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Impact of Climate Change on Naulsing Gad Storage Hydropower Project (410 MW), Jajarkot

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, a thesis entitled **"Impact of Climate Change on Naulsing Gad Storage Hydropower Project (410MW), Jajarkot"** Submitted by Krishna Bahadur Khadka in partial fulfillment of the requirements for the degree of Masters of Science in Water Resources Engineering.

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ABSTRACT

Nepal is going through an unprecedented deficit of electrical power particularly in dry season. This is mainly due to the lack of reservoir type hydropower projects. For the reservoir project, the impact of climate change should be incorporated during planning, design & implementation for long term sustainability and effectivity. The past recorded data analysis and projected future data analysis is essential to draw relevant conclusions.

Climate change study in long term aspect is very important to maximize the benefit from any reservoir project. Prediction of future flow scenarios using models like HEC-HMS model developed by Hydrologic Engineering Center, US Army Corps of Engineers, a numerical models is essential and is used for the climate change impact study of Naulsing Gad Storage Hydropower Project.

The simulation was performed on different Scenario of long term average flow for the period of 2015-2100. Naulsing Gad scheme being a single purpose reservoir project, simulation was carried out with a lone objective of assessing and maximizing the project benefits in long run incorporating the climate change impact on the basin. The flow scenarios in immediate future(2015-2044), mid-term future(2045-2074) and long term future(2075-2104) was predicted using HEC-HMS model and flow trend, maximum, minimum, Q_{40}, flood analysis & energy change trend analysis was performed for all RCP scenarios. Furthermore, the past recorded data of discharge precipitation and temperature of projected area was also analyzed and past trend and projected future trend was compared.

HEC-HMS, the simulation model used in this study, performed quite robustly in simulating future operation discharge. The future discharge in all RCP scenario is found to be increasing and also future flood & energy is increasing in most cases. Past data also showed increasing trend of extreme precipitation and temperature in most stations. So, impact of climate change on river flow considered in this study is of indicative nature and hence should be given almost importance in any further planning, design and implementation of Naulsing Gad Storage HEP for long term sustainability & effectivity.

Keywords: Climate change, RCP, FDC, RCM, GCM, HEC-HMS, Geo-HMS, Scenario

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ACRONYMS AND ABBREVIATIONS

AOGCM	Atmosphere Ocean General Circulation Models
AR5	Fifth Assessment Report
CCMA	Canadian Centre for Climate Modeling and Analysis
CanESM2	Canadian Earth System Modeling
Cumecs	Cubic meter per second
DHI	Danish Hydraulic Institute
DEM	Digital Elevation Model
DHM	Department of Hydrology and Metrology
DSS	Decision Support System
DP	Dynamic Programming
ER	Evaporation Rate
et al.	and others (from the Latin et *alii*)
etc.	and so forth (from the Latin *et cetera*)
FS	Feasibility Study
GA	Genetic Algorithm
GCM	General Circulation Model
Geo-HMS	Geospatial hydrological modeling system
GIS	Geographic Information System
GLOF	Glacier Lake Outburst Phenomena
GUI	Graphical User Interface
GWh	Giga-Watt hour
Ha	Hector
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System

HMGN	His Majesty Government of Nepal
HSY	Himalayan Sediment Yield
HWL	Head Water Level
INPS	Integrated Nepal Power System
ICIMOD	International Committee for Integrated Mountain Development
IOE	Institute of Engineering
i.e.	That is (from the Latin *id est*)
IPCC	Inter-governmental Panel on Climate Change
JICA	Japan International Co-operation Agency
MAF	Monthly Average Flow
MCM	Million Cubic Meters
MW	Mega-Watt
NEA	Nepal Electricity Authority
NSE	Nash – Sutcliffe Efficiency
PMP	Probable maximum precipitation
PMF	Probable maximum Flood
PPT	Precipitation
PROR	Peaking Run of River
PRECIS	Providing Regional Climates for Impact Studies
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RegCM4	Regional Climate Model
ROR	Run of River
SRTM	Shuttle Radar Topographic Mission

Sq. km	Square Kilometer
SDSM	Statistical Down Scaling Method
SRM	Snowmelt Runoff Model
TWL	Tail Water Level
TU	Tribhuvan University
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat

1. INTRODUCTION

1.1 General

The major rivers of Nepal are fed by melt-water from over three thousand glaciers scattered throughout the Nepal Himalayas. These rivers feed irrigation systems, agro-processing mills and hydroelectric plants and supply drinking water for villages for thousands of kilometers downstream.

Climate change will contribute to increased variability of river runoff due to changes in timing and intensity of precipitation as well as melting of glaciers. Runoff will initially increase as glaciers melt, then decrease later as the glaciers disappear. Climate change may alter rainfall and snowfall patterns. The incidence of extreme weather events such as droughts, storms, floods and avalanches is expected to increase. This can lead to loss of lives and severely reduce agricultural production. Traditional wisdom and knowledge to cope with such natural hazards that once ensured food security may no longer prove effective.

Climate change has been a major global issue since last decade and serious concerns have arisen at national and international level to assess the nature and extent of changes. Himalaya regions are sometime referred as third pole which has 34660 km2 of glacier reserved. Higher temperatures will increase the ratio of rain to snow accelerate the rate of snow – and glacier melt; and shorten the overall snowfall season. Since the end of the Little Ice Age, the temperatures have been generally increasing and the majority of the world's glaciers are retreating (IPCC, 2001). Increasing temperature shifts the permanent snowline upward. This could cause a significant reduction of water storage in the mountains, which is likely to pose serious problems of water availability to many people living downstream. The Himalayan glaciers are melting faster in recent years than before (IPCC, 2007). However, the degree of sensitivity may vary among the river systems. The magnitudes of snowmelt floods are determined by the volume of snow, the rate at which the snow melts and the amount of rain that falls during the melt period (IPCC, 1996). Because the melting season in the Himalayas coincides with the summer monsoon season, any intensification of monsoon or accelerated melting would contribute to increased summer runoff that ultimately would result in increased risk of flood disasters (IPCC, 2001). Stream -flow in most of the rivers in Nepal is at a minimum in early spring because flows recede rapidly after the summer rains.

This period of minimum flow is problematic for the run-of-river hydroelectric facilities. Snow fed rivers provides sustained flow even during this critical period through the melt-water contribution. A possible decrease in river runoff, as indicated by most projections, would reduce not only the electricity generation of existing plants but also the total hydropower potential of Nepal. In addition, there might be significant declines in the dry season flows and an increasing trend in the number of flooding days because of climate change, which is critical for hydropower generation. The flows of glacier-fed rivers first increase due to warming, as more water is released by the melting of snow and glaciers. As the glaciers get smaller and the volume of melt-water reduces, the dry season flows will no longer be supported by melt-water and eventually will decline. Therefore, the reduced dry season flow caused by a temperature rise could result in reduced hydropower potential. Climate change will lead to increased climatic variability, which would lead to increased frequency and magnitude of hydro meteorological extreme events.

1.2 Objectives of study

The main objective of this study is to identify the impact of climate change on Naulsing Gad Hydel project. Beside the overall objective; the specific objective can be listed as below:

- To identify changes in discharge/ water level impact by climate change process.
- To analyze seasonal variation of water availability in the Rivers.
- To find out the Annual / seasonal/ extreme/ low flow/ high flow change with long term data analysis.
- To quantify and analyze the impacts of climate change on discharge, hydrological parameters.
- To analyze past recorded data to study the past temperature & precipitation change trend analysis & and compare it with projected future results.
- To suggest the policy makers and developer for appropriate policy for the future to manage the future impacts on the effect of climate change on river discharge.

1.3 Scope of Work

The scope of the work is divided into four main tasks, namely data collection and data analysis, which are briefly described below:

Task 1: To collect the data and information about discharge and major meteorological parameters of Naulsing Gad HEP.

Task 2: To process the data

Task 3: Use different GCMs Models to define changes in climate that are applied to observed climate input data to create calculated data series.

Task 4: To feed those calculated data series into appropriate hydrological model to assess the resulting changes in river flow.

Task 5: To use the derived future discharge for climate impact study.

Task 6: To study the past recorded data critically to assess the past trend of climate change.

Task 7: To compare the result derived from past recorded data and future projected discharge.

Key Activities

- Based on the above scope of work, the following key activities carried out in relation to the project:
- Collecting and cleaning of observed precipitation, temperature and discharge data from DHM stations
- Screening of the hydro-meteorological stations based on their data quality
- Setting up, calibrating and validating HEC-HMS hydrological model using the current data.
- Preparation /Acquisition of future precipitation data for three RCPs 2.6, 4.5 and 8.5.
- Re-running HEC-HMS model using future climate data
- Comparison of the discharges of the three RCPs and three future time windows with the baseline period for selected station.

1.4 Limitation of Study

Followings are the the limitations of study:

- The research is done neglecting the seepage loss, multidimensional impact of climate change in river basin and effect of upstream development.
- The catchment consists of about 50 Km^2 snow area and hence, snowmelt runoff model (SRM) model within this area gives the better results.
- The evapotranspiration is assumed to be constant for future also.
- The sediment scenarios analysis is not carried out while analyzing various aspect of climate change impact.

2. LITERATURE REVIEW

2.1 General

Water availability and its quality will be the main pressures on, and issues for, societies and the environment under climate change (IPCC, 2007). Only a proper management of water with its wise use will be the solution to cope with climate change impacts on water resources. Water demand has been increased day by day with the increased population, change of economy and development of new technology. The changing patterns of rainfall and temperature will have effect on agriculture water use, hydro powers and drinking water etc. Study of climate change and its impact assessment is very essential for an efficient, effective and sustainable planning of water resources.

Researchers have come up with different results regarding climate change in the regional and national levels. For example, The climatic trend in Nepal reveals a significant warming in recent decades (Devkota et al., 2014 and Lohani, 2007) and climate change scenarios for Nepal across multiple general circulation models show considerable convergence on continued warming, with averaged mean temperature increases of 1.2°C and 3°C projected by 2050 and 2100 respectively (World Bank, 2009). Miller et al. (2012) states that the impacts of glacier melt changes are minimal for the Ganges where increases in rainfall may lead to increased flows but with greater variability. Another study shows that annual average discharge and seasonal discharges would increase with rise in temperature in the Kali Gandaki basin with future climate (Manandhar et al., 2013). Similarly Immerzeel et al. (2013) have found out that precipitation and temperature are projected to increase in the Ganges basin until the end of this century. They conclude that increases in future runoff are projected in the Langtang watershed as a result of increasing precipitation. In Nepal, the average annual rainfall of the country is about 1,750 mm (Devkota, 2010 and GoN, 2010), ranging from more than 5,000 mm in the central part of the country to less than 250 mm in the higher north. In the recent years, the events increase the possibility of climatic extremes such as irregular monsoon pattern, droughts and floods (Devkota et al., 2013 and Gautam, 2008).

The basis of climate change analysis in river basin is to study the hydrologic cycle through hydrological model for future climate scenarios. A model is a simplified representation of reality. Hydrological modeling has become essential in water resources research and management from small watersheds to large basins. Hydrological models help understand the past and current state of water resources in the study basin and provide a way to explore the implications of management decisions and biophysical changes (Johnston and Smakhtin, 2014). Universities, academic institutions, research centers and consultants have developed a number of hydrological models all across the globe with specific objectives, capabilities and use. Some models are designed to look at only hydrology of a catchment whereas some have additional capabilities such as agricultural modeling, water management and energy generation, among others.

Previous studies (Gourbesville, 2008) indicate that in the next 30 years water use will increase by 50% in the world. By 2025 about 4 billion people will live under conditions of severe water stress. Continuous deterioration in water quality in most developing countries is additional challenge. Therefore, development of priority water infrastructures and improvements of water management have essential and complementary roles in contributing to sustainable growth and poverty reduction in developing countries. One way of improving water management is through increasing the efficiency of utilization of dam reservoirs.

2.2 Rainfall Runoff modeling approaches

Hydrologic system model is an approximation of the actual system occurring in natural world which links the input parameters, processes it using different mathematical concepts and finally gives the output. In hydrologic system model the input for the system are measurable hydrologic variables like precipitation, temperature, wind speed, humidity etc. Similarly, the processing structure is the set of mathematical equation which may be physically based or empirical for transformation of input to output. Finally, the output parameters are again the hydrological parameters which have to be obtained after analysis. In a system approach a whole system is deconstructed into smaller sub-system and each sub-system is studied separately. For simplicity, a hydrological basin can be considered as a series of interlinked process and storage from the precipitation to the stream discharge at the lowest outfall. The hydrologic phenomenon of precipitation runoff relationship can be modeled by a set of mathematical and physical abstractions, which can describe the different phases of the hydrological cycle. Though the main concept of every model is the same, i.e. to obtain the desired output from the analysis of input the models differ in the way they represent the physical processes of the hydrologic cycle and the catchment characteristics. These differences could be both spatially and temporally. Some model could represent whole basin as one system and some models could represent the basin by number of sub-system. Similarly, the time scale of analysis can differ from model to model. Some models are capable of representing the system on smaller time scale and some represent in bigger time scale.

A wide variety of rainfall runoff models are currently used by researches, however the applications of these models are dependent on the purpose for which the models are made. Broadly classifying the hydrological model, it could be classified into three major classes namely black box, conceptual model and physically based model. Black-box models are those models which are fully based on observation data. These models need calibration and validation of input-output relationship e.g. Unit hydrograph. Conceptual models are the models in which the basic processes (snowmelt, infiltration) are separated to some extent, but their algorithms are essentially calibrated input-output relationship e.g. HEC-HMS. Physically based modes are those in which mathematical-physical equation is used to represent the system. Since all the physical relation are used these model does not require calibration and validation. But, the main problem with these models is the complex calculation and the need of numerous parameters as input. But, this categorization cannot be rigidly followed since there is considerable overlap between various models. Therefore, the rainfall runoff model can be classified into number of groups based on different method of classification. Few of the classification methods are:

1. Lumped, Distributed and Semi-distributed model:

A distributed model is one in which the spatial variations of characteristics and processes are considered explicit, while in a Lumped model, these spatial variations are averaged or ignored. Semi-distributed models consider the spatial variability of model parameters and variables partially by dividing a basin into a number of smaller sub-basins, which in turn are treated as a single unit. The parameters within a sub-basin are considered to be constant.

2. Deterministic or Stochastic model:

Deterministic model is that model, in which all input parameters and processes in a model are considered free of random variation and known with certainty. Instead if the model describes the random variation and incorporates the description in the predictions of output it is called stochastic model.

3. Measured or fitted parameter model:

Measured-parameter model is one in which model parameters can be determined from system properties, either by direct measurement or by indirect methods that are based upon the measurements. Fitted-parameter model includes parameters that cannot be measured. Instead, the parameters must be found by fitting the model with observed values of the input and the output through calibration and validation method.

In recent years due to the enhancement of the computing power, several computer-based mathematical models have been developed. These computer-based precipitation-runoff simulation models may or may not incorporate snow/glacier melt part. While hydrological simulation of watershed area covering the snow and glacier by rainfall runoff model it is very important to include snow and glacier melt in these model. For this a simple concept can be applied. The melt volume of the snow and glacier could be assumed as precipitation and can be given as input to the model for simulation.

Runoff modelling with TANK model:

The TANK model is a simple Lumped model developed in 1950s by Sugawara and his colleagues. TANK model is a kind of deterministic, lumped, conceptual model. It is widely used model around the world due to its simple concept and need of less parameter for calibration and validation. In TANK model, whole basin is assumed to be composed of vertically arranged TANKs. The number of TANKs to be arranged depends upon the analysis required and on the characteristics of the basin. Here, precipitation is put into the top of the first TANK along with the reduction as evapo-transpiration. The part of the precipitation is allowed to pass into second TANK at the bottom and part of the precipitation is allowed to flow out of the TANK representing surface flow. Similarly, the part of the flow into the second TANK is allowed to pass in third TANK and part of it is passed outside representing base flow. The process is continues to last TANK in which there is only base flow. The basic principle of this model is that discharge is proportional to storage. Proper care must be taken during the use of this model. This model is not useful for large basin.

Runoff modeling with HEC-HMS:

The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) system is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. So, HEC-HMS is considered the standard model in the United States for hydrologic design problems such as the design of drainage systems, quantifying the effect of land-use change on flooding, etc. In this system a model of watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for the representing each flux. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the seamless movement between the different parts of the program.

This model draws on over 30 years' experience with hydrologic simulation software. The initial program release was Version 1.0. The maiden release included a number of "firsts" for HEC including object-oriented development in the C^{++} language and multiplatform support in a program with a GUI. The second major release was called Version 2.0 and focused on continuous simulation. Here soil moisture accounting method was added. The third major release was called Version 3.0 and introduced new computation features and brand new GUI. The meteorological model was enhanced with new methods for snowmelt and potential evapo-transpiration simulation. The fourth major release was called Version 4.0 and focused primarily on new computation features. A broad range of surface erosion and sediment transport features were added to the sub-basin, reach, reservoir and other elements. The enhancement of the program is running on.

This program has an extensive array of capabilities for conducting hydrologic simulation. For the representation of a watershed basin model is used. The basin model can be made in HEC-GeoHMS or simply the tools in the software could be used. The available elements in the software are sub-basin, reach, junction, reservoir, diversion, source and sink. An assortment of different methods is available to simulate infiltration losses. Options for event modeling include initial constant, SCS curve number, exponential, Green and Ampt and Smith Partange. The three-layer soil moisture accounting method can be used for continuous modeling of complex infiltration and evapo-transpiration environment. Canopy and surface components can also be added when needed to represent interception and capture processes. Seven methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark, Snyder, and SCS techniques. The modified Clark method, Mod Clark is a linear quasi-distributed unit hydrograph method. Five methods are included for representing base-flow contributions to sub-basin outflow. These methods are recession, the constant monthly method, linear reservoir method, the nonlinear Boussinesq. Similarly for hydrological routing there are total of six methods namely lag method, Muskingum method along with straddle stagger method, modified plus method, kinematic wave, Muskingum-Cunge method. The channel losses can be simulated by using constant loss or by percolation method. Similarly, reservoirs can also be represented along with the control of the pumps. The diversion structures can also be represented by using available methods like user-specified function, lateral weir, and pump station, observed diversion flows. Metrologic data analysis is performed by the meteorological model and includes shortwave radiation, long wave radiation, precipitation, evapo-transpiration and snowmelt.

Every simulation system has limitation due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation, and simplified flow representation. All of the mathematical models included in the program are deterministic means that every time a simulation is computed it will yield exactly the same results as previous times it was computed. Plans are underway to develop a stochastic capability through the addition of Monte Carlo analysis tool. The model uses constant parameter values meaning that the parameters are time stationary. The design of the basin model only allows for dendritic stream networks. It means that like a tree the stream network combines with each other while moving down and form a bigger river. The key idea is that a stream does not separate into two streams. The design of the process also does not account for computing a simulation for backwater in the stream network.

2.3 Climate change

Nowadays climate change has become a common topic in different International forums. It has been a major global issue and serious concerns have arisen at national and international level. Water sector is the most sensible part and is greatly affected by climate change. Climate change has enormous effect on hydrology and hydrological cycle and poses challenge on future water availability. Climate change impacts mainly in Himalayan region may have significant changes in precipitation, temperature as well as on glacier retreat causing in the change of flow pattern thus affecting socio-economic life of people. The effect of climate change has already seen on the discharge of rivers and its greater effect has been seen on those rivers originating from high mountains that contains the glacier and snow. Higher temperatures will increase the ratio of rain to snow; accelerate the rate of snow and glacier melt and shorten the overall snowfall season. Similarly, climate change can cause erratic rainfall events (i.e. higher intensity of rains but less number of rainy days and unusual rain) with no decrease in total amount of annual precipitation thus changing the river flow pattern.

In the recent years, Nepal is witnessing continuous disturbances in its ecology due to climate change resulting floods, severe landslides, GLOFs, etc. The global mean temperature is expected to increase between 1.4 to 5.8°C over hundred years. Nepal's temperature has increased by 1.8°C during last 32 years. In Nepal average temperature increase was recorded as 0.06°C per year and that in Terai and Himalayas was 0.04°C and 0.08°C/year respectively (Shrestha et al, 1999). It may be due to solar radiation absorbed by glacial lakes as well as radiation absorbed by land because of snow melting in the Himalayan region. A major finding of the ICIMOD work is that glaciers in Nepal retreated dramatically between 1994 and 1998. Himalayan glaciers are retreating at rates ranging from 10 to 60m per year and many small glaciers have already disappeared.

Climate change can cause rapid melting of snow and glacier in higher Himalayan region thus causing the rise in flow in summer. Similarly the change in the precipitation causes variation of flow in the river. This will eventually cause change in the inflow to any water resources project. Therefore, climate change data should be used in the calibration and validation of any hydrological model.

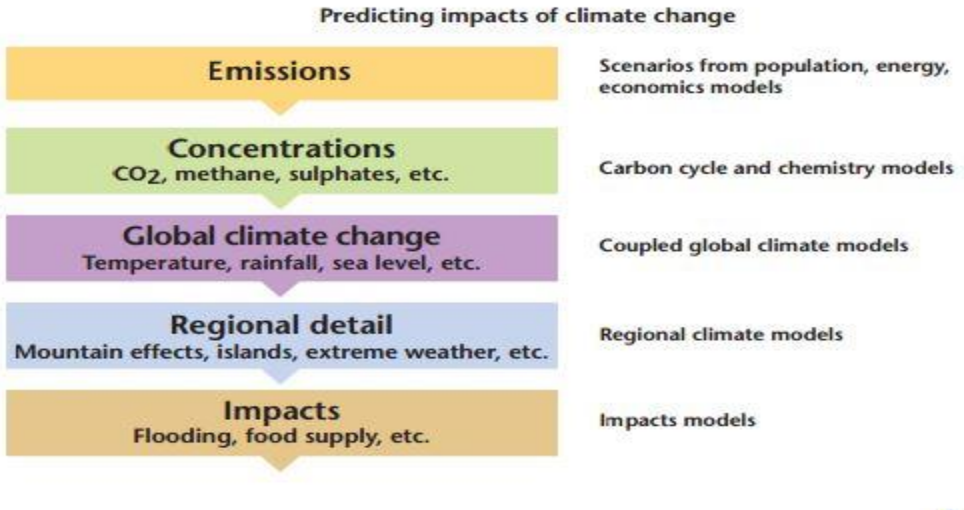
Global Climate Models (GCM), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally or regionally averaged estimates of the climate response, only GCM, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis (IPCC, 2013). GCM depict the climate using the three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600km. Examples of GCM developed at different parts of the world are CCSR/NIES, CGMI2, ECHAM4/OPYC3, HadCM2/3 and Model. A problem with GCMs is that they have coarse resolution and are unable to resolve fine scale features at regional scale. Hence, they need to get downscaled to bridge this gap and get situation specific information about climate to investigate climate change impacts.

The recent climate data published by IPCC is AR5. There has been a fundamental change from AR4 to AR5 in the way that the IPCC is dealing with the climate change scenarios. Unlike the sequential form of scenario development in AR4, the AR5 provides better integration, consistency and consideration of feedback with the new parallel approach. Representative Concentration Pathways (RCPs) are newly developed greenhouse gas emission scenarios and adopted in the IPCC's Fifth Assessment Report AR5 (IPCC, 2013). The scenario set containing emission, concentration and land-use trajectories is composed of four RCPs, RCP2.6, RCP4.5, RCP6 and RCP8.5 representing radiation forcing values respectively +2.6, +4.5, +6 and+8.5 W/m^2 in the year 2100. RCP2.6 assumes that global annual Greenhouse gases emissions (measured in CO_2 equivalence) will peak between 2010 and 2020 with emissions declining substantially thereafter. Emissions in RCP4.5 will peak around 2040, and then decline. Similarly in RCP6, emission will peak around 2080, and then decline and in RCP8.5, emission continue to rise through the 21st century.

2.4 Climate Change Models

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis, (IPCC, 2014)

GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans. Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments. Moreover, many physical processes, such as those related to clouds, also occur at smaller scales and cannot be properly modeled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterization. This is one source of uncertainty in GCM-based simulations of future climate. Others relate to the simulation of various feedback mechanisms in models concerning, for example, water vapour and warming, clouds and radiation, ocean circulation and ice and snow albedo. For this reason, GCMs may simulate quite different responses to the same forcing; simply because of the way certain processes and feedbacks are modeled. (IPCC, 2014)



Source: PRECIS Handbook

Figure 2-1: The main stages of climate change scenarios

General Circulation Model

It is often shortened to GCM. The abbreviation can also refer to a global climate model, which is almost the same as a General Circulation Model, but is used when the model is dealing specifically with global climate change. A GCM can be used for weather forecasting, understanding climate and predicting climate change. General Circulation Models are divided into several types depending on which factors they include in their simulation of climate and weather. The two main types of General Circulation Models are Atmospheric and Ocean models. Combing these two Models make up a complete climate model. When two systems are connected the resulting more complete system is called a 'coupled' model. Coupled atmosphere-ocean General Circulation Models (AOGCMs) are the models most often used to make the predictions of future climate. These predictions are sometimes called scenarios. Advanced coupled atmosphere-ocean General Circulation Model can also to some extent predict regional climate changes.

Regional Climate Model (RCM)

It is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (GCM). GCMs are typically run with horizontal scales of 300km. RCMs can resolve features down to 50km or less. This makes for a more accurate representation of many surface features, such as complex mountain topographies and coastlines. It also allows small islands and peninsulas to be represented realistically, whereas in a global model their size (relative to the model grid box) would mean their climate would be that of the surrounding ocean.

The Precis Model

PRECIS stands for "Providing Regional Climates for Impacts Studies". It is a regional modeling system developed at the Hadley Centre at the UK Met Office .Precis is based on an improved version of the atmospheric component of the Hadley Centre coupled global model HADCM3.PRECIS is a limited area model and may be used with horizontal resolutions of 50 and 25 km with 19 levels in the atmosphere (from the surface to 30 km in the stratosphere) and four levels in the soil.

The initial and boundary conditions for PRECIS are provided by HADAM3P-a global atmosphere-only model with a resolution of order of 150 km, forced by surface boundary conditions (sea-surface temperature and sea-ice fraction) from HADCM3 and observations. PRECIS uses the same formulation of the climate system as its parent GCM which helps to ensure that the regional model provides high resolution regional climate change projections consistent with the continental scale climate change from the GCM.

Downscaling of Climate Change Projections

General Circulation Model (GCM) provides regularly spaced, coarse resolution (1-4 degrees ~ 100-400 km) climatologically and meteorological information, in 3-dimensional gird, by integrating hydrodynamic equations, which are derived from three basic conservation laws and ideal gas law. Atmospheric processes, which deals with fine spatial scale, such as clouds, convective precipitation, etc. may not perfectly resolve in GCMs as the detailed topography and land-use are not properly represented. GCM results are more representative over the countries, where the topography is flat and away from the coastlines due to the fact that minimal and unified local forcing over a large region. Nevertheless, GCM results would be acceptable for climate change adaptation studies, developing general trends of rainfall and temperature, etc. but not for more specific analytical tasks such as forecasting of changes in agriculture yields at farm level, estimating surface runoff, River discharges at basin level etc.

Therefore, climate information derived from GCMs need to be downscaled for a country like Nepal, as it has a varying topography towards northern parts of the country. Regional Climate Model (RCM) is the most reliable option for downscaling coarse resolution GCMs outputs to fine resolutions (12, 20 and 25 km) grid in incorporating local topography in Nepal and neighborhood. PRECIS, RegCM4, SDSM and WRF models were used for downscaling of GCMs climate information over Nepal.

2.5 Representative Concentration Pathways (RCP)

The amount of future greenhouse gas emissions is a key variable. Development in technology, changes in energy consumption & generations, land use, global and regional circumstances and population growth must be also considered.

The IPCC AR5 is due for publication in 2013-2014 A.D. it's finding will be based on a new sets of scenarios that replace the Special Reports on Emission Scenarios (SRES) standards employed on two previous reports. New scenarios are called RCP. There are 4 pathways RCP2.6, RCP4.5, RCP6 & RCP8.5. RCP2.6 also known as RCP3-PD forcing for each RCP and PD means peak and decline. "One high pathways" for radioactive forcing reaches greater than 8.5 w/m^2 by 2100 A.D. and continues to rise for some amount of time, 2 intermediate stabilization pathways in which radiative pathways forcing is stabilized at approximate 6 w/m^2 and 4.5 w/m^2 after 2100 A.D. and one pathways where radiative forcing peaks at approximately 3 w/m^2 before 2100 A.D. and declines. This emissions scenarios includes the time paths for emissions and concentrations of full suite of GHGs and aerosols and chemically active gases as well as land use and land cover.

RCP are referred to as pathways in order to emphasize that primary purpose is to provide time dependent projections of atmospheric greenhouse gases (GHG) concentrations. The term pathways meant to emphasize that it is not only a specific long term concentration or radiative forcing each that outcome.

2.5.1 Why Scenarios?

Scenarios of different rates and magnitudes of climate change provide a basis for assessing the risk of crossing the identifiable threshold in both physical change and impacts on biological and human system.

In climate research, scenarios describe plausible trajectories of different aspects of future that are constructed to investigate potential consequences of anthropogenic climate change. Scenarios represent many of major driving forces including process, impact and potential responses. The goal of working with scenarios is not predict the future but to better understanding uncertainties and alternatives future in order to consider how robust different decisions or options may be consider a wide range of possible future. Each RCP contains starting value and estimated emission up to 2100 based on assumptions about economic activity, energy sources, population growth and others socio-economic factors.

2.6 Climate change related studies in Nepal

Development of climate change scenario is essential in assessing the vulnerability of various sectors like agriculture and water resources etc in undertaking proper adaptation measures and identifying the sensitivity of different sectors to climate change.

Different studies have been conducted in Nepal for the assessment of climate change. Water related extreme events occurring more frequently because of complex interaction between climatology, hydrology and ecology in mountainous region like Nepal are likely to dictate a changed path in water resources management in development of the country.

The impact of climate change scenario is studied in Bagmati watershed as a selected hydrological unit. The study shows the increasing trend of temperature at various gauging stations. The frequent occurrence of extreme events in recent decade than previous as well as apparent change in monsoon pattern is some of the indicators of climate change in Nepalese climate.(ref: Proceedings of year end workshop, 2003, Climate change in water resources in South Asia)Another study on Hydrological changes and its impact on water resources of Bagmati watershed, Nepal show that the changed scenario of water availability needs to be properly taken into account for long term planning. There would be change in hydroelectric power generation capacity of power plants, change in water availability of other sector of water use.

Changes in flows of hydropower have a direct impact in hydropower generation because hydropower decreases with lower flows. (Sharma and Shakya, 2006). Two GCM models Canadian climate Centre model and Geophysical Fluid Dynamics Laboratory model are applied to analyze the effect of climate change in two places of Nepalese eastern part

Dhankuta and the western part Pokhara. The model results shows the summer months get more increased precipitation and relatively decreasing precipitation in winter months. But the limitation of models is the low resolution due to the unsatisfactory inclusion of topographical features. The results of climate change will be improved with high resolution of grid. (Yogacharya, 1997)

The Regional circulation models (RCM) with greater resolution are likely to represent the topographical features more precisely which will improve the confidence in results of climate change.

2.7 Tools to assess the impact of climate change

Hydrological phenomena are extremely complex and may never be fully understood. However, in the absence of perfect knowledge, they may be represented in a simplified way by means of system concept. Hydrologic system model is an approximation of the actual system. Its input and output are measurable hydrologic variables and its structure is a set of equations linking the inputs and outputs and central to the model structure is the concept of system transformation. In a system approach a whole system is deconstructed in to smaller sub-system and each sub-system is studied separately. For simplicity, a hydrologic basin can be considered as a series of interlinked process and storage from the precipitation to the stream discharge at the lowest outfall.

The general description of tool HEC-HMS for rainfall runoff simulation to assess the impact of global climate change is given as following.

2.7.1 Choice of HEC-HMS model

The U.S. Army Corps of Engineers 'Hydrologic Modeling System' (HEC-HMS) is new - generation software for precipitation-runoff simulation. HEC-HMS is a significant advancement over HEC-1 in terms of both computer science and hydrologic engineering. HEC-HMS is comprised of a graphical user interface, integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities. The Data Storage System, HEC-DSS (HEC, 1994), is used for storage and retrieval of time series, paired-function, and gridded data, in a manner largely transparent to the user.

Hydrologic modeling system is designed to simulate the precipitation-runoff process of dendritic watershed system. It is designed to be applicable in wide range of geographic area including large River basin water supply and flood hydrology and small urban or natural watershed runoff. HEC-HMS is a useful tool to carry out the study regarding urban drainage, flow forecasting, future urbanization impact. In this model hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence.

HEC-HMS model has been used to carry out the impact study of imperviousness. Although this model is extensively used for flood hydrology, it has also been used to carry out the study regarding the future urbanization impact in some cases (Ref; Castro Valley watershed). This model is a single event as well as continuous model. So the study is intended to predict the likely flood hazard in the years to come using the daily rainfall and runoff data.

The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt, and soil moisture accounting. Advanced capabilities are also provided for gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark). Supplemental analysis tools are provided for parameter estimation, depth-area analysis, flow forecasting, erosion and sediment transport and nutrient water quality. The software features a completely integrated work environment including a database, data entry utilities, computation engine and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the software. Simulation results are stored in HEC-DSS (Data Storage System) and can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

2.8 Review on past studies:

2.8.1 Review of Feasibility Study of Naulsing Gad HEP

The "Identification and Feasibility Study of Storage Projects" (IFSSP) was carried out during 1999-2001 to identify potential storage hydropower projects in the country so that the projects could be implemented to fulfill the increasing demand of peak power in the INPS. Naulsing Gad Storage Hydroelectric Project was conceived as one of the attractive project among the screened and ranked storage projects during (IFSSP-2001). This coarse screening and ranking phase of the study has identified a total of 93 potential storage projects. Naulsing Gad Storage Hydroelectric Project has been one of the selected projects recommended for the further.

