HYDRO-METEORLOGICAL STUDY OF BUDHIGANDAKI STORAGE HYDROELECTRIC PROJECT

A Dissertation Presented to the Central Department of Hydrology and Meteorology

In Partial Fulfillment of Requirements for Award of Masters of Science in Meteorology

By

RAJESH SIGDEL

(T.U Registration No. 5-23790-2005)

Central Department of Hydrology and Meteorology

Tribhuvan University, Kirtipur

Kathmandu, Nepal

August, 2013

Tribhuvan University
Tri-Chandra Multiple Campus
(Estd. 1918 A.D.)

Ph. No. 4-244047

Office of the Campus Chief
Saraswati Sadan,
Kathmandu, Nepal.

Ref. No.:-

Date: August 27, 2013

TRI-CHANDRA MULTIPLE CAMPUS 1918 A.D. SARASWATI-SADAN KATHMANDU

RECOMMENDATION

This is to certify that Mr. Rajesh Sigdel has prepared the Dissertation entitled "HYDRO-METEOROLOGICAL STUDY OF BUDHIGANDAKI STORAGE HYDROELECTRIC PROJECT" to fulfil the Masters Degree of Science in Meteorology of the Tribhuvan University which is the record of the candidates own work carried by him under our supervision and guidance.

Dissertation Supervisor

…………………..

Mr. Suresh Marahatta
(Assistant Lecturer)
Department of Meteorology
Tri-Chandra College, Ghantaghar, Kathmandu, Nepal

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY
CENTRAL DEPARTMENT OF HYDROLOGY & METEOROLOGY

Phone No.: 4-331418, 4-333887
Office of the Head of Department
Kirtipur, Kathmandu, Nepal
Fax No.: 977-1-4331964

Date: August 27, 2013

Ref. No. :

LETTER OF APPROVAL

This Dissertation entitled "HYDRO-METEOROLOGICAL STUDY OF BUDHIGANDAKI STORAGE HYDROELECTRIC PROJECT" submitted by Mr. Rajesh Sigdel has been approved as a partial fulfilment for the Masters Degree of Science in Meteorology.

....
Mr. Suresh Marahatta
Supervisor

....
Prof. Dr. Lochan Prasad Devkota
Head of Department and Internal Examiner

....
Mr. Kiran Shankar Yogacharya
External Examiner

DECLARATION

I hereby declare that the work presented in this thesis has been submitted by myself and has not been submitted elsewhere for the award of any degree. All the sources of information have been specifically acknowledged by reference to the authors or institutions.

Rajesh Sigdel
Rajesh2sigdel@gmail.com
Central Department of Hydrology & Meteorology
Kirtipur, Kathmandu, Nepal
Date: August 27, 2013

ACKNOWLEDGEMENTS

I would like to express my great appreciation to Mr. Suresh Marahatta, Department of Hydrology and Meteorology, Tri-Chandra College, my research supervisor, for his patient guidance, enthusiastic encouragement and useful critiques of this research work. His help and advice during the entire study is gratefully acknowledged.

It is great pleasure for me to express my deepest sense of gratitude to Mr. Utsav Bhattarai, Hydrologist Engineer, for his untiring help, practical suggestions, constant support and encouragement throughout the study period.

My grateful thanks are also extended to Mr. Resham Baniya for his help in doing the data analysis through the GIS (Geographical Information System).I am also thankful to Prof. Dr. Lochan Prasad Devkota (Head of Department, Central Department of Hydrology & Meteorology), Associate Professors, Mr. Deepak Aryal, Dr. Binod Shakya, Mr. Tirtha Adhikari, Dr. Madan Sigdel, Mr. Binod Dawadi, CDHM, TU for their encouragement all over the study period. I would also like to thank throughout all the faculties and staff members of Central Department of Hydrology and Meteorology for all kinds of support during the study period. I am also grateful to Mr. Subash Kandel and Madan Shrestha of Central Department of Hydrology & Meteorology, T.U., Kirtipur for their support for preparation of this report.

My sincere thank goes to Mr. Jagat Kumar Bhusal, Chairman, SOHAM-Nepal, Kiran Shankar Yogacharya, Former Director General, DHM, Mr Binod Devkota, Mr. Binod Parajuli, and Mr. Ramchandra Karki, for their help in collecting the data and all the technical advice.

I am grateful to NEA, DHM, IOE Library, TU Library and RECHAM Consult for providing valuable data, information and literatures. Similarly, I acknowledge all the authors and writers, of whom the work is cited.

I express my thanks to my friends Mr. Kumar Aryal, Mr. Promos Silwal, Mr. Subash Rimal, Mr. Arvin Rajbahak, Mrs. Anita Ale Magar, Mr. Bikky Karki, Mrs Binita Acharya, Mr. Ganga Tiwari, Mr. Dhruba Lochan Adhikari and Mr. Raju Pokharel who has done a lot for me and only words are not sufficient to convey my gratitude to them. Finally, my sincere gratitude goes to my beloved parents and all my family members for their continuous support due to which I could complete my study.

Rajesh Sigdel

2013 A.D

Abstract

Budhigandaki storage hydroelectric project was first detected in 1974 A.D. by SMEC, following the study of the Gandaki River basin; Budhigandaki is one of the most favored due to its high potential and its location in Central Nepal near the main load center. Budhigandaki is a tributary of the Narayani originated from Lark Himal and Ladak Himal in Tibet. The total river length is about 188 km and the total basin area is about 5007 km^2. Annual rainfall in the Arughat is 2614 mm. Statistical

Analysis showed that the 24 hour maximum rainfall for 50 year and 100 year return periods are 160 mm and 173 mm respectively. There are three major flood disaster occurred in Budhigandaki River on 05 Mar 1968, 17 Jun 1968 and 02 Aug 1968. This was caused by LLOF at Lapubensi upstream of hydrological station no 445. The highest flood was 5210 m^3/s recorded at hydrological station 445. A one-dimensional hydraulic model in HEC-RAS was developed and executed which enabled the analysis of flooding under different scenarios. Hydraulic models coupled with Geographic Information System are powerful tools for quantitative and qualitative monitoring of spatial and temporal variation of flows in the river. For purpose of Elevation-Area-Volume curve it shows the area of 32.87 km^2.

Table of Contents

List of Tables

List of Figures

List of Acronyms

%	Percentage
^{o}C	Degree Celsius
A.D.	Of the Christian era (from the Latin *anno domini*)
B.S.	Bikram Sambat
BOOT	Build, Own, Operate and Transfer
d.f	degree of freedom
DC	Direct Current
DEM	Digital Elevation Model
DHM	Department of Hydrology and Meteorology
et al.	And others (from the Latin *etalii)*
FAO	Food and Agriculture Organization
FDC	Flow Duration Curve
FSWL	Full Supply of Water Level
GBM	Ganga Brahmaputtra Meghna
GHG	Green House Gases
GIS	Geographical Information System
GLOF	Glacier Lake Outbrust Flood
GW	Giga watt
HEC-RAS	Hydraulic Engineering Center's River Analysis Systerm
HEP	Hydro-Electric Project
i.e.	That is (from the Latin *id est*)
ICIMOD	International Centre for Integrated Mountain Development
IIDS	Institute for Integrated Development Studies
IOE	Institute of Engineering
IPCC	Intergovernmental Panel on Climate Change
KW	Kilo-Watt
LLOF	Landslide Lake Outbrust Flood
MASL	Mean above Sea Level
MCM	Million Cubic Meter
MM	Millimeter
MW	Mega-Watt
NEA	Nepal Electricity Authority
NIPS	National Integrated Power System
NST	Nepal Standard Time
PET	Potential Evapotranspiration

PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPM	Parts Per Million
PPT	Precipitation (Rainfall)
RECHAM	Research Centre of Hydrology and Meteorology
ROR	Runoff River
SMEC	Snowy Mountain Engineering Corporation
SOHAM-Nepal	Society of Hydrologist and Meteorologist – Nepal
Sq. Km	Square Kilometer
TRMM	Tropical Rainfall Measuring Mission
TU	Tribhuvan University
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
WECS	Water and Energy Commission Secretariat
WMO	World Meteorological Organization
Yr-1	per year

CHAPTER I
INTRODUCTION

1.1 Background

Like its topography, the hydrological and meteorological systems of Nepal are highly heterogeneous, both temporally and spatially. The steep elevation gradient, young geology, sharp physiographic change within short distances, orographic factors influence the spatial variability of precipitation pattern. The depleting forest cover, population pressure and increasing urbanization, cultivation and steep slopes have combined effect on the dynamics of hydrologic cycle and water induced environment of peak floods and sediment concentrations. Nepal has a huge hydropower potential. The average annual precipitation is about 1857.6 mm (Practical Action, 2009) about 80% of which occurs during monsoon season (June to September). The total average annual runoff from the river of Nepal is 224.27 billion m^3 (IIDS, 2000).

Abundant rain-fed and snow-fed water resources and country's topography provided ideal conditions for the development of some of the world's largest hydroelectric projects in Nepal. The water storage potential of 88 billion m^3 and the diversified climatic and physical environment are notable factors that account for large hydropower generation in Nepal. Nepal's theoretical hydropower potential is estimated at 83,290 MW (Shrestha, 1966). (But in present context hydroelectricity potential of Nepal could exceed) and out of this gross potential 42000MW has been found technically and economically feasible (NEA, 1984). However this figure is taken from feasibility study of Budhigandaki hydroelectric project 1983. The largest capacity project identified are Mahakali river at Pancheswor (6000 MW) and Karnali river at Chisapani (10500 MW). There are altogether 6000 rivers and rivulets in three major river basins namely Koshi, Gandaki and Karnali including some southern rivers and two border rivers, Mechi and Mahakali in Nepal (IIDS, 2000). The watershed area of Nepal is 194,471 km^2 including the Tibetian part, of these area 76% lies within Nepal. The basinwise potential for power generation is in the table below:

Table 1.1: Theoretical Hydropower Potential of Nepal

River Basin	Capacity on Small River Courses CA of 300-1000 km^2	Capacity on Major River Courses CA>1000 km^2	Total Potential GW	Technically Feasible GW	Economically Feasible GW
Saptakoshi	3.6	18.75	22.35	11.4	10.86
Saptagandaki	2.7	17.95	20.65	6.73	5.27
Karnali and Mahakali	3.5	32.68	36.18	25.49	25.1
Southern Rivers	1.04	3.07	4.11	0.98	0.88
Country Total	9.8	72.45	83.29	44.6	42.11

(Source: Shrestha, 1966)

1.2 Rationale of the Study

In spite of tremendous hydropower potential, we are facing acute load shedding up to 18 hours in dry seasons. Nepal has been facing a power crisis since 1992 (IIDS, 2000). In present situation, Nepal has developed only approximately 700 MW of hydropower. The electricity demand in Nepal is increasing by about 7-9% per year. About 40% of population in Nepal has access to electricity through the grid and off grid system (NEA, 2012). The hydropower system in Nepal is dominated by run-of-river projects. There is only one seasonal storage project in the system. There is shortage of power during winter and spill during wet season. To reduce this unbalance of production of electricity, any of storage type plant is needed.

Budhigandaki storage Hydro-Electric Project (HEP) which is located in the Central Development Region of Nepal, 79 km far from Kathmandu valley, major load center, construction of Budhigandaki storage HEP is more essential to meet the growing energy demand per year and system requirement. Demand forecast shows that the electricity demand will be about 2200 MW after 2020 A.D.

1.3 Objectives of the Study

The main objective of the study was the Assessment or estimation of different hydro-meteorological parameter for Budhigandaki Storage HEP. Based on this specific objective following objectives were developed.

- Hydrological and meteorological analysis of study area
- Flood inundation analysis by HEC-GeoRAS.
- Reservoir capacity analysis.
- Prepare the Elevation-Area-Volume Curve of Reservoir
- Sedimentation analysis of basin

1.4 Scope of the Study

The study will be useful to establish the river flow characteristics at Dam Site of Budhigandaki HEP. The estimation of high flow, flow duration curve, flood frequency analysis, diversion flow, depth area volume relation inundation of different scenario etc., and help to implement the project. Besides, the study will provide scientific review of the basin status.

1.5 Significance of study

Any water related project needs hydrological design parameters. The present study provides a case study of verifying such design parameters for BGHEP. This is in line with guideline of DOED.

1.6 Overview of Content

This report presents in Five Chapters. Chapter I provide introduction including background of the study, rationale of the study, objectives of the study, scope of study and significance of study. Chapter II includes the literature review related to this research. Chapter III includes the brief description of the study area; it also includes theoretical background and methodology. Chapter IV gives the result and discussion of the study. At last Chapter V present Conclusion and Recommendation.

CHAPTER II
LITERATURE REVIEW

2.1 History of Hydropower Development

Humans have been harnessing water to perform work for thousands of years. By using water for power generation, people have worked with nature to achieve a better lifestyle. The mechanical power of falling water is an age-old tool. The Greeks used water wheels for grinding wheat into flour more than 2,000 years ago. Besides grinding flour, the power of water was used to saw wood and power textile mills and manufacturing plants. For more than a century, the technology for using falling water to create hydroelectricity has existed.

