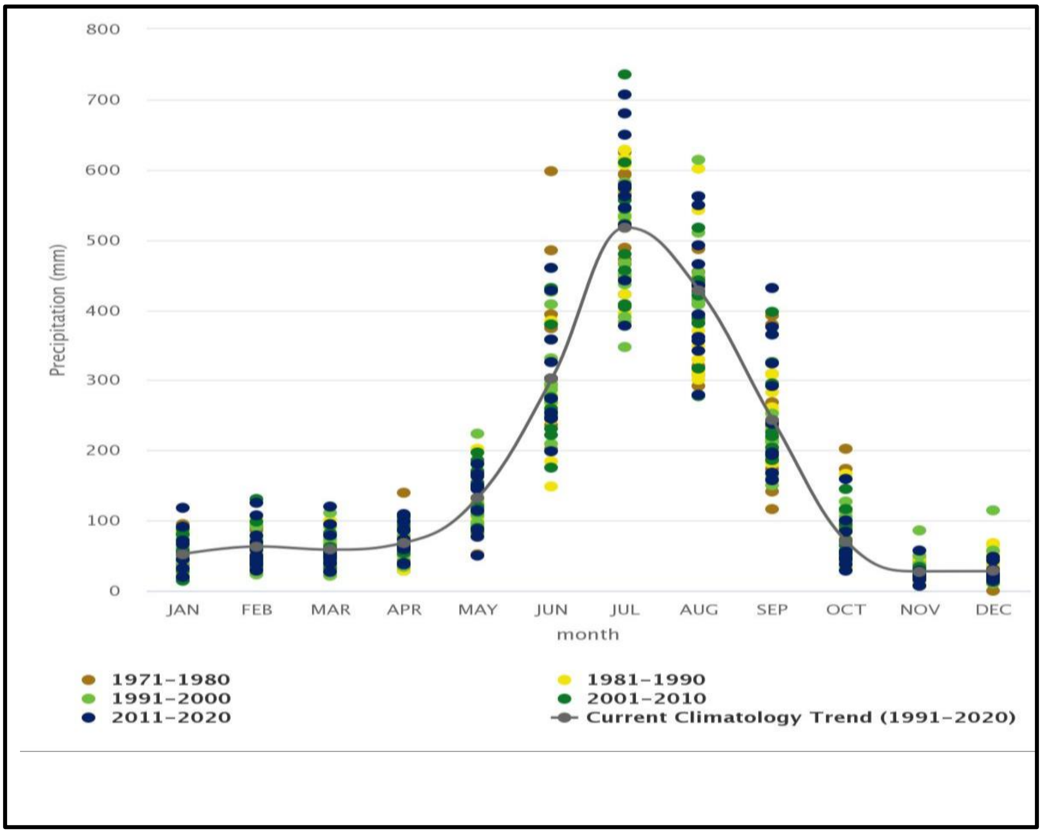
APPENDIX F: TEMPERATURE AND RAINFALL TRENDS

The average annual temperature and annual rainfall pattern of the Nepal from 2000 to 2017 (*NAP 2021-2050*) is presented as below:



The Variability and Trends of Mean – Temperature & Precipitation of the Nepal across Seasonal Cycle from 1971 to 2020





Precipitation (mm)
800
700
600
500
400
300
200
100
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
month
1971–1980
1981–1990
1991–2000
2001–2010
2011–2020
Current Climatology Trend (1991–2020)

Impact of Variation in Climatic Parameters on Hydropower Generation

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