Project Development Department (PDD), Engineering Services, NEA has conducted the Feasibility Study of Naulsing Gad Storage Hydroelectric Project. All the required works for the feasibility study have been completed. The EIA study of the project and transmission line will be conducted in the coming year.

2.8.2 Identification of Gaps on Past Study

The various past study incorporates the various aspects like smart design consideration, integrated and multipurpose use of resource, project risk reduction and sensitivity analysis, financial and economic analysis, sediment simulation and so on. However, impact of climate change which is growing global issues in the contemporary world is not duly adopted and incorporated in planning, design and decision making of various nation pride water resource projects like Naulsing Gad Storage HEP, 411 MW. So, to bridge up such problem, this thesis work is focused on identification of potential impacts of climate change on Naulsing Gad HEP.

2.9 Conclusion of literature review

Climate change has been a common topic at the present date. The effect of climate change could be seen on various fields but its main and large effect is seen in the water resource sector. Particularly the snow and glacier of Himalayan region are the first to bear this effect of climate change. Due to climate change the glaciers of Himalayan region are retreating at faster rate. This has huge impact on the socio-economic condition of the country. Due to climate change the ice reserve in Himalayan is decreasing day by day. This has effect the local hydrological processes in those areas. Not only that the pattern of rainfall has also changed. There has been erratic rainfall (i.e. higher intensity of rains but less number of rainy days) in Nepal in past year. This unusual pattern of rainfall has caused variation of flow pattern of river. The dry season flow is decreasing but there is flashflood at irregular interval. This change in flow pattern has caused serious problem in water resource project. Hence proper study of climate change impact on hydrological process is needed for proper utilization of water in future. The most recent climate change scenario released by IPCC is documented in AR5 report. In this new report IPCC has incorporated new greenhouse gas emission scenario. So, in present date AR5 data has to be used in climate change analysis.

For analysis of hydrological processes, generally the system is modeled by different hydrological model. There are varieties of the hydrological models which can be used to simulate the response of the catchment to particular type of input. HEC-HMS model is one of option to simulate the catchment response.

It is very important to predict the future flows using the projected precipitations so that the different aspects of storage project can be analyzed successfully. Assessment of low flows, high flows, flood, and energy in different time windows of future in different RCP scenarios gives the indicative information which will helpful for planning of project considering long term sustainability of project.

3. DESCRIPTION OF THE PROJECT

3.1 Location

Naulsing Gad Storage Hydroelectric Project is located in Jajarkot District in the mid-western development region of Nepal between Longitude 82^{0}14’00”E - 82^{0}19’12”E and Latitude 28^{0}47’28”N-28^{0}58’00”N. Naulsing Gad is a tributary of the Bheri River in the Karnali Basin. The dam site of the project is located just down strteam of the confluence of Udheri Khola which is approximately 9.25 km upstream from the confluence of the Naulsing Gad and the Bheri-River and the powerhouse is located on the left bank of Naulsing Gad River approximately 500 m upstream from the suspension bridge at Dali. Originally, the powerhouse was identified at the right bank Bheri-River. Due to the adverse geological condition, the powerhouse location is shifted to the left Bank of Naulsing Gad river.

Naulsing Gad Storage Hydroelectric project does not have motorable access till now. Khalanga being, the district headquarters of Jajarkot a 107 km long Chhinchhu-Jajarkot feeder road has been constructed to connect district headquarter with the national road network. Presently this road has been extended upto Rinna village located on the right bank of Bheri River. A bridge over Bheri River will be required to reach the Powerhouse site. Additional 25 km of project road between Power house to headwork will also be required for the project construction.

Apart from Chhinchhu- Jajarkot feeder road, Middle Hill Lok Marg and Puspa Lal Marg (Dolpa Rajmarg) are also being constructed in the vicinity of the project area. Middle Hill Lok Marg starts from Dang-Mushikot-Rari Village and goes up to the proposed powerhouse of Nalsin Gad Hydropower Project. Another road network being constructed in the vicinity of Naulsing Gad Hydropower Project is Dolpa Rajmarg which is known as Puspa Lal Marg as well. This road starts from Salli Bazar and ends at the Dunai. Several options seem to be available to access the Project area. Therefore, the detailed design study of the access road with alternative will be carried out and finalize the most feasible route to the project area in coming fiscal year.

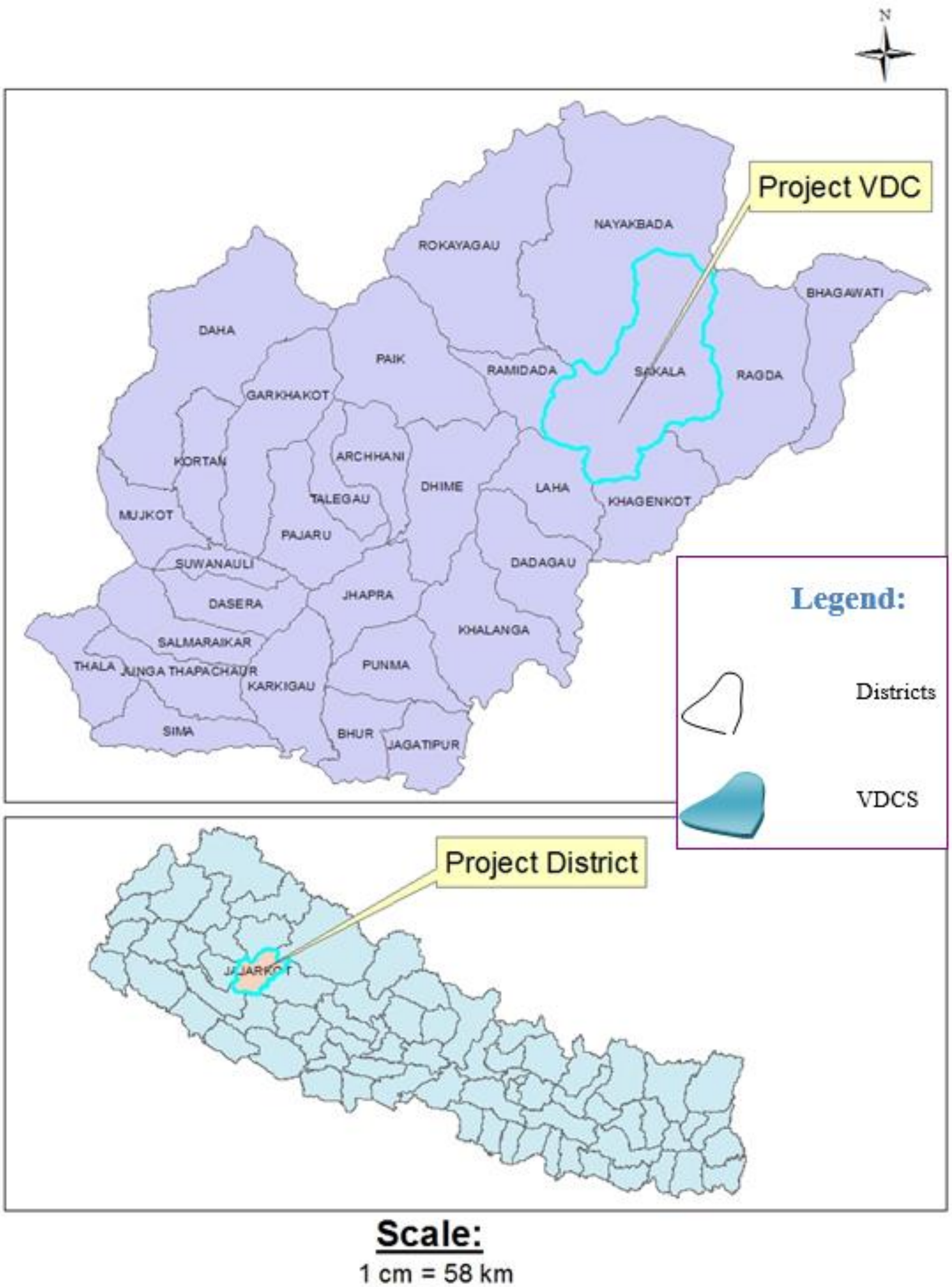


Figure 2-2: Study Area

3.2 Main Features of Project

Name of the Project	Naulsing Gad Storage Project
District	Jajarkot
Location of Project Site	
Longitude	$82^0$14’00”E- $82^0$19’12”E
Latitude	$28^0$47’28”N- $28^0$58’00”N
Name of the River	Nalsyagu Gad River
Types of Scheme	Storage
Project Road	25 Km
Geology	
Dam Site	Dolomite with frequent intercalation of black Shale
Tunnel	Limestone, Dolomite and Shale
Powerhouse	Sandstone
Seismic Survey	58 Profiles – Total 8165 meter
Core Drilling	14 Holes – Total 602 meter
Hydrology	
Catchment Area (up to Dam site)	571.5 Km^2
Average Precipitation	1718 mm
Average Monthly Flow	29.35 m^3/s
Flood Discharge (1 in 20 years wet season)	675 m^3/s
Flood Discharge (1 in 10,000 years wet season)	2244 m^3/s
Probable Maximum Flood (PMF)	4488 m^3/s
Sediment Yield	3960 t/km^2/year

Diversion Tunnel

Shape	Circular shaped
Type	Concrete Lined
Diameter	8.0 m
Length	1145 m

Reservoir

Full Supply Level (FSL)	1570 masl
Minimum Operating Level (MOL)	1498 masl
Total Storage Volume	419.6 Million m^3
Live Storage Volume	296.3 Million m^3

Dam

Types of Dam	Rock fill with impervious core
Maximum Height above Foundation	200 m
Crest Elevation	1580.30 masl
Length of Crest	545.00 m
Width of Crest	10 m

Spillway

Gated Spillway

Type	Ogee shaped, open chute way with gate controlled weir, flip bucket and plunge pool
Design flood	2978 m^3/s
Overflow Crest Elevation	EL. 1555.30 m
Effective overflow Width	24 m
Length of Spillway Chute	420.00 m

Length of Plunge Pool	170 m
Radial Gate (No. and W x H)	2 Nos. (12.0 m x 18.0 m)
Side Spillway/Emergency Spillway	
Type	Ogee shaped, non gated side channel overflow weir
Design flood (1 in 1000 years)	1510 m^3/s
Overflow Crest Elevation	EL. 1570.50 m
Effective overflow Width	120 m
Main Intake	
Type	Sloping
Deck Level	1575 masl
Intake Tunnel	1 No.
Invert Level of Intake	1481.0 masl
Intake Openings	6 Nos. (5.0 m x 3.5 m)
Headrace Tunnel	
Length	8215 m
Type	Concrete lined modified Horse Shoe
Finished Diameter	5.7 m
Surge Tank	
Type	Restricted Orifice
Height	171.97 m
Diameter	12.0 m
Max Water Level	1607.30 masl
Min Water Level	1454.12 masl

Top Level	1610.97 masl
Invert Level (of tunnel below surge tank)	1439.00 masl
Inclined Shaft	
Shape	Circular
Inclination	60^o
Height	564 m in two stages
Diameter	4.2 m
Length	900 m
High Pressure Tunnel	
Type	Steel Lined Penstock
Length	90 m
Finished Diameter	3.9 m
Powerhouse	
Type	under Ground
Size (L x W x H)	106 m x 13 m x 31 m
Tail Water Level (turbine pit)	867.6 masl
Turbine	
Type of Turbine	Vertical Axis Pelton Turbine
Number of Units	4 No
Turbine Centre Line Level	872 masl
Installed Capacity	410 MW (4 x 102.5 MW)
Tailrace	
Shape	Inverted D shaped
Type	Concrete Lined

Length	1280 m
Size (W x H)	4.5 m x 3.5 m
Tail Water Level (at outlet)	863.3 masl

Transmission Line

Length	112 km
Voltage	400kV
Circuit	Double
Interconnection Point	Kohalpur S/S

Power

Maximum Gross Head	698.0 m
Designed Net Head	635.5 m
Maximum Net Head	684.36 m
Minimum Net Head	612.11m
Design Discharge	75.0 m^3/s
Maximum Power Flow	77.92 m^3/s
Minimum Power Flow	69.69 m^3/s
Overall Efficiency	87.80%
Maximum Daily Generation	12 equivalent hrs
Minimum Daily Generation	2 equivalent hrs
Installed Capacity	410 MW

Energy

Dry Season Energy (November to April)	643.29GWh
Wet Season Energy (May to October)	150.88GWh
Spill energy	611.89GWh

Total Energy	1406.06 GWh
Regulated Energy	56.19%
Plant Factor (Spill Energy not Considered)	22.11%
Discharge Utility Factor (Spill Energy not Considered)	53.83%
Plant Factor (Inclusive of Spill Energy)	39.15%
Discharge Utility Facto (Inclusive of Spill Energy)	98.09%

Project Cost

Total Project Cost (Base Cost)	737.39 MUS$ (2012 Price Level)
Local; Component	157.75MUS$ (2012 Price Level)
Foreign Component	579.64 MUS$ (2012 Price Level)
Installation Cost	1799 US$ per kW

Financial Indicators

Total Project Cost (Base Cost)		NRs. 64,153.19 Million
		(At exchange rate of NRs. 87.00)
Financial Cost		NRs. 108,263.74 Million
Total Debt		NRs. 81,608.08 Million
Total Equity		NRs. 26,655.66 Million
Interest Rate on Debt		8.0%
Expected Return on Equity	:	14%
Average Energy Cost (for 14 % return on equity)		NRs. 9.11/kWh for Total Energy (2012 Price Level)
Average Energy Cost (for 14 % return on equity)		NRs. 16.09/kWh for Saleable Energy (2012 Price Level)

Debt Service Ratio	:	2.0 (in the first year of operation)
Financial Internal Rate of Return	:	8.9%
Benefit Cost Ratio	:	1.15 (at 10% discount rate)
Pay Back Period	:	12.18 Years
Analysis period	:	25 years

Economic Indicators (Based on Avoided Cost)

Economic Internal Rate of Return	:	21.88%
Benefit Cost Ratio	:	2.25 (at 10% discount rate)
Net Present Value	:	738.64 MUS$ (at 10% discount rate)
Specific Energy Cost for Hydro	:	16.31 US cent/kWh (at 10% discount rate)
Specific Energy Cost for Thermal	:	36.72 US cent/kWh (at 10% discount rate)

Economic Indicators (Based on LRMC Cost)

Winter Season Energy Rate	:	12.72 US cent per kWh
Summer Season Energy Rate	:	3.82 US cent per kWh
Emission Benefit	:	0.598 US cent per kWh
Economic Internal Rate of Return	:	11.12%
Benefit Cost Ratio	:	1.13 (at 10% discount rate)
Net Present Value	:	76.57 MUS$ (at 10% discount rate)

Environmental Impact Assessment (Based on Prefeasibility Study)

Relocation of Houses	150
Inundation of Farmland	270 ha.
Inundation of Forestland	290 ha.
Number of People Affected	825
Environmental Cost	11.81 MUS$

3.3 Topographic Characteristic of the Basin

Naulsing Gad River is one of the major tributaries of Thuli Bheri River and the river system of Karnali River Basin. The catchment area of Naulsing Gad River consists of mountain range having the altitudes from El. 2100 to El. 5100. These are the major source of snow melt run off on the basin. The total area of Naulsing Gad River basin up to intake site is 571.5 km^2, in which, about 50 km^2 is covered by snow. Glacier lakes are not identified in this basin. The river flows almost north to south. The detail break down of catchment area is shown in Table 3-1.

Table 3-1: Catchment Characteristic

Area(km^2)	**Naulsing Gad Dam Site**	**P/H**
Total Area	571.5	622
Area Below 5000 m	571.5	622
Area Below 3000 m	521.5	573

Source: Feasibility Study, NEA, 1998

The average precipitation of the catchment area is found to be 1718.69 mm with instantaneous wind speed recommended to be 120 km/hr.

3.4 Meteorological and Hydrological Stations

The established meteorological station (station no. 418) by DHM is used for study purpose. The precipitation data from 1990-2014 are used for analysis purpose. Similarly, gauging station viz Thuli Bheri, Rimna (station no. 265) & SinjhaKhola, Diware (station no. 225) are used for predicting flows at Naulsing Gad basin.

3.5 Stream Flow Data

Flow data from 2008 to 2012 are acquired from Naulsing Gad Project Development Committee.

Table 3-2: Observed Flow data

Observed Monthly Average Discharge Data at Intake of Naulsing Gad HEP:					
Month/Year	2008	2009	2010	2011	2012
Jan		12.4	9.7	10.3	11.9
Feb		11.0	8.5	9.7	8.4
Mar		10.0	9.1	8.6	7.5
Apr		10.0	7.4	10.6	7.7
May	17.6	14.2	6.8	12.5	9.3
Jun	63.4	14.3	8.8	34.1	14.5
Jul	117.3	60.2	96.4	174.2	60.9
Aug	151.3	118.2	102.5	172.7	
Sep	70.8	75.0	98.7	94.2	
Oct	37.3	45.5	87.3	61.1	
Nov	22.6	16.9	15.6	41.6	
Dec	16.2	10.1	11.3	25.3	

3.6 Climate study

All regions of the Naulsing Gad basin experience the effects of the Indian southwest monsoon which occurs between mid-June and the end of September on average, occasionally extending to mid-October. In this period relative humidity is at their maxima, high temperatures are less extreme compared to the period immediately prior to the monsoon and stream flows in all areas experience huge amount of the annual runoff. The intensity of precipitation varies throughout the basin according to the degree of exposure, south facing slopes receiving more rainfall than those facing north and, due to the orographic nature, precipitation intensities increase with elevation.

3.7 Precipitation

The precipitation data is important for assessment of climate change impact. The precipitation data of project area are collected. The precipitation station of vicinity area is identified. The followings data of precipitation are used for various purposes of study i.e. precipitation of station no. 418, being the station within catchment used for HEC-HMS Modeling. Other for trend analysis of vicinity area.

Table 3-3: Rainfall station

S. No.	Station	Index No.	Lat (North)	Long (East)
2	Jumla	303	$29^0$17'	$82^0$10'
3	Sheri Ghat	305	$29^0$08'	$81^0$36'
20	Mushikot (Rukumkot)	514	$28^0$38'	$82^0$29'
Note: Index No. 418 is inside the basin.				

3.8 Evaporation

The evaporation is determined from ET_O / CWR8 software using the temperature, humidity, sun shine hours, wind velocity etc. of vicinity area as acquired from DHM which is as follows. The input data for the software are as follows:

Table 3-4: Input data for ETo Software

Months	Input Parameters of ETo Software/FAO				
	$T_{max.}$	$T_{min.}$	Avg. Humidity (%)	Wind Speed(m/s)	Avg. Sunshine Hour(hr./day)
Jan	13.6	-4.0	64.8	2.1	6.6

Feb	14.6	-1.9	64.9	5.2	7.0
Mar	18.1	1.3	65.0	6.1	7.1
Apr	21.6	4.8	63.9	6.1	8.4
May	24.9	9.4	67.8	6.5	6.9
Jun	26.8	14.5	74.4	5.0	7.3
Jul	26.8	16.9	80.5	5.5	3.8
Aug	25.5	16.5	83.9	4.4	3.9
Sep	24.8	14.0	83.5	4.6	4.8
Oct	22.0	6.5	74.3	5.6	8.9
Nov	18.8	0.6	70.8	3.6	8.4
Dec	15.3	-3.1	68.3	4.5	7.8

The output of the software is given as follows:

Table 3-5: Output of ETo Software

Output of ETo Software & CWR8 Software /FAO		
Months	Average ETo (mm/day)	
	ETo Software	CWR8 Software
Jan	1.9	1.92
Feb	2.9	2.84
Mar	3.8	3.71

Apr	4.8	4.7
May	5.2	5.07
Jun	4.9	4.84
Jul	3.9	3.92
Aug	3.4	3.4
Sep	3.2	3.32
Oct	3.7	3.75
Nov	2.7	2.81
Dec	2.5	2.5
Average	3.58	3.57

3.9 Temperature

ETo software to estimate evaporation requires the temperature and hence, temperature data from 1990 to 2005 of stations 303, 312 & 514 are acquired from DHM.

Table 3-6: Average Min. & Max. Temperature

Average Max. & Min. Temperature-1990-2005		
Description	Tmax	Tmin
Jan	13.56	-4.01
Feb	14.61	-1.87
Mar	18.12	1.33
Apr	21.62	4.75

May	24.93	9.37
Jun	26.79	14.55
Jul	26.84	16.94
Aug	25.51	16.51
Sep	24.83	13.96
Oct	22.03	6.46
Nov	18.81	0.62
Dec	15.34	-3.12

3.10 Humidity

ETo software requires humidity and hence, humidity of DHM stations no. 514, 303 & 312 are used.

Table 3-7: Average Humidity of Project Area

Average Monthly Humidity:1990-2005	
Months	Avg. Humidity (%)
Jan	64.8
Feb	64.9
Mar	65.0
Apr	63.9
May	67.8
Jun	74.4

Jul	80.5
Aug	83.9
Sep	83.5
Oct	74.3
Nov	70.8
Dec	68.3

3.11 Wind

The wind and sunshine hour as required for ETo Software to estimate evaporation are acquired from DHM.

Table 3-8: Average Wind Speed

Average wind speed :2000-2009 (Station No.:303)		
Months	Wind Speed(m/s)	Wind Speed(Km/hr)
Jan	2.11	7.60
Feb	5.18	18.66
Mar	6.14	22.11
Apr	6.11	22.00
May	6.54	23.55
Jun	5.04	18.15
Jul	5.46	19.65
Aug	4.45	16.01

Sep	4.62	16.62
Oct	5.61	20.18
Nov	3.59	12.91
Dec	4.50	16.20

3.12 Sunshine Hour

The sunshine hour as required for ETo Software to estimate evaporation are acquired from DHM. The sunshine hour data of 2002-2009 of station no. 303 are collected which are presented in following table.

Table 3-9: Average Wind Speed

Average Sunshine Hour:2002-2009 (Station No.303)	
Months	Avg. Sunshine Hour(Hr./day)
Jan	6.6
Feb	7.0
Mar	7.1
Apr	8.4
May	6.9
Jun	7.3
Jul	3.8
Aug	3.9
Sep	4.8

Oct	8.9
Nov	8.4
Dec	7.8

4. RESEARCH METHODOLOGY

4.1 General

For the analysis DEM were downloaded using ArcGIS 10 from (http//earthexplorer.usgs.gov//). After the processing of the DEM, all the data required for the modeling in HEC-HMS is generated. Daily precipitation data of the meteorological stations with in the vicinity of the Naulsing Gad Basin is acquired from DHM. Thiessen Polygons are prepared and weights of the meteorological stations in the delineated Sub basins are calculated. These weights of the sub-basin are one of the input data in HEC-HMS model. After the completion of all the inputs in the HEC-HMS model the model is run for selected period of the time. Now the output results are compared with the observed discharge at the gauging stations. If the output results are not found matched with the observed data within the specified limit, the parameters of the watersheds are calibrated again to bring the watershed parameters to optimum level. The calibration process terminates once the deviations of the output results compared to the observed data falls within the specified limits. After the calibration of the parameters, it is validated for the selected year. By using the calibrated & validated parameters, the model is used to generate the future flow data by using corrected RCM precipitation data by the HEC-HMS. For determining the effect of climate change precipitation obtained from AR5 scenario is used. Finally the effect of climate change on stream flow is analyzed.

To accomplish the work and to achieve the objectives as stated in this study, following methodology has been adopted:

- Acquisition and processing of hydrological and meteorological data.
- Downloading and processing of DEM.
- Extraction of Area-Altitude distribution of watershed area.
- Estimation of evaporation using ETo / CWR8 Software
- Preparation of hydrological, meteorological and watershed characteristic data for input to HEC-HMS.
- Model execution and Simulation run in HEC-HMS.
- Calibration and validation of HEC-HMS at selected outlet of the basin.

- Use of future precipitation and temperature data obtained from AR5 scenario for analyzing the effect of climate change on river flow.
- Analysis of change in hydropower potential at selected points due to climate change.

4.2 Acquisition and processing of data

The acquisition and processing of different relevant data for this study are explained in following sections:

4.2.1 Topographic data

The DEM of study area is prepared by downloaded DEM data using arc GIS 10.Thus formed DEM is to extract topographic variables, such as basin geometry, stream networks, slope, aspect, flow direction, etc.

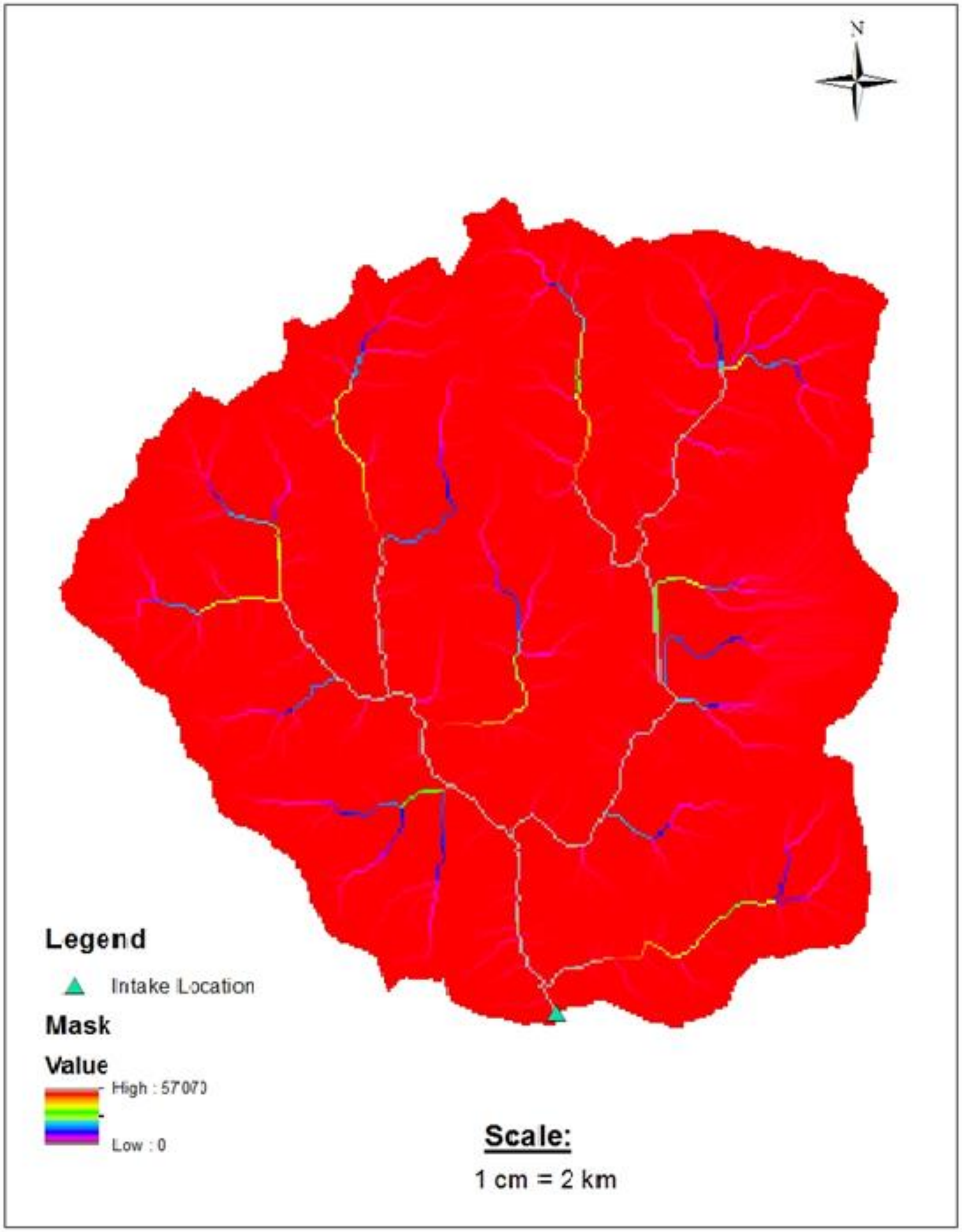


Figure 4-1 Catchment River Network Delineation

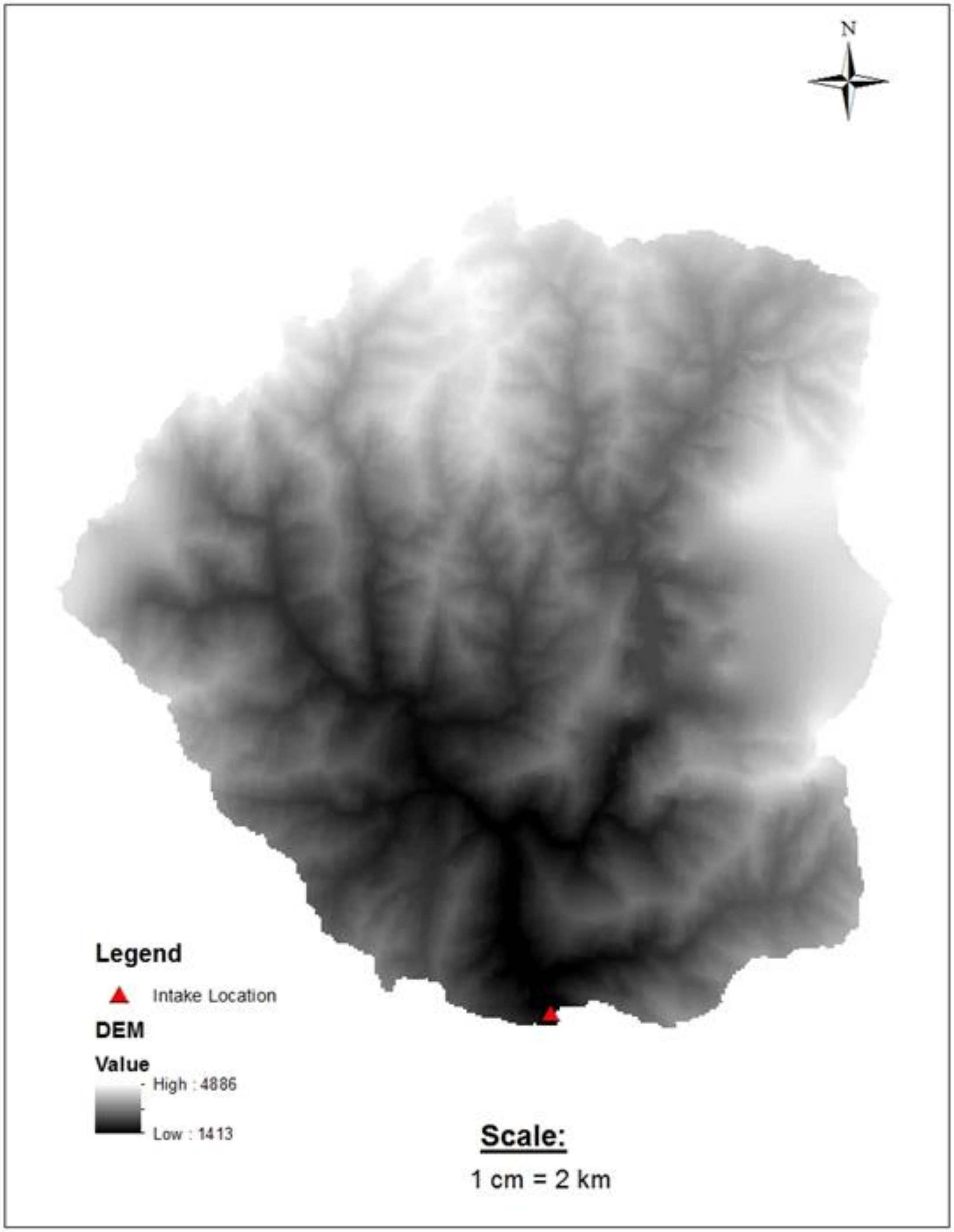


Figure 4-2: DEM of Naulsing Gad

4.2.2 Hydrological data

The hydrological data are required for calibration and validation purposes, for which daily discharge data provided by Naulsing Gad Storage Hydel Project Development Committee is selected. The data of 2008 to 2010 is used for calibration and is validated for the year 2010-2012. The hydrological data are acquired from DHM, Hydrology division.

4.2.3 Precipitation data

The precipitation data are used as model input in HEC-HMS to simulate catchment response. In this study, daily precipitation data of 1 rainfall station within the Naulsing Gad watershed was used. The daily precipitation data is acquired from DHM, Meteorological section from 1990-2014. Furthermore, the precipitations data of vicinity of project area are also used for the trend analysis of the precipitation.

For the future precipitation to estimate future flows, the selection of GCM depends on its availability and applicability for the study using desired method. In the present study, for the statistical downscaling method using SDSM, GCM predictors of Fifth Assessment Report (AR5) is required. Thus, the second generation of Earth System Model, CanESM2 is essential for the study purpose. CanESM2 is the fourth generation coupled global climate model developed by the Canadian Centre for Climate Modeling and Analysis (CCCMA) of Environment Canada. Moreover, CanESM2 represents the Canadian contribution to the IPCC Fifth Assessment Report (AR5). The grid size of the predictors is 2.8125° by 2.8125°. For completion of this task, the AR5 GCM precipitation data after down scaling using SDSM Model and bias correction, RCM future Precipitation data for Naulsing Gad basin, more precisely Karnali basin was used.