In the 1700's mechanical hydropower was used extensively for milling and pumping. In 1882, the first hydroelectric facility in the U.S was built in Appleton, Wisconsin and produced direct current (DC) for local industry. By 1886, there were about 40 to 50 hydro plants in the U.S and Canada. Many new hydro plant designs rapidly came about from 1895 to 1915 but plant design became more standardized after World War-I. The surplus power from these water projects was sold to existing power distributors to pay for the construction and operation costs of these facilities. Cheap and abundant hydropower attracted lots of industrial development nearby and increased farm irrigation.
After the world war-II, leaders of African and Asian nations have replicated the western US model to meet energy and water needs of their own countries and many large scale hydropower projects were built in India, Pakistan and Egypt between 1950 and 1980. None of the projects in the US, former Soviet Union and India had the objectives of exporting energy to its neighbors to earn revenue for the country. In recent decades, the concept of production of electrical energy has been changed. Now, it has been traded between two or more nations after agreement upon certain terms of trade. Exporting electricity to a neighboring country to earn revenue for the government is one of the stated objectives of developing large scale Hydropower Projects in Nepal.

Nepal has a hundred year history of hydropower development. The first hydropower plant in Nepal was the Pharping Hydropower Plant (500KW) commissioned in 1911 (MoE, 2008). There was no gradual development for about three decades until the 640 KW Sundarijal Hydropower plant came into operation, followed by the 2400 KW Panauti Hydropower Plant, which was commissioned in 1965. Later on other plants like Phewa (1 MW), Trishuli (21 MW), Sunkoshi (10 MW), Tinau (1MW), Gandak (15 MW) were installed in two party collaboration and whereas Devighat (14.1 MW), Kulekhani-I (60 MW), Kulekhani-II (32 MW) and Marshyandi (69 MW) in total 228 MW were installed within multi-party collaboration (MoE, 2008).

Government of Nepal introduced Build, Own, Operate and Transfer (BOOT) modality for hydropower development since year 1950. Till January 2010, after democracy re-settlement in 2046 B.S, to attract the private and public sector constitute was revised and made law on electricity act 2049 (10 yrs task report, 2065 B.S). Thus in ten years which is comparably short period our installed capacity were upgraded up to 617 MW. From private sector, Khimti (60 MW), Bhotekoshi (36 MW), Indrawati (7.5 MW), Chilime (22.1 MW), Piluwakhola (3 MW) and Khudi (4 MW), total 133 MW electricity has been yield. Meanwhile from public partnership Puwakhola (6.2 MW), Myagdi tatopani (2 MW), Chatara (3.2 MW), Modi (14 MW) and Kaligandaki-A (144 MW) are made.

Now country has around 700 MW installed capacity. From total electricity, NEA yields 532 MW whereas from private sector 174MW (MoE, 2009).

2.2 International Energy Consumption and production

At present, the annual primary energy consumption of the world is 402 Exajoules (11×10^{13}kWh/year, average power is 1.27×10^{7}MW). About 40% of this energy is consumed in transportation sector and 60% by industries, domestic and social consumers. World energy demand is increasing at an annual growth rate of about 3.5-5%.

2.3 Types of Energy

Based on their origin there are different types of energy, some of them are listed as follows.

a. Hydropower

Hydro energy is simply energy that is generated from water and converted to electricity, where water moving down through causes turbine to rotate and energy is generated.

b. Nuclear Power

Nuclear energy usually means the part of the energy of an atomic nucleus, which can be released by fusion or fission of radioactive decay. U^{235}, U^{233} and Pu^{239} are used as nuclear fuels in nuclear reactors (thermal reactors) and are known as fissile (fissionable) material. Out of these only U^{235} occur in nature, and U^{233} and Pu^{239} are produced from Th^{232} and U^{238} respectively in fast breeder reactor (Khan, 2006).

c. Thermal Power

A thermal power station is a power plant in which water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations in due to different fossil fuel resources generally used to heat water.

d. Solar Power

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps and fans to convert sunlight into useful outputs. The earth continuously intercepts solar power of 178 billion MW, which is 10,000 times the world's demand (Khan, 2006).

e. Wind Power

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electrical power. The power available in the world over the earth surface is estimated to be 1.6×10^7MW, which is more than the present energy requirement of the world.

f. Biomass

A bio fuel is a fuel that uses energy from a carbon fixation. These fuels are produced from living organism. This biomass can be converted to energy in three different ways: thermal conversion, chemical conversion and Mechanical conversion.

2.4 Sources of energy consumption in Nepal

Firewood alone contributes 89% of total energy consumption in Nepal. The rest is from modern sources of energy, of which consumption of petroleum accounts to 8%, renewable energy shares 0.53% and coal contribute 1.76%. A mere 1.82% of the total energy consumption is met by electricity. It shows that Nepal has not been able to realize its potential in electricity generation through Hydropower (MoE, 2008).

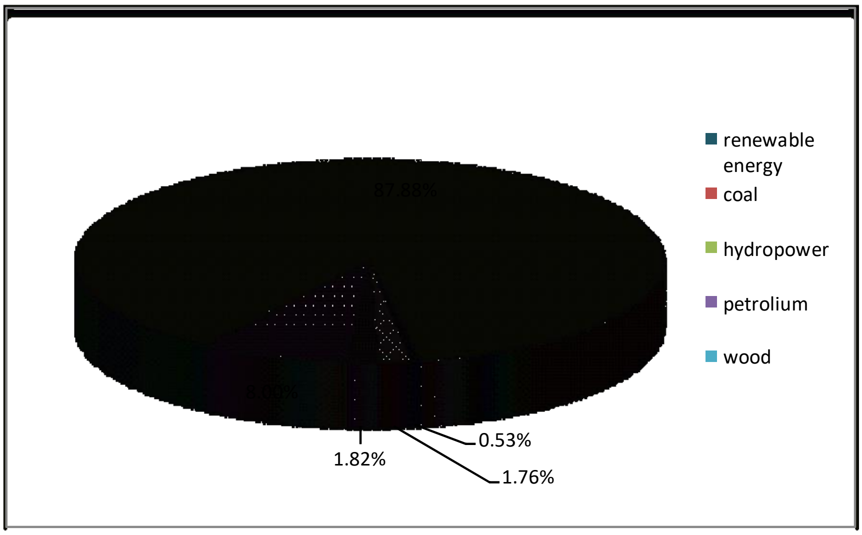


Figure 2.1: Energy Consumption in Nepal
Source: WECS 2005

2.5 Indo-Nepal Treaties

Nepal and India have to live and engage with each other in many spheres: social, economic and political. Of all the engagements, when two countries deal with the issue of water resources at the same time, it is a very sensitive issue, because water is the most important natural resources that Nepal possesses and whereas India needs high dam structure and huge energy quantity, although most of it has yet to be exploited. The size and topography of Nepal are such that the three countries of the Indian sub-continent, Nepal, India and Bangladesh, could benefit immensely, if Nepal's 6,000 rivers are harnessed optimally. At present 28 multipurpose and multi-facility project are identified which benefit Nepal, India and Bangladesh as their energy as well as irrigation and other flood control management (Springer, 2009). There are both people-to-people and official aspects to the water resources relationship between Nepal and India, the former from time immemorial and the latter since at least the time of British India, as set down in a number of treaties.

a. Koshi Treaty (April 25, 1954)

b. Mahakali Treaty (Feb 12, 1996)

c. Gandak Treaty (Dec 4, 1959)

2.6 Justification for Storage Type Plant

Although the storage type power plants require huge initial capital investment, they are only means for the efficient and controlled use of the available water. In Nepalese rivers, there is considerable variation in flow during monsoon and non-monsoon season and as the Run off River (ROR) plants are usually designed for the flow available for only 40% to 70% of time of the year, there is a huge wastage of waterpower during the monsoon season. This could be utilized by storage type plants.

The important aspects of storage type plant supply power during the peaking hours. During monsoon season all the ROR plants run at full capacity and there is sufficient energy available to meet the demand. We cannot even sale the surplus energy to the neighboring countries since they too produce sufficient energy during monsoon. So the only alternative is to store water by the construction of dams and use stored water when required. Nepal's only reservoir power scheme, so far, built in 1982, is the dam built over a medium size river called Kulekhani River. The plant has a total capacity of 92 MW (Kulekhani I and Kulekhani II) and is absorbing the seasonal as well the daily peaks of the Nepalese power system. So to cope with the increasing power demand and to absorb the peaks, other storage type plants should be commissioned.

Once a dam is built, it not only serves for power peaking but also for other purposes like irrigation water supply, flood mitigation, drinking water supply, navigation etc. Also, after meeting the domestic power need, the surplus energy can be sold to the neighboring countries at higher rate. Therefore, although the domestic need can be fulfilled by small scale plants, interest has been given by national and international agencies in the construction of high dams like Karnali Chisapani Dam (270m), Koshi High Dam (239 m), Mahakali Pancheshwor Dam (315 m), West Seti project (195m).

However, the important things that shall be in the priority list of consideration while proposing a high dam are the disasters that might be caused by the failure of dam due to factors like poor design, seismic vulnerability, etc. Other environmental impacts due to the construction of dam like submergence of cultivated lands, effects on aquatic life, land degradation, silt deposition, settlement problems, etc. should also be assessed. As Nepal is in the seismically vulnerable zone, the designers should be aware of the associated inherent seismic risks.

2.6.1 Why Not Budhigandaki Storage Hydro-Electric Project

Since, the prefeasibility study of Budhigandaki HEP had been done in 1983-84 around 29 years ago, and found quite feasible during that time, but in this long time elapsed, many scenarios have been changed. It has changed the socio economic, political status and consensus of the people and the societies. Along with the project decision for implementation the development strategies has been in discussion and accordingly the financing strategies are the part of the development strategies.

The most plants that are being implemented or committed/planned are ROR types including 456MW Upper Tamakoshi HEP. With addition of more ROR plants, there will be increasing surplus of energy during wet season and deficit in dry season. The dry season flow becomes almost one tenth of flow in the wet season. During this last half decade, Nepal has facing acute load shedding. It has been recorded that there has been a power supply of around 250 MW in winter where as the peak demand is almost equal to 850 MW resulting the power deficit of around 600 MW which has to be fulfilled in peak demand time (NEA, 2011).

Being a storage type plant, Budhigandaki HEP has a great significant role in the Nepalese power system. Assuming that the existing Kulelkhani Project can absorb the morning peaks during the dry season, the evening peaks shall be absorbed by Budhigandaki storage HEP (NEA, 2011).
With countries desperate need of solving the power crisis and well understanding the need of storage project, a long term strategic plan has been formulated such as the water Resource Strategy (2002), Water Resource Plan (2005) and later also the Bidhut Sankat Nirupan Action Plan (2008), Ten Year Electricity Development Plan (2065) and later Twenty Year Hydropower Development Plan (2066).

2.6.2 Bidhut Sankat Nirupan Action Plan 2065

Bidhut Sankat Nirupan Action Plan 2065 (the electricity crisis mitigation action plan 2065) with realization of a need for the storage project power supply demand fulfill and system balance, it has been mentioned 37 points plan categorizing immediate action plan, short term action plan and long term action plan and in plan no 22, (immediate action plan category), had given the full authority by the government to NEA to promote Budhigandaki with seeking suitable model and partner.

2.6.3 Ten Years Electricity Development Plan 2065

In ten years hydropower development plan to develop the 10000 MW in 10 years, besides other project, it has been recommended to the development of ROR and Storage project in 70:30 ratios to meet the demand and system balance, Budhigandaki HEP development has been prioritized for the internal consumption and plan to be completed in 2018 in operation i.e. if arrangement has to be made in the earliest manner and construction activities has to be started within the couple of years.

2.6.4 Twenty Years Hydropower Development Plan (2066)

The twenty year hydropower development plan (2066) has planned to develop the 25000 MW within 20 years. As before, Budhigandaki Hydroelectric Project has been considered as a potential storage project to develop for the supply and balance of power system for domestic use. This plan has listed Budhigandaki HEP to be computed in 2019 with the subsidiary company of Nepal Electricity Authority.

2.7 Energy Demand Forecast

Load forecast made by NEA, according to the power system master plan studies is presented **in Table 2.1**.

Table 2.1: Load Forecast of Nepal

Fiscal year	Energy (GWh)	System Peak Load (MW)
2010-2011	4430.7	967.1
2011-2012	4851.3	1056.9
2012-2013	5349.6	1163.2
2013-2014	5859.9	1271.7
2014-2015	6403.8	1387.2
2015-2016	6984.1	1510
2016-2017	7603.7	1640.8
2017-2018	8218.8	1770.2
2018-2019	8870.2	1906.9
2019-2020	9562.9	2052
2020-2021	10300.1	2206
2021-2022	11053.6	2363
2022-2023	11929.1	2545.4
2023-2024	12870.2	2741.1
2024-2025	13882.4	2951.1
2025-2026	14971.2	3176.7
2026-2027	16142.7	3418.9
2027-2028	17403.6	3679.1

(Source: NEA, 2011).

The proposed Budhigandaki storage project is one of the most attractive projects in the Central Development Region of Nepal. The region being laden with all the major industries of Nepal, including the load center Kathmandu valley, it is only 79 km far. It is considered as one of the most energy hungry parts of Nepal till there is no other plant to saturate this deficit.

To meet the growing energy demand per year and system requirement, construction of Budhigandaki Storage Project is much more essential. Feasibility study and detail engineering design of the project can be done consequently within 3 years. After this, construction of the project can be completed within 6 years. Demand forecast chart shows that after 2020, electricity demand will be about 2200 MW. That means new plant having totaled installed capacity of more than 1000 MW should be generated to meet the increasing demand within coming 8 years. After West Seti (750MW) and Upper Seti (140MW), no single plant having such a high installed capacity has been planned to be commissioned in near future, Budhigandaki project may be the potential plant to cope with increasing demand.

2.8 Types of Hydropower Project

There are three types of hydropower: impoundment, diversion, and pumped storage. Some hydropower plants use dams and some do not.

a. Impoundment or Storage Types

The most common hydroelectric power plant is storage type. Impoundment types, uses a dam to store river water in a reservoir. Water released from the reservoir flow through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity need or it maintain a constant reservoir level.

b. Diversion Types

A diversion, sometimes called ROR, which utilize the minimum flow in a river having no appreciable poundage on its upstream side. It may not require the use of a dam. A plant without poundage has no storage and is, therefore, subject to seasonal river flow and serves as a peaking power plant while a plant with poundage can regulate water flow and serve either as a peaking or base load power plant.

c. Pumped Storage Types

When the demand for electricity is low, pumped storage facility stores energy by pumping from a lower reservoir to an upper reservoir. During periods of high electricity demand, the water released back to the lower reservoir to generate electricity. The pumps are run by some secondary power from some other plant in the system.

d. Tidal Plants Types

The tidal waves produced in the oceans which rise and fall due to the attraction of the moon to earth, can be used for the generation of electricity. In other words, the tidal range, i.e. the difference between high and low tide levels is utilized to generate power. This is accomplished by constructing a basin separated from the ocean by a partition wall and installing turbines in openings through this wall.

2.9 Reservoir Project

A barrier in the form a dam constructed across the river which create the pool of water on the upstream side of the barrier is known as dam reservoir. A reservoir is a lake-like area where water is kept until it is needed. They come in all shapes and sizes. Reservoirs are either man-made or natural. Natural ones are part of the land and are not made by people. Lakes and ponds are natural reservoirs. Building a man-made reservoir is a big job. It takes from 5 to 8 years to plan, few years to build, and cost lots of money, too.

Depending upon the purpose served by a given reservoir, the reservoir may be classified into the following four categories:

a. Storage or Conservation Reservoir.

A storage or conservation reservoir can retain such excess supplies during periods of peak flows, and can release them gradually during low flow as and when the need arises.

b. Flood Control Reservoir.

It generally called a flood-mitigation reservoir, stores a portion of the flood flows in such a way as to minimize the flood peaks at the areas to be protected downstream.

c. Distribution Reservoir.

It is a small storage reservoir constructed within a city water supply system, which can be filled by pumping water at a certain rate and can be used to supply water even at rates higher than the inflow rate during periods of maximum demands.

d. Multipurpose Reservoir.

A reservoir planned and constructed to serve not only one purpose but various purposes (i.e. irrigation, industrial, hydroelectric etc.) together is called a multipurpose reservoir.

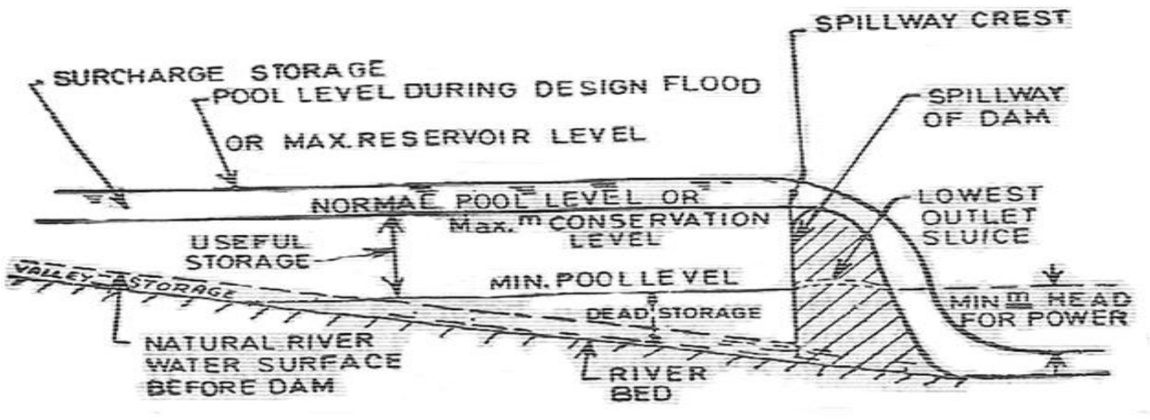


Figure 2.2 Storage Zones of Reservoir

2.9.1 Reservoir Sedimentation

Every river carries certain amount of sediment load. The sediment particles try to settle down to the river bottom due to the gravitational force, but may be kept in suspension due to the upward currents in the turbulent flow which may overcome the gravity force. When the silt-laden water reaches a reservoir in the vicinity of a dam, the velocity and the turbulence are considerably reduced. The bigger suspended particles and most of the bed load, therefore, get deposited in the head reaches of the reservoir. Fine particles may travel some more distance and may finally deposit farther down in the reservoir. The deposition of sediment in the reservoir is known as 'Reservoir Silting' or Reservoir Sedimentation'. The deposition of the sediment will automatically reduce the water storing capacity of the reservoir, and if this process of deposition continues longer, a stage is likely to reach when the whole reservoir may get silted up and become useless.

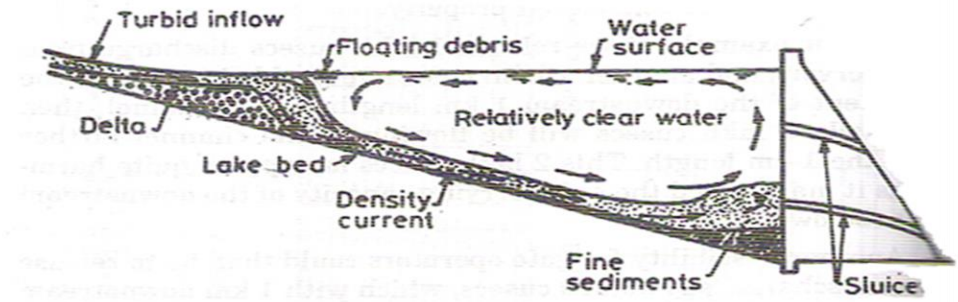


Figure 2.3: Process of Sediment Accumulation in Typical Reservoir.

Due to mountainous topography, most part of the rain water converted to surface flow and sub surface flow is not sufficient. The result is that most of the springs dry up after few weeks or months without rain. However, our Himalayan originated rivers remains perennial flow throughout the year. But this also suffers from variation of discharge.

Reservoirs trap flood water which carries a lot of sediments. Trapping the water means reducing the velocity of flow and in result, suspended materials carried by river start to deposit in the reservoir. This long term phenomena reduce the reservoir volume day by day and finally it is no longer possible to store the design volume of water which means project becomes useless.

CHAPTER III

METHODS AND MATERIALS

3.1 Location of the Study Area

The Budhigandaki is a tributary of the Trishuli River, which is a tributary of the Narayani River, the deepest river of Nepal. The catchment area of the basin as measured from GIS is 5,007 km^2 out of which about 27% lies in Tibet and the remaining 72% lies inside Nepal. The basin lies in Gorkha and Dhading district in the Western and Central Development Regions of Nepal between latitudes 28^{o}02' and 28^{o}48' N and longitudes 84^{o}30' and 85^{o}45' E. The hydrology of the basin has been established with respect to the Gauging Station No. 445 at Arughat, located approximately 32 km upstream of its confluence with the Trishuli River. Topographically, the basin lies within the central middle mountain region surrounding by the Mahabharat hills to the south and the Greater Himalayan range in the north.

3.2 Drainage System

Budhigandaki River originates from two main branches: one Shiar Khola from the Lark Himal and Mowang Khola, from the Ladak Himal in Tibet. The highest elevation of this basin is about 7747m. It flows in the south direction for 50 km to Nepal-Tibet border. Total distance from origin to the gauging station (index no.445) is 156 km. The Budhigandaki flows north to south and joins Trishuli at the Benighat at an elevation of 332 m. The average slope of the basin is about 4%. About 24 km upstream of the confluence, the Ankhu Khola, originating from Ganesh Himal, joins this river. Some of the major tributaries of the Budhigandaki are Larke, Sayale, Sanamchu, Sayar, Chuling, Bhalu, Yaru, Pangair, Dowan, Namrung, Machi, Richet, Aarkhet, Manu and Kastekhola.

Since 1964, DHM has maintained a gauging station in Budhigandaki River at Arughat Station No. 445 (28 03' 37"N, e 84 48' 59"E, Elevation 520 m above sea level), about 32 km upstream of its confluence with the Trishuli river. The average daily and monthly flow and instantaneous maximum and minimum annual discharges and water levels are available at Arughat; the long-term mean annual flow of Bhudigandaki River at Arughat is about 161m^3/s (DHM, 2010). These data have been used with appropriate transposition factor to determine the hydrologic design parameters of the project.

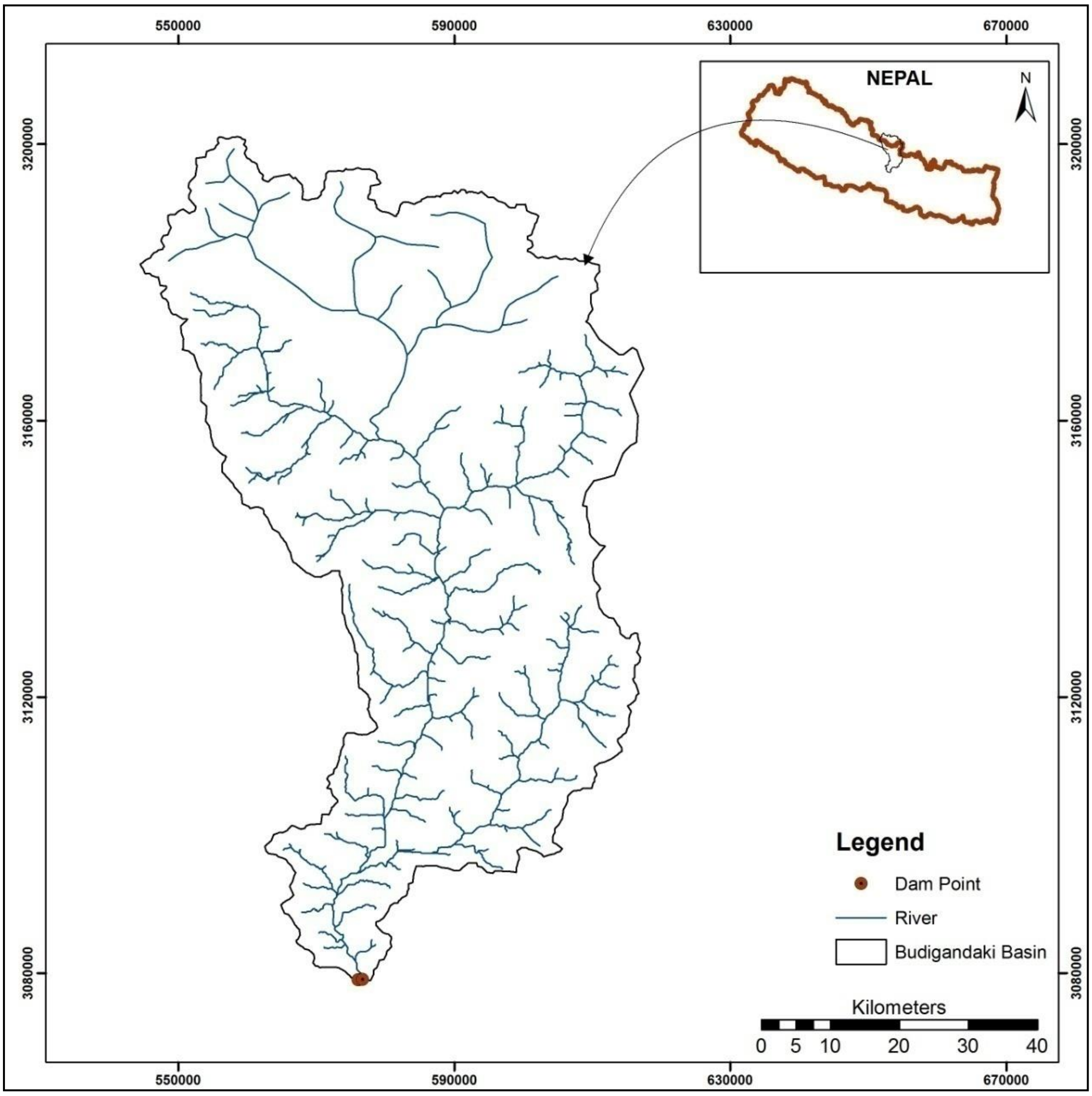


Figure 3.1: Location Map of Budhigandaki Basin

3.3 Topography and physiographic

The Budhigandaki basin is bordered in the north by vast Tibetan Plateau, in south and east by the Trishuli River basin and in west by the Marshyangdi basin. Following the change of elevation from the foothill of Mahabharat mountain ranges to high snow peaked Himalaya, the climate changes from Sub-tropical to Temperate in the North. There are two distinct seasons, a rainy season from May through September, when monsoon brings about 90% of annual rainfall and a dry season from October through April (DHM, 2001). About 97% of the basin area lies in Gorkha district and 3% in Dhading. Approximately, area within 336 masl to 3000masl covers 31% (1543 km^2), area within 3000 m to 5000 masl covers 43% (2160 km^2), and area above 5000 masl covers 26% (1304 km^2). The basin is characterized by rugged terrain and consists of numerous mountains and valleys. The elevation within the basin varies from 336 masl to 7,747 masl.