4.3 Extraction of different hydraulic data for HEC-HMS modeling

For this purpose, HEC-GeoHMS extension in Arc-GIS is selected as it is designed for processing of DEM data to automatically generate some important HEC-HMS input files (basin and map file).

In HEC-GeoHMS, the following steps are accomplished in a sequence:

4.3.1Terrain Processing

A terrain model is used as an input to derive eight additional data sets that collectively describe the drainage patterns of the watersheds and allows for stream and sub basin delineation. The first five data sets in grid representation are the flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. The next two data sets are the vector representation of the watersheds and streams and they are the watershed polygons and the stream segments. The last data set, the aggregated watersheds, is used primarily to improve the performance in watershed delineation. After terrain pre-processing is completed, the resulting data sets serve as a spatial database for the study. With the information centralized in the spatial database, pertinent data sets can be extracted for subsequent on building the hydrologic models.

4.3.2 HMS Project Setup and Basin processing

In this step, the HMS project area is generated by the selection of the main outlet of the Basin as a project point in the flow accumulation map. Main nodes in the basin which are our prime interest of our studies and gauging stations for the calibrations are selected as Batch Points. As per the selection of the Batch points the delineated watersheds (sub basins) are modified automatically by the Hec-GeoHMS. itself. After the modification of sub basins, significantly small watersheds if formed are merged to form larger one as per requirement and minimizing possible errors in the future processes.

4.3.3 HMS model generation

This step includes auto-naming of sub-basins, reaches and junctions, generation of HMS schematics and adding coordinates to hydrologic elements. Finally, the HMS basin model to be used in HEC-HMS is generated including background map file.

4.3.4 HMS model generation

This step includes auto-naming of sub-basins, reaches and junctions, generation of HMS schematics and adding coordinates to hydrologic elements. Finally, the HMS basin model to be used in HEC-HMS is generated including background map file.

4. 4 Estimation of precipitation

Thiessen polygons are created based on the meteorological data of the study area using "Create Thiessen polygons" command in Arc GIS. Then the Thiessen polygon created is intersected to the sub basins which enabled to calculate gauge weight of each meteorological station form Sub basins.

$$W_i = \frac{A_i}{A}$$

Where, i = index for gauge stations

W_i= gauge weight

A_i = intersected Thiessen polygon area

A = Total area of sub-basin under consideration

The catchment of this basin occupies only one meteorological station i.e 418. This station is covered by Thiessen polygon and hence, no necessity of Thiessen Polygon.

4.5 Modeling of watershed in HEC-HMS

4.5.1 Basin model

Basin model generated by HEC-GeoHMS is imported in HMS. Basin model comprise of hydrologic network that contains HEC-HMS model elements and their connectivity are shown. This step creates an HMS Link layer, which shows the connectivity, and the HMS Node layer, which shows sub basin and junction node locations. Node locations for sub basins are placed at the center of the sub basin.

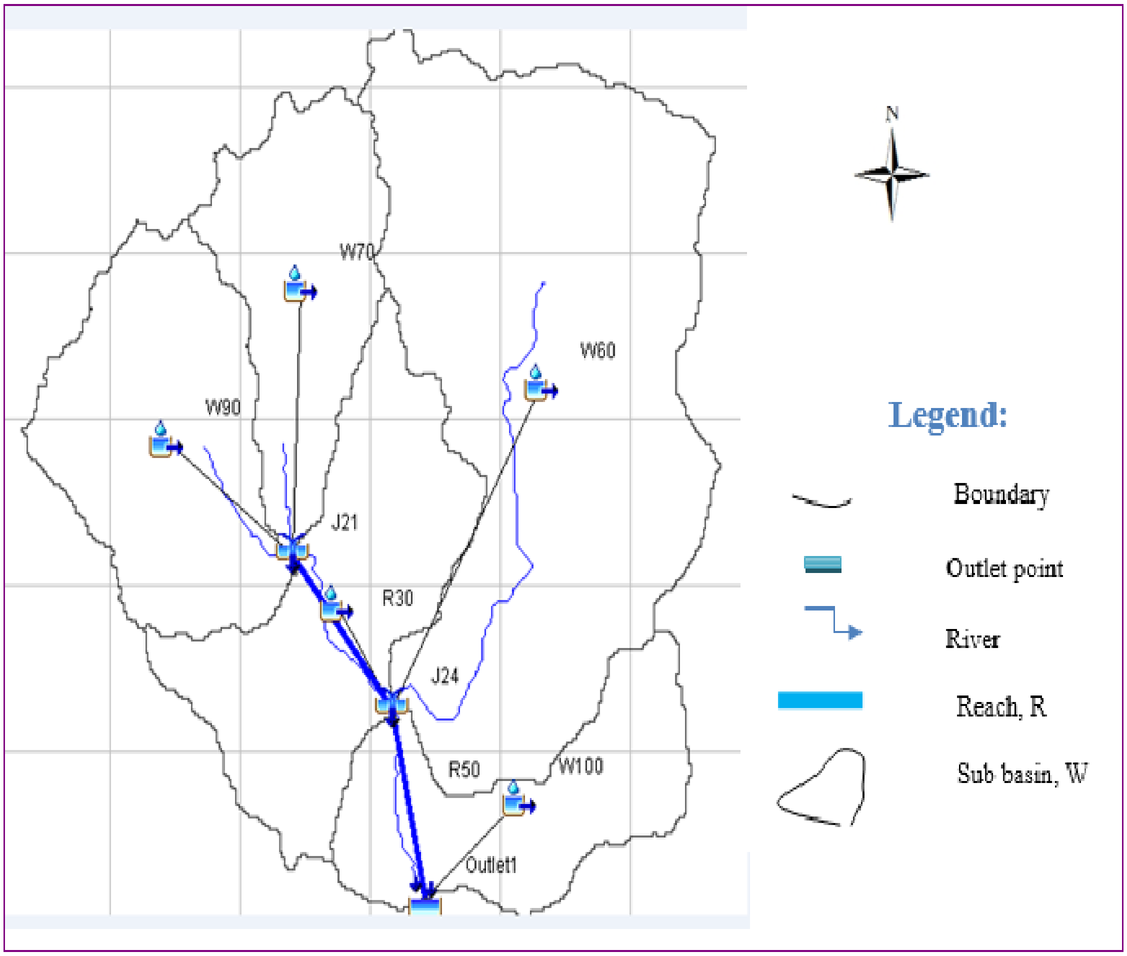


Figure 4-3: Basin Model in HEC-HMS

The Naulsing Gad basin comprises of 5 sub basins & 2 main reaches. The area and length of each basin and reach are given as follows:

Table 4-1 Sub Basin & Reach Details

S.N.	Sub Basin Designation	Catchment Area (Km^2)
1	W100	68.23
2	W80	97.81
3	W70	67.81
4	W90	93.59

5	W60	243.25
Total Catchment Area:		571.5
S.N.	Designation	Length of Reach (m)
1	R50	6940
2	R30	7825

The different models selected for rainfall-runoff simulation are as follows:

Loss model: Green & Ampt Loss Model

Runoff Transform model: Snyder's Unit Hydrograph

Base flow Model: Recession Model

Channel routing model: Muskingum-Cunge model

Canopy Model: Simple Canopy Model

Surface Model: Simple Surface Model

4.5.2 Green & Ampt Loss Model

Green and Ampt (1911) proposed a simple model based on Darcy's law. This model is based on assumption of a sharp wetting front, a constant hydraulic conductivity in the wetted zone and a constant negative water pressure at the wetting front. It relates the volume of infiltrated water to the time from beginning of infiltration. So the Green and Ampt infiltration model is a conceptual model of infiltration of precipitation in a watershed.

The model uses the Darcy's law to the wetted zone

$$F=\frac{K(L+S)}{L}$$

Where,

L=Distance from soil surface to the wetting front

S= Capillary sanction at the wetting front

K= Hydraulic Conductivity.

Using Continuity eq. we have $F= \eta L$

Where, η is the available porosity.

G-A model can be written as:

$f=K(F+\eta S)/F$

The hydraulic conductivity at any time (K_t) can be determined by the equation of

$$K_t = F-\eta\,(H+S)\,\frac{\left[\ln\left(F+\eta\left(H+S\right)\right)\right]}{\eta\left(H+S\right)}$$

Where, H is the height of ponding above the soil surface.

The parameters needed to use the Green & Ampt model are initial loss, volume moisture deficit, wetting front suction and hydraulic conductivity. Initial loss may be estimated in the same manner as the initial abstraction for other loss models however other parameters are estimated according to the soil type and texture.

4.5.3 Snyder's Unit Hydrograph

Snyder collected rainfall and runoff data from gauged watersheds, derived the UH as and parameterized these UH, and related the parameters to measurable watershed characteristics. For the UH lag, he proposed:

$T_p=CC_t\,(LL_c\,a)^{0.3}$

Where, C_t = basin coefficient; L = length of the main stream from the outlet to the divide; L_c = length along the main stream from the outlet to a point nearest the watershed centre; and C = a conversion constant (0.75 for SI and 1.00 for foot-pound system).

The parameters C_t and C_p are better to be found via calibration, as they are not physically-based parameters. Bedient and Huber (1992) report that C_t typically ranges from 1.8 to 2.2, although it has been found to vary from 0.4 in mountainous areas to 8.0 along the Gulf of Mexico. They also report that C_p ranges from 0.4 to 0.8, where larger values of C_p are associated with smaller values of C_t.

Alternative forms of the parameter predictive equations have been proposed. For example, the Los Angeles District, USACE (1944) has proposed to estimate T_p as:

$T_p=CC_t(L\,L_c a/\mathrm{sqrt}(s))^N$

Where, S = overall slope of longest watercourse from point of concentration to the boundary of drainage basin; and N = an exponent, commonly taken as 0.33.

Cudworth (1989) has proposed estimating T_p as a function of t_c, the watershed time of concentration. Time of concentration is the time of flow from the most hydraulically remote point in the watershed to the watershed outlet, and may be estimated with simple models of the hydraulic processes. Various studies estimate t_p as 50-75% of t_c.

Snyder peaking time and Snyder peaking coefficient is related with the imperviousness given by the different scientist as follows:

$C_t=7.81/I^{0.78}$

$C_p=0.89*C_t^{0.46}$

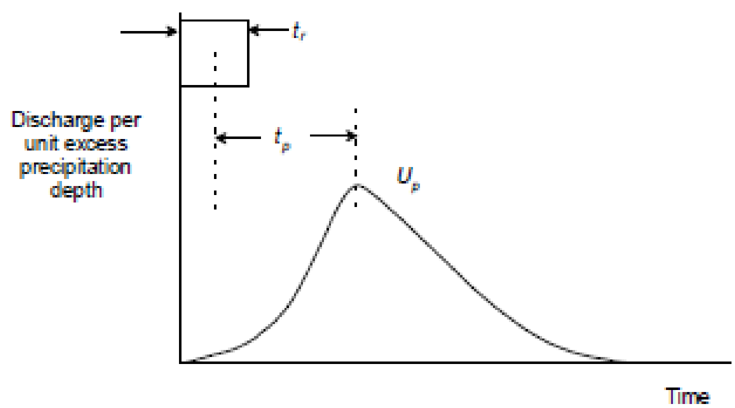


Figure 4-4:Synder Unit Hydrograph

4.5.4 Recession Model

The recession model has been used often to explain the drainage from natural storage in a watershed (Linsley et. al, 1982). It defines the relationship of Q_t, the base flow at any time t, to an initial value as:

$Q_t = Q_0 k^t$

Where Q_0 = initial base flow (at time zero); and k = an exponential decay constant. The base flow thus computed is illustrated in Figure 5-8. The shaded region represents base flow in this figure; the contribution decays exponentially from the starting flow. Total flow is the sum of the base flow and the direct surface runoff reaches zero (all rainfall has run off the watershed), the total flow and base flow are identical.

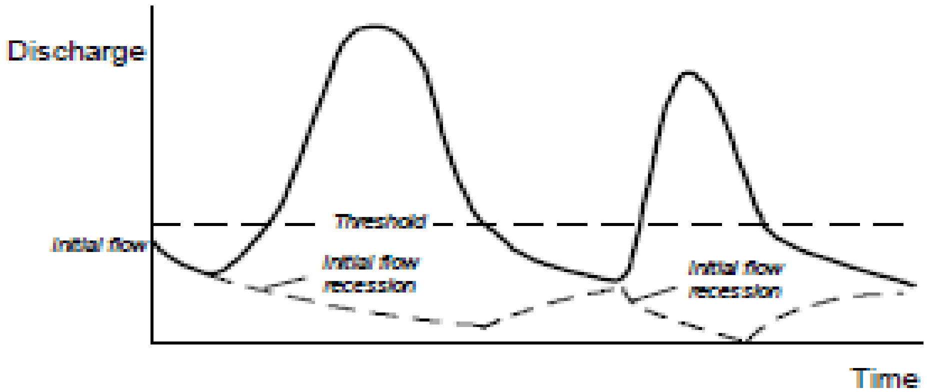


Figure: 4-5: Base flow chart

4.5.5 Muskingum-Cunge model

The model is based upon solution of the following form of the continuity equation, (with lateral inflow, q_L, included):

$$(\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L \qquad (4.1.a)$$

And the diffusion form of the momentum equation:

$$S_f = S_o - \frac{\partial y}{\partial x} \qquad (4.1.b)$$

<u>Muskingum Model Equation:</u>

$$O_t = \left(\frac{\Delta t - 2KX}{2K(1-X)+\Delta t}\right)I_t + \left(\frac{\Delta t + 2KX}{2K(1-X)+\Delta t}\right)I_{t-1} + \left(\frac{2K(1-X)-\Delta t}{2K(1-X)+\Delta t}\right)O_{t-1} \qquad \textit{(4.3.c)}$$

A finite difference approximation of the partial derivatives, combined with above Equation (4.3.c) yields:

$O_t = C_1I_{t-1} + C_2I_t + C3O_{t-1} + C_4(q_o\Delta X)$ (4.4.d)

The coefficients are

$$C_1 = \frac{\frac{\Delta t}{K} + 2X}{\frac{\Delta t}{K} + 2(1-X)} \qquad .C_2 = \frac{\frac{\Delta t}{K} - 2X}{\frac{\Delta t}{K} + 2(1-X)}$$

$$C_3 = \frac{2(1-X)-\frac{\Delta t}{K}}{\frac{\Delta t}{K}+2(1-X)} \qquad C_4 = \frac{2(\frac{\Delta t}{K})}{\frac{\Delta t}{K}+2(1-X)}$$

The parameters K and X are (Cunge, 1969; Ponce, 1978):

$$K = \frac{\Delta X}{C} \qquad X = \frac{1}{2}\left(1 - \frac{Q}{BS_o c \Delta x}\right)$$

c = dQ/dA

4.6 Meteorological model

The principle purpose of this model is to prepare meteorological boundary conditions for sub-basins. The gage weight model is used to represent rainfall in the basin. The parameters describing which gages to use and what weight to apply are specified separately for each sub-basin. The gage weights for selected 10 gauge stations are used in this study.

4.7 Control Specifications

Control specifications are one of the main components in a project, even though they do not contain much parameter data. Their principle purpose is to control when simulations start and stop, and what time interval is used in the simulation.

4.8 Time Series data

The precipitation gauge data and stream flow gauge data are manually entered which are stored in HEC-HMS model as time series data in HEC-DSS (Data Storage System) format which HMS can read, navigate and interpret.

The precipitation data of the selected 1 station and the stream gauge data of the station 418 for Year 2008 - 2012 are entered manually and stored as time series data in DSS format. The RCM precipitation data of selected station for year 2015 to 2104 are entered manually and stored as time series data in DSS format.

4.9 Calibration and Validation of HEC-HMS model

Calibration uses observed hydro-meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search often is referred to as optimization. Year 2008-2010 is selected as calibration period.

Validation of model determines the applicability of the model with calibrated parameters to simulate the runoff for a time period other than the calibration period. It is just the comparison of simulated and observed runoff for selected time period. Year 2010 - 2012 is selected as validation period.

Unless the model is satisfactorily validated, the calibration process is repeated to search for new parameter values.

4.10 Quantitative approach of Model evaluation

The quantitative approach comprises of Nash Efficiency and volume deviation, which can do the quantitative justification of the calibration and validation.

Nash - Sutcliffe efficiency

The Nash – Sutcliffe efficiency (NSE, 1970) criteria is given as

$$\mathbf{Efficiency} = 1 - \left[\frac{\sum_{1}^{n} (\mathbf{Q_{obs}} - \mathbf{Q_{cal}})^2}{\sum_{1}^{n} \left(\mathbf{Q_{obs}} - \bar{\mathbf{Q}} \right)^2} \right]$$

Where, Q_{obs}, Q_{cal} and $\overline{Q}$ are the observed, simulated and observed mean daily flow over the n day period respectively.

Volume deviation

The volume deviation is given as

$$D_v(\%) = \frac{V_{obs} - V_{cal}}{V_{obs}} \times 100$$

Where, V_{obs} and V_{cal} are the observed and calculated volume of annual runoff respectively.

In addition to Nash- Sutcliffe efficiency and volume deviation, coefficient of determination (R^2-value) is also determined. It is the square of coefficient of correlation and is a more convenient and useful way for interpreting the dependence between the variables. It gives the percent of variation explained by one variable on other.

If the predicted and observed values are equal, then NSE, D_v and R^2-value produces the optimal value of 1, 0 and 1.

4.11 Simulation Run

After calibration and validation of the model, it is run for year 2015 to 2104 for obtaining future stream flow data.

4.12 Application of Simulated Future Flow

4.12.1 Climate Change Impact Assessment

For the assessment of climate change in the Naulsing Gad River Basin bias corrected RCM data of precipitation is used as the input. In climate change, AR5 scenario is used. Precipitation data is extracted from CANESM2 Model. Since the recent trend of climate change shows that the temperature is increasing yearly, the given temperature data increased the volume of snow and glacier melt in the model. The amount of glacier and snow melt is more sensitive to temperature than precipitation and glacier area

Once the change in river flow is obtained from climate change analysis river hydrograph before and after climate change is analyzed to determine the change in potential of river due to climate change. For this, firstly change in total volume of water in a year due to climate change is determined. Secondly, flow duration curve and Q_{40} for each year is determined to represent change in hydropower potential.

The impact of climate on river flow is essential for long term planning of water resource for sustainability and integrity. The trend analysis of low flows and flood in different future time window gives the idea for sustainable and integrated planning of water resource structure.

Comparison of current and future flows at outlet of the study basin should carried out so that it can be used to summarize long periods of daily hydrologic data into a much more calculated for a sufficiently long hydrologic record.

Low flows: This is the dominant flow condition in most rivers. In natural rivers, after a rainfall event or snowmelt period has passed and associated surface runoff from the catchment has subsided, the river returns to its base- or low-flow level. These low-flow levels are sustained by ground water discharge into the river. The seasonally-varying low-flow levels in a river impose a fundamental constraint on a river's aquatic communities because it determines the amount of aquatic habitat available for most of the year. This has a strong influence on the diversity and number of organisms that can live in the river.

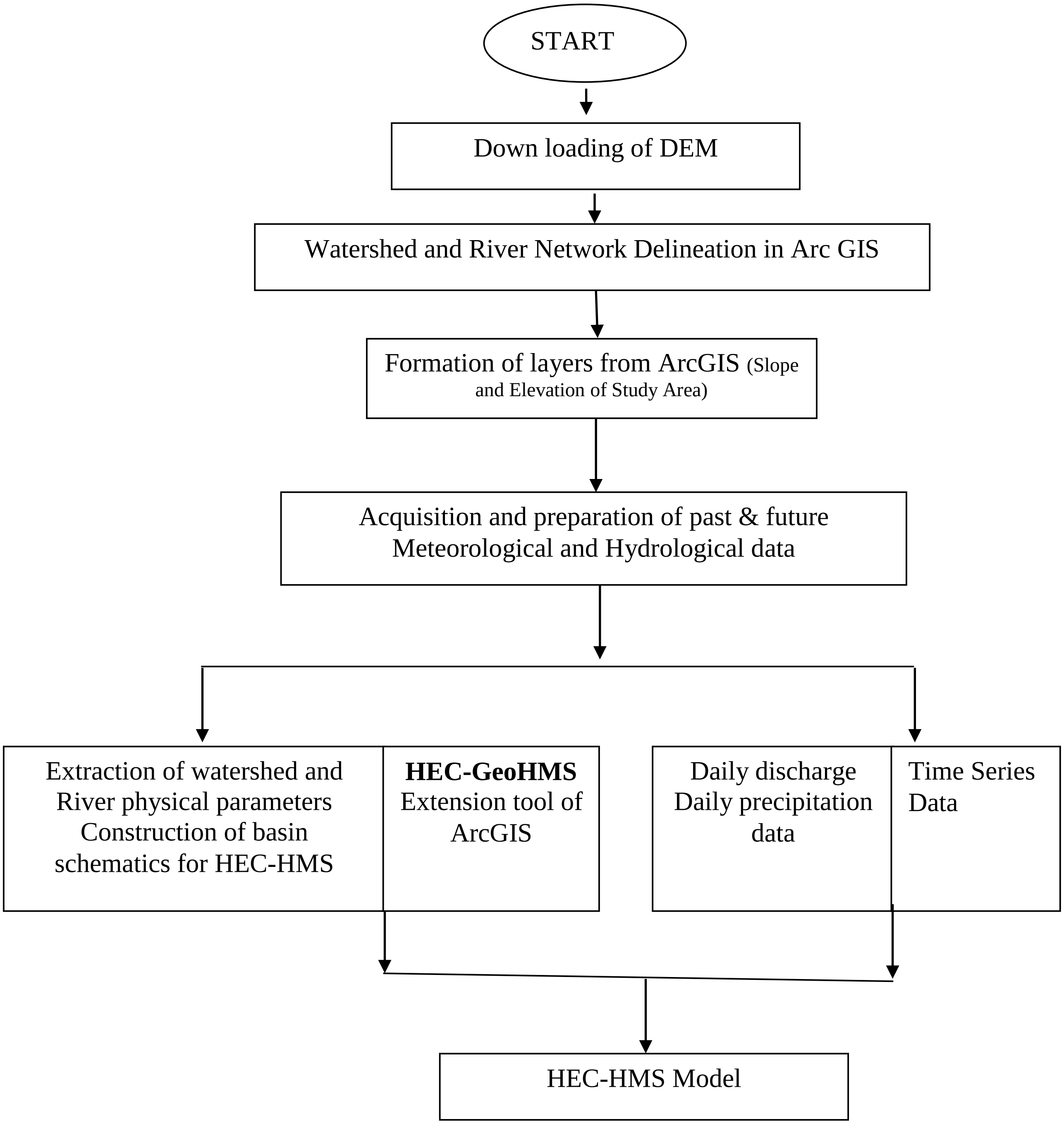
Extreme low flows: During drought periods, rivers drop to very low levels that can be stressful for many organisms, but may provide necessary conditions for other species. Water chemistry, temperature, and dissolved oxygen availability can become highly stressful to many organisms during extreme low flows, to the point that these conditions can cause considerable mortality. On the other hand, extreme low flows may concentrate aquatic prey for some species, or may be necessary to dry out low-lying floodplain areas and enable certain species of plants such as bald cypress to regenerate

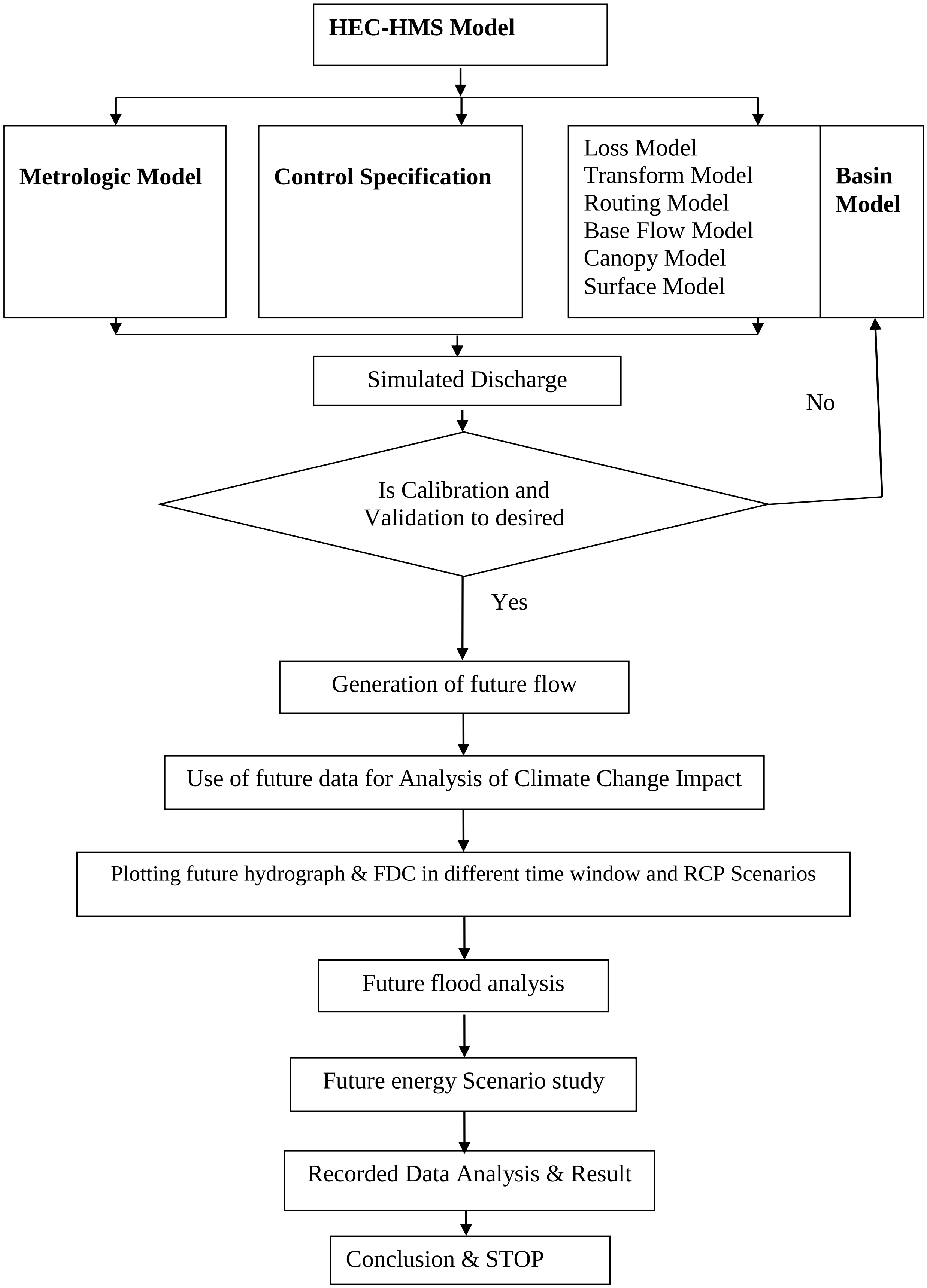
Daily and Monthly Hydrographs: daily hydrographs were generated for the study basin outlet for the three RCPs (2.6, 4.5 and 8.5) each for three different future time windows – immediate future (2015-2044), mid-term future (2045-2074) and long-term future (2075-2104) and compared with the baseline period. For the purpose of discussion and illustration, sample graphs for the baseline period and future time windows for RCP 2.6 have been presented.

4.12.2 Comparison of Current and future flood

It is important for any water resource engineer to investigate the trend of the flood change in different future time windows. This gives the substantial input for the design of hydraulic structure to compensate future hazardous flood. The flood analysis at intake of Naulsing Gad HEP was carried out for RCP 2.6 scenario using Gumbel frequency analysis method for immediate future (2015-2044), mid-term future (2045-2074) and long-term future (2075-2104) and compared with the baseline period. It is seen that flood of different return period is continuously increasing.

4.13 Overall Methodological Flow Chart




HEC-HMS Model
Metrologic Model
Control Specification
Loss Model
Transform Model
Routing Model
Base Flow Model
Canopy Model
Surface Model
Basin Model
Simulated Discharge
No
Is Calibration and Validation to desired
Yes
Generation of future flow
Use of future data for Analysis of Climate Change Impact
Plotting future hydrograph & FDC in different time window and RCP Scenarios
Future flood analysis
Future energy Scenario study
Recorded Data Analysis & Result
Conclusion & STOP

5. RESULTS AND ANALYSIS

5.1 Hydrologic Models Results

In this study, HEC-HMS model was employed to simulate stream flows for the Naulsing Gad basins using data from the Department of Hydrology and Meteorology (DHM). The hydrologic models were firstly calibrated using historical data until the best statistical performance was found and the simulated flow pattern could follow the historical flow pattern. The calibrated parameters were assumed to same for the future scenario and used for simulation of runoff for future scenario. The parameters used for calibration of hydrological models are shown on Annex. Table 5-1 provides the statistical results for the entire calibration and validation period separately. The statistics indicate that all hydrologic models were well calibrated yielding Nash Sutcliffe Efficiency Index (NSE) greater than 0.7, percentage volume bias within $\pm 10\%$ and the correlation coefficient (r) greater than 0.6.