3.4 Glacier and Glacier Lakes

Glaciers and glacial lakes are usually located in remoteness area, where human access is tough due to the difficulties of terrain. An inventory of Glacier, Glacial lakes as well as carrying out Glacier Lake Outburst Flood (GLOF) requires extensive time and resources together with undergoing hardship in the field. Analysis of glacier is very important for such infrastructure's life and its storage capacity. The inventory identified a total of 1,466 glacial lakes in Nepal, coverage an area of 64.780 km^2. There were 116 glacial lakes mapped in the Gandaki basin with a total area of 9.538 km^2. Budhigandaki sub-basin has only 12 glaciers, comprising of area 0.709 km^2 (ICIMOD, 2011).

Table 3.1: Glacial Lake of Gandaki Basin

Basin	Number	Area (sq.km)
Trishuli	50	1.678
Budhigandaki	12	0.709
Marshyangdi	22	5.158
Seti	6	0.113
Kaligandaki	26	1.880
Basin total	116	9.538

(Source: ICIMOD, 2011)

There has been three landslides so far at Lapubensi, located at latitude of 28º 10' 40" N and longitude of 84º 53' 00" E. First landside occurred at March 5, 1968, second at June 17, 1968 and third at August 2, 1968. Among them third one is more devastating, which washed away the bridge and few houses at Arughat Bazar. Gauge staff was also washed away which is at 18 km downstream from Lapubensi. According to the report on "Landslide in Budhigandaki at Lapubensi," the slide had occurred from above east bank of the river at a point where the river valley was only about 30.5m wide. Flow in the river was completely cut off and the backwater above the blockage was estimated by the local people as an approximately 61m above the normal river bed. The backwater extended approximately 1.6 km upstream from the slide (Yogacharya K, 1969).

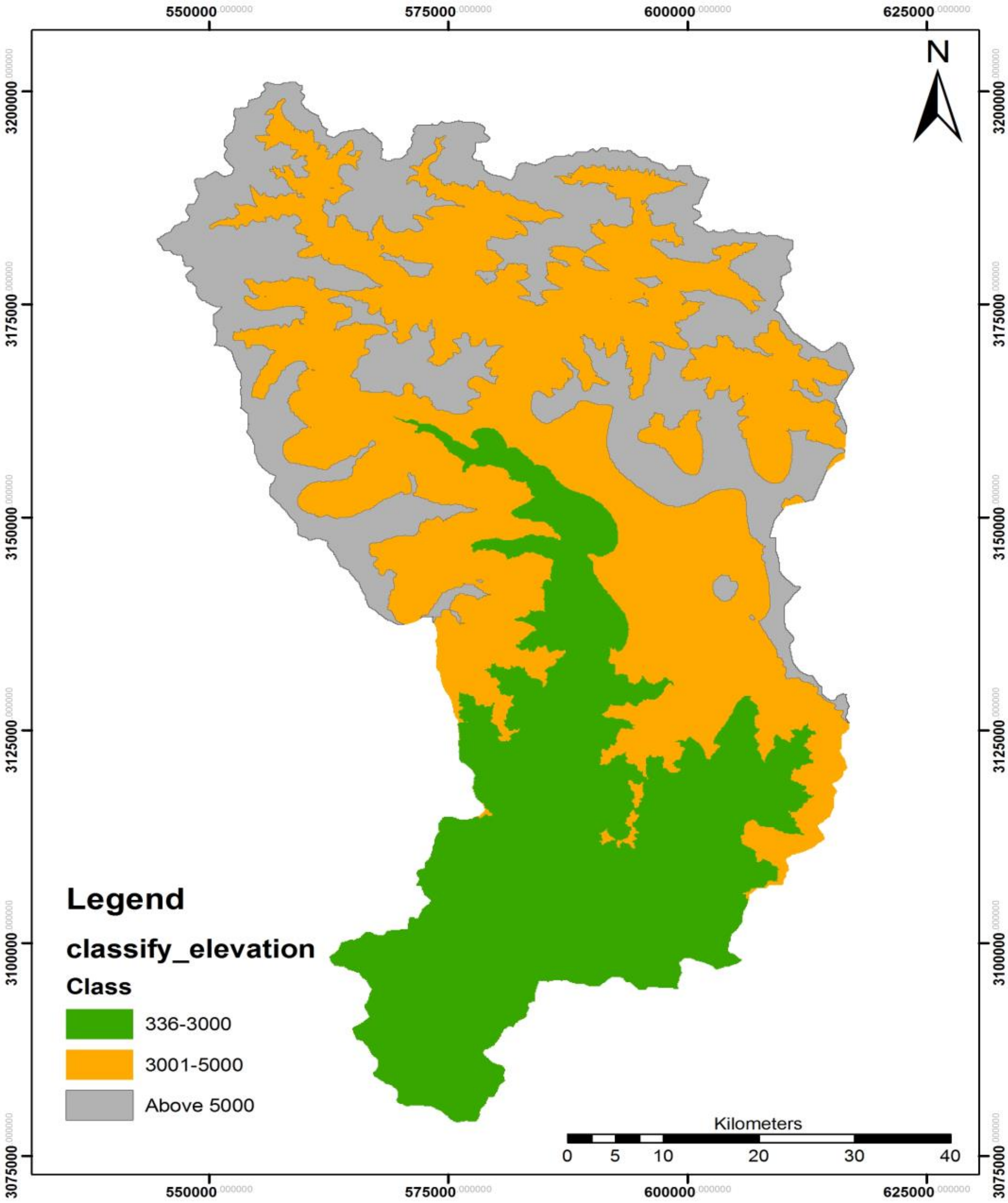


Figure 3.2: Basin Map of Budhigandaki Basin

3.5 Microclimate

Micro climates are climate that exist over small areas, where the conditions of the temperature, precipitation, humidity, winds, pressure and clouds are different to the general surroundings.

3.5.1 Assessment of the impact of artificial reservoir to the micro climate

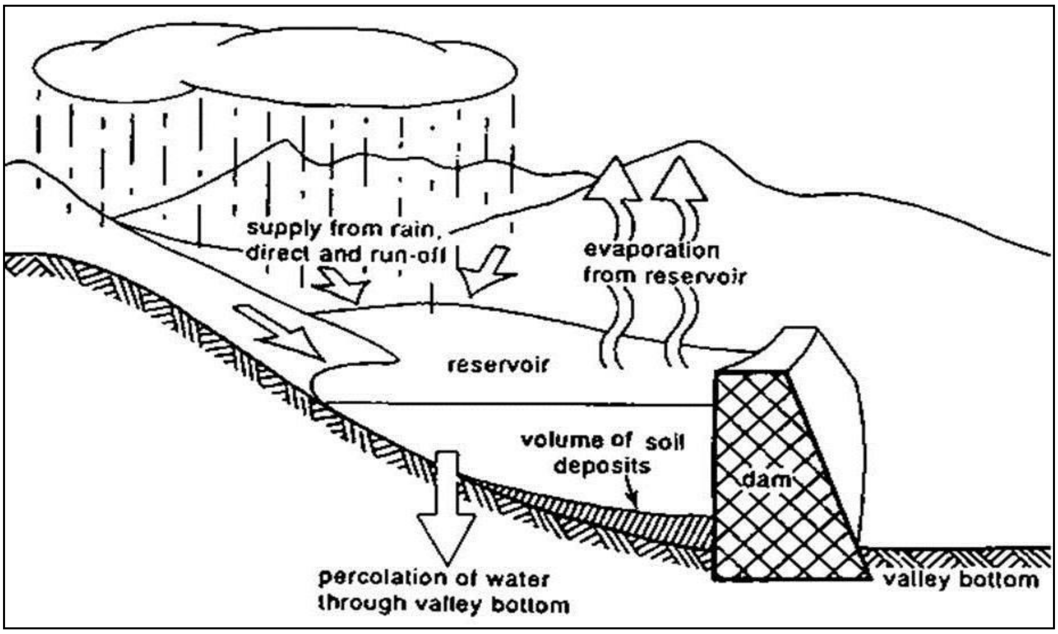


Figure 3.3: Description of Hydrological Cycle

After the construction of reservoir it affects the climate of the surrounding area (microclimate). Reservoirs may change the local micro-climate increasing humidity and reducing extremes of temperature, especially in dry areas. Changes of the microclimate are the result of the changes to the energy balance due to the presence of the water body, which has greater heat capacity than the ground and absorbs greater latent heat because of the increase of evaporation. For a complete research, statistical analyses on meteorological measurements like temperature, humidity, precipitation, etc around the dam area have to be done, before the construction. And then we can compare the two groups of meteorological data, those referring to the climate before the dam construction and those after.

3.6 Socio-Economic Issue

It has been widely perceived the socio-economic and environmental impact of the storage project is rather large in scale and more complicated than the run of the river project. In Budhigandaki Storage HEP, even during the prefeasibility study times in 1983 to 1984 era, the displacement of people and inundation was around 10,000. The proposed reservoir area touches 12 VDC of Gorkha district and 11 VDC of Dhanding district. During this time of 29 years, the increase of population and development of infrastructures in the reservoir area has been assessed with the preliminary environmental study in 2010 and household counting in the reservoir area in 2011.

Table 3.2: Preliminary Environmental Impact at Different Level of Reservoirs (As per preliminary study in 2009/10)

S.N	Particulars	Reservoir level and its cost		
		480 masl	500 masl	520 masl
1	Cultivated land (ha)	1,682	2,116	2,592
2	Forest land (ha)	1,147	1,525	1,903
3	Loss of Agricultural production (MT)	5,197	6,538	8,010
4	Number of residential structure owners (no of HH relocates)	3,242	3,322	3,483
5	Total number of relocates (av. HH size 7.6) = A	24,639	25,247	26,470
6	Number of land owners population (land holding 0.1 ha) = B	16,820	21,158	25,922
7	Number of affected community structures (main structures)	67	87	107
8	**Number of people resettlement (A+B)**	**41,459**	**46,405**	**52,392**

Source: NEA, 2011

3.7 Theoretical Background

3.7.1 Log-Pearson Type III Distribution

The procedure to be adopted in using this distribution to arrive at the flood discharge of any given return period is as follows. If X is the variate of a random hydrologic series, then the series of Y variates where

$$y = \log x \qquad (3.1)$$

are first obtained. For this Y series, for any recurrence interval T, gives

$$y_T = \bar{y} + k_T\sigma_y \qquad (3.2)$$

Where k_T = a frequency factor which is a function of recurrence interval T and the coefficient of skew C_s,

σ_y = standard deviation of the Y variate sample

$$= \sqrt{\sum (y-\bar{y})^2/(N-1)} \text{ and} \qquad (3.3)$$

C_s = coefficient of skew of variate Y

$$= \frac{N\sum(y-\bar{y})^3}{(N-1)(N-2)\sigma_y^3} \qquad (3.4)$$

$\bar{y}$ = mean of the y value

N = sample size (number of years of record).

The design flood is now given by

$$x_T = \text{antilog}(y_T) \qquad (3.5)$$

When the skew is zero, i.e. $C_s = 0$, the log-Pearson Type III distribution reduces to **Log Normal Distribution.**

3.7.2 Chi- Square Test

Chi-square test was first purposed and established by Karl Pearson to test whether there is significant discrepancy between observed frequencies and expected frequencies by chance or due to some factor playing part (or role) i.e. to test whether or not the expected (or hypothetical or theoretical) distribution fits well into the observed (or sample or experimental) distribution of qualitative data. Therefore this test is called chi-square test of goodness of fit.

$$x^2 = \sum_{i=1}^{k} \frac{(Oi - Ei)^2}{Ei} \qquad (3.6)$$

Where, x^2= Chi- square

Oi = Observed value from 1 to k

Ei = Estimated value from 1 to k

3.7.3 Hydraulic Simulation

The Hydraulic Simulation will be carried out to assess the flood prone areas as shown in the flow chart given below in **Figure. 3.4**. The process is briefly described below.

a) Pre-RAS Application

In order to carry out the preliminary data preparation to feed into the HEC-RAS, HEC-GeoRAS, an extension in GIS environment has been used. In addition to data preparation, this extension is also used to calculate the inundation areas from the result of HEC-RAS model.

The Pre-RAS application of HEC-GeoRAS was used to prepare HEC-RAS input data file. The following data sets were used in the Arc view GeoRAS environment and exported to the HEC-RAS model.