The calibration and validation results are as follows:

Table 5-1: Result of HEC-HMS Model

Description	Period	NSE	Volume Bias (%)	Correlation Coefficient
Calibration Part	2008-2010	76.12%	-9.2	0.966
Validation Part	2010-2012	71.24%	-7.6	0.94

The calibration and validation hydrograph, scatter plot & volume balance between the observed and simulated discharge, are in satisfactory agreement which are given as follows:

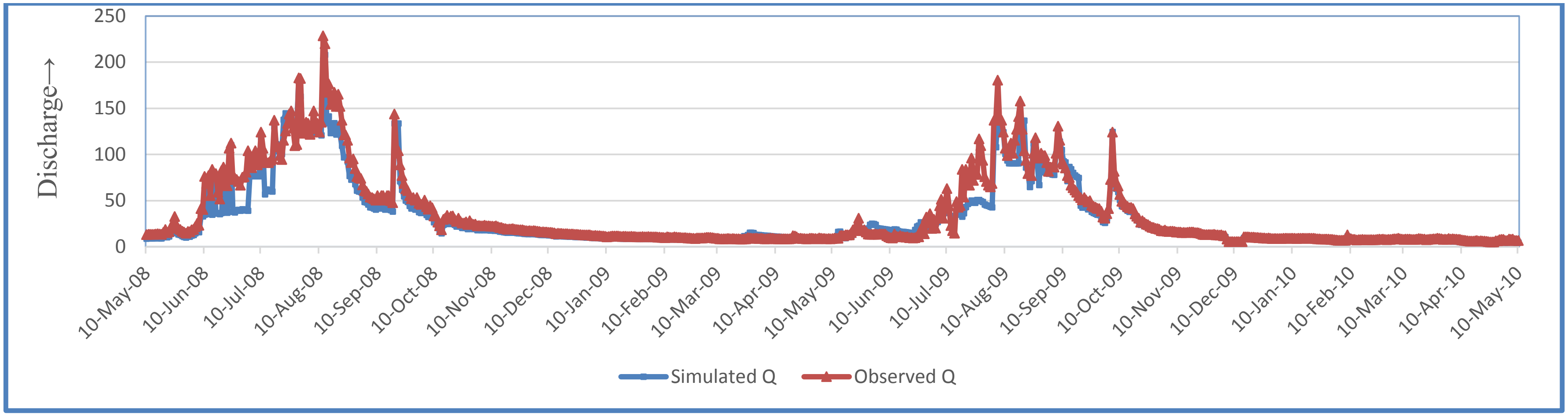


Figure 5-1: Calibration Part of HEC-HMS Model: 2008-2010

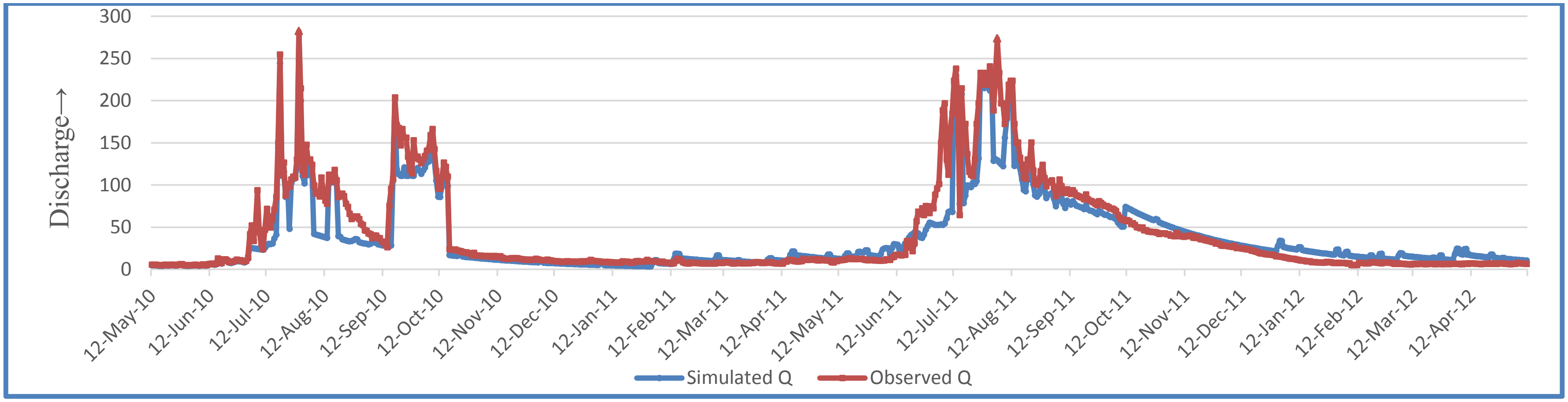


Figure 5-2: Validation part of HEC-HMS Model:2010-2012

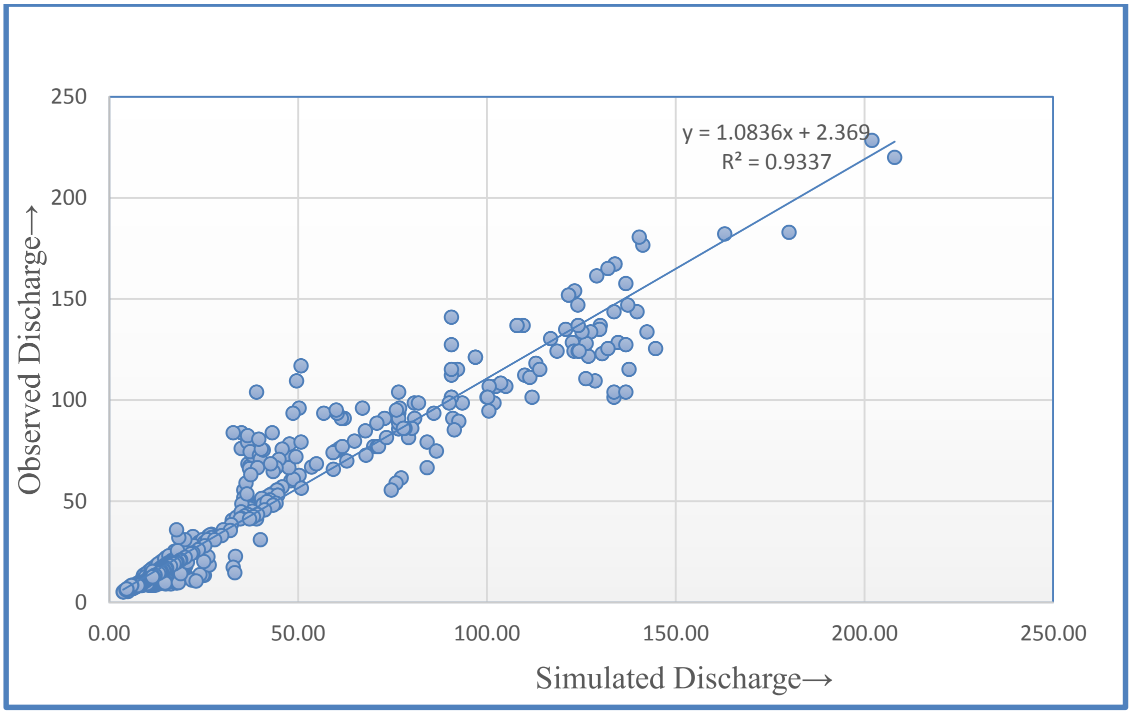


Figure 5-3: Scatter Plot for Calibration Part

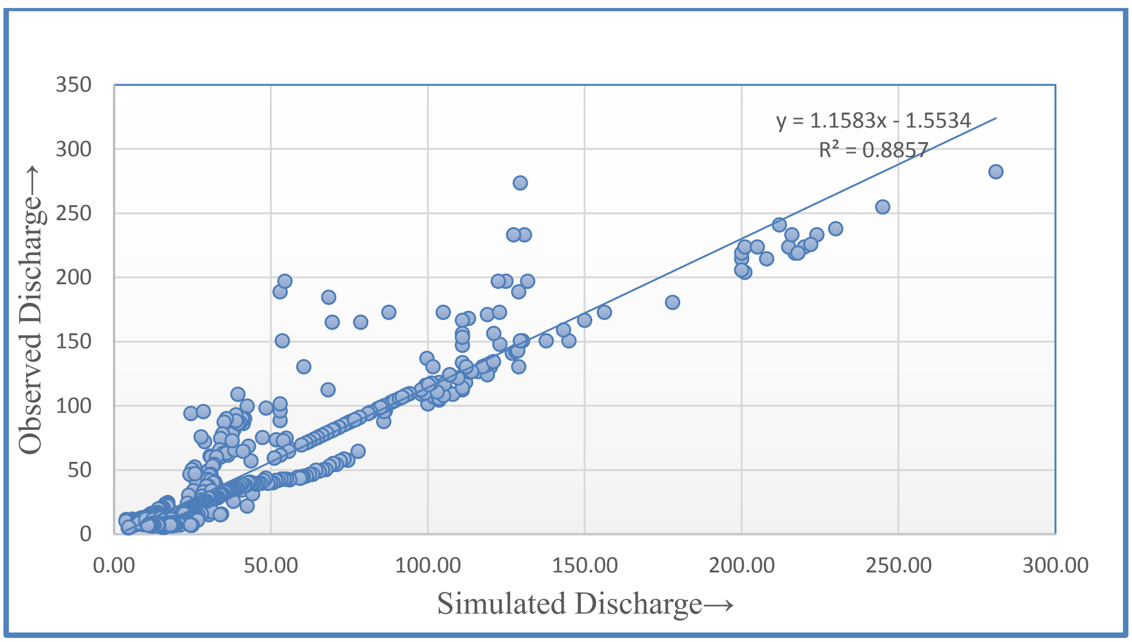


Figure 5-4: Scatter plot for calibration and validation

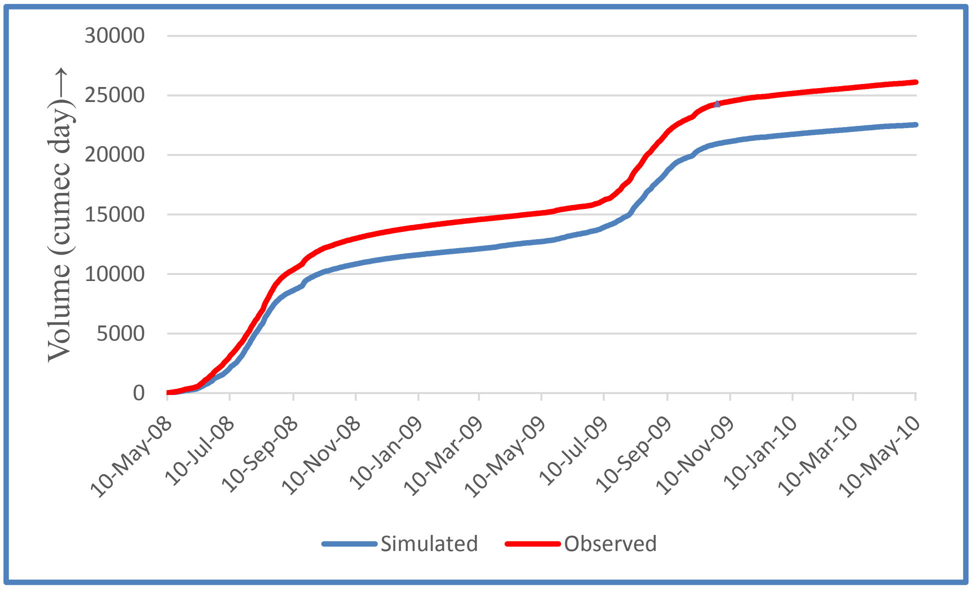


Figure 5-5: Volume Balance between observed and simulated discharge for calibration part

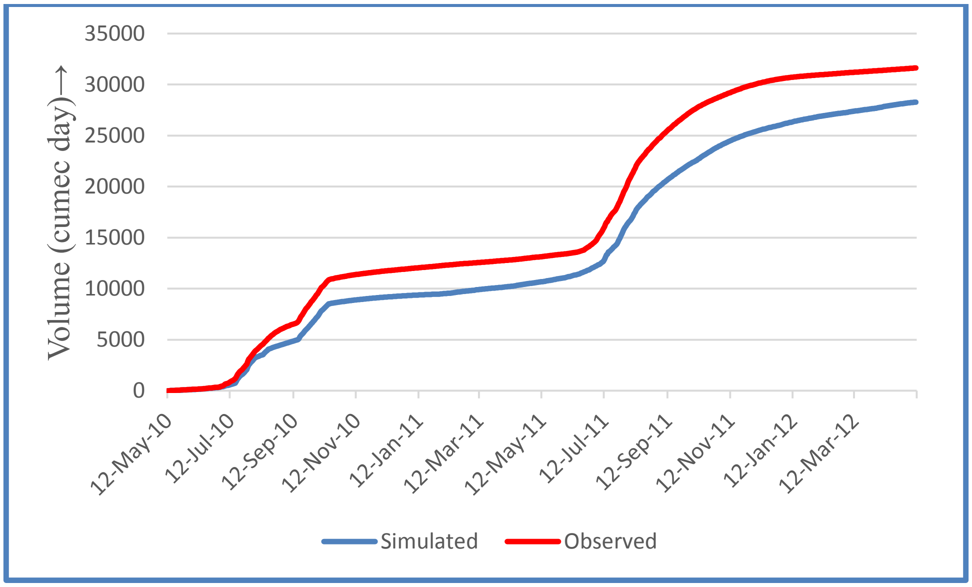


Figure 5-6:Volume Balance between obseved and simulated discharge for validation part

5.2 Baseline and Future Hydrograph Result

The HEC-HMS model was run using calibrated and validated parameters & AR-5 RCM future precipitation data to estimate the future river flows. The daily and monthly future hydrograph for immediate future (2015-2044), medium term future (2045-2074) and long term future (2075-2104) for different RCP scenario (2.6, 4.5 & 8.5) were plotted.

From the result, it is found that the peak of the different RCP scenarios in different future period found to be increasing from 2015 to 2104. The future peak discharge is relatively higher than baseline discharge. The peak discharge occurred on August in each scenario. However, on minute observation on the daily hydrograph, the peak occurrence time in comparison to the baseline hydrograph, found to be shift slightly later. The magnitude of peak normally seems to be increased. However, no fixed trend has not observed. The monthly peak discharge from all scenarios in future flow found to be 151 cumec.

Table 5-2: Monthly flow:RCP-2.6 Scenario

Monthly Flow (Cumec):RCP - 2.6 Scenario:				
Month	Baseline	Q2015-2044	Q2045-2074	Q2075-2104
Jan	5.57	8.90	8.88	7.81
Feb	4.45	8.50	7.93	6.69
Mar	4.13	8.86	9.14	8.46
Apr	4.74	9.24	9.67	8.86
May	7.90	10.22	10.05	9.53
Jun	23.41	38.83	41.83	39.35
Jul	87.78	56.06	56.90	49.89
Aug	103.94	109.12	114.00	124.60

Sep	64.21	73.90	78.00	80.60
Oct	37.38	43.00	48.00	49.80
Nov	13.63	17.67	18.07	16.05
Dec	8.00	12.08	12.15	10.95
Mean Flow	30.43	37.96	33.38	33.02
Maximum flow	103.94	109.12	114.00	91.09
Minimum flow	4.13	8.50	7.93	6.69

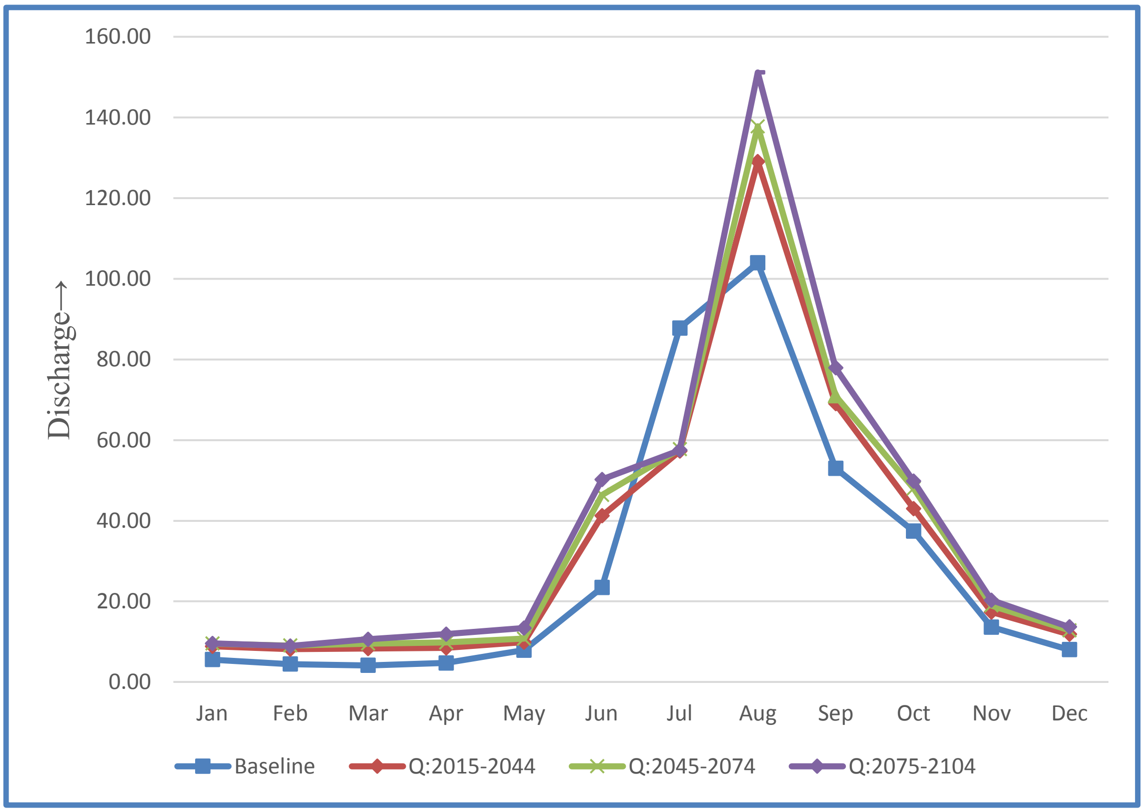


Figure 5-7: Monthly Hydrograph:RCP-2.6 Scenario

Table 5-3: Monthly flow:RCP-4.5 Scenario

Monthly Flow (Cumec) : 4.5 Scenario:				
Month	Baseline	Q2015-2044	Q2045-2074	Q2075-2104
Jan	5.6	9.2	8.9	10.6
Feb	4.5	8.7	8.4	8.9
Mar	4.1	10.0	9.0	9.5
Apr	4.7	9.4	9.6	10.7
May	7.9	9.2	11.1	11.4
Jun	23.4	35.9	45.4	55.0
Jul	87.8	56.4	59.4	65.0
Aug	103.9	126.1	133.3	141.4
Sep	58.0	69.0	76.0	81.4
Oct	37.4	43.0	48.0	49.8
Nov	13.6	18.2	17.9	17.1
Dec	8.0	12.6	12.1	11.6
Mean Flow	30.4	39.0	34.0	34.2
Maximum flow	103.9	115.1	114.0	93.2
Minimum flow	4.1	8.7	8.4	7.3

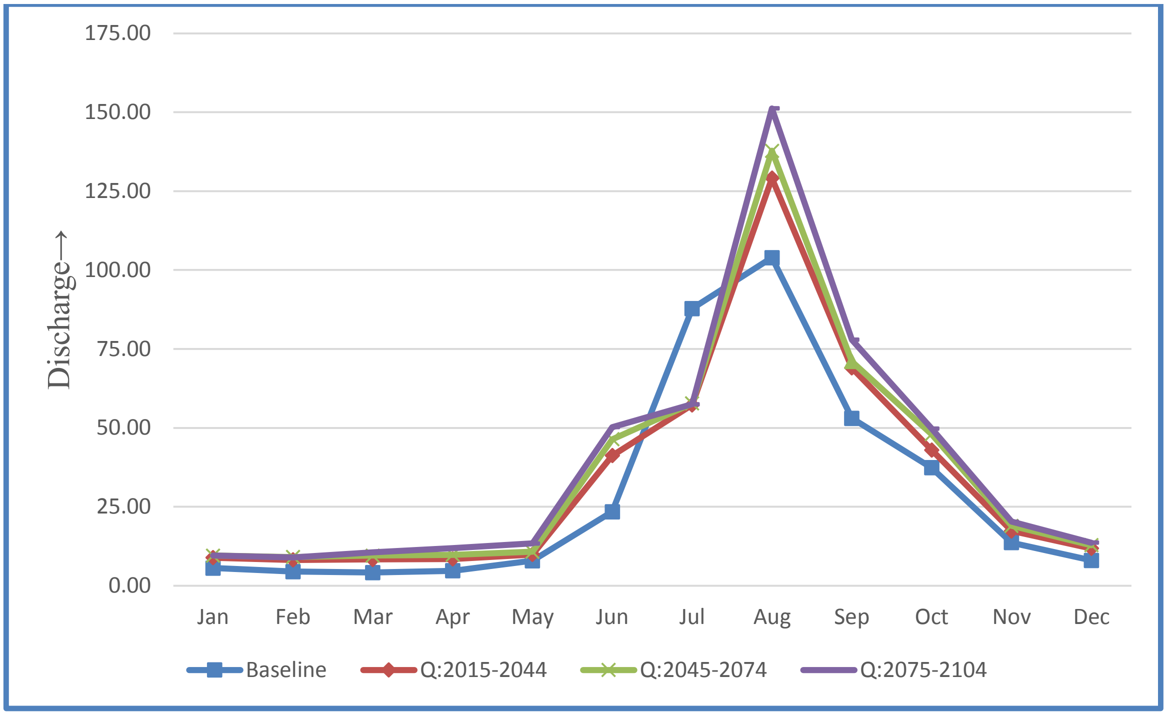


Figure 5-8: Monthly Flow: RCP-4.5 Scenario

Table 5-4: Monthly Flow: RCP 8.5 Scenario

Monthly Flow (Cumec):8.5 Scenario				
Month	Baseline	Q2015-2044	Q2045-2074	Q2075-2104
Jan	5.6	8.86	9.51	9.57
Feb	4.5	8.14	9.07	8.94
Mar	4.1	8.31	9.53	10.59
Apr	4.7	8.46	9.79	11.88
May	7.9	9.86	10.77	13.40
Jun	23.4	41.21	46.39	50.22
Jul	87.8	57.26	57.75	57.49

Aug	103.9	129.10	137.80	151.20
Sep	58.0	69.00	71.00	77.90
Oct	37.4	43.00	48.00	49.80
Nov	13.6	17.33	18.97	20.30
Dec	8.0	11.82	12.84	13.65
Mean Flow	30.43	38.29	34.21	40.34
Maximum flow	103.94	108.99	114.00	107.95
Minimum flow	4.13	8.14	9.07	8.94

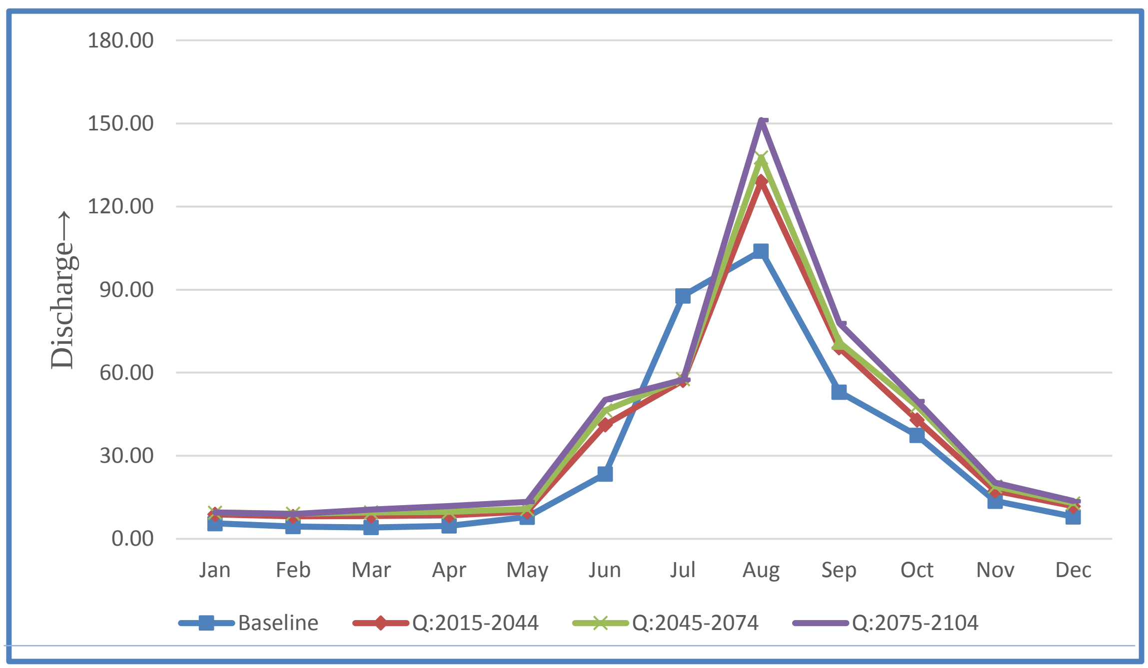


Figure 5-9: Monthly Flow: RCP-8.5 Scenario

It can be seen that although the nature of the hydrograph is almost similar for all the three time windows, high flow events are expected to increase in frequency and magnitude in the future for all scenarios and time span seems to be sharp peak. Similarly, Figure shows the more monthly flows for the three future time windows compared with the baseline. It is interesting to note that the mean monthly flows are continuously increasing from the immediate future to the long term future for all RCPs. The rising limb of the hydrograph has also shifted towards the right indicating projected monsoon to start later in the future. A very similar trend is seen for RCP 2.6, RCP 4.5 and RCP 8.5 too, but with increasing magnitudes of the flows. As expected, magnitudes are the highest for RCP 8.5 (high loading case) and minimum for RCP 2.6 (low loading case) as shown in the figures.

FDC in different time horizon was plotted for all RCP scenario and it is found that no fixed trend but in most cases, FDC curve shift to upward direction. The base flow in different time horizon in different RCP scenario found to random pattern. However, in most RCP scenario, the base flow goes on increasing indicating snow melt. In RCP 4.5, the base flow founds to increase from 2015-2045 and subsequently decreased in time span of 2045-2074 but increased from 2075-2104.

Table 5-5: FDC:RCP-2.6 Scenario

Flow Duration Curve(FDC):RCP -2.6 Scenario:				
% of Time	Baseline	$Q_{2015\text{-}2044}$	$Q_{2045\text{-}2074}$	$Q_{2075\text{-}2104}$
0%	103.9	109.1	114.0	124.6
10%	85.4	72.1	75.9	77.5
20%	58.8	53.4	55.1	49.9
30%	33.2	41.7	46.1	46.7
40%	19.5	30.4	32.3	30.0
50%	10.8	14.9	15.1	13.5
60%	7.9	11.0	10.9	10.1
70%	6.3	9.5	9.8	9.1

80%	4.9	9.0	9.2	8.5
90%	4.5	8.9	8.9	7.9
100%	4.1	8.5	7.9	6.7

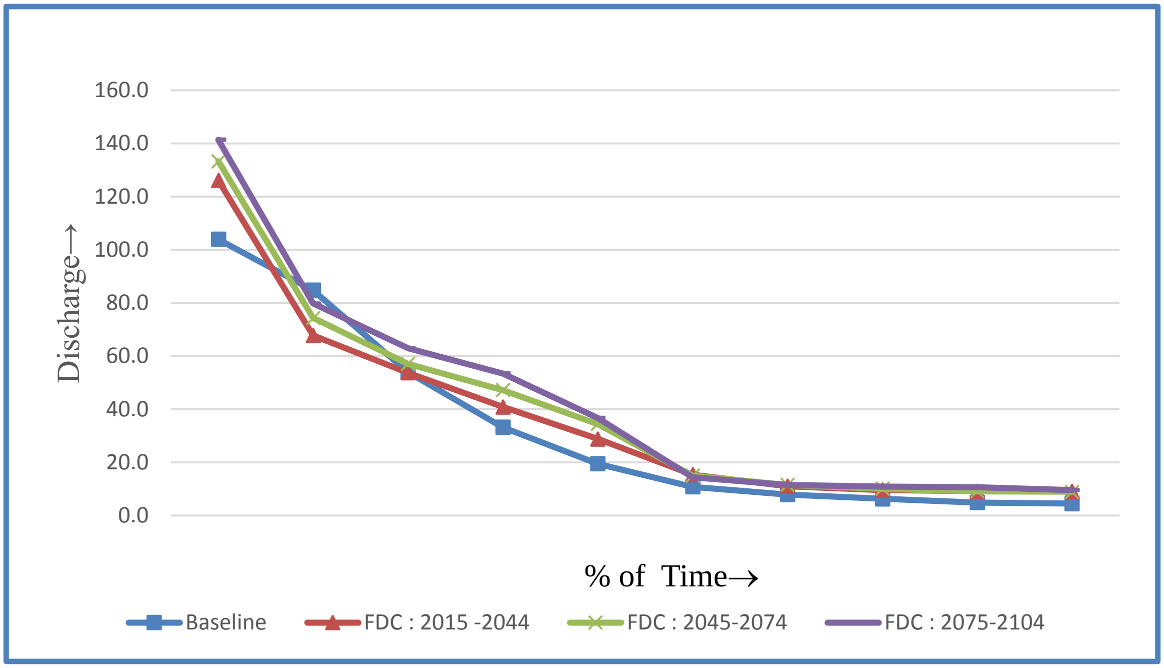


Figure 5-10: FDC: RCP-2.6 Scenario

Table 5-6: FDC:RCP-4.5 Scenario

Flow Duration Curve (FDC):RCP - 4.5 Scenario:				
% of Time	Baseline	$Q_{2015-2044}$	$Q_{2045-2074}$	$Q_{2075-2104}$
0%	103.9	126.1	133.3	141.4
10%	84.8	67.7	74.3	79.8
20%	53.9	53.7	57.1	63.0
30%	33.2	40.9	47.2	53.4

40%	19.5	28.8	34.4	36.7
50%	10.8	15.4	15.0	14.4
60%	7.9	11.1	11.5	11.5
70%	6.3	9.6	10.1	10.9
80%	4.9	9.2	9.1	10.6
90%	4.5	9.2	8.9	9.6
100%	4.1	8.7	8.4	8.9

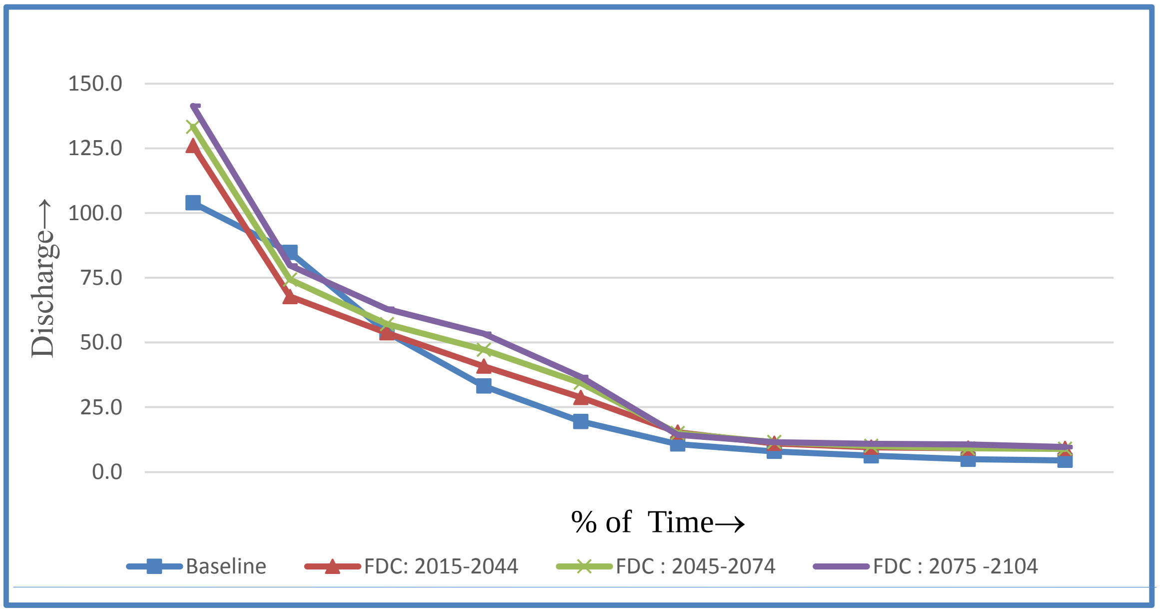


Figure 5-11: FDC: RCP-4.5 Scenario

Table 5-7: FDC: RCP-8.5 Scenario

Flow Duration Curve(FDC):RCP - 8.5 Scenario:				
% of Time	Baseline	Q2015-2044	Q2045-2074	Q2075-2104
0%	103.94	129.10	137.80	151.20

10%	84.80	67.83	69.67	75.86
20%	53.88	54.41	55.80	56.04
30%	33.19	42.46	47.52	50.09
40%	19.50	31.66	35.42	38.00
50%	10.81	14.58	15.90	16.97
60%	7.94	10.65	11.60	13.50
70%	6.26	9.16	10.09	12.34
80%	4.90	8.54	9.59	10.84
90%	4.48	8.33	9.51	9.67
100%	4.13	8.14	9.07	8.94

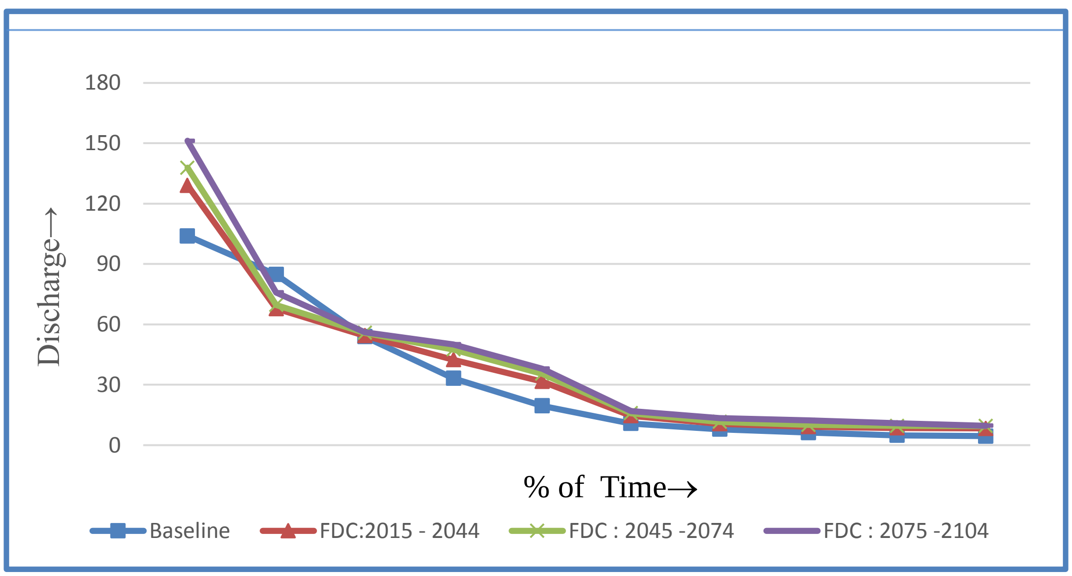


Figure 5-12: FDC: RCP-8.5 Scenario

The monthly flow for different RCP scenario during period 2015-2044 was calculated and result showed that peak discharge goes on increasing with the RCP scenarios. Moreover, it is interesting to note that the timing of peak also seems to be shifted i.e a bit later than base line hydrograph.

Table 5-8: Comparison of RCP Flow

Comparison of Different RCP Flow : 2015-2044				
Month	Baseline	RCP 2.6	RCP 4.5	RCP 8.5
Jan	5.57	8.90	9.2	8.86
Feb	4.45	8.50	8.7	8.14
Mar	4.13	8.86	10.0	8.31
Apr	4.74	9.24	9.4	8.46
May	7.90	10.22	9.2	9.86
Jun	23.41	38.83	35.9	41.21
Jul	87.78	56.06	56.4	57.26
Aug	103.94	109.12	126.1	129.10
Sep	64.21	73.90	69.0	69.00
Oct	37.38	43.00	43.0	43.00
Nov	13.63	17.67	18.2	17.33
Dec	8.00	12.08	12.6	11.82
Mean Flow	30.43	37.96	39.0	38.29
Maximum flow	103.94	109.12	115.1	108.99
Minimum flow	4.13	8.50	8.7	8.14

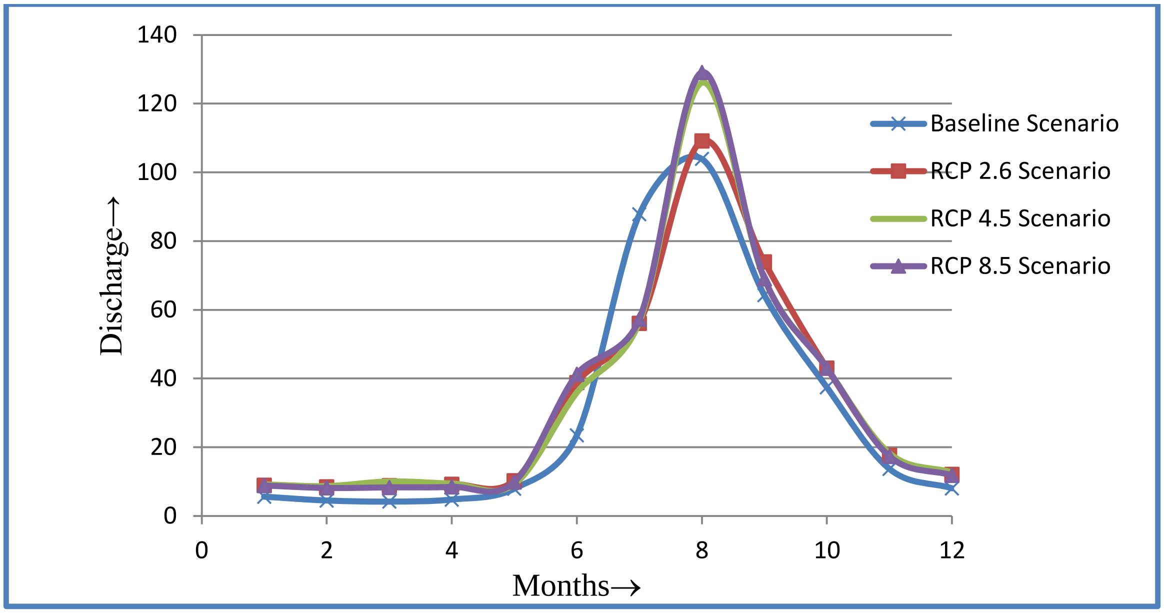


Figure 5-13:RCP Scenario Comparison

The FDC of different RCP scenarios plotted and result shows that as RCP increases the FDC almost seems to overlapped, no substantial changed. However, the RCP FDC is shifted upward than baseline one.