- TIN model as DEM input
- River Banks
- Flow path
- Centre line of river
- Cross-section cut lines

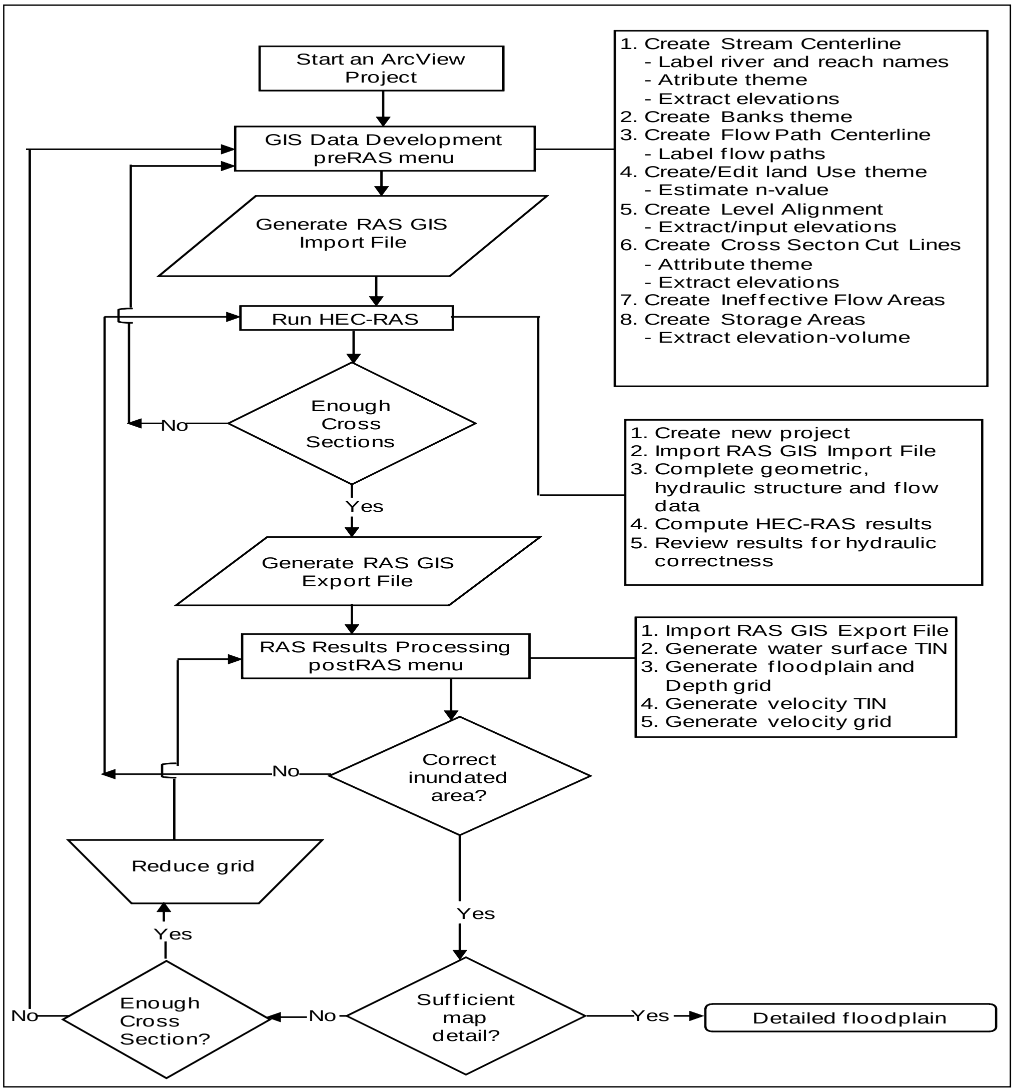
The pre-RAS operation was carried out in the order and sequence as described in the model reference manual and then the geometry file was exported to HEC-RAS model. The geometric data i.e. the river cross-section data is the basic data required for the model.

b) HEC RAS Model Application

The HEC-RAS 4 Beta (freely available software) is used to generate one-dimensional flow model. The geometric data exported from HEC GeoRAS was imported in this application. The model was run in HEC RAS and the output file again imported in HEC GeoRAS. After importing the HECRAS output in GIS through Post-GeoRAS operation, further analysis like changes in flood depth over the flood plain was done and subsequent maps were prepared in the GIS environment.

c) Post Geo-RAS Application

The results obtained from the HEC-RAS model were imported to the Arc View GIS environment using Post Geo-RAS application. The HEC-RAS model output in terms of water surface TIN for various years return periods will be imported in GIS through Post Geo-RAS and when analyzed, it gives the inundation depths.

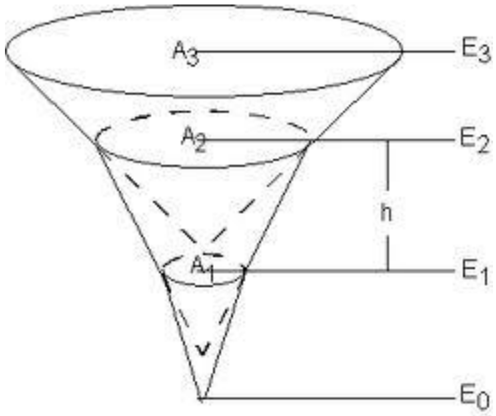


Source; HEC RAS Manual

Figure 3.4: Flow Chart for the Calculation of Flood Inundation

3.7.4 Reservoir Capacity of Reservoir

There are three different methods for defining storage capacity: Volume Vs Elevation, Area Vs Elevation, and known geometry. In all three cases a relationship between elevation and volume will be computed. For the volume vs. elevation option this is explicitly defined. If area vs. elevation is specified, then a corresponding volume for each elevation is computed using the conic method. The conic method is illustrated below.



The volume between incremental areas A_1 and A_2 is computed using the following equation:

$$\Delta V_{12}=\frac{h}{3}\left(A_1+A_2+\sqrt{A_1A_2}\right) \tag{3.7}$$

Where:

ΔV_{12} = the volume between areas A_1 and A_2.

A_i = surface area i.

h = vertical distance (E_2-E_1) between surface areas A_1 and A_2.

E_i = elevation of surface area i.

The same equation is used to compute the volume between each adjacent set of surface areas, with the bottom area assumed to be 0. If the basin geometry option is chosen then an elevation vs. volume relationship is computed directly from the geometry defined for the basin.

3.7.5 Installed Capacity.

Installed capacity or the plant capacity of a system is the maximum power that can be generated at a time by operating all the generators installed. Installed capacity of a hydropower plant is governed by the peak demand and the head and discharge available at the site. The installed capacity can be calculated from the peak discharge and the head available

$$\text{Installed Capacity (P installed)} = \eta * \rho * g * Q * H \tag{3.8}$$

Where,

P = Power in Watts

η = efficiency (micro: 50-60%, small > 80%)

ρ = density of water (1000 kg/m^3)

g = Acceleration due to gravity (9.81 m/s^2)

Q = Discharge passing through the turbine (m^3/s)

H = Head or drop (m) of water (difference between forebay level and turbine level or tail water level)

3.7.6 Probable Maximum Flood (PMF)

Probable maximum flood is defined as the flood resulting from the most several combinations of critical meteorological and hydrologic conditions that are reasonably possible in the region. Generally, probable maximum flood (PMF) is considered to be equivalent to approximately twice the 10,000 year flood.

3.7.7 Probable Maximum Precipitation (PMP)

Probable maximum precipitation is defined as the depth of rainfall that approaches the upper limit of what the atmosphere can produce. Probable maximum precipitation is necessary for estimating the probable maximum flood, basis of which main hydraulic structures are to be designed. Chow's equation is used for statistical approach of PMP in this study. This approach is recommended by WMO manual.

$$\mathbf{PMP = P + K^{*}\sigma} \quad (3.9)$$

Where, P = mean of instantaneous maximum

σ= standard deviation of instantaneous maximum.

K is frequency factor which depends upon the statistical distribution of the series, number of year of recorded and the return period (This factor heavily depends on rainfall duration and Chow's limits is 6 to 30).

3.8 Methodology

In this study, different methods and different tools are adopted. 19 monthly rainfall stations were used in Isohyetal analysis. GIS and HEC-GeoRAS are the tool for analysis study basin and inundation area. Total 47 years (1964 to 2010) of daily discharge data are used for long term mean monthly and annul discharge. And for flood frequency analysis, maximum instantaneous data of these years are used. Three hydrological stations were used for data consistency, and 19 hydrological stations lie in Narayani basin which is used for hydrological analysis.

3.8.1 Method of Data Collection

Generally, secondary data is carried out for this study. The meteorological and hydrological data were collected from Department of Hydrology and Meteorology (DHM). For literature review, journals, book reports and past study of related subject matter were collected from RECHAM, SOHAM, TU-library, IOE library, and NEA library and from different websites. The detailed methods for the calculation and estimation of these parameters are further described in the subsequent sections.

3.9 Average Depth of Precipitation

Since most hydrological problems require knowledge of the average depth of rainfall over a significant area such as a river basin, some procedure must be used to connect the rainfall measured at the individual rain gauges to the areal averages. It is never possible to determine the exact average depth of rainfall. There are three methods of treating the rain gauge records to arrive at an approximation answer and in general the three methods give three different approximations (Reddy, 2004). They are:

(i) Arithmetic Mean Method

$$P = \frac{P1+P2+\ldots+Pn}{n} \quad (3.10)$$

Where, P is the average depth of rainfall and P_1, P_2,.....P_n are the rainfalls records at stations 1,2, ...etc. and n is the number of rain gauge stations with the area.

(ii) Thiessen Polygon Method

$$P = \frac{A1P1+A2P2+\ldots+AnPn}{A1+A2+\ldots+An} \quad (3.11)$$

Where, P_1, P_2 ..., P_n, are the rainfalls recorded at rain gauge stations with A_1, A_2 ..., A_n as the polygonal areas around them. Since $A_1 + A_2 + \ldots + A_n = A$, the area of the basin.

(iii) Isohyetal Method

$$P = \frac{A1P1+A2P2+\quad+AnPn}{A} \quad (3.12)$$

Where, P_1, P_2 ..., P_n are the rainfalls recorded at rain gauge stations with A_1, $A_{2, \ldots,}$ A_n as the polygonal areas around them. And ‘A’ is total area of the basin.

The first two methods are used for this study.

(iv) Penman’s Method

Out of different analytical methods for the calculation of evaporation loss from the reservoir viz. Mass Transfer Method, Energy Balance Method, and Water Budget Method, the combined method of Mass Transfer Method and Energy Balance Method has been adopted. This method is also called the Penman’s Method.

Penman’s equation, incorporating some of the modifications suggested by other investigator is,

$$PET = \frac{(A\times Hn+Ea\times\gamma)}{(A+\gamma)} \quad (3.13)$$

Where

PET = daily potential evapotranspiration in mm per day

A = slope of the saturation vapor pressure vs. time curve at the mean air temperature, in mm of mercury per ^{o}C

H_n= net radiation in mm of evaporable water per day

E_a = parameter including wind velocity and saturation deficit

γ = psychrometric constant = 0.49 mm of mercury/^oC

$$H_n = H_a(1-r)\times\left(a+b\times\frac{n}{N}\right) - \sigma\times T_a^4\times\left(0.56-0.092\times\sqrt{e_a}\right)\times\left(0.10+0.90\times\frac{n}{N}\right) \quad (3.14)$$

Where

H_a = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day

a = a constant depending upon the latitude ϕ and is given by a = 0.29*cosϕ

b = a constant with average value of 0.52

n = actual duration of bright sunshine in hours

N = maximum possible hours of bright sunshine

r = reflection co-efficient (albedo) or (0.05)

σ = Stefan-Boltzmann constant =$2.01*10^{-9}$ mm/day

T_a = mean air temperature in degree Kelvin =273 +^oC

e_a = actual mean vapor pressure in the air in mm of mercury

The parameter E_a is estimated as

$$E_a=0.35\left(1+\frac{u_2}{160}\right)(e_w-e_a) \quad (3.15)$$

In which

u_2 = mean wind at 2 m above ground in km/day

e_w = saturation vapor pressure at mean air temperature in mm of mercury

$$4.584 \exp\frac{(17.27\ t)}{(237.3+\ t)}$$ mm of Hg, where t = Temperature in ^oC

e_a = actual vapor pressure

(v) WECS/DHM 1990 – Method

In 1990 WECS with collaboration DHM published a report on "Methodologies for Estimating Hydrologic Characteristics of Ungauged Location in Nepal". They developed a regression equation for estimating the hydrologic characteristics of the ungauged basin. The method consists of the regression equation for estimating the long term average monthly flow. The equation is as follows:

Q(mean month) = C x (Area of the basin)^{A1} x (Area below 5000m+1)^{A2} x (monsoon wetness index) ^{A3} (3.16)

Where the basin characteristics like area of the basin, area below 5000m and monsoon wetness index remain same, whereas the coefficients C, A1, and A2 are different for each month

(vi) WECS/DHM 2004 Method

Sharma and Adhikari (2004) modified the 1990's method using long term flow data of larger number of rivers gauging sites. The regression equation, thus, developed is of the form:

$$\mathbf{Y = a + bX_1 + cX_2 + dX_3} \tag{3.17}$$

Where Y is the discharge for a given month after an appropriate transformation, a, b, c and d are coefficients. X1, X2 are average elevation of the catchment (m) and annual precipitation (mm) respectively. X3 represents catchment area below 3000 m or 5000M as required. It is noted here that X1 =4041.5m, X2 =1457mm, X3 =1543km2 (< 3,000m) or 3703 km2 (< 5,000m). This gives runoff coefficient (runoff-discharge ratio).

Limitation of WECS/DHM 1990 and WECS/DHM 2004 methods is; it only considers the area below 5000 masl. So these methods can only be used in pre-feasibility level study for any hydroelectric project.

(vii) Regional Monthly Flow Regression Analysis

Homogeneity test is to be carried out for the purpose of regional analysis. The stream flow records of 13 gauging stations of Narayani/Gandaki basin were collected and used for the Regression Analysis. The mean monthly flow of these stations is given in **Table 3.3.**

Table3.3: The Data used for Regression Analysis

SN	Stations	Location	River Name	Data period from		Area (km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1	415	Andhi Muhan	Andhi Khola	1964	1991	476	4.8	3.9	3.2	3.0	6.3	33.4	100.0	94.3	67.3	26.8	9.9	6.2	29.9
2	420	Kota Gaun	Kali Gandaki	1964	2006	11400	112.0	92.2	83.2	93.1	136.0	380.0	1190.0	1460.0	1000.0	442.0	223.0	150.0	443.0
3	428	Laha Chowk	Mardi Khola	1974	1995	160	3.4	2.9	2.8	2.8	3.9	14.7	48.2	60.0	42.0	17.5	7.1	4.4	17.5
4	430	Phool Bari	Seti	1964	1984	582	12.9	11.4	11.3	13.0	19.1	49.8	130.0	147.0	103.0	54.5	25.3	16.9	49.5
5	438	Sisaghat	Madi	1975	2006	858	17.1	15.0	15.1	17.8	28.8	80.9	215.0	225.0	156.0	64.9	32.1	22.2	75.0
6	439.7	Bimalnagar	Marshyandi	1987	2006	3774	51.3	44.6	43.8	55.4	102.0	263.0	557.0	656.0	413.0	176.0	94.4	65.1	210.0
7	445	Arughat	Budhi Gandaki	1964	2010	4270	35.71	30.54	35.29	58.13	102.86	223.51	409.79	439.04	316.23	153.82	79.31	49.38	161.14
8	446.8	Betrawati	Phalakhu	1971	1995	162	2.5	2.0	1.8	2.0	2.9	12.1	35.8	43.8	30.7	12.0	5.5	3.4	12.9
9	447	Betrawati	Trishuli	1967	2008	4850	48.4	42.8	42.9	54.9	98.7	262.4	551.6	628.7	414.7	179.4	89.2	60.7	206.2
10	448	Belkot	Tadi	1969	2006	653	9.6	7.3	5.2	5.6	9.9	34.3	99.1	129.0	92.3	43.2	21.8	13.1	39.4
11	449.91	Kalikhola	Trishuli	1994	2006	16760	174.0	146.0	139.0	179.0	383.0	1070.0	2610.0	3040.0	1860.0	723.0	364.0	237.0	914.0
12	465	Manahari	Manahari	1964	2006	427	6.2	5.1	4.6	5.6	6.7	17.4	57.5	74.2	59.4	19.3	10.9	7.8	19.7
13	470	Lothar	Lothar	1964	2004	169	1.9	1.5	1.4	1.4	2.1	5.7	25.0	30.2	23.0	9.4	1.1	2.6	8.9

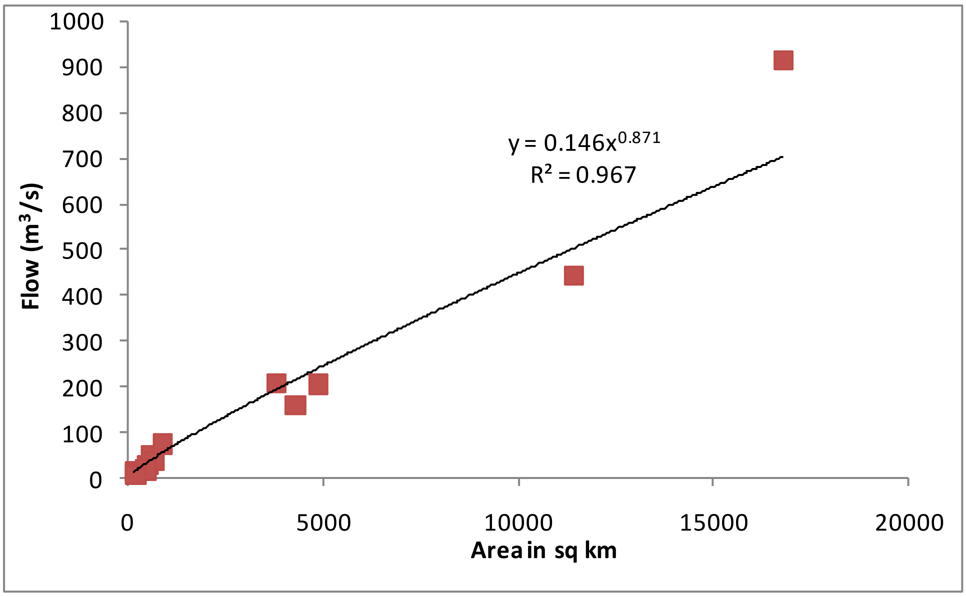


Figure 3.5: Relation between Annual Average Flow and Area

Table 3.4: Coefficient Values of Long Term Monthly and Annual Average Flows

Coefficient	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
m	0.028	0.02	0.018	0.014	0.016	0.083	0.437	0.535	0.457	0.174	0.034	0.038	0.146
n	0.888	0.90	0.918	0.973	1.027	0.951	0.86	0.852	0.824	0.838	0.952	0.888	0.871
R^2	0.967	0.96	0.953	0.946	0.946	0.952	0.964	0.97	0.973	0.97	0.90	0.965	0.967

v) Transformation Method

Transformation method is based on the principle that for a hydrological similar catchment, the gauged basin can be transformed to ungauged basin using Catchment Area Ratio (CAR) method.

$$\frac{Q_{damsite}}{Q_{arughat}} = \left(\frac{A_{damsite}}{A_{arughat}}\right)^q \times \left(\frac{P_{damsite}}{P_{arughat}}\right)^n \qquad (3.18)$$

For average flow q is close to 1 and for instantaneous high flow it is close to 0. Actually it is a function of WECs/DHM method. It is noted here that when n =0, it is only area transformation. If q=1 and n=1, the equation (3.18) becomes:

$$\frac{Q_{damsite}}{Q_{arughat}} = \left(\frac{A_{damsite}}{A_{arughat}}\right) \times \left(\frac{P_{damsite}}{P_{arughat}}\right) \qquad (3.19)$$

In our case Arughat (445) has the measured flow data. It has to be transformed to the dam site. A relation "fairly accurate for instantaneous peaks" takes the following form, which is also suggested by DHM for the instantaneous flood flows (DHM, 2004). For the instantaneous flood flows, the transposition factor will be taken as:

$$\frac{Q_{damsite}}{Q_{arughat}} = \left(\frac{A_{damsite}}{A_{arughat}}\right)^{0.5} \tag{3.20}$$

During the Marshyangdi project NEA has carried out the exponent value for Gandaki basin as 0.8 for transform factor. Budhigandaki also lies in Gandaki basin so here, transformation was done by following equation.

$$\frac{Q_{damsite}}{Q_{arughat}} = \left(\frac{A_{damsite}}{A_{arughat}}\right)^{0.8} \tag{3.21}$$

CHAPTER IV

RESULT AND DISCUSSIONS

4.1 Meteorology

4.1.1 Rainfall Data and Analysis

Department of Hydrology and Meteorology (DHM) is the sole authority for the establishment of meteorological, climatological and hydro-metric stations and collection, processing and publishing of hydrological and meteorological data. A fully equipped climatological station has rain gauge (manual or automatic), maximum-minimum thermometer, pan-evapometer, sunshine recorder, wind vane, where as there are number of stations, which have only manual rain gauge recording 24-hour rainfall, every morning at 8:45 AM Nepal Standard Time (NST).

Most of the study area lies in wind ward side. The rainfall occurring in this catchment is, therefore, quite high in amount. There are three rainfall stations lying in the study area, they are Station No. 801, 806, 1002. From some years station no 806 is not in operation. Here we identified the relevant stations and obtained secondary data (monthly rainfall data). The average rainfall of the station along with other stations lying nearby is given in **Table 4.1**.

Table 4.1: Precipitation Station and their Normal and Annual Values used in the Study

S.N	Index	station	Long(E)	Lat(N)	Elev	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
1	801	Jagat setibas	84.9	28.37	1334	51	29.1	43.1	64	64.4	83.5	175.6	306.9	254	151.3	38.4	9.6	15.2	1303.7
2	802	khudi bazzar	84.37	28.28	823	51	28.4	46.7	79.7	103.7	232.3	538.7	867.6	838.4	490.5	94.6	18.5	23.2	3367.1
3	807	Kunchha	84.35	28.13	855	51	22.8	35.1	55.1	100.2	275.8	507.1	630.1	529	344.2	80.1	14	23.2	2616.9
4	808	Bandipur	84.42	27.93	965	51	24.3	22.9	35.1	81.7	217.7	326.2	437.5	314	190.6	50.7	15.3	28	1787.9
5	809	Gorkha	84.62	28	1097	39	22.7	18.7	43.9	79.7	186	323.9	444.6	362.5	186.4	43	8.1	18.2	1736.7
6	815	Khaireni	84.1	28.03	500	38	21.2	25	37.5	111.4	327.5	448.3	554.1	438.4	267.3	71.2	17.2	22.5	2363.6
7	816	Chame	84.23	28.55	2680	35	33	48	78	46	51	104	189	143	145	83	18	16	953.3
8	817	Damauli	84.28	27.97	358	35	18.8	24.7	34.5	101.6	248.9	337.9	458.8	307.5	199.9	45.5	5.6	21.1	1782.4
9	820	Manang	84.02	28.67	3420	34	26.4	22	34	23.8	29.8	42.9	60	78.6	66.5	37	13.2	16.8	428.5
10	823	Gharedhunga	84.62	28.2	1120	33	21	30.1	63.7	81.5	241.8	508.3	797.9	729.6	410.6	97.6	14.1	22.7	2951.9
11	902	Rampur	84.42	27.62	256	42	18.1	14.6	21.9	55.6	165.3	342.4	573.3	438.3	276.7	77.2	8.8	17.5	2009.6
12	903	Jhawani	84.53	27.58	270	51	17	18.8	23	60.6	146.7	298.4	542.4	454.8	287.4	78.9	9.3	18.3	1955.6
13	1001	Timure	85.38	28.28	1900	51	18.8	20	49.3	31.6	42	100.8	229.2	217.5	144	45.3	6	13	893.4
14	1002	Arughat	84.82	28.05	518	49	23.7	31.8	55.8	83.7	205.8	430.2	682.9	644.2	358.5	65.8	14	17.9	2614.2
15	1004	Nuwakot	85.17	27.92	1003	39	17.4	20.9	32.2	56.2	123.1	309.2	533.1	547.5	271.6	65.4	9.2	15.9	2022
16	1005	Dhading	84.93	27.87	1420	51	21	23.6	36.3	74.5	196.5	358	512	515.3	292.1	42.5	11.7	15.5	2103.2
17	1007	Kakani	85.25	27.8	2064	37	19.5	25.6	41.3	68.7	202.1	483.8	737.5	753.2	400.7	80.4	9	18.1	2864.9
18	1038	Dhunbeshi	85.18	27.72	1085	37	16.4	15.8	28.5	50	138.3	256.3	435.4	390.6	219.5	58.1	8.7	17.3	1648.8
19	1057	Pansayakhola	85.07	28.01	1240	36	22.2	31.7	42.7	74.9	210.2	483.8	842.9	827.9	472.5	81.4	13	17.2	3128.4

There is various estimation of precipitation in various literatures, in geological society of America (2006) estimate 1005.0 mm by Tropical Rainfall Measuring Mission (TRMM) model using 10 km spatial resolution satellite map. The present study reveals that the long term average rainfall of basin is 1457.0 mm. The study area receives 80.9% of annual rainfall in monsoon season (June – September). Among monsoon months, July is the wettest month which receives 380 mm (i.e., 26% of the total annual rainfall). Likewise, November is the driest month which receives 8.0 mm (i.e., < 1% of the total annual rainfall).While the average precipitation of the Budhigandaki basin upstream of

Arughat Station (1002) is 1203.0 mm. **Figure 4.1** shows the monthly rainfall distribution of the study area i.e. upstream of Budhigandaki Dam site.

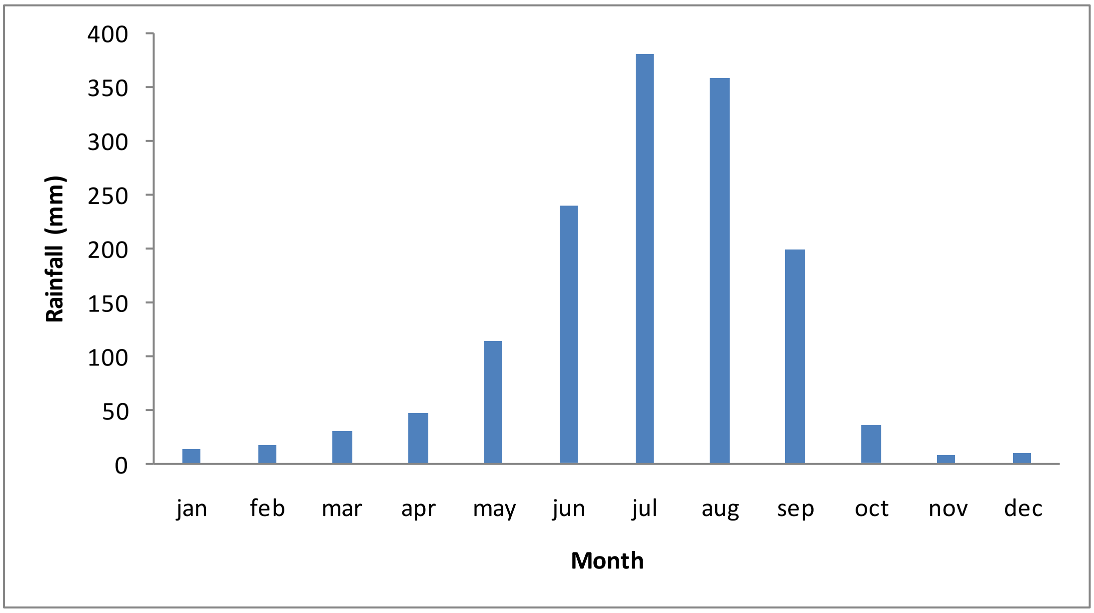


Figure 4.1: Mean Monthly Rainfall of Budhigandaki Basin.