Table 5-9: Comparision of RCP FDC

Comparison of FDC of Different RCP Scenario : 2015-2044				
% of Time	Baseline	RCP 2.6	RCP 4.5	RCP 8.5
0%	103.94	109.12	126.10	129.10
10%	84.80	72.12	67.74	67.83
20%	53.88	53.45	53.71	54.41
30%	33.19	41.75	40.86	42.46
40%	19.50	30.37	28.81	31.66
50%	10.81	14.88	15.41	14.58

60%	7.94	10.97	11.06	10.65
70%	6.26	9.53	9.59	9.16
80%	4.90	8.97	9.21	8.54
90%	4.48	8.86	9.16	8.33
100%	4.13	8.50	8.66	8.14

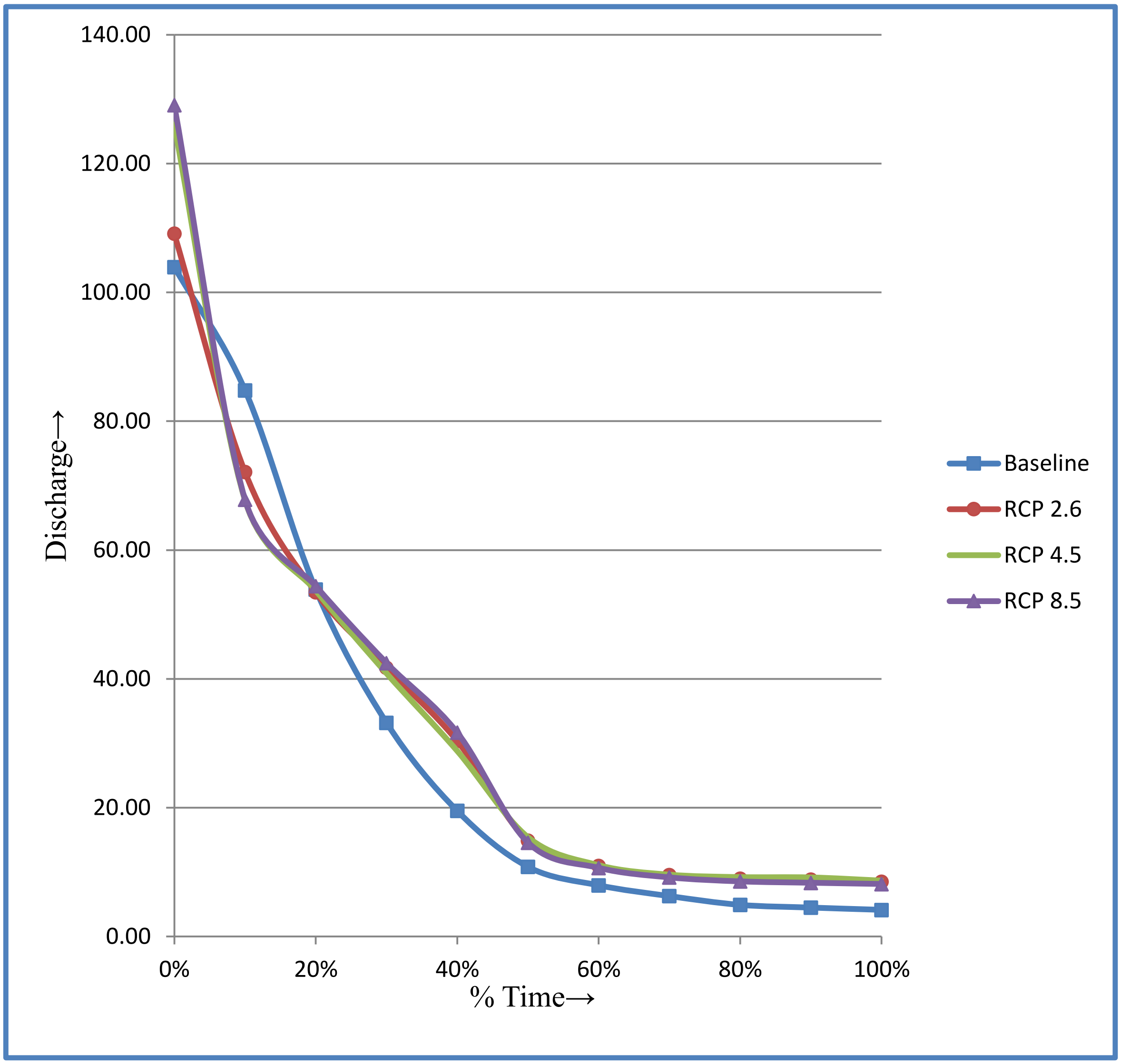


Figure 5-14: FDC Comparison

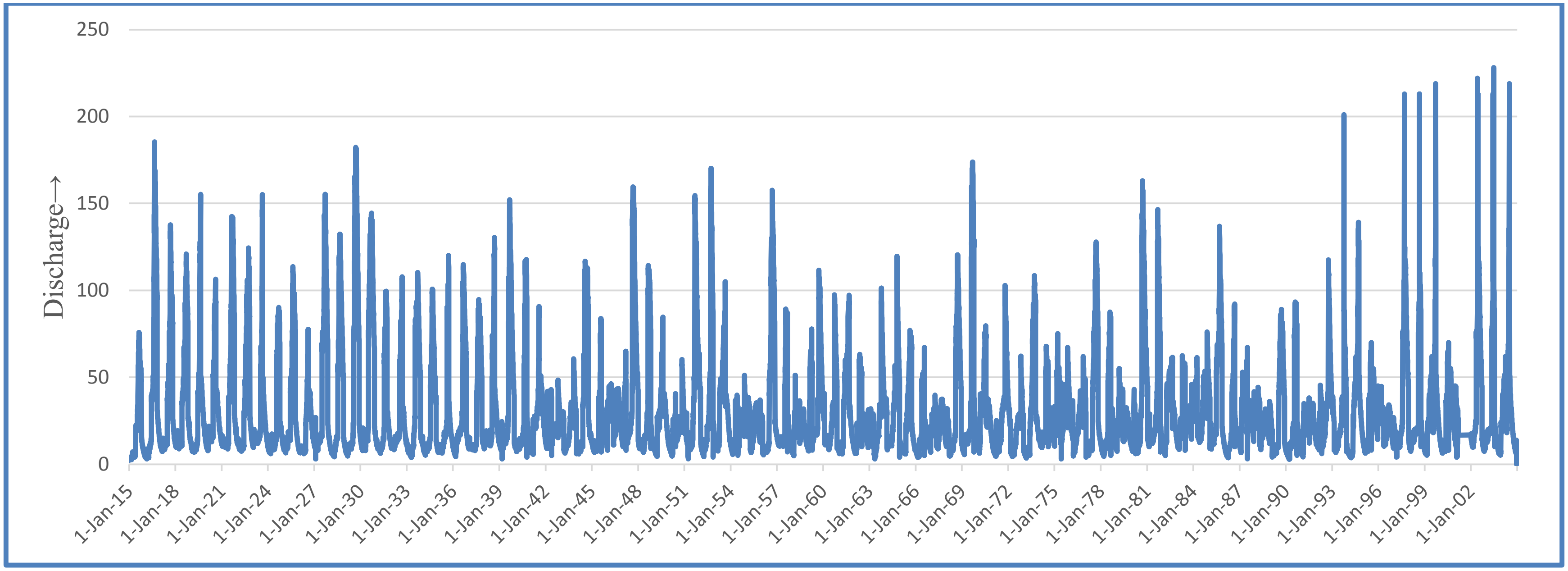


Figure 5-15: Daily Hydrograph for RCP 2.6

The daily hydrograph for RCP 2.6 scenario was presented graphically and it is seen that daily peak follows random nature. The peak with the increase of time window seems to be increased from present to the end of century. Also, magnitude & frequency of peak discharge is more at the end of century.

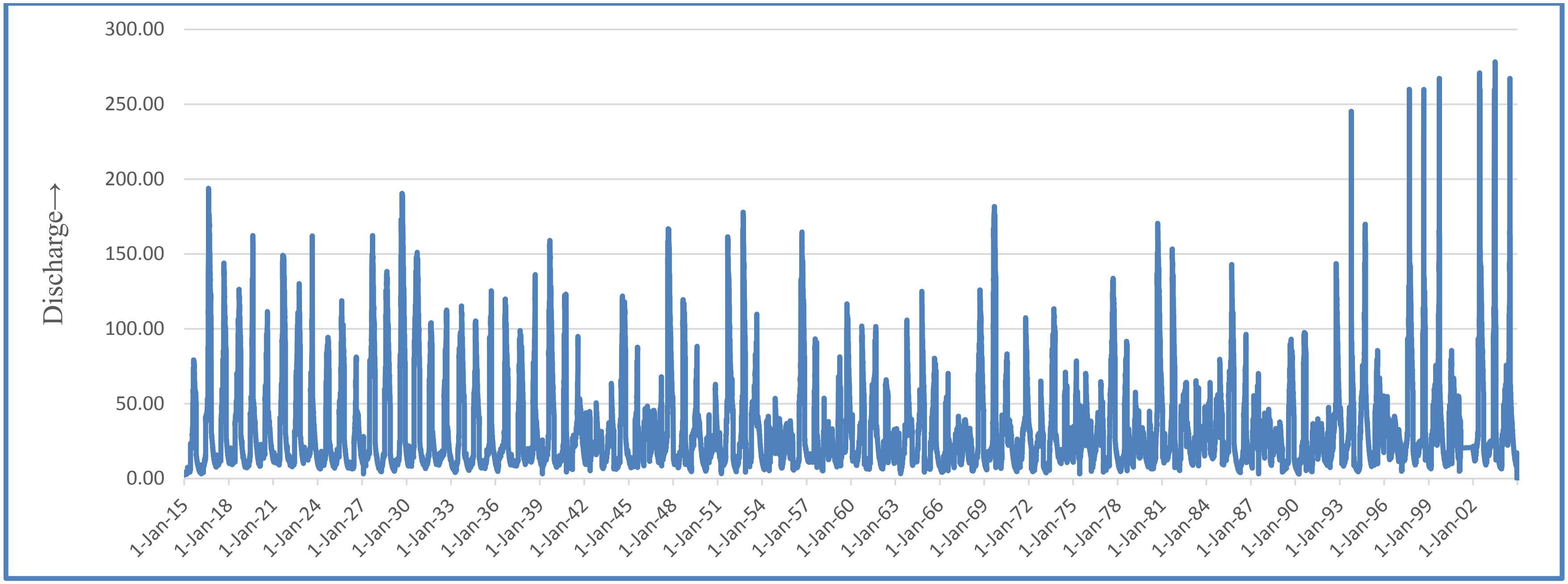


Figure 5-16: Daily Hydrograph for RCP 4.5

The daily hydrograph for RCP 4.5 scenario was presented graphically and it is seen that daily peak follows random nature. The flows in comparison to RCP 2.6 seems to 10% more.

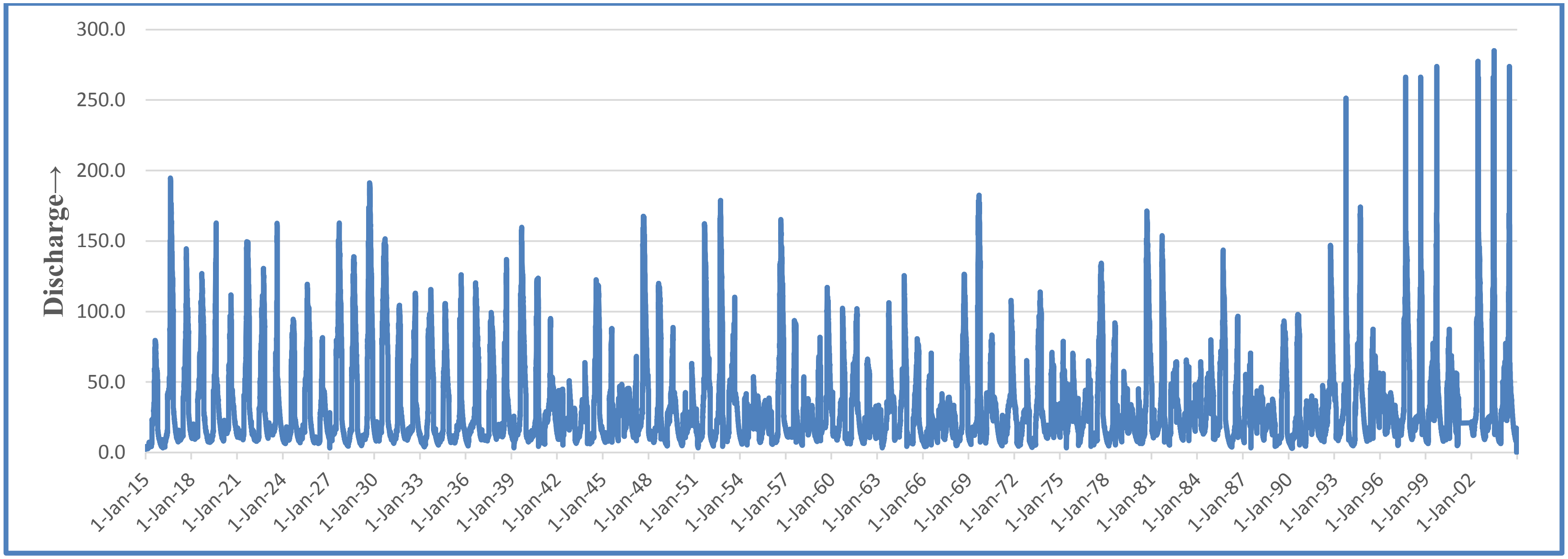


Figure 5-17: Daily Hydrograph : RCP-8.5 Scenario

The daily hydrograph for RCP 8.5 scenario was presented graphically and it is seen that daily peak follows random nature. The flows in comparison to RCP 2.6 seems to 14 % more.

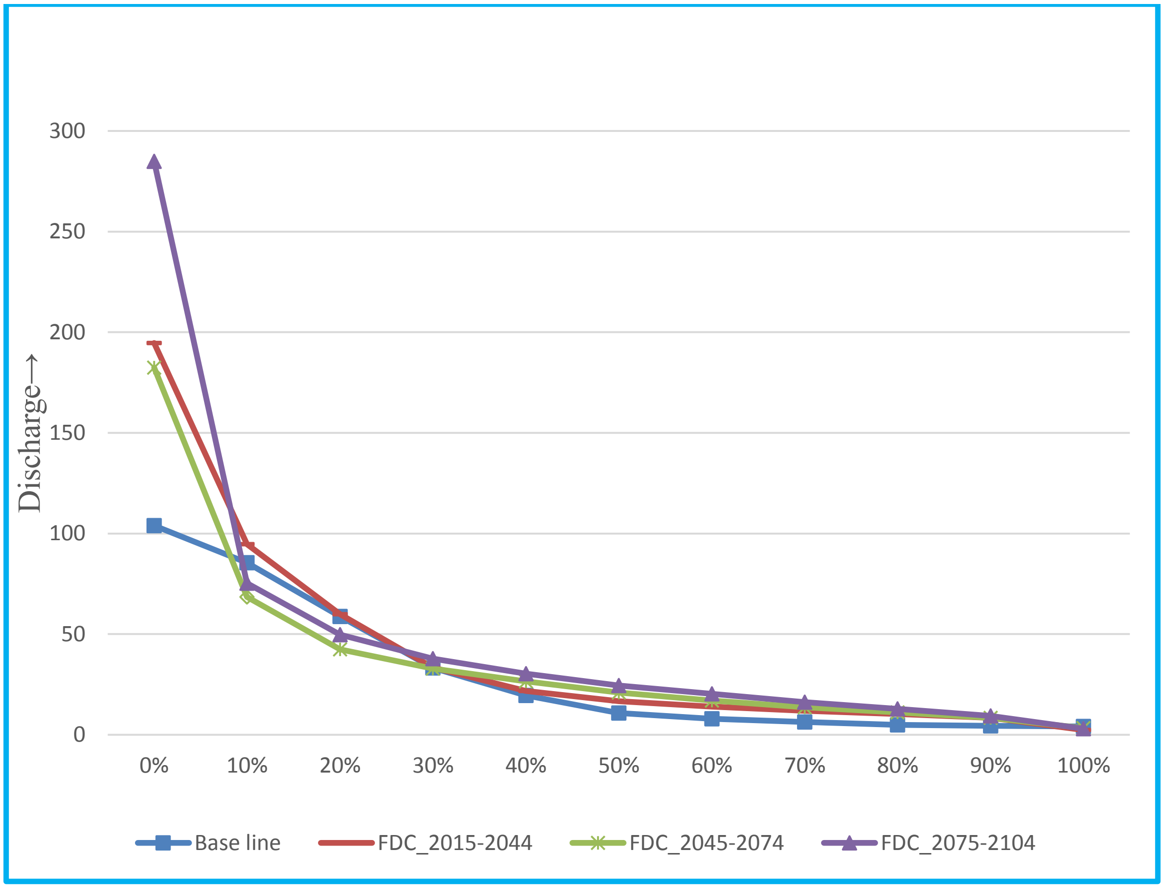


Figure 5-18: Daily FDC for RCP scenario 2.6

Table 5-10:Daily FDC Calculation for RCP-2.6 Scenario.

Flow Duration Curve(FDC):RCP -2.6 Scenario:				
% of Time	**Baseline**	**$Q_{2015-2044}$**	**$Q_{2045-2074}$**	**$Q_{2075-2104}$**
0%	103.94	185.40	173.80	228.00
10%	85.42	90.20	65.14	64.76
20%	58.84	57.10	40.42	44.50
30%	33.19	31.80	31.25	33.30
40%	19.50	20.74	25.23	26.90

50%	10.81	15.81	19.90	21.55
60%	7.94	13.36	16.22	17.95
70%	6.26	11.38	13.06	14.36
80%	4.90	9.80	10.51	11.22
90%	4.48	8.02	7.99	8.37
100%	4.13	3.1	2.77	2.89

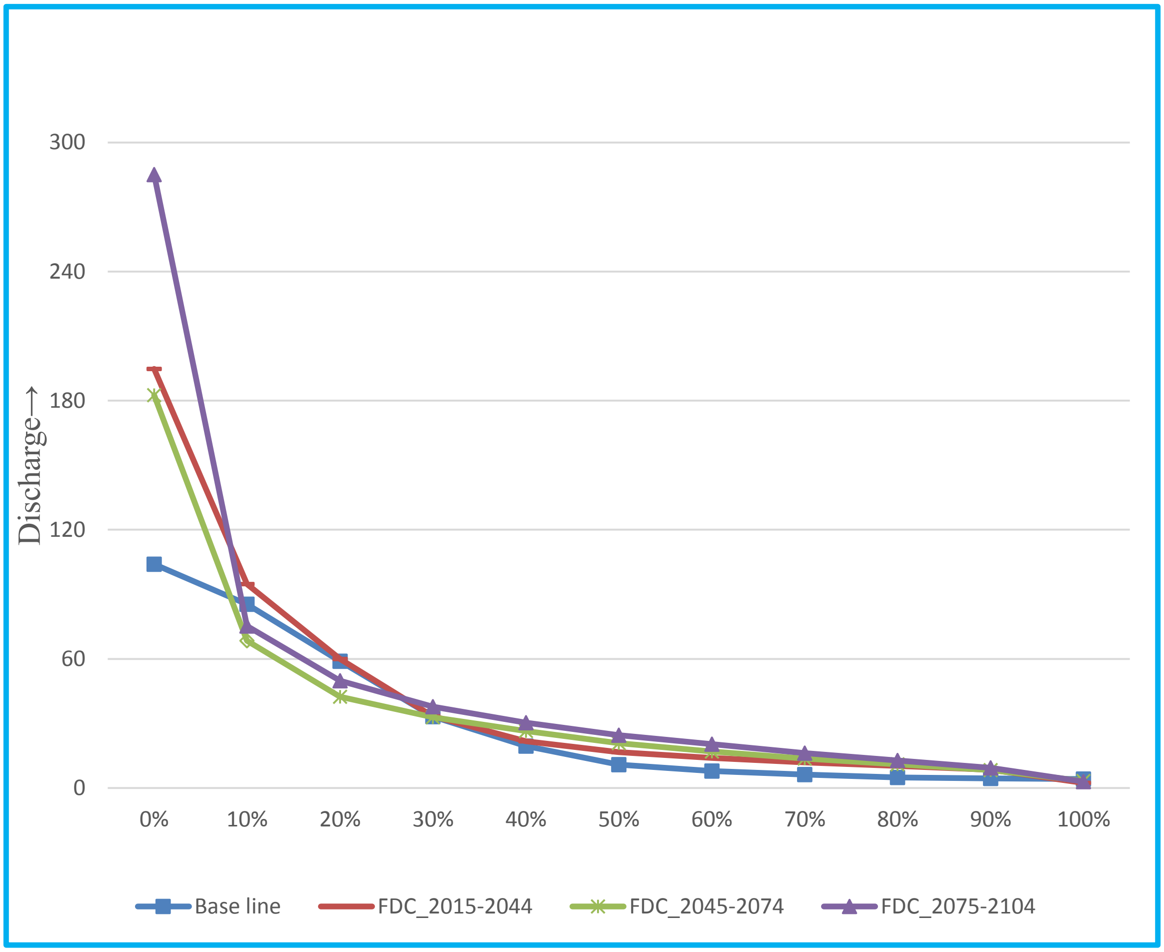


Figure 5-19: Daily FDC for RCP-4.5 Scenario

Table 5-11: Daily FDC Calculation for RCP-4.5 Scenario.

Flow Duration Curve(FDC):RCP -4.5 Scenario:				
% of Time	**Baseline**	**$Q_{2015-2044}$**	**$Q_{2045-2074}$**	**$Q_{2075-2104}$**
0%	103.94	193.74	181.62	278.16
10%	85.42	94.26	68.07	74.18
20%	58.84	59.67	42.24	49.17
30%	33.19	33.23	32.65	37.31
40%	19.50	21.68	26.36	29.95
50%	10.81	16.52	20.80	24.14
60%	7.94	13.96	16.95	20.08
70%	6.26	11.89	13.64	15.99
80%	4.90	10.24	10.98	12.61
90%	4.48	8.38	8.35	9.27
100%	4.13	2.30	3.24	3.02

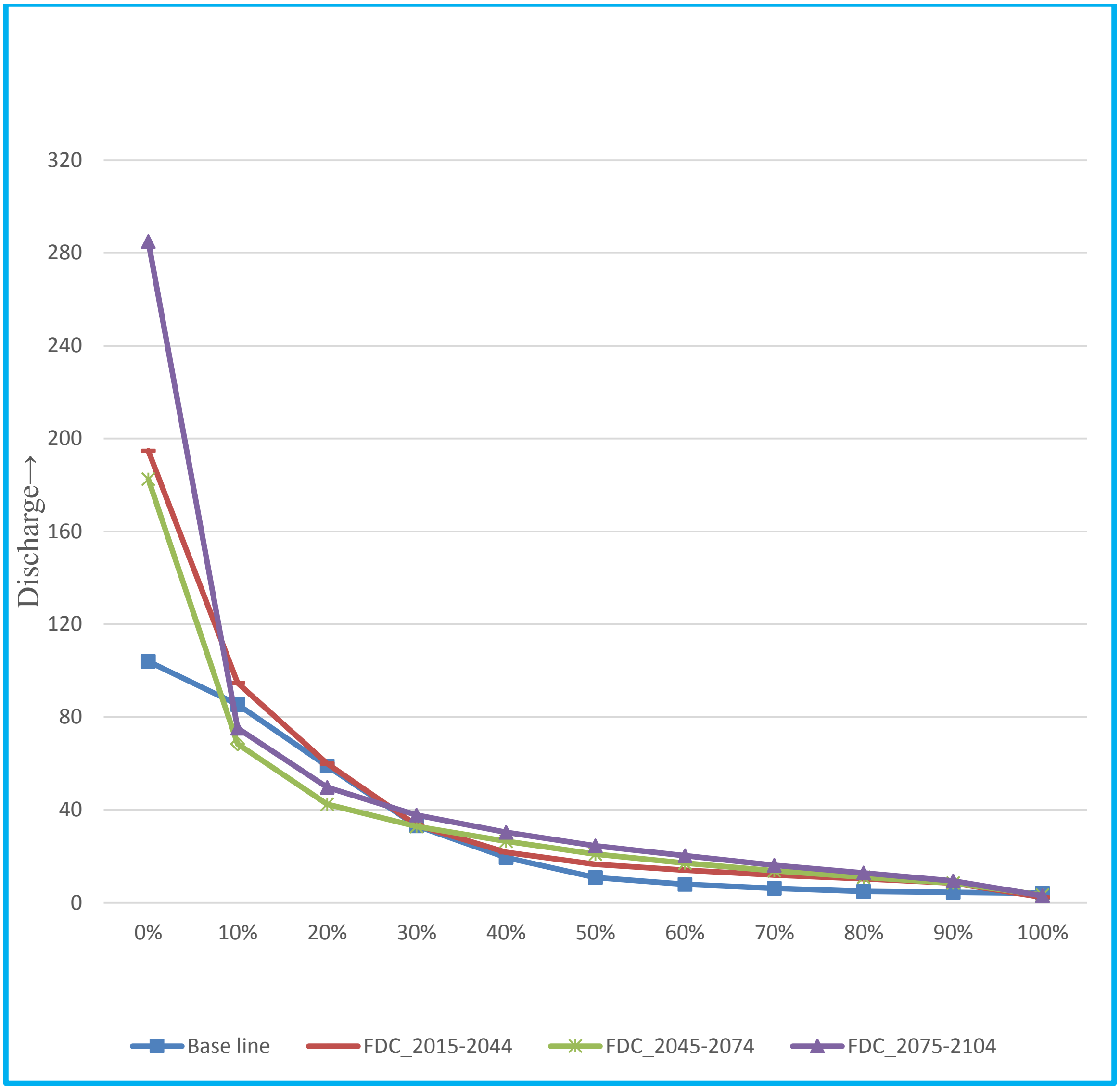


Figure 5-20:Daily FDC for RCP 8.5 Scenario.

Table 5-12: Daily FDC Calculation for RCP-8.5 Scenario.

Flow Duration Curve(FDC):RCP -8.5 Scenario:				
% of Time	**Baseline**	**$Q_{2015-2044}$**	**$Q_{2045-2074}$**	**$Q_{2075-2104}$**
0%	103.94	194.67	182.49	285.00
10%	85.42	94.71	68.40	75.25

20%	58.84	59.96	42.44	49.77
30%	33.19	33.39	32.81	37.79
40%	19.50	21.78	26.49	30.35
50%	10.81	16.60	20.90	24.48
60%	7.94	14.02	17.03	20.31
70%	6.26	11.94	13.71	16.14
80%	4.90	10.29	11.03	12.81
90%	4.48	8.42	8.39	9.39
100%	4.13	2.31	3.26	3.03

From the daily FDC curve of different RCP for different time window, it is found that the Q_{40} is increasing timewise and RCP scenario wise and also the base flow increases 2015-2044 and decreases which is in similar as that of monthly FDC. However, the discrepancy found in daily FDC than that of monthly FDC is that future base flow in compare to that of base line flow founds to be decreasing on each RCP scenario indicating dry days are drier.

5.3 Future Flood Trend Analysis and Result

The Gumbel, Lognormal & Log Pearson Extreme value frequency analysis method were adopted for flood trend analysis because of simplicity to calculate. Based on simulated future discharge results, flood of different return period for immediate future, medium term future and long term future was calculated for all RCP scenario. The result showed that flood goes on increasing from 2015-2104. It is good symbol of increasing nature of flood quantity in future and hence, it should be incorporated in design of hydraulic structures.

Table 5-13: Gumbel Flood Comparison

Return Period(T)	Gumbel Flood Comparison: RCP 8.5 Scenario			
	Baseline	2015-2044	2045-2074	2075-2104
2	104.44	113.18	116.71	126.8
10	182.05	204.51	152.95	229.0
25	221.12	250.47	216.53	280.5
50	250.10	284.57	263.70	318.7
100	278.86	318.42	310.51	356.6
200	307.52	352.14	357.16	394.4
500	345.33	396.63	418.70	444.2
1000	373.91	430.26	465.21	481.9

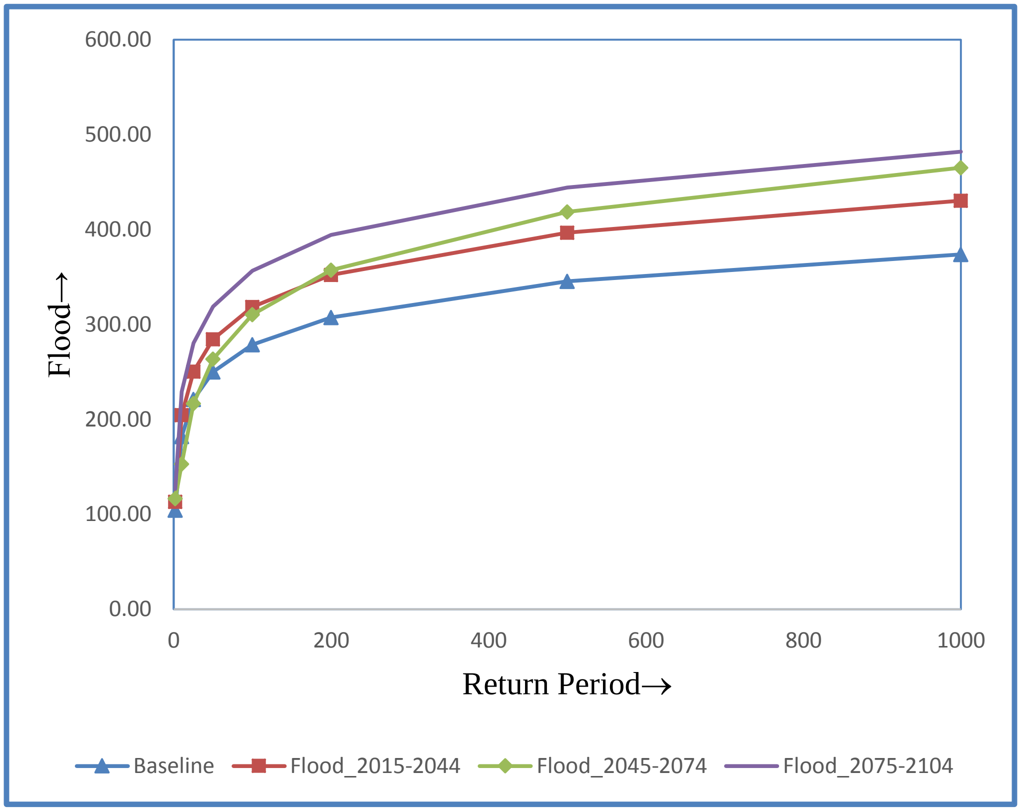


Figure 5-21: Future Flood Comparison: Gumbel Method-RCP 8.5

Table 5-14: Future flood using Log Normal Method

Return Period(T)	Comparison of Log Normal Flood : RCP 8.5 Scenario			
	Baseline	2015-2044	2045-2074	2075-2104
2	77.36	120.47	125.42	140.4
10	100.92	177.47	174.64	192.0
25	111.24	204.49	210.20	215.3
50	118.45	224.09	213.17	231.9
100	125.33	243.29	228.69	247.8
200	132.00	262.38	243.94	263.4

500	139.23	283.57	260.68	296.9
1000	146.86	306.46	278.57	330.5

From the above chart and table, It is seen that the flood is increasing in each time window for RCP 8.5 scenario by 6%, 2% & 1.5% for 2015-44, 2045-74 & 2075-2104 respectively.