There is various method of estimating average rainfall: Arithmetic Average, Theissen Polygon and Isohyetal method. Here we have calculated average rainfall by Arithmetic Average and Isohyetal method.

4.1.2 Arithmetic Average Method

As there are three rain gauge stations at study area. We have used four stations (station no. 801, 1002, 1001, 816). The arithmetic average rainfall is therefore 1440.0 mm.

4.1.3 Isohyetal Method

In this method, contour line was drawn using GIS from point data measured all over the country and clip by the study area. Because of unavailability of Tibetan data here we take the reference of practical action 2009. By this method, the average rainfall came to be 1457.0 mm. The Isohyetal map of the Budhigandaki Basin is depicted in **Figure 4.2**.

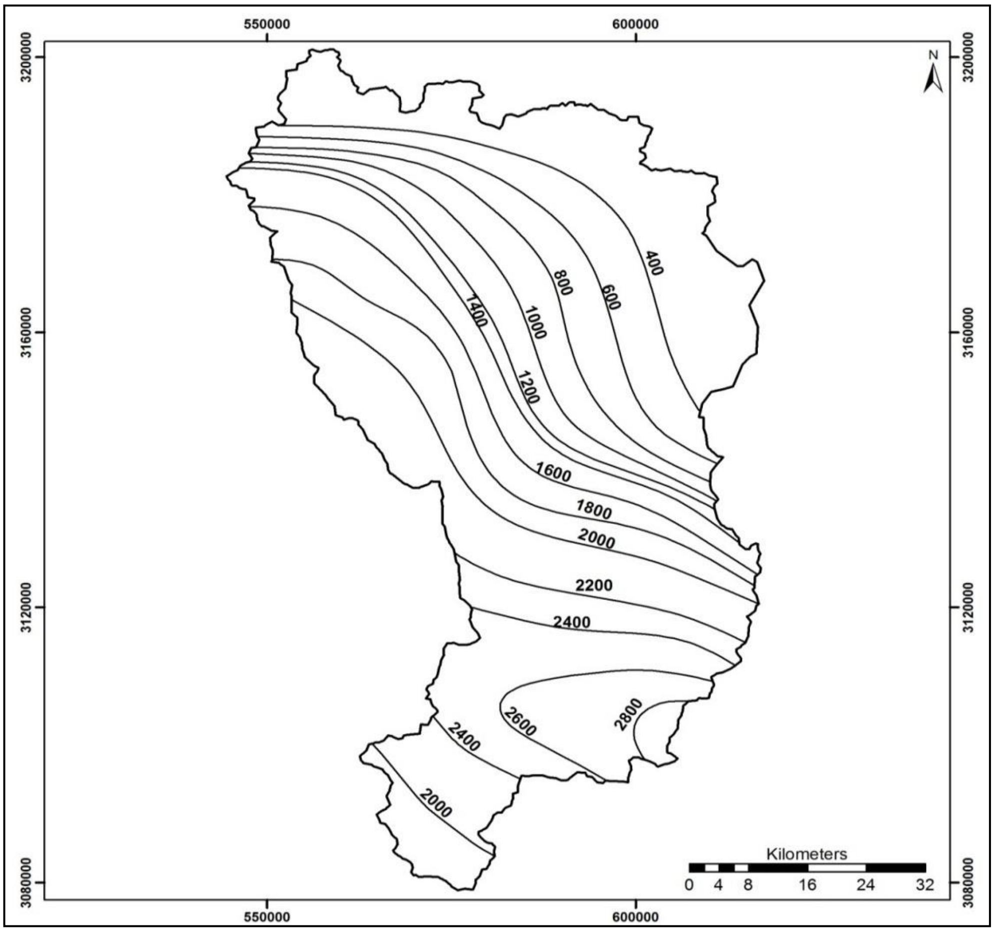


Figure 4.2: The Isohyetal Map of Budhigandaki Basin.

4.1.4 Frequency Analysis of 24 hr Rainfall of Arughat

The frequency analysis of maximum 24 hour rainfall was carried out by Gumbel Distribution method. The monthly rainfall values (1976 to 2005) shows annual rainfall value as high as 150 mm in 1979. The highest intensive rainfall expected once in 100 year return period is equal to or exceeding 173.4 mm. **Table 4.2** and **Figure 4.3** show the maximum 24 hour rainfall for the different return periods.

Table 4.2: The 24-hr Rainfall for Various Return Periods

Return Period	Correction Factor	Gumbel Coefficient	Rainfall (mm)
2	0.36	0.15	96.64
5	1.49	0.86	117.20
10	2.25	1.54	130.81
15	2.67	1.92	138.49
20	2.97	2.18	143.87
25	3.19	2.39	148.01
50	3.90	3.02	160.77
100	4.60	3.65	173.44

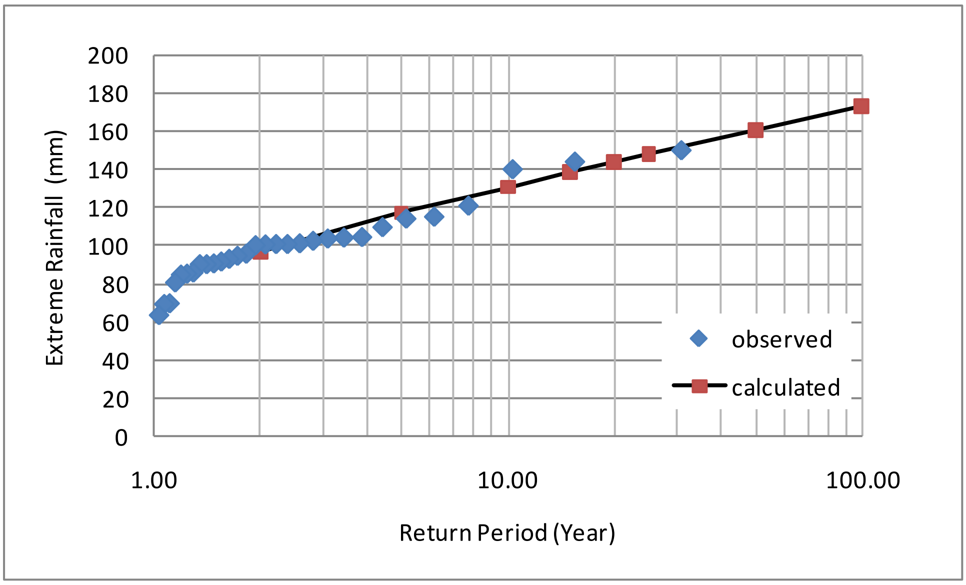


Figure 4.3: 24 Hours Maximum Rainfall for different Return Periods

4.1.5 Probable Maximum Precipitation (PMP)

From the result of 30 years data, mean of annual maximum values is 99.7 mm and standard deviation is 20.18 mm. Thus the PMP is 402 mm.

4.1.6 Evaporation and Evapotranspiration

Evaporation is one of the major factors that have to be considered in the design of large capacity reservoir. However, in the past studies of Budhigandaki hydroelectric project prefeasibility (1984) and in review (2011) no consideration was given in reservoir evaporation. As there is large surface area huge amount of water gets lost from the reservoir. So, in this report evaporation loss from the reservoir has been considered in the reservoir capacity determination.

Relevant data required for the calculation of evaporation loss from reservoir such as vapor pressure, temperature, relative humidity are given in table. For exact calculation of evaporation loss, average of monthly average of several years should be taken. There are very few meteorological stations which have relative humidity, vapor pressure and other parameter; in this study except mean temperature other parameters are carrying from Kathmandu airport (1030). The temperature data are taken from Dhunbensi (1038). This is lies outside the study area. **Table 4.3** shows the detail of calculation where mean annual PET comes as 1554.38 mm/month.

Table 4.3: Calculation of PET

month	H_a	r	u	n	N	n/N	Temp(°c)	Temp(°K)	T^4	RH	e_w	e_a	A	a	b	σT^4	H_n	E_a	PET(mm/day)	PET(mm/month
JAN	9.19	0.05	15.30	6.08	10.61	0.57	13.33	286.33	6721599893.44	78.96	10.37	8.19	0.68	0.26	0.52	13.51	2.39	0.84	2.28	70.76
FEB	11.04	0.05	21.56	6.62	11.22	0.59	15.70	288.70	6946711525.63	75.10	12.31	9.24	0.78	0.26	0.52	13.96	3.46	1.22	3.32	93.02
MAR	13.06	0.05	28.48	7.20	12	0.60	19.94	292.94	7363848958.88	66.31	15.50	10.28	0.97	0.26	0.52	14.80	4.57	2.15	4.45	137.87
APR	14.92	0.05	28.86	7.62	12.81	0.59	23.88	296.88	7768695209.96	61.63	18.89	11.64	1.14	0.26	0.52	15.62	5.60	2.99	5.49	164.82
MAY	15.91	0.05	24.40	6.77	13.52	0.50	25.25	298.25	7912537629.85	68.94	20.76	14.31	1.26	0.26	0.52	15.90	5.98	2.60	5.85	181.47
JUN	16.29	0.05	20.37	5.33	13.86	0.38	26.30	299.30	8024427624.16	73.96	23.23	17.18	1.37	0.26	0.52	16.13	5.81	2.39	5.69	170.67
JUL	16.05	0.05	14.02	3.55	13.69	0.26	25.97	298.97	7989417873.22	82.23	23.59	19.40	1.39	0.26	0.52	16.06	5.17	1.60	5.04	156.34
AUG	15.3	0.05	11.37	3.67	13.08	0.28	25.77	298.77	7968051850.85	83.35	23.52	19.60	1.39	0.26	0.52	16.02	5.01	1.47	4.89	151.58
SEP	13.77	0.05	11.15	4.85	12.37	0.39	24.41	297.41	7824087033.25	82.72	22.33	18.47	1.33	0.26	0.52	15.73	4.87	1.44	4.75	142.51
OCT	11.78	0.05	12.88	7.28	11.56	0.63	21.77	294.77	7549315663.97	80.34	18.65	14.99	1.12	0.26	0.52	15.17	4.49	1.39	4.36	130.87
NOV	9.73	0.05	10.82	7.37	10.78	0.68	17.78	290.78	7149584129.11	81.40	14.10	11.48	0.89	0.26	0.52	14.37	3.12	0.98	3.01	90.22
DEC	8.62	0.05	11.30	6.20	10.41	0.60	14.33	287.33	6815837825.45	82.06	10.87	8.92	0.71	0.26	0.52	13.70	2.17	0.73	2.07	64.24
																			annual	1554.38

4.2 Hydrology

4.2.1 Reference Hydrology

Budhigandaki is a major tributary of Sapta gandaki River Basin.DHM has established the hydrometric Station at Arughat (index no. 445), which is about 32 km upstream of Dam Site. Similarly, the other gauging station available is on the Ankhu Khola (index no. 445.3), the major tributaries of Budhigandaki river. The details of these gauging stations are shown in **Table 4.4.**

Table 4.4: DHM Hydrological Gauging Station in Budhigandaki River Basin

S. No	Gauge Station	Type of Station	River	Location	Operator	Comments
1	445	Cable way Water level and Rain gauge	Budhigandaki River	Arughat abour 40 km upstream of Dam site	DHM	Established in 1964
2	445.3	Water level and Cable way	Ankhu Khola	D/S of 445 Gauge station and U/S of Proposed Dam site	DHM	Data not processed

The total catchment area of Budhigandaki at Arughat and at the proposed dam site of project is 3873 km^2 and 5007 km^2 respectively. The hydrological parameters established at the gauged station at Arughat are transposed to the dam site using the different method as explained in the following section. Observed flow of neighbor stations and transformed flow of Dam Site using equation 3.21 are listed in the **Table 4.5**.

Table 4.5: Observed and Transformed Flow of Budhigandaki

Station	445	447	450	Damsite
River	Budhigandaki	Trishuli	Narayani	Budhigandaki
Location	Arughat	Betrawati	Devighat	Damsite
Area (km^2)	3873	4643	32099	5007
Ppt(mm)	2607	1687		1457
	Observed Flow	**Observed Flow**	**Observed Flow**	**Transposed From #445**
Month	**(m^3/s)**	**(m^3/s)**	**(m^3/s)**	**(m^3/s)**
Jan	35.7	43.5	367.8	43.9
Feb	30.5	38.4	302.1	37.5
Mar	35.3	38.5	281.5	43.1
Apr	58.1	48.9	355.1	72.4
May	102.9	88.6	644.6	126.4
Jun	223.5	235.4	1 695.6	274.7
Jul	409.8	494.9	3949.3	503.6
Aug	439.0	564	4596.2	539.5
Sep	316.2	372.1	3275.9	388.6
Oct	153.8	160.9	1566.4	189.0
Nov	79.3	80	793.4	97.5
Dec	49.4	54.5	495.0	60.7
Annual	161.14	206.6	1526.9	198.0

4.2.2 Homogeneity Test

Consistency and accuracy of data is most important properties for hydrological analysis. For ungauged river basin homogeneity test is needed for Regional flood analysis and other further calculations. For homogeneity test 19 hydrological stations (**Table 4.6**) of Narayani basin were used. **Figure 4.4** shows that, station no 445 lies between 95% confidence limits. Whereas gauging station number 410, 450, 460, and 440 fail to pass the homogeneity test and hence, are to be omitted from the further analysis (**Figure 4.4**)**.** Hence, based upon this test, considering the remaining stations, further hydrological studies have been carried out. It is to be noted that station no's 406.5 and 439.3 have been omitted for further study because of their long missing record lengths more than ten years. Thus only 13 station records have been used for developing regional monthly regression relationships.

Table 4.6: Stations used for Homogeneity Test

S.N	Stations	Location	River Name	Area (km^2)	Data Period From	
1	410	Seti Beni	Kali Gandaki	6630	1964	1995
2	419.1	Kali Gandaki	Ansing	11400	1996	2012
3	420	Kota Gaun	Kali Gandaki	11400	1968	2008
4	430	Phool Bari	Seti	582	1964	1984
5	439.7	Bimalnagar	Marshyandi	3774	1988	2006
6	439.8	Marsandi River	Goplingghat	3850	1974	1985
7	445	Arughat	Budhi Gandaki	4270	1964	2012
8	447	Betrawati	Trishuli	4850	1977	2012
9	449.91	Kalikhola	Trishuli	16760	1994	2006
10	450	Devghat	Narayani	31100	1963	2010
11	415	Andhi Muhan	Andhi Khola	476	1964	1991
12	428	Laha Chowk	Mardi Khola	160	1974	1995
13	438	Sisaghat	Madi	858	1975	2006
14	440	Garambeshi	Chepe Khola	308	1964	2006
15	446.8	Betrawati	Phalakhu	162	1971	1995
16	448	Belkot	Tadi	653	1969	2006
17	460	Rajaiya	Rapti	579	1963	2006
18	465	Manahari	Manahari	427	1964	2006
19	470	Lothar	Lothar	169	1964	2003

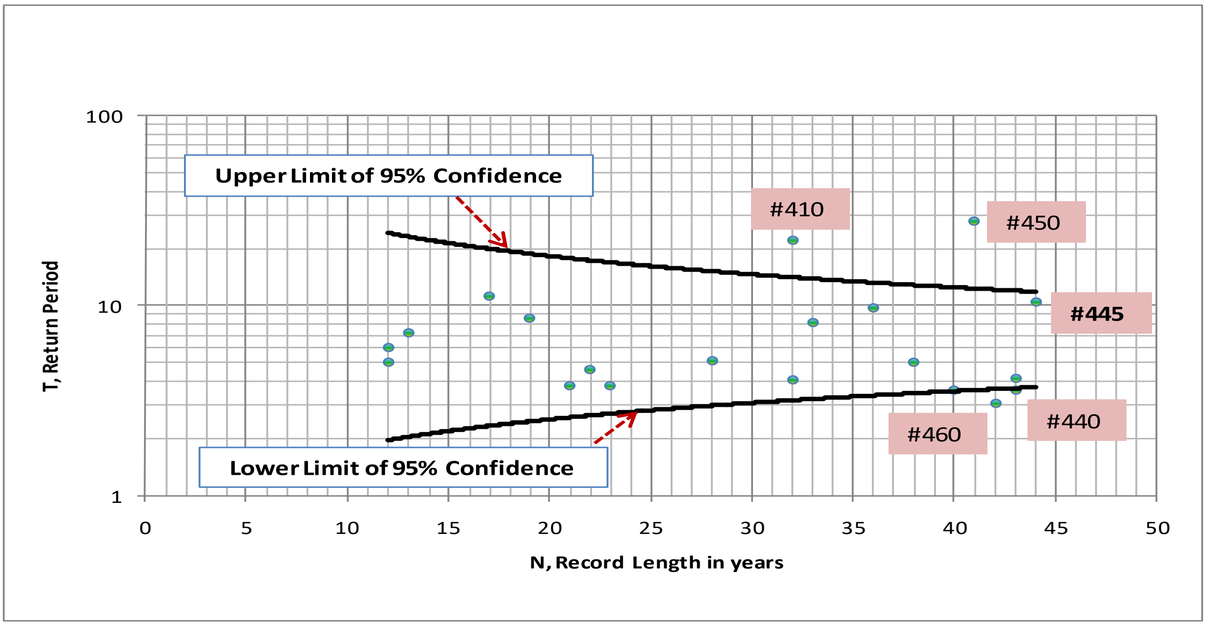


Figure 4.4: Homogeneity Test in Narayani River Basin

4.2.3 Assessment of Long Term Average Flows

The routine procedure of DHM for the collection of hydrological data consists of taking discharge measurements 6 to 7 times in a year to include the entire flow regime of low, medium and high flows. These discharge measurement data are used to construct the rating curve at the station, which is review every year. The water levels (gauge height) are recorded three times a day at 8:00, 12:00, and 16:00 hours daily. The station rating curve is then used to convert the validated water level data into the corresponding discharge data. The monthly mean and the annual extreme high and low flow for each gauging stations are published on regular basis for public use of the data.

4.2.4 Flow Analysis

The latest available processed digital daily stream flow data and the annual instantaneous flood and low flow data at Arughat of Budhigandaki River (index no. 445) from 1964 to 2010 and neighboring stations are collected from DHM.

Table 4.7: Stream Gauging Stations nearby the Project Area

River	Gauging site	Station No	Area(km^2)	Records(from – to)*	Main River Basin
Trishuli	Betrawati	447	4643	1967-2008	Narayani
Ankhu Khola	Ankhu Khola	445.3		1988-2006	Narayani
Trishuli	Kali Khola	449.91		1994-2008	Narayani
Trishuli	Bhorletar	449.95		1994-2006	Narayani
Narayani	Devghat	450	32099	1963-2010	Narayani

*column in this indicate; data of some years may be completely or partially missing.

4.2.5 Long Term Hydrology

For the proper assessment of the power potential of the project, long term flow data are essential. Hence, the long-term flow data need to be generated for the proposed intake site. This should be based on long-term recorded data of the available gauged hydrological stations. The hydrological analysis was, therefore, carried out using long term flow data of Arughat. For Budhigandaki basin upstream of dam site area below 3000 masl is 1543 km^2, area between 3000 and 5000 masl is 2159 km^2 and area below 5000 masl is 3703 km^2. Mean monthly and annual flows at dam site were estimated by the following methods.

i) WECS/DHM 1990 – Method

Table 4.8: Monthly Average Flow estimated by WECS/DHM 1990 Method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Mean
Q(m3/s)	43.9	37.2	35.4	42.2	65.3	58.2	480.6	554	411.	183	92.4	59.7

ii) WECS/DHM 2004 – Method

It is noted here that X1(average elevation of catchment) =4041.5m, X2 (annual precipitation) =1457mm, X3(catchment area) =1543km2 (< 3,000m) or 3703 km2 (< 5,000m). This gives runoff coefficient (runoff-discharge ratio).

Table 4.9: Monthly Average Flow estimate by WECS/DHM 2004 Method

Month	Constant	Coefficient of (b) Avg. Elevation	Coefficient of (c) Annual Precipitation	Coefficient of (d) A<3,000 m	Coefficient of A<5,000 m	Transformation	Monthly Average
Jan	-16.7	1.36	0.47	0.82	-	Ln	56.7
Feb	-17.2	1.42	0.456	0.814	-	Ln	48.9
Mar	0.384	-	-	-	0.091	Square Root	35.1
Apr	0.181	-	-	-	0.104	Square Root	42.4
May	0.0001	-	-	-	0.136	Square Root	68.5
Jun	-19.5	1.61	0.709	0.872	-	Ln	229.6
Jul	-16.3	1.26	0.759	0.884	-	Ln	484.0
Aug	-14.7	1.24	0.622	0.871	-	Ln	680.3
Sep	-13.7	1.09	0.594	0.872	-	Ln	437.2
Oct	-15.3	1.21	0.6	0.846	-	Ln	206.4
Nov	-16.7	1.36	0.543	0.826	-	Ln	100.8
Dec	-17	1.39	0.504	0.822	-	Ln	70.0
						Average	205.0

WECS/DHM 1990 and WECS/DHM 2004 methods only consider the area below 5000 masl. So these methods can only be used in pre-feasibility level study for any hydroelectric project.

iii) Regional monthly flow regression Analysis

Based on the monthly flow data, regression equation for each month has been derived with regression parameters shown in **Table 3.4**(Example of fitting equation to the data for the annual average flow is shown in **Figure 3.5).** The estimated (transformed of daily discharge using equation 3.20) and generated long term mean monthly flows by this method for the Budhigandaki at Arughat and Dam Site are shown in **Table 4.10.** The average annual mean flows came to be 243 m^3/s. It is noted here that the flow values for Arughat gauging site were also estimated by this method and compared with its observed long term mean monthly values. As the coefficient of determination is very good (> 0.9), depicted in **Figure 3.5**, it can be said that the regression equations, thus, derived are quite capable to estimate the flow at Dam Sites for Budhigandaki Basin. Regression equation and graph of each month are shown in **Appendix-B.**

Table 4.10: Long Term Mean Monthly Flow Estimated by Regional Method

Stations	CA (km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Arughat (regional)	3870	43.0	37.4	35.4	43.3	77.4	214.3	532.0	609.7	413.2	176.6	88.5	58.3	194.1
Arughat(observed)	3870	36.0	30.8	35.7	58.8	104.8	228.1	412.4	440.1	313.4	154.3	80.1	49.8	162.0
Dam site (regional)	5007	54.0	47.1	44.8	55.7	100.8	273.8	663.9	759.3	510.9	219.2	113.1	73.3	243.0
Dam site(estimated)	5007	43.9	37.5	43.4	71.4	126.4	274.7	503.6	539.5	388.6	189.0	97.5	60.7	198.0

iv) Transformation Method

Long term stream flow series for the Dam Site of the Budhigandaki River has been generated by transforming the observed mean monthly flow records at Arughat Gauge site using Equation (3.20) and presented in **Table 4.11**. From this method, the long term mean annual flows at the Dam site came to be 198 m^3/s. It gives the runoff coefficient of 0.86 (i.e., runoff volume is less than rainfall volume) which is admissible. It shows that equation (3.20) had produced good estimates in this case. From pure area transformation (i.e. equation 3.18), the average runoff came to be 208 m^3/s. As the transposition by area gives runoff coefficient of 0.9, it is rarely happen, because our study area covers 1304 km^2 above 5000m (i.e., snow cover area). The value obtained by using equation (3.19) has given the completely inadmissible of the runoff coefficient i.e. 1.09 with annual average runoff of 252.2 m^3/s. Here, result obtained from Equation (3.20) method taken as the representative flow.

Area of Arughat	3870	km^2	Annual Precipitation at Arughat	1203	mm
Area at Dam Site	5007	km^2	Annual Precipitation at Dam Site	1457	mm

Table 4.11: Estimate Flows by Transpose Method

Months	**Flow at Arughat**	**Rainfall at Arughat**	**Rainfall at Dam site**	**Flow at Dam Site (m^3/s)**		
	(m^3/s)	**(mm)**	**(mm)**	**Using Eq. (3.21)**	**Area Transformation**	**Using Eq. (3.19)**
Jan	35.7	14.0	13.2	**43.9**	46.2	43.5
Feb	30.5	14.0	17.7	**37.5**	39.5	50.0
Mar	35.3	50.9	31.1	**43.3**	45.6	27.9
Apr	58.1	50.9	46.6	**71.4**	75.2	68.9
May	102.9	50.9	114.7	**126.3**	133.0	299.8
Jun	223.5	239.4	239.8	**274.5**	289.0	289.4
Jul	409.8	239.4	380.6	**503.3**	529.8	842.2
Aug	439.0	239.4	359.0	**539.2**	567.6	851.2
Sep	316.2	239.4	199.8	**388.4**	408.8	341.2
Oct	153.8	25.6	36.7	**188.9**	198.9	285.2
Nov	79.3	25.6	7.8	**97.4**	102.5	31.2
Dec	49.4	14.0	10.0	**60.6**	63.8	45.4
Average	161.1	100.3	121.4	**198**	208.3	252.2
Sum		1203	1457			
Runoff Coefficient	1.09			**0.86**	0.90	1.09

4.2.6 Selection of Appropriate Flow Hydrograph

All the flow data estimated from the above-mentioned methods were plotted in **Figure 4.5** to compare their values and are given in **Table 4.12.** It shows that the Regional Method has predicted higher values than other methods; especially in monsoon season (June to Sep).It is because regional method has incorporated the high flows resulting from high rainfall that occurs in other basins of the region. Further the Regional Method is based on the average of the large and small area, spatial heterogeneity; various monsoon patterns as