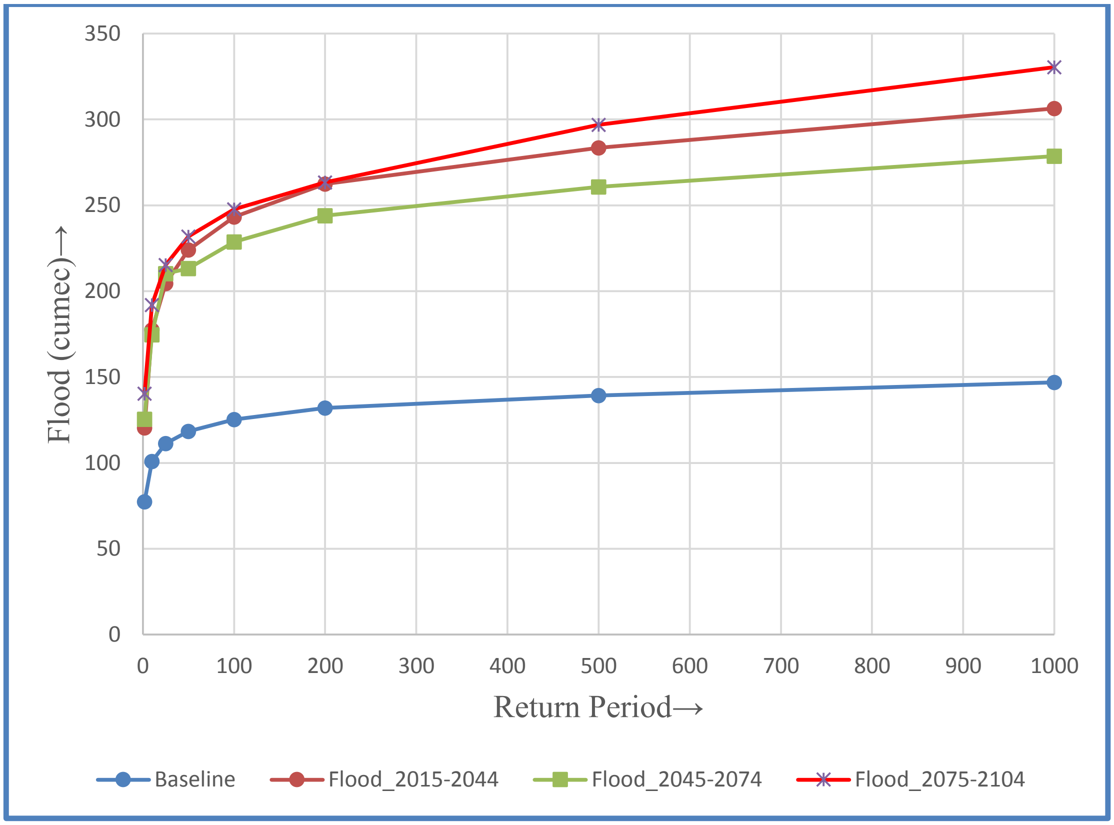


Figure 5-22: Future Flood Comparison using Log Normal Method: RCP 8.5 Scenario

Table 5-15: Future Flood Comparison Using Log Pearsion III Method

Return Period(T)	Comparison of Flood: Log Pearson III Method : RCP 8.5 Scenario			
	Baseline	2015-2044	2045-2074	2075-2104
2	77.89	119.28	123.30	138.1
10	100.42	178.49	176.23	193.7

25	109.61	208.67	203.81	222.2
50	115.81	231.32	224.88	243.9
100	121.54	254.26	218.52	237.4
200	126.95	277.63	268.60	288.6
500	132.63	291.65	294.81	315.1
1000	138.57	334.53	358.90	377.0

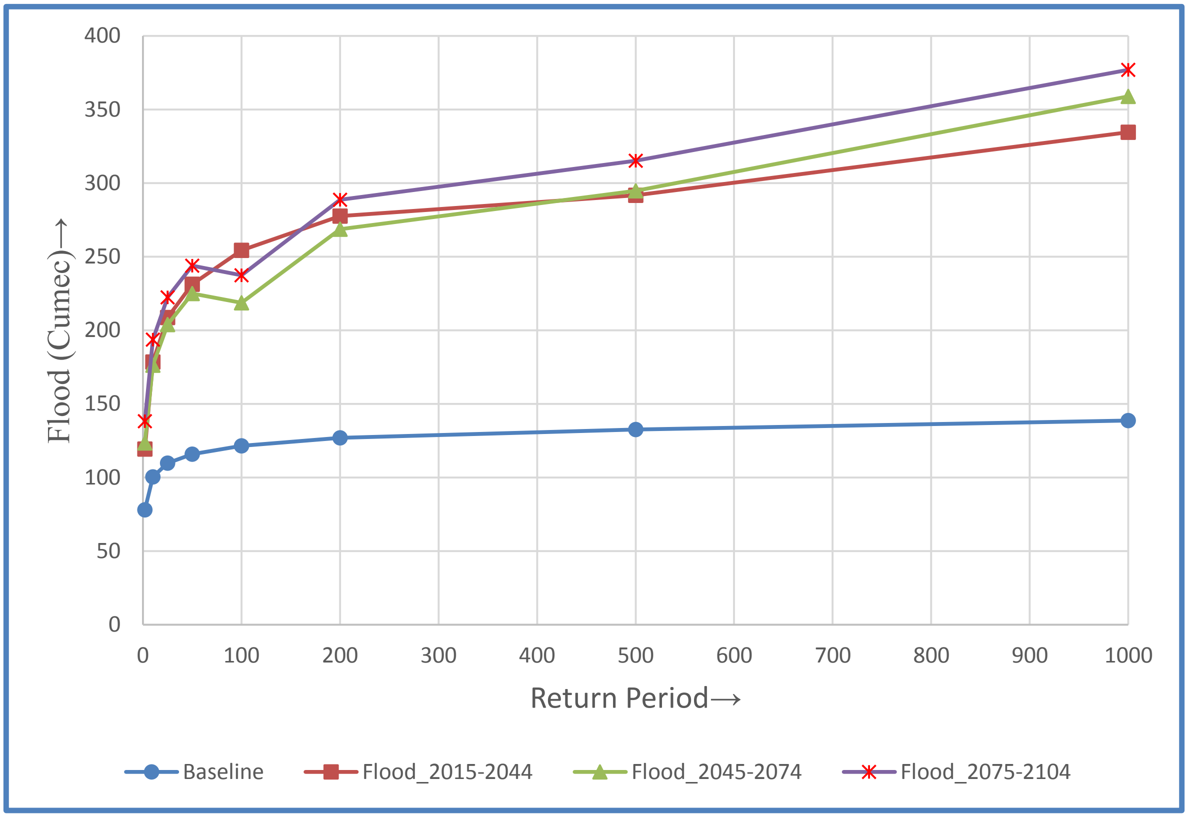


Figure 5-23: Future Flood Coparison using Log Pearsion III Method:RCP:8.5

From the above graph and charts, increasing trend of flood in future for all time windows was seen which is similar to trend as in Gumbel Method. However, flood of 2015-44 increased by a bit more than Gumbel i.e. by 10-12%.

5.4 Future Annual Energy Change Trend Analysis and Results

The trend of net annual energy change for was carried out for immediate future (2015-2044), mid-term future (2045-2074) and long-term future (2075-2104) and compared with the baseline period. It is seen that energy of different return period is continuously increasing in most of cases. The net annual energy is calculated assuming general simple assumptions as follows**:**

Table 5-16: Energy calculation assumptions

Gross head	698	m
Environmental release	10	%
Wet flushing discharge	10	%
Dry flushing discharge	5	%
Evaporation Loss	2	%
Wet season outage	10	%
Dry season outage	5	%

The result of the energy scenario study is presented as follows:

Table 5-17: Energy Comparison in future:RCP 2.6 Scenario

Time Span	Net Annual Energy	Unit
Baseline	977.7	GWhr
2015-2044	1318.3	GWhr
2045-2074	1379.4	GWhr
2075-2104	1373.7	GWhr

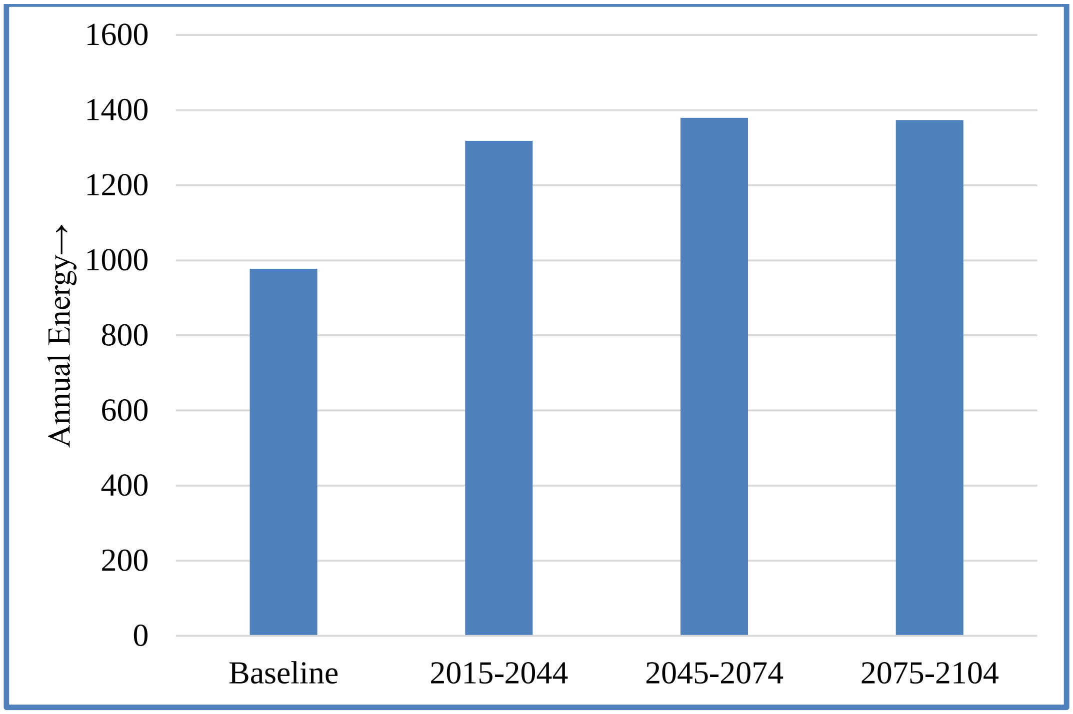


Figure 5-24 Annual Energy Comparison : RCP 2.6 Scenario

The annual energy in RCP 2.6 scenario showed that annual energy will be increased by 34% in time window 2015-2044, again increase with decrease rate (5%) in interval 2045-2074 and ultimately decrease by 1% in 2075-2104.

Table 5-18: Annual Energy Comparison : RCP 4.5 Scenario

Time Span	Net Annual Energy	Unit
Baseline	977.7	GWhr
2015-2044	1356.7	GWhr
2045-2074	1462.0	GWhr
2075-2104	1572.5	GWhr

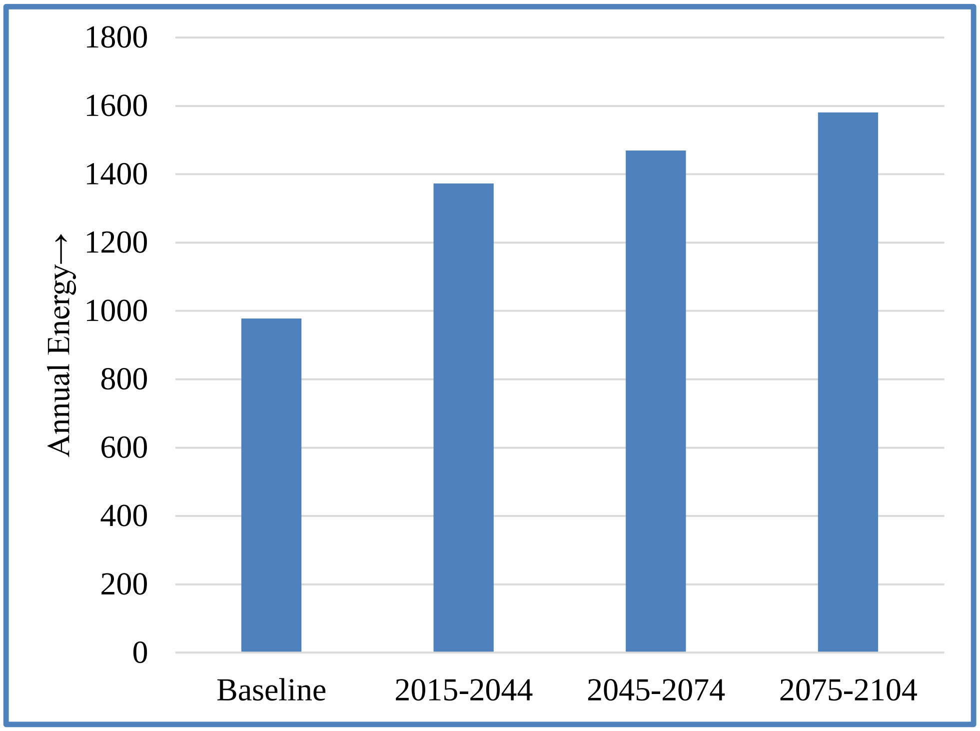


Figure 5-25:Annual Energy Comparison :RCP 4.5 Scenario

The annual energy in RCP 4.5 scenario showed that annual energy will be increased by 36% in time window 2015-2044, again increase with decrease rate (7.5%) in interval 2045-2074 and ultimately increase by 7.6% in 2075-2104.

Table 5-19: Annual Energy Comparison: RCP 8.5 Scenario

Time Span	Net Annual Energy	Unit
Baseline	977.7	GWhr
2015-2044	1372.9	GWhr
2045-2074	1469.4	GWhr
2075-2104	1581.1	GWhr

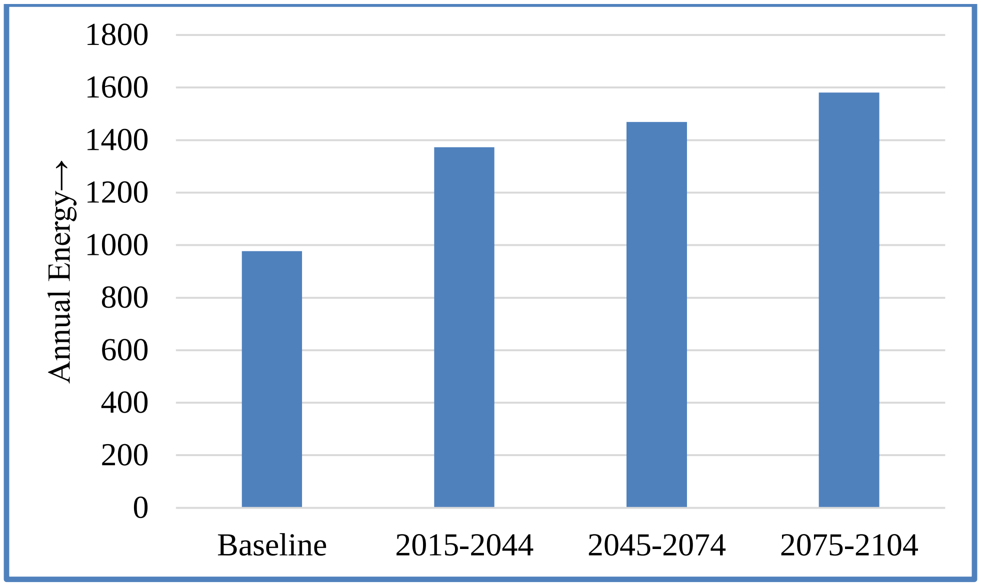


Figure 5-26 : Annual Energy Comparison : RCP 8.5 Scenario.

The annual energy in RCP 4.5 scenario showed that annual energy will be increased by 37% in time window 2015-2044, again increase with decrease rate (7.1%) in interval 2045-2074 and ultimately increase by 7.5% in 2075-2104.

Finally, from the energy scenario analysis, it is seen that the annual energy is increasing in most of cases.

5.5 Analysis of Recorded Data & Result

The use of past recorded data for assessing the climate change impact is very important because recorded data gives the reality of past. The different climate change assessment tools and their projected results should be compatible with the past scenario and reality that was felt. By analysing the past data, applicable and indicative predictions for future can be drawn, so climate data like precipitation, temperature, humidity etc. data of Naulsing Gad HEP and vicinity area was collected and analysed.

The temperature data of station no. 303, 312 & 514 are chosen and annual maximum, minimum & average temperature were analysed. The following table gives the the temperature scenario of project area.

The plot of temperature at various stations was done and result was presented as shown in fig. below.

These plots give the clear scenario of past and indicative information for future.

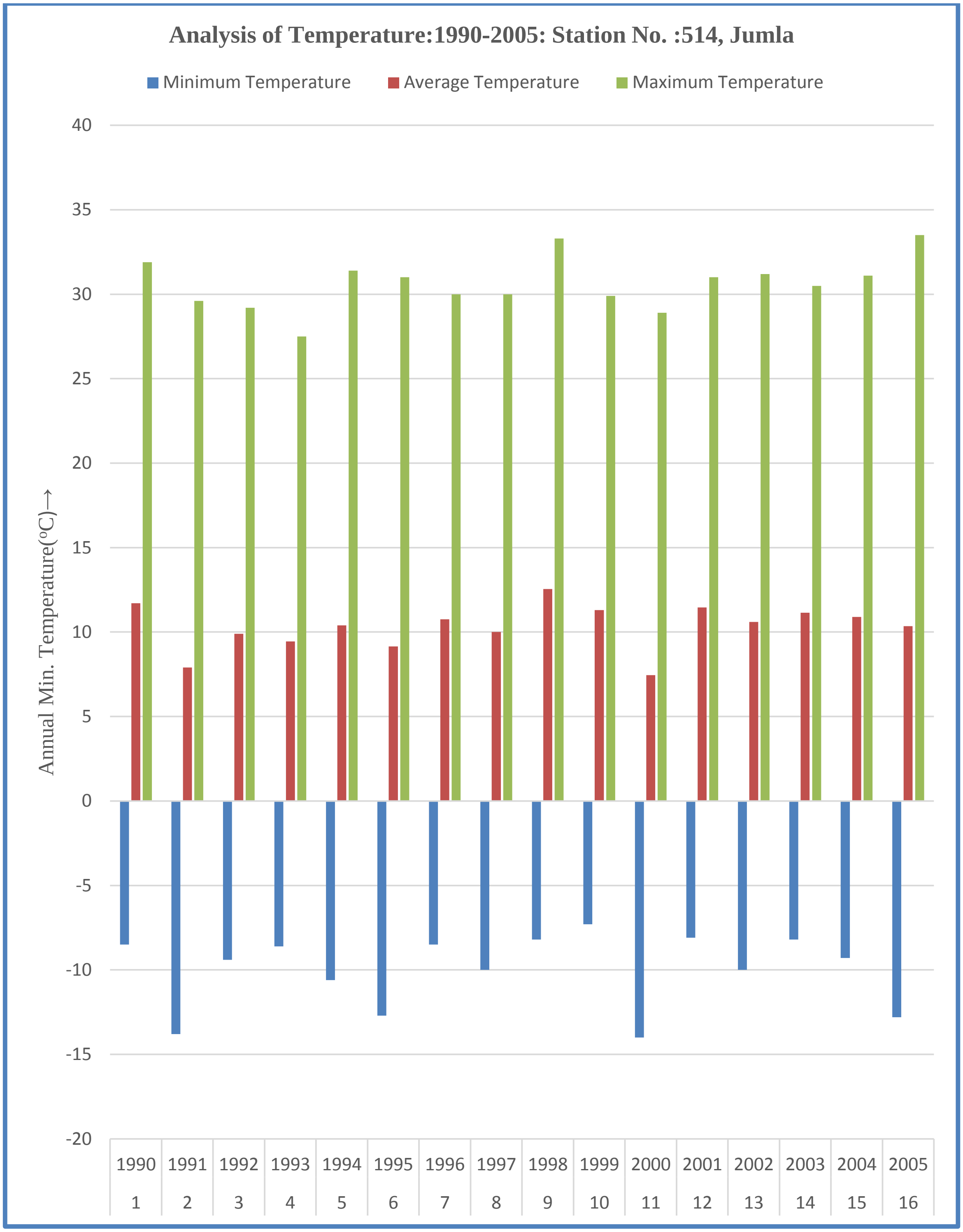


Figure 5-27: Presentation of Past Temperature data of station no. 514

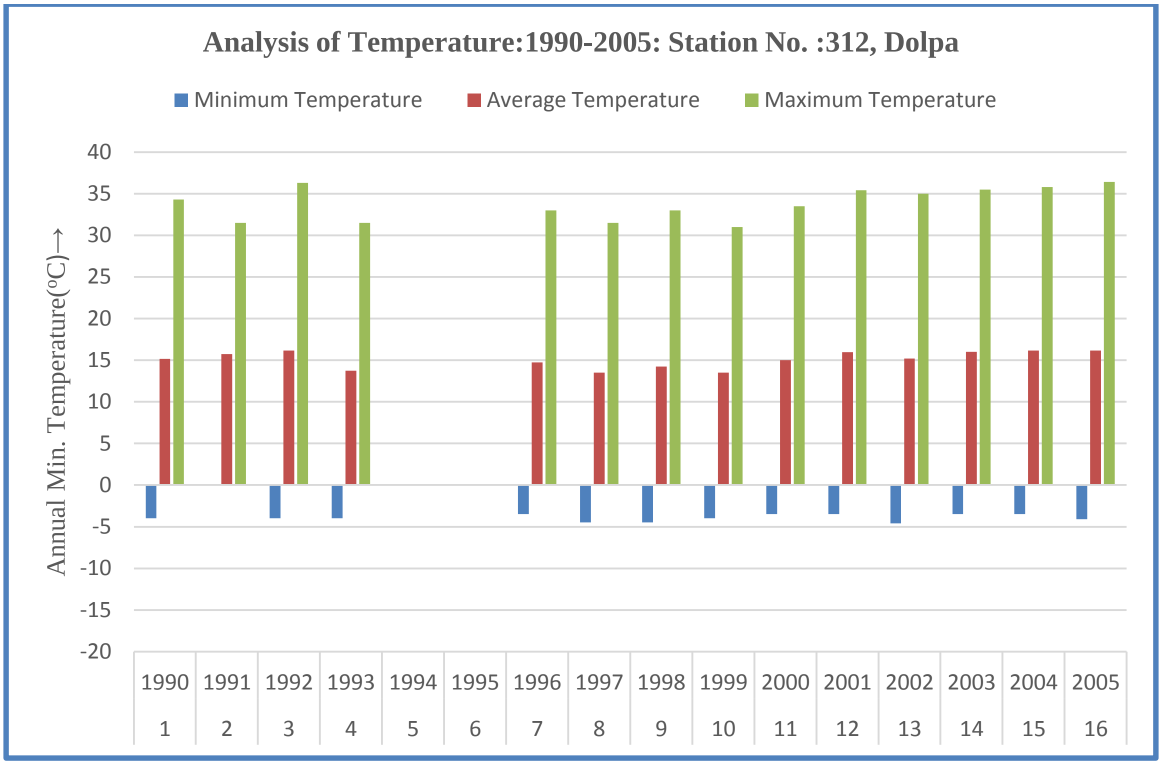


Figure 5-28: Presentation of Past Temperature data of station no. 312

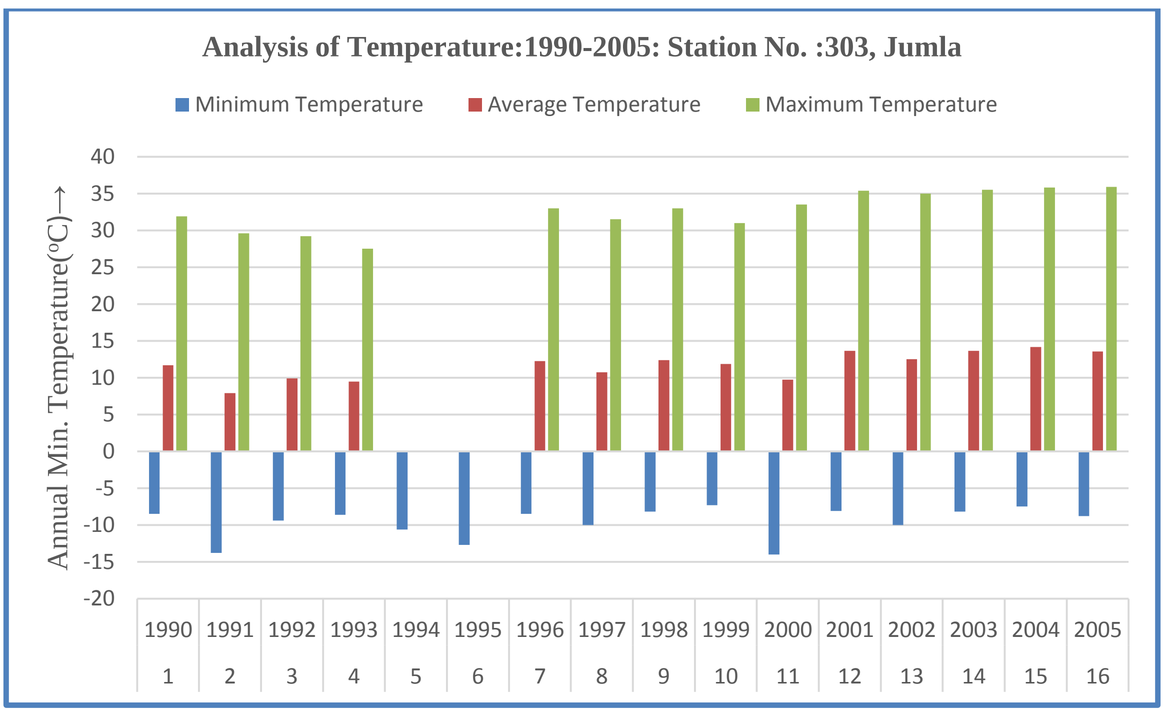


Figure 5-29: Presentation of Past Temperature data of station no. 303

The past data of station no. 514 showed that the maximum of recorded temperature data (1990-2005) is 33.3 ^oC which was occurred on 2005 A.D. Similarly, the minimum temperature, within this period is found to be -14 ^oC occurred in 2000 A.D. which is too lowest and abnormal in compare to the other recorded data. Based on recorded data, it is seen that the max. Temperature, minimum temperature and average temperature has followed no specific trend. However, the in most data trend is increasing year by year.

The temperature data of station no. 312 from 1990-2005 was plotted as shown and it is seen that maximum temperature was found to 35.9 ^oC in 2005 A.D. Similarly, abnormal minimum temperature of -14 ^oC in 2000 A.D. is found. The maximum and minimum temperature are mostly found to be increasing.

The temperature data of station no. 303 showed that the maximum and minimum temperature during this period found to be 36.4 ^oC & -4.6 ^oC respectively. The temperature data shows no specific trend but it is clearly seen that the maximum and average temperature are increasing year wise in most cases.

So, the temperature data of 3 station clearly indicates the signal of global warning showing hot days becomes hotter and cold days become colder year by year in most of data or cases.

The past precipitation data of project area are collected and presented graphically as shown below.

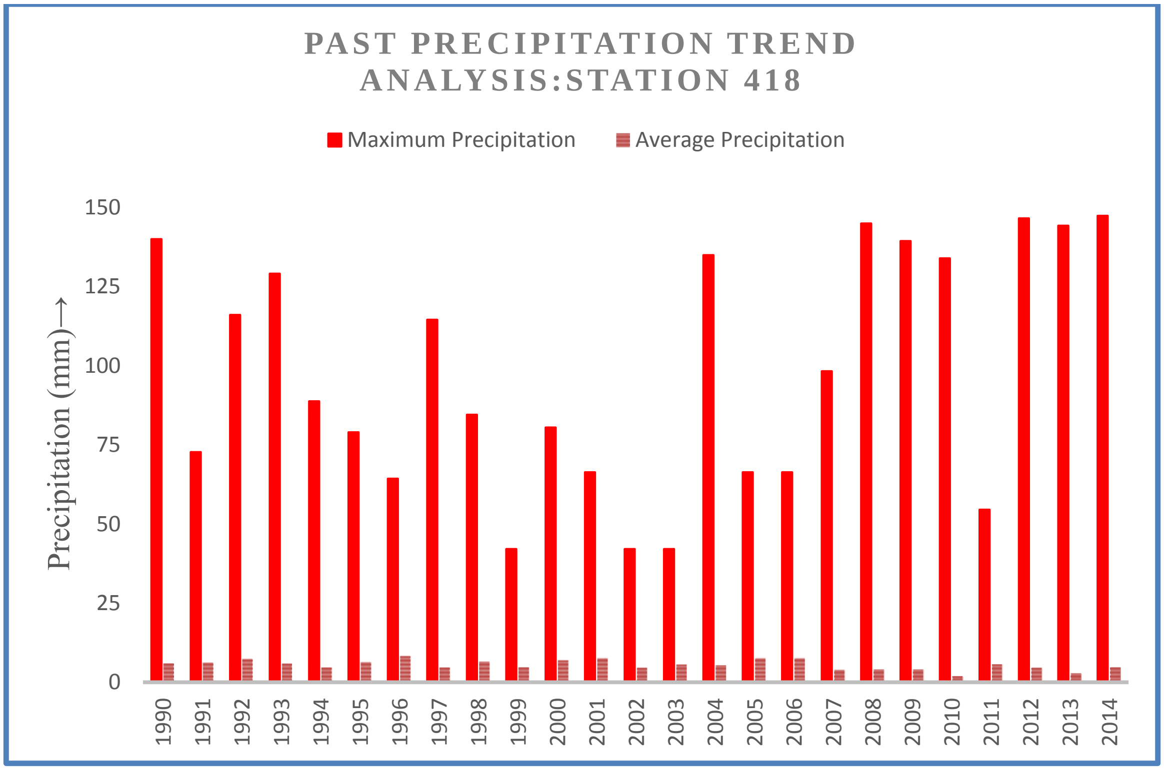


Figure 5-30: Maximum and Average precipitations of station no. 418.

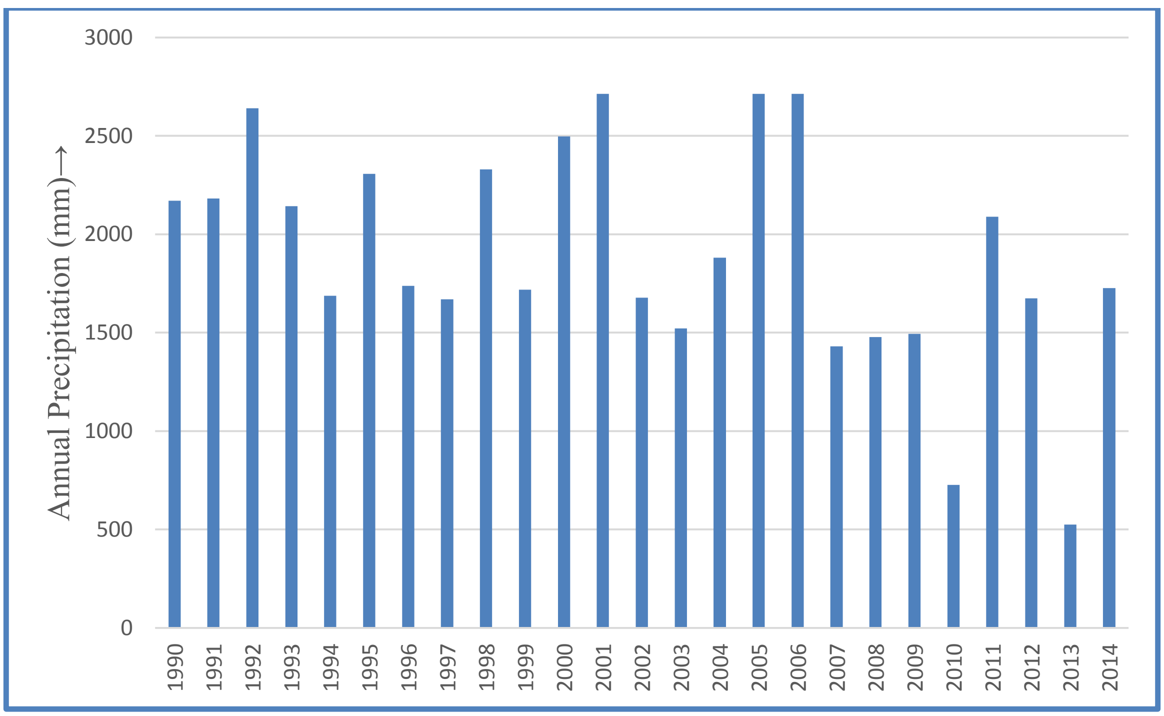


Figure 5-31: Annual precipitations of station no. 418.

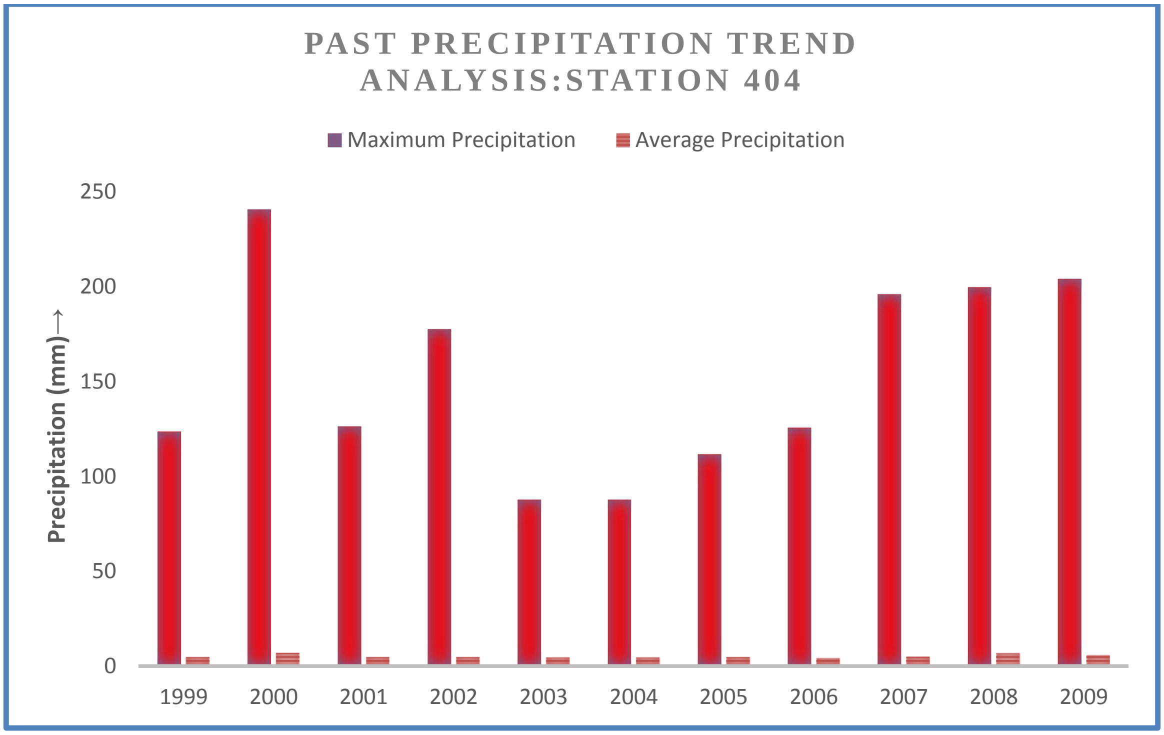


Figure 5-32: Maximum and Average precipitations of station no. 404.

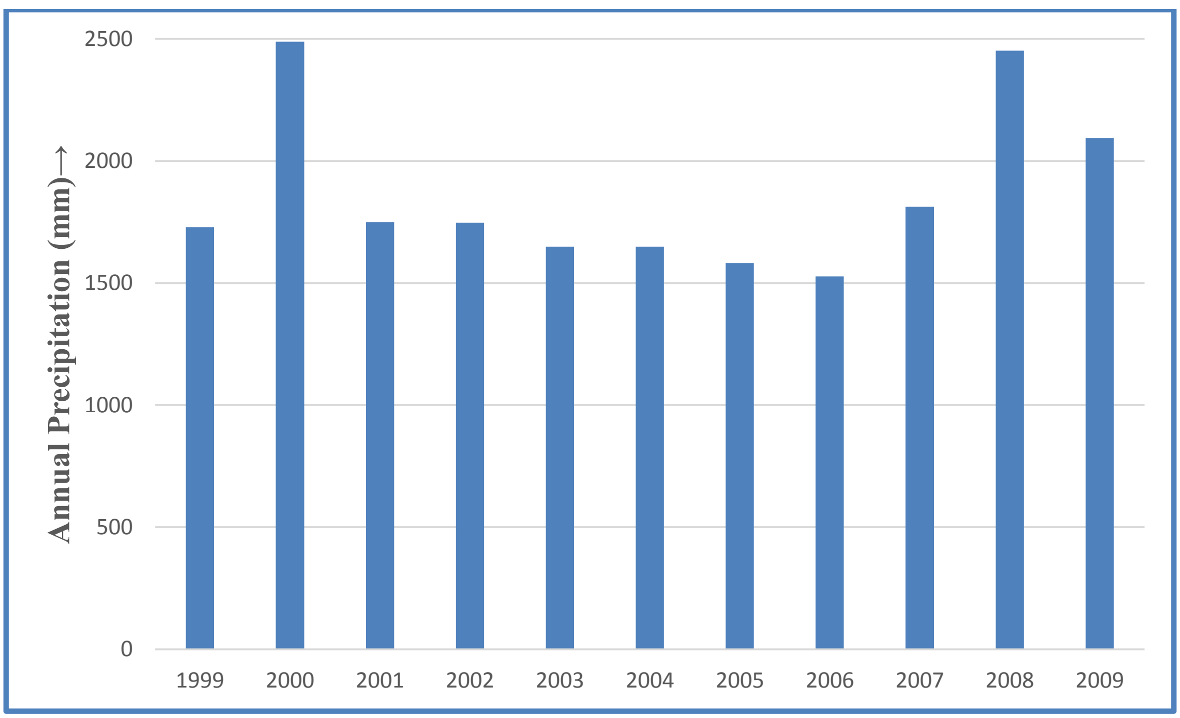


Figure 5-33: Annual precipitations of station no. 404.

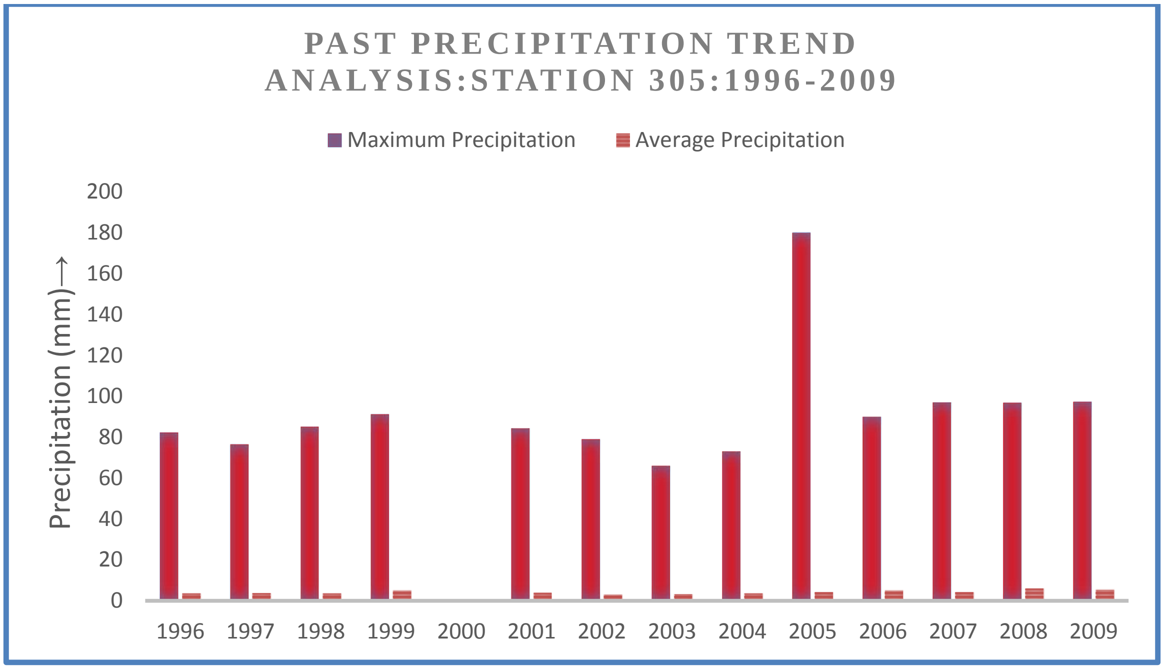


Figure 5-34: Maximum and Average precipitations of station no. 305.

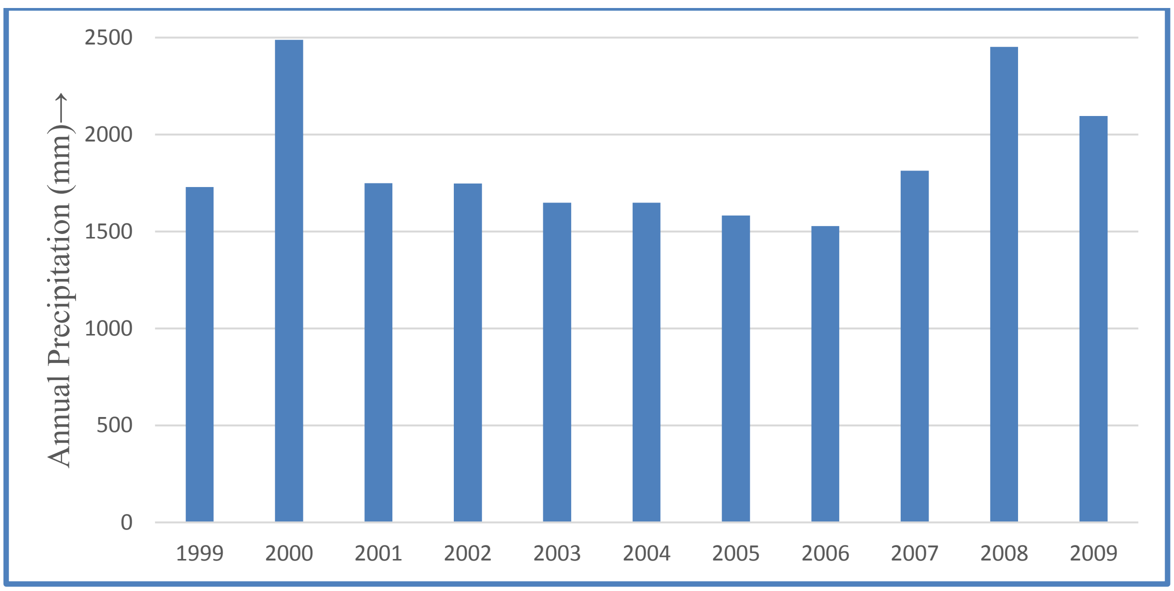


Figure 5-35: Annual precipitations of station no. 305.

The past precipitations study of station no. 418 showed that no fixed trend. However, the maximum precipitation of last 4 year clearly indicates increasing trend. Similarly, data of station no. 404 showed maximum rainfall of recorded years equal to 240.7 mmm in 2000 A.D. and also, the maximum precipitation recorded at station 305 in 2005 A.D. (i.e. 180 mm) is quite abnormal and interesting in compare to the data of same stations.

So, from past data of precipitation, it is seen that though annual rainfall is significantly not changed the maximum precipitations found to be increasing. Also, abnormal rainfall pattern in some station in limited number and frequency shows the extremity caused due to climate change.

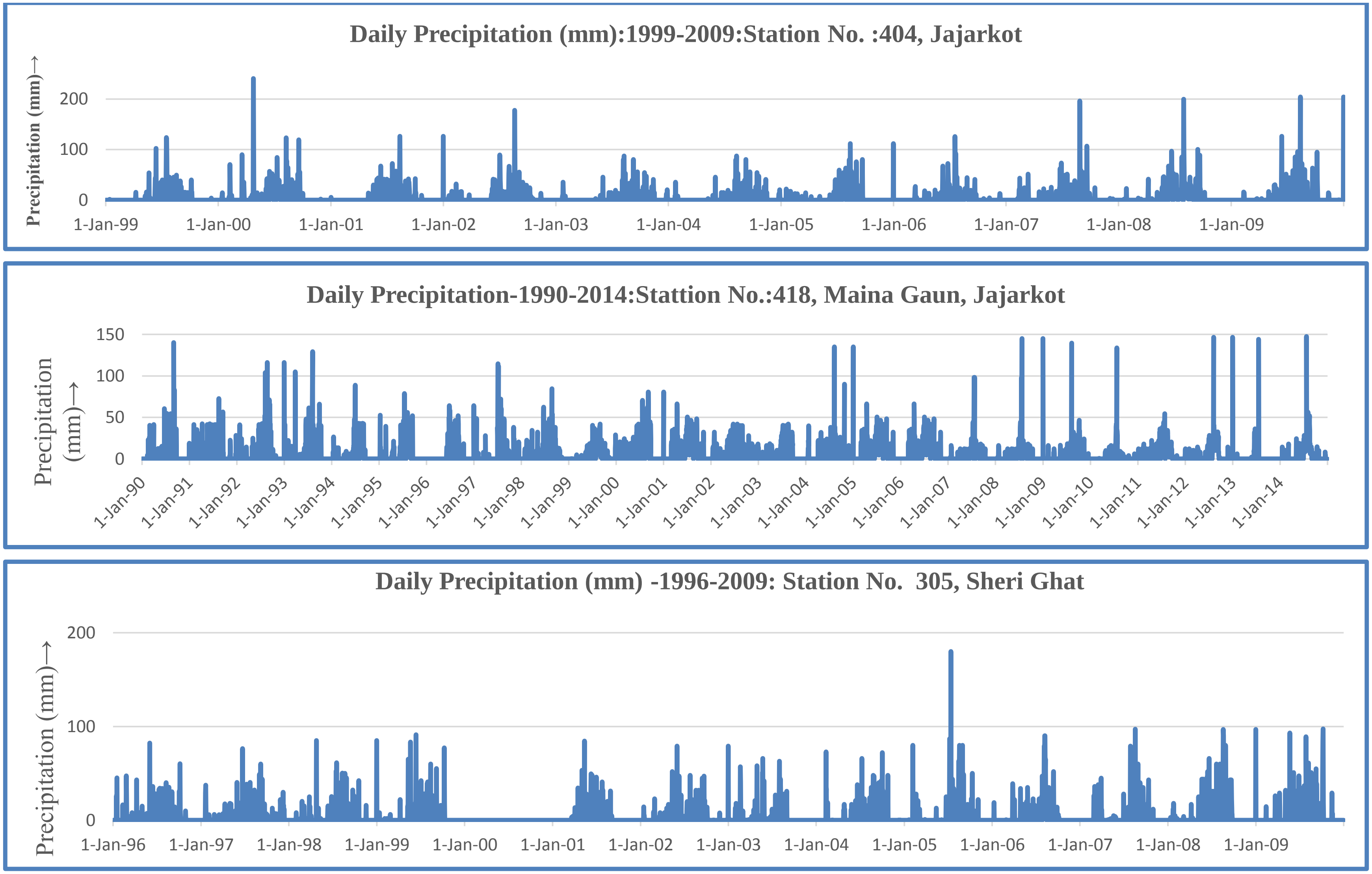


Figure 5-36: Plot of daily recorded precipitation of different stations of project area.

5.6 Comparison & compatibility of results from past & projected future data

The past precipitation and temperature data were analysed. Basically, the maximum, minimum, average etc. are studied for 3 sets of stations for different time periods. It is seen that no specific trend but maximum precipitation & temperature is increasing in most of cases of recorded past data and projected future data.

Table 5-20: Past recorded min., max. & aanual precipitation & temperature scenario

Climatic Parameters	**Rainfall (mm)**				**Temperature (^{O}C)**			
Station No.	418	305	404	Among Three	303	514	312	Among Three
Period	1990-2014	1996-2009	1999-2009		1990-2005	1990-2005	1990-2005	
Maximum	148	180	241	240.7	36	36	34	36.4
Minimum					-14	-5	-14	-14.0
Daily	5	4	5	4.9	12	15	10	12.4
Annual	1898	1406	1862	1721.9				

Table 5-21:Future max., average & annual precipitation scenario

Description	**2015-2044**			**2045-2074**			**2075-2104**			**2015-2104**			**2015-2104**
	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP
Max.	134	94	137	125	112	140	111	119	266	134	119	266	266
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daily	2.88	2.94	2.88	2.85	2.92	3.02	2.96	2.99	3.73	2.9	3.0	3.2	3.0
Annual	1053	1073	1050	1040	1067	1102	1079	1092	1361	1058	1077	1171	1102

From above table, the maximum recorded precipitation of project area is found to be 240.7 mm & maximum precipitation of future is found to be 266.2 mm. The future projected annual precipitation follows no any specific trend but the maximum precipitation is increasing. Furthermore, though the projected future maximum precipitation is higher the projected future annual precipitation are relatively lower than past recorded precipitation data. In other word, future precipitation is found to be erratic.

Table 5-22:Maximum, minimum & average discharge of Naulsing Gad HEP

Description	**Base line**	**2015-2044**			**2045-2074**			**2075-2104**			**2015-2104**			**2015-2104**
	2008-2012	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP
Max.	282.3	185.4	193.7	194.7	173.8	181.6	182.5	228.0	278.2	295.0	228.0	278.2	295.0	295
Min.	4.10	2.2	2.7	2.7	3.1	3.2	3.3	2.9	3.0	3.0	2.2	3.2	3.3	2.2
Daily Average	39.53	32.82	34.30	34.46	29.51	30.84	30.99	30.38	34.08	34.56	30.9	33.1	33.3	32.4

The recorded 4 year flow data of project site and projected future flow data was studied. Mainly study is focused on the maximum, minimum and average flow so that climatic variability assessment becomes easier. From above table, it is found that minimum flow of past is 4.1 cumec while minimum of future flow is 2.2 cumec. Similarly, maximum flow of past is found to be 282.3 cumec whereas future maximum is 295 cumec. It is seen that maximum flow is found to be increasing whereas minimum flow is decreasing in most cases.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

The conclusions drawn from this study are as follows:

1. It was found that trend analysis of past climate data did not show any particular pattern or trend of climate change, although natural climatic variability was clearly observed.
2. In most of recorded data of most of stations showed that the maximum temperature & maximum precipitation found to be increasing.
3. Comparison of future discharge with the baseline period showed consistent increase for all time windows & RCP scenarios, the maximum values being predicted in the long term future towards the end of the century. However, no particular trend or pattern of correlation between the precipitation and discharge was observed in all the three scenarios.
4. The Climate change Scenario shows that there will be increase in River flow in the future. Due to the increased flow, the annual energy generation from Naulsing Gad storage project will be significantly increased in future, more dominant in the time window 2015-2044.
5. The analysis of future flood in different time windows shows that future flood will be increasing in all scenarios under different return period. The magnitude and intensity of flood will be maximum at end of century.
6. The analysis of past recorded data and projected future data has shown that there are somewhat climate change impact indications on river flow. Though projected future annual precipitations are relatively less than past recorded annual precipitation, the maximum projected future precipitation are of higher intensity. The past temperature data showed that though no significant change in average temperature, the extreme temperature are in increasing trend in most cases.

   So, impact of climate change could be significant and should be given almost importance in planning, design and implementation of Naulsing Gad Storage HEP.

6.2 Recommendations

The extreme flows (high and low) analysis of the short term past data showed varying trends with no particular trend valid. Similarly, a fixed relationship between the precipitation and discharge was not observed from the current study. The current study of climate change was based on data from only one GCM. Although downscaled and bias corrected data were used, the results that are presented in this report are obtained from the use of a single GCM data. Therefore, it is recommended that similar study needs to be carried out using at least three other GCM datasets for the study of climate change impact on this project. Only after comparison of the results with the present study, we can make concrete recommendations to the policy makers for managing future climate change impacts on operation of Naulsing Gad HEP.

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ANNEXES

ANNEX A: Parameter of HEC-HMS Model

Loss Model (Green and Ampt Loss)

Sub Basin	Initial Content	Saturated Content	Suction (mm)	Conductivity (mm/HR)	Impervious (%)
W100	0.4	0.5	150	0.55	33
W80	0.45	0.5	200	0.55	11
W70	0.45	0.5	150	0.55	38
W90	0.45	0.46	200	1.242	32
W60	0.3	0.5	140	0.75	12

Base Flow Model
(Recession)

Sub Basin	Initial Type	Initial Discharge (m^3/s)	Recession Constant	Threshold Type	Ratio to peak
W100	Discharge	2	0.978	Ratio to Peak	0.4
W80	Discharge	1.8	0.992	Ratio to Peak	0.3
W70	Discharge	1.3	0.98	Ratio to Peak	0.33
W90	Discharge	1	0.98	Ratio to Peak	0.3
W60	Discharge	1.6	0.98	Ratio to Peak	0.3

Transform Model (Snyder Unit Hydrograph Model)

Sub Basin	Lag Time (HR)	Peaking Coefficient
W100	1	0.5
W90	5	0.5
W70	3	0.5
W60	4	0.5
W100	8	0.49

Routing Model (Muskingum Cunge Channel Routing Model)

Reach	Time Step Method	Length(m)	Slope (m/m)	Manning's n	Shape	Width	Side Slope (xh:1v)
R30	Automatic Fixed Interval	6940	0.005	0.035	Trapezoid	14	1
R50		7825	0.005	0.035	Trapezoid	12	1

Canopy (Simple Canopy)

Sub Basin	Initial storage (%)	Maximum Storage (mm)	Crop Coefficient
W100	6	1500	1

W80	5	900	1
W70	7	600	1
W90	5	800	1
W60	6	1500	1

Surface (Simple Surface)

Sub Basin	**Initial storage (%)**	**Maximum Storage (mm)**
W100	10	1500
W80	12	900
W70	24	600
W90	14	800
W60	10	1500

ANNEX B: Sample Calculation of Annual Net Energy

Scenario: Baseline

Gross head	698	m
Environmental release	10	%
Wet flushing discharge	10	%
Dry flushing discharge	5	%
Evaporation Loss	2	%
Wet season outage	10	%
Dry season outage	5	%

Months	Days	Discharge (m3/s)	Discharge for power generation (m3/s)	Gross Head	Combined Efficiency	Power (KW)	Dry season energy (Kwh)	Wet season energy (kwh)
Jan	31	5.6	4.6	698	0.8	23781	17693234	
Feb	28	4.5	3.7	698	0.8	19029	12787253	

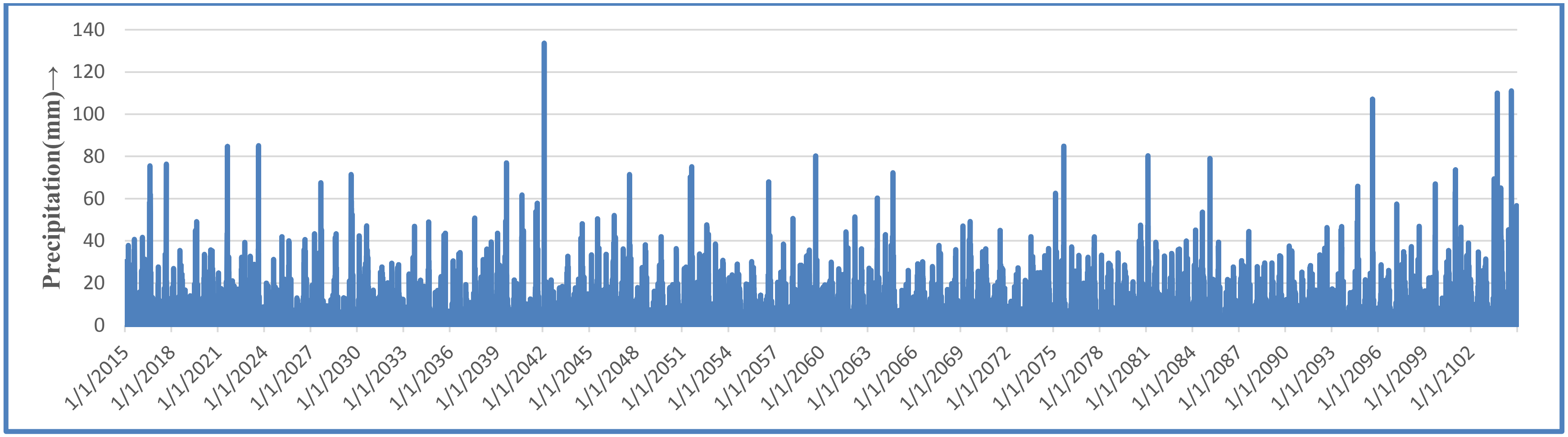
Mar	31	4.1	3.4	698	0.8	17653	6566839	6566839
Apr	30	4.7	3.7	698	0.8	19015		13690727
May	31	7.9	6.2	698	0.8	31712		23593665
Jun	30	23.4	18.3	698	0.8	94025		67698115
Jul	31	87.8	68.5	698	0.8	352495		262256370
Aug	31	103.9	81.1	698	0.8	417376		310527831
Sep	30	64.2	50.1	698	0.8	257853		185654300
Oct	31	37.4	29.2	698	0.8	150106		111678709
Nov	30	13.6	10.6	698	0.8	54733		39407669
Dec	31	8.0	6.6	698	0.8	34186	12717350	12717350
Annual energy generation :							977.7	GWhr

Scenario:2015-2044 RCP 2.6

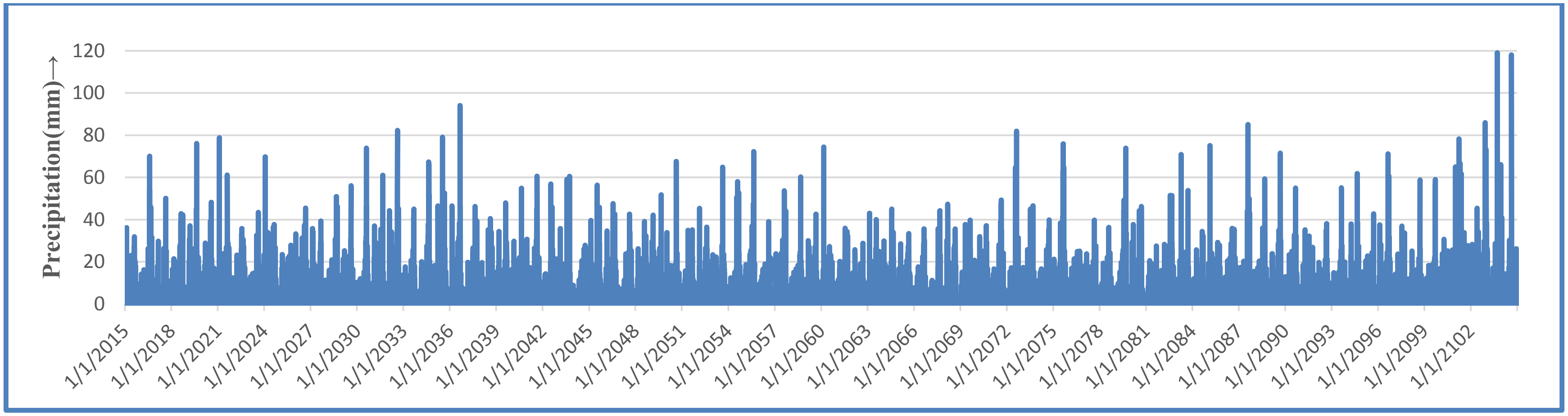
Gross head		698	m					
Environmental release		10	%					
Wet flushing discharge		10	%					
Dry flushing discharge		5	%					
Evaporation Loss		2	%					
Wet season outage		10	%					
Dry season outage		5	%					
Months	Days	Discharge (m3/s)	Discharge for power generation (m3/s)	Gross Head	Combined Efficiency	Power (KW)	Dry season energy (Kwh)	Wet season energy (Kwh)
Jan	31	8.9	7.4	698	0.8	40481	30118083	
Feb	28	8.5	7.1	698	0.8	38642	25967752	
Mar	31	8.9	7.4	698	0.8	40263	14977761	14977761

Apr	30	9.2	7.7	698	0.8	42008		30246098
May	31	10.2	8.5	698	0.8	46480		34581047
Jun	30	38.8	32.2	698	0.8	176560		127123531
Jul	31	56.1	46.5	698	0.8	254892		189639747
Aug	31	109.1	90.6	698	0.8	496132		369121891
Sep	30	73.9	61.3	698	0.8	335998		241918702
Oct	31	43.0	35.7	698	0.8	195506		145456757
Nov	30	17.7	14.7	698	0.8	80347		57849956
Dec	31	12.1	10.0	698	0.8	54933	20435173	20435173
Total seasonal energy in KWh							91498769	1231350664
Total seasonal energy in KWh after deducting outage							86923831	1231350664
Annual energy generation in GWhr							1322.8	
Annual energy generation :							1318.3	GWhr

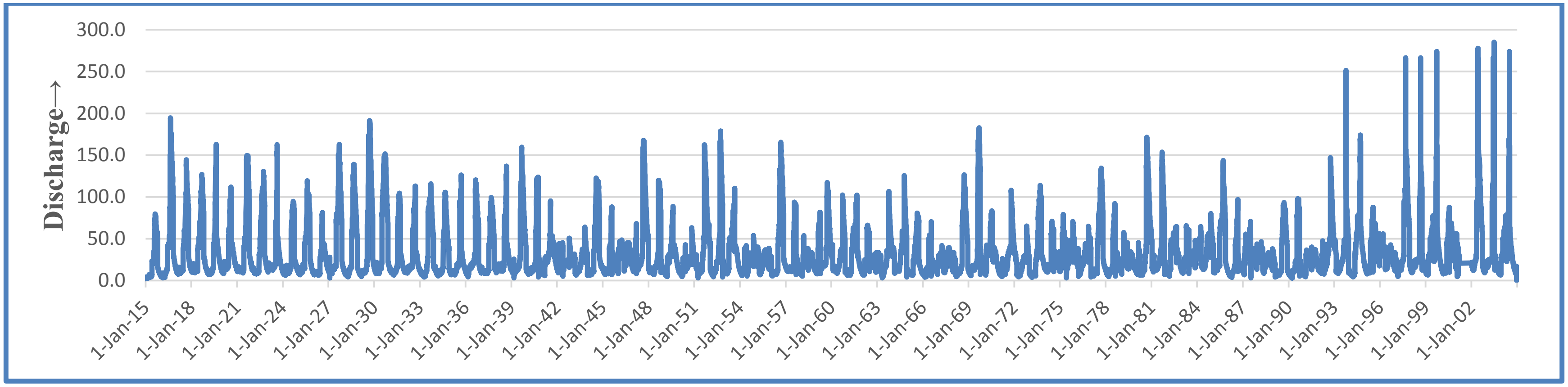
ANNEX C: Daily Future Precipitation: RCP 2.6 Scenario



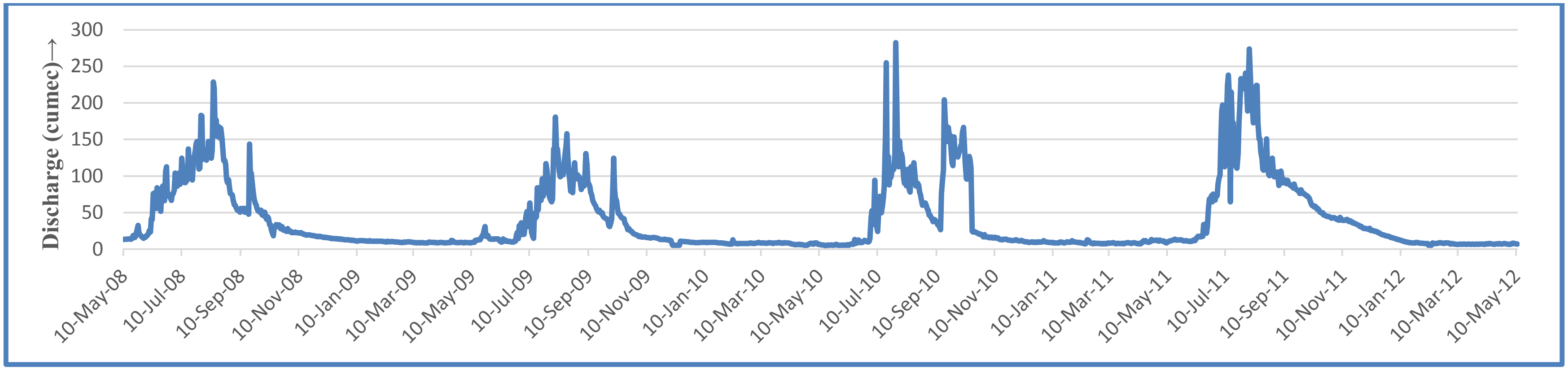
ANNEX D: Daily Future Precipitation : RCP 4.5 Scenario



ANNEX E: Daily Future Precipitation : RCP 8.5 Scenario



ANNEX F: Daily observed Hydrograph :2008-2012



ANNEX G: Max., min. & average future precipitation

Assessment of Climate Change Impact based on Recorded Temperature Data of Naulsing Gad Storage HEP										
Station No.:		303			312			514		
Location:		Jumla			Dolpa			Jumla		
Latitude:		29^o 17'			28^o 56'			28^o 39'		
Longitude:		82 10'			82^o 55'			82^0 29'		
S.N.	**Year**	**Temperature (^{o}C)**								
		Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
1	1990	-8.5	31.9	11.7	-4	34.3	15.15	-8.5	31.9	11.7
2	1991	-13.8	29.6	7.9	0	31.5	15.75	-13.8	29.6	7.9
3	1992	-9.4	29.2	9.9	-4	36.3	16.15	-9.4	29.2	9.9
4	1993	-8.6	27.5	9.45	-4	31.5	13.75	-8.6	27.5	9.45
5	1994	-10.6	NA	NA	NA	NA	NA	-10.6	31.4	10.4
6	1995	-12.7	NA	NA	NA	NA	NA	-12.7	31	9.15

7	1996	-8.5	33	12.25	-3.5	33	14.75	-8.5	30	10.75
8	1997	-10	31.5	10.75	-4.5	31.5	13.5	-10	30	10
9	1998	-8.2	33	12.4	-4.5	33	14.25	-8.2	33.3	12.55
10	1999	-7.3	31	11.85	-4	31	13.5	-7.3	29.9	11.3
11	2000	-14	33.5	9.75	-3.5	33.5	15	-14	28.9	7.45
12	2001	-8.1	35.4	13.65	-3.5	35.4	15.95	-8.1	31	11.45
13	2002	-10	35	12.5	-4.6	35	15.2	-10	31.2	10.6
14	2003	-8.2	35.5	13.65	-3.5	35.5	16	-8.2	30.5	11.15
15	2004	-7.5	35.8	14.15	-3.5	35.8	16.15	-9.3	31.1	10.9
16	2005	-8.8	35.9	13.55	-4.1	36.4	16.15	-12.8	33.5	10.35

ANNEX H: Annual maximum, average and annual precipition of various stations

Assessment of Climate Change Impact based on Recorded Precipitation Data of Naulsing Gad Storage HEP										
Station No.:		418			305			404		
Location:		Jajarkot			Sheri Ghat			Jajarkot		
Lattitude:		28^0 59'			29^o 8'			28^o 42'		
Longitude:		82^o 17'			81^o 36'			82^o 12		
S.N.	**Year**	**Precipitation (mm)**								
		Maximum	Average	Annual	Maximum	Average	Annual	Maximum	Average	Annual
1	1990	140.1	5.9	2169.5						
2	1991	72.8	6.2	2182.1						
3	1992	116.1	7.3	2639.7						
4	1993	129.2	5.9	2142.9						
5	1994	88.8	4.6	1687.6						
6	1995	79	6.3	2306.7						

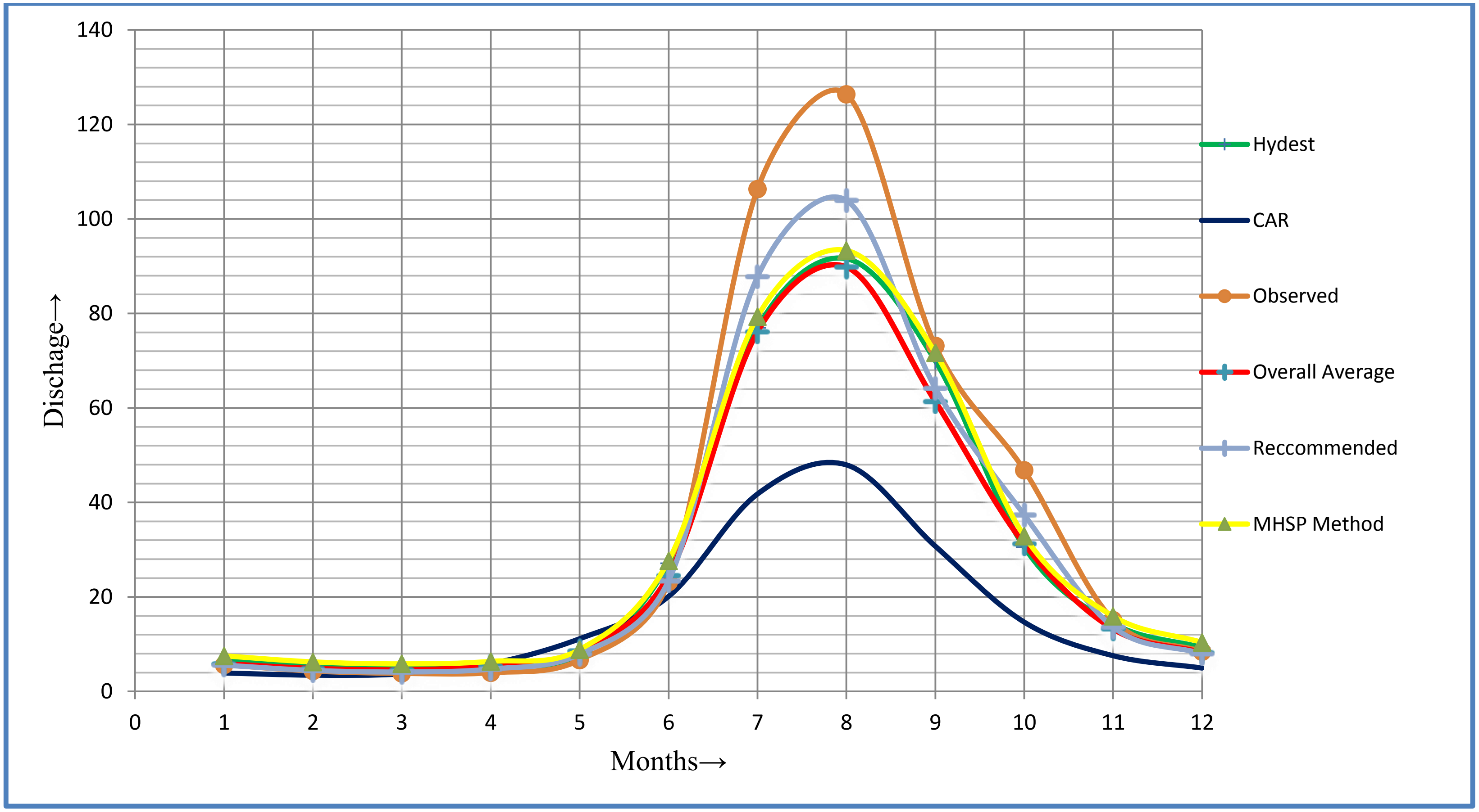
7	1996	64.4	8.2	1737.6	82.3	3.6	1304.8			
8	1997	114.6	4.6	1669.2	76.5	3.7	1359.8			
9	1998	84.6	6.5	2330.3	85.1	3.5	1279.2			
10	1999	42.2	4.8	1717.8	91.3	4.9	1498.1	123.7	4.7	1729.2
11	2000	80.6	6.9	2497.2	-	-	-	240.7	6.9	2487.8
12	2001	66.4	7.5	2713.0	84.4	3.9	1194.5	126.4	4.8	1749.2
13	2002	42.2	4.6	1678.2	79	2.9	1049.6	177.6	4.8	1746.8
14	2003	42.2	5.6	1521.7	66	3.3	1103.8	87.7	4.5	1648.3
15	2004	135	5.4	1881.4	73	3.6	1305.6	87.7	4.5	1648.3
16	2005	66.4	7.5	2713.0	180	4.2	2132.8	111.7	4.8	1582.5
17	2006	66.4	7.5	2713.0	90	5.0	1836.4	125.7	4.2	1527.5
18	2007	98.3	3.9	1430.5	97	4.2	-	196	5.0	1812.2
19	2008	145	4.0	1477.2	96.8	5.9	-	199.8	6.7	2452.2
20	2009	139.5	4.1	1493.6	97.4	5.2	-	204.2	5.8	2094.5

21	2010	134	2.0	725.6						
22	2011	54.6	5.7	2088.8						
23	2012	146.6	4.6	1673.6						
24	2013	144.3	2.9	523.9						
25	2014	147.5	4.7	1725.5						

ANNEX I:Baseline discharge

Comparison of Monthly Flow:						
Month	Flow, Q m^3/s					
	Hydest	CAR	Observed	MHSP	Overall Average	Recommended
January	6.5	3.9	5.6	7.5	5.9	5.57
February	5.5	3.5	4.3	6.3	4.9	4.45
March	5.1	3.7	3.8	5.8	4.6	4.13
April	5.5	5.9	4.0	6.4	5.4	4.74
May	7.7	11.2	6.7	8.9	8.6	7.90
June	27.2	20.1	23.2	27.7	24.5	23.41
July	77.0	41.8	106.3	79.3	76.1	87.78
August	91.6	48.0	126.4	93.3	89.8	103.94
September	70.0	30.7	73.2	71.7	61.4	64.21
October	30.5	14.7	46.8	32.9	31.2	37.38
November	14.4	7.6	15.1	15.9	13.3	13.63
December	9.3	5.0	8.4	10.4	8.3	8.00
Mean Monthly Flow	29.2	16.3	35.3	30.5	27.8	30.43
Maximum flow occurred	91.6	48.0	126.4	93.3	89.8	103.94
Minimum flow	5.1	3.5	3.8	5.8	4.5	4.08

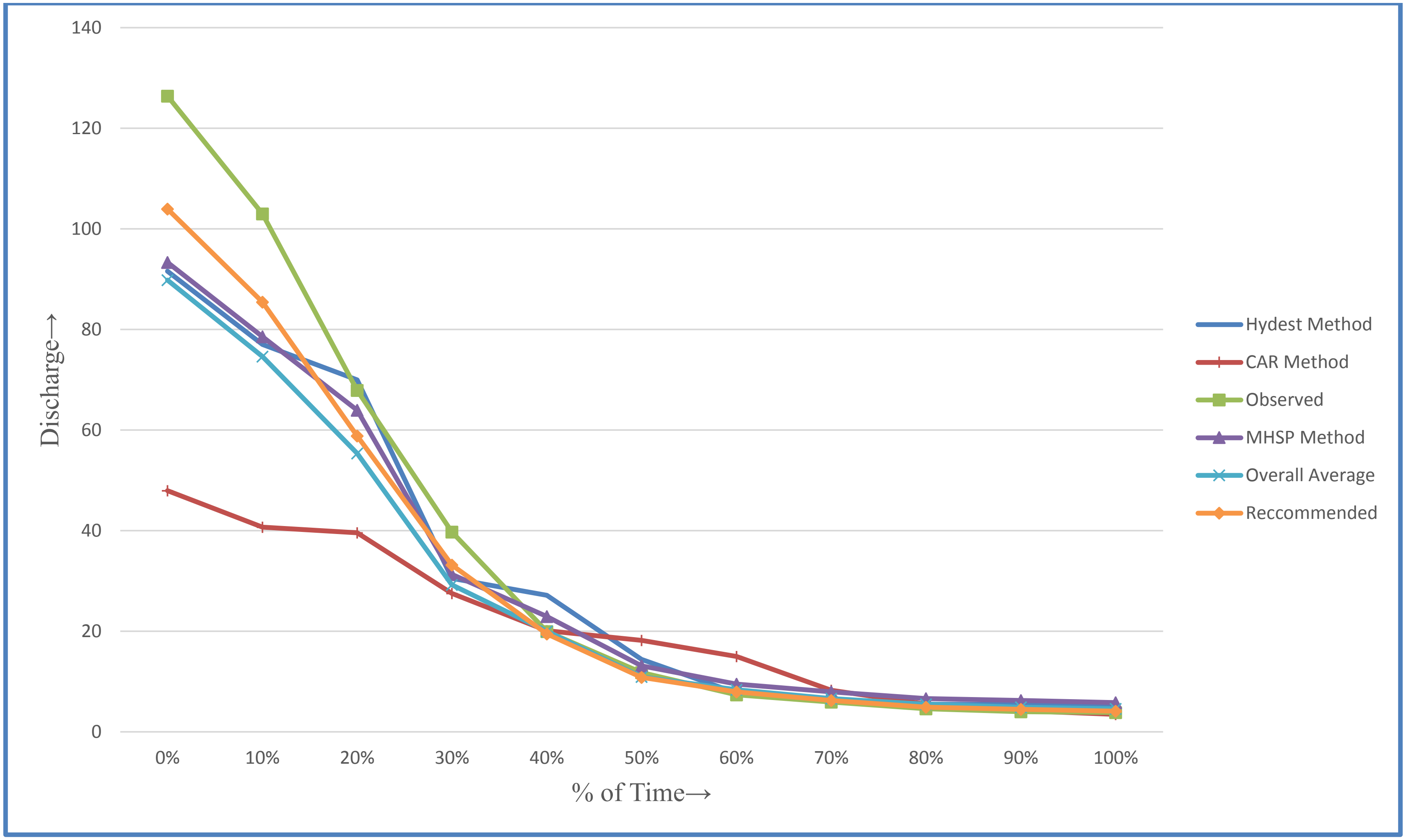
NNEX J: Baseline Flow Estimation



ANNEX K: Estimation of Baseline FDC

Flow Duration Curve(FDC):							
% of Time	**Discharge (Cumec)**						
	Hydest	**CAR**	**Observed**	**MHSP**	**Overall Average**	**Recommended**	**Remarks**
0%	91.6	48.0	126.4	93.3	89.8	103.9	
10%	77.0	40.7	103.0	78.5	74.6	85.4	
20%	70.0	39.6	67.9	63.9	55.4	58.8	
30%	30.5	27.6	39.7	31.3	29.2	33.2	
40%	27.2	20.1	20.0	23.0	20.0	19.5	**Q40**
50%	14.4	18.2	11.8	13.2	10.9	10.8	
60%	7.7	15.0	7.4	9.5	8.4	7.9	
70%	6.5	8.3	6.0	7.9	6.6	6.3	
80%	5.5	5.5	4.6	6.6	5.5	4.9	
90%	5.5	4.2	4.0	6.3	4.9	4.5	
100%	5.1	3.5	3.8	5.8	4.6	4.1	

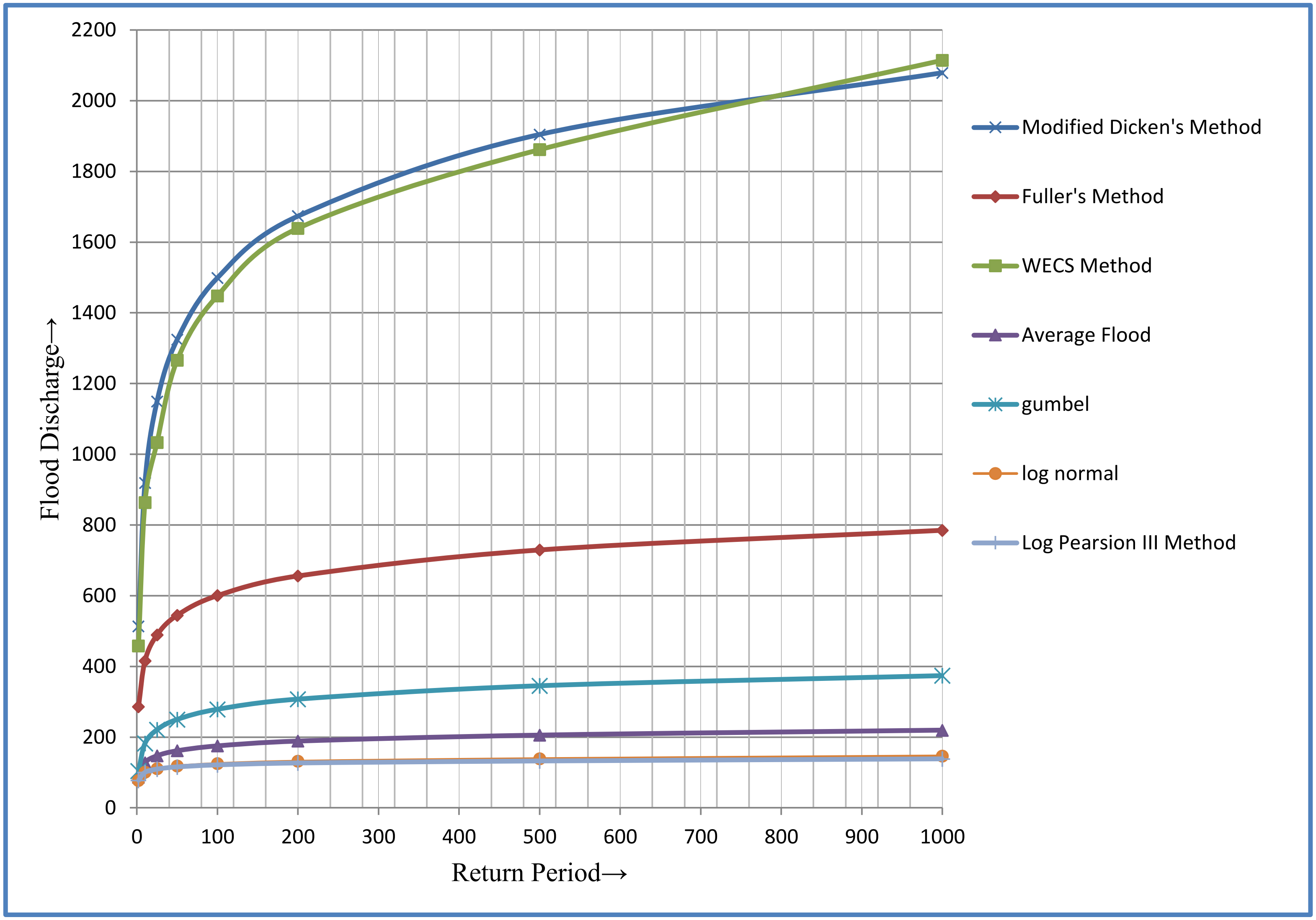
ANNEX L: Comparison of Baseline FDC



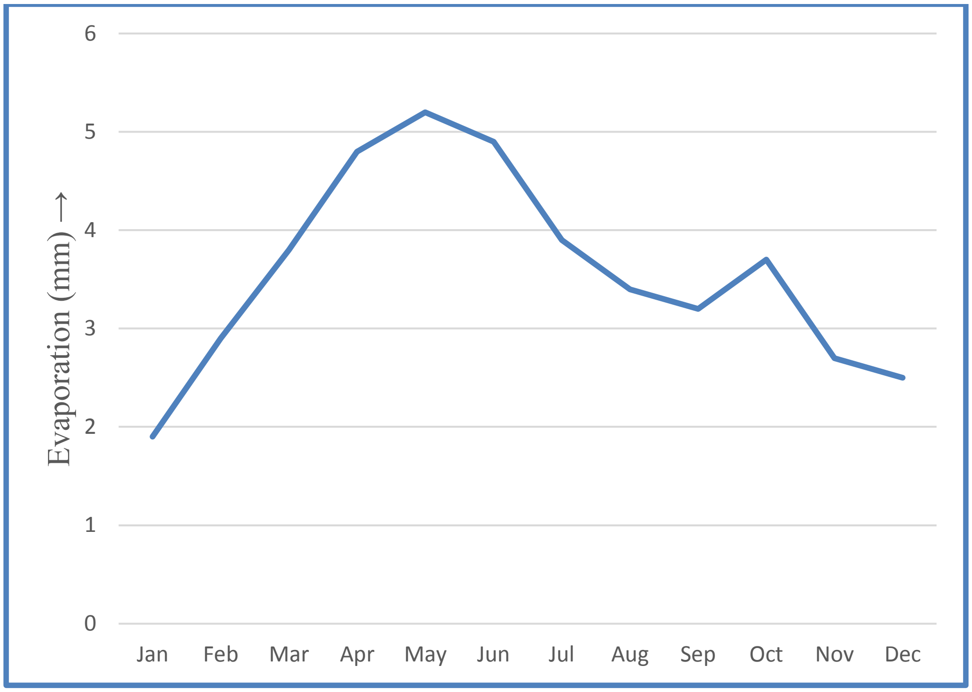
ANNEX M: Comparison of Baseline Flood

Comparison of Baseline Flood:							
Return Period	**Method**						**Average**
	Modified Dicken's	**Fuller's**	**WECS**	**Lognormal**	**Log Pearsion III**	**Gumbel Method**	
2	513.5	286.5	457.82	77.4	77.888	104.4	86.6
10	918.9	415.6	863.71	100.9	100.424	182.1	127.8
25	1149.7	489.1	1033.77	111.2	109.611	221.1	147.3
50	1324.4	544.7	1265.82	118.5	115.806	250.1	161.5
100	1499.0	600.3	1448.3	125.3	121.5	278.9	175.2
200	1673.6	655.9	1639.16	132.0	126.953	307.5	188.8
500	1904.4	729.4	1861.60	139.2	132.634	345.3	205.7
1000	2079.0	785.0	2114.22	146.9	138.568	373.9	219.8

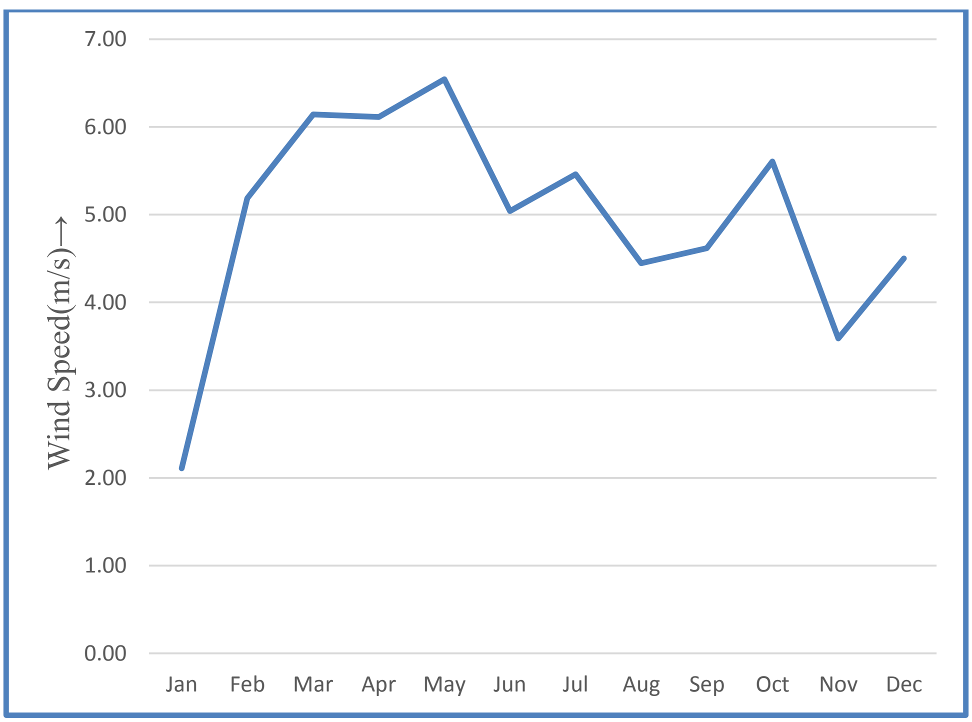
ANNEX N: Plot of Base line flood



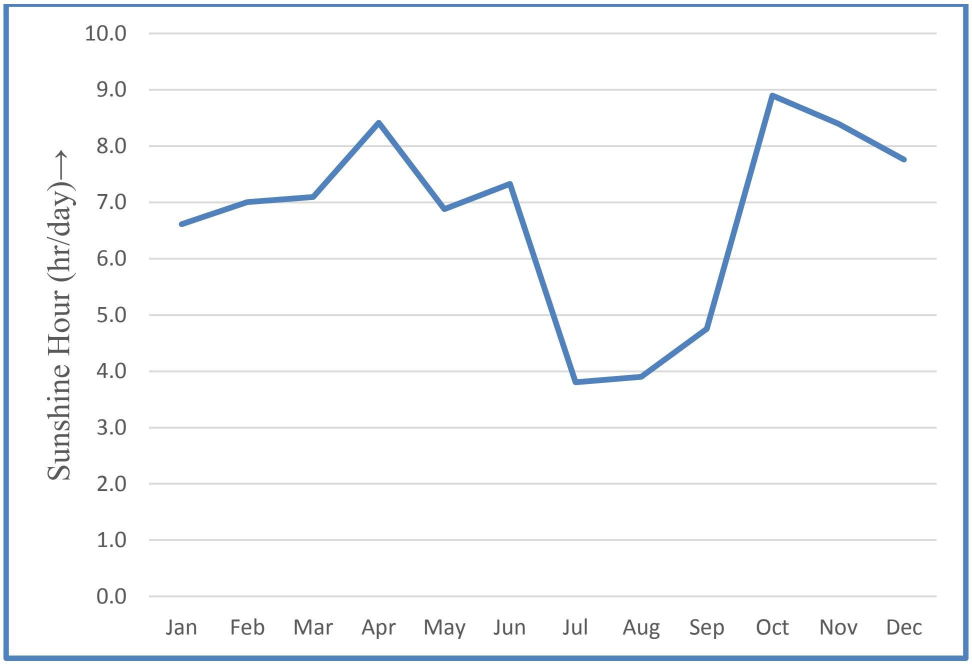
ANNEX O:Monthly Evaporation of Project area



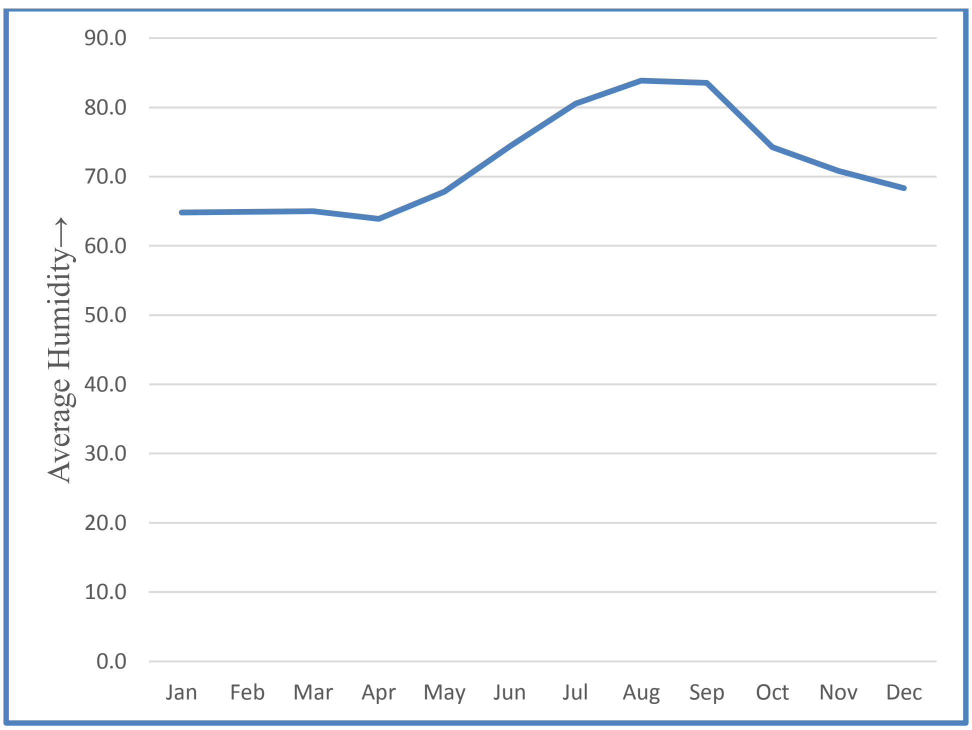
ANNEX P:Monthly wind speed of project area.



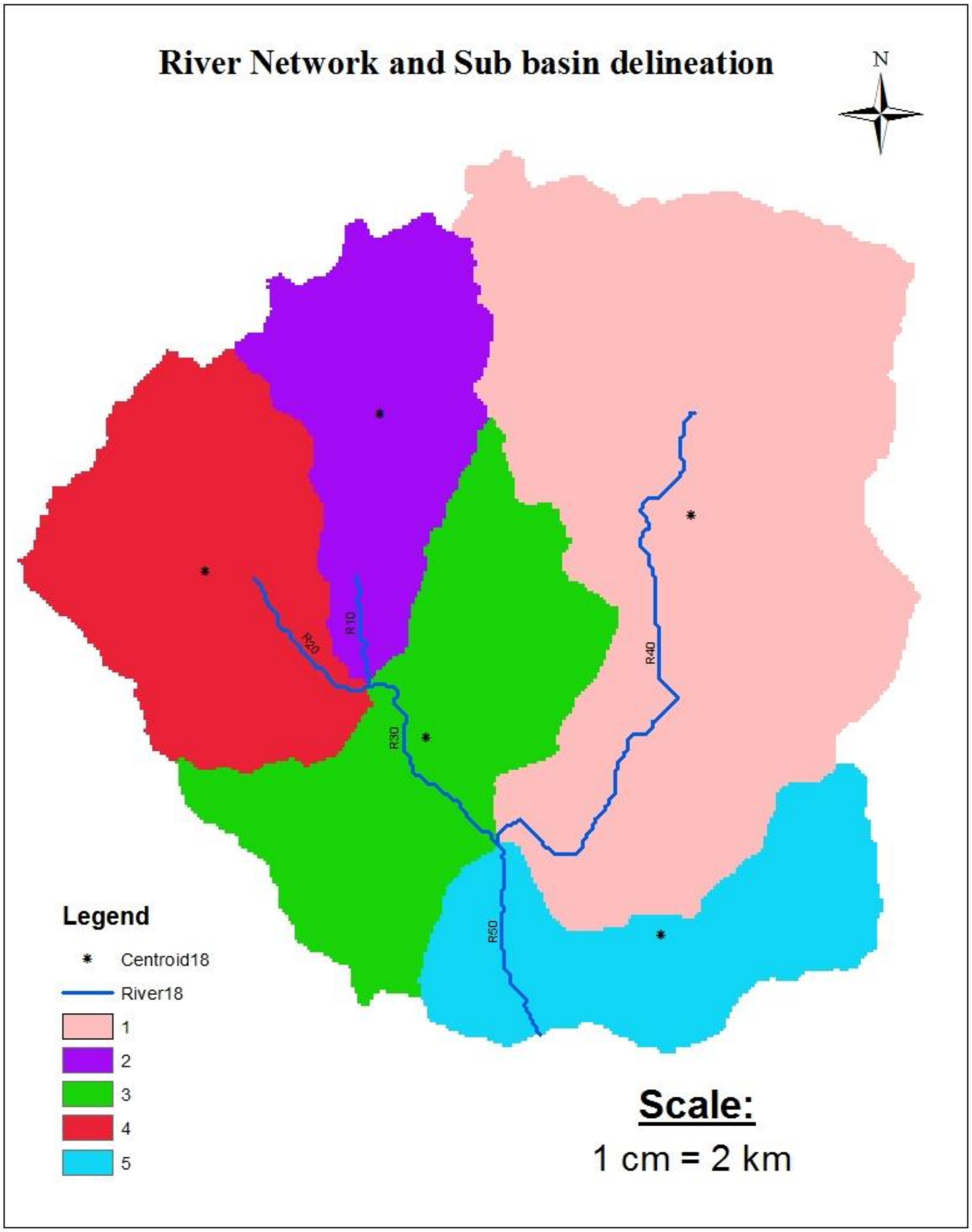
ANNEX Q:Sunshine Hour of Project area



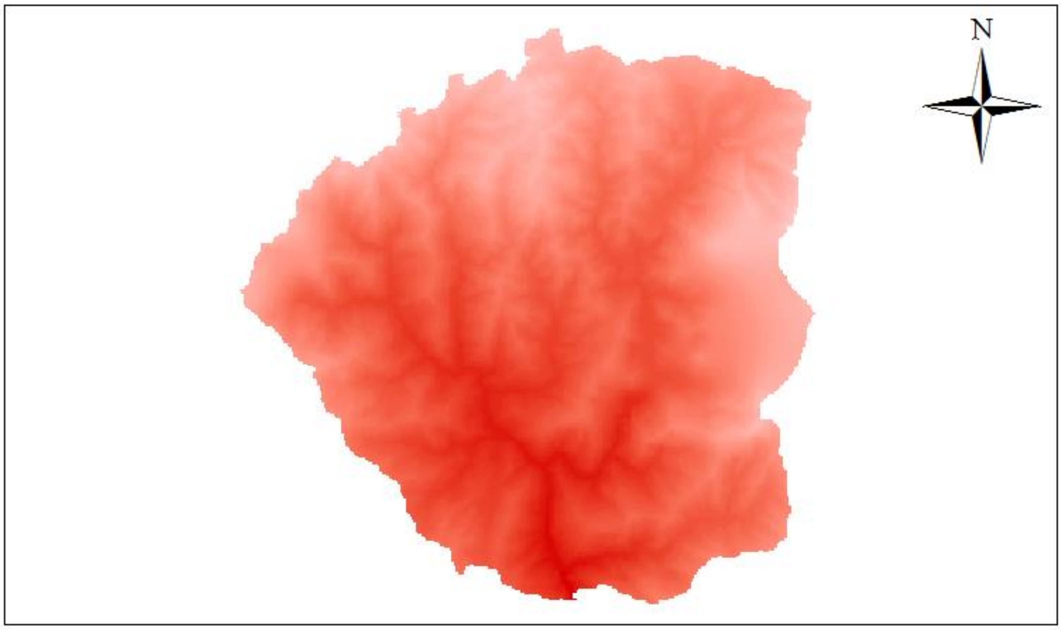
ANNEX R: Average Humidity of Project Area

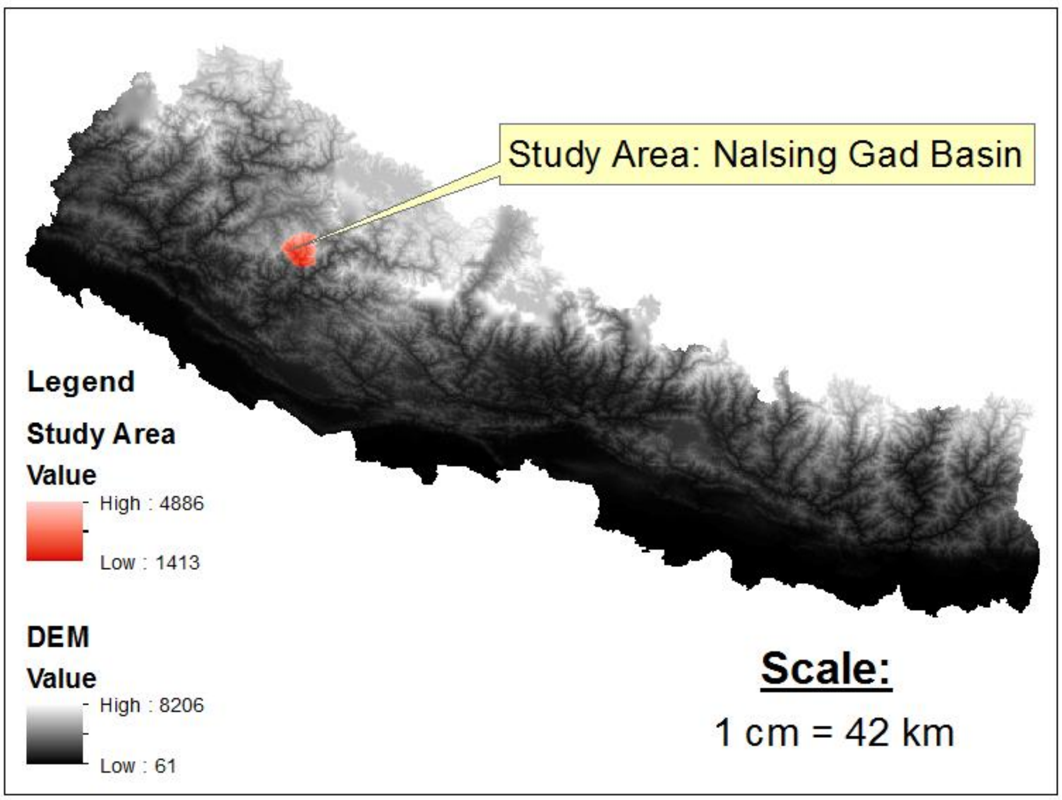


ANNEX S:River Network and sub basin delineation of Naulsing storage HEP



ANNEX T: Study Area & it’s Delineation





ANNEX U: Google Earth View of Project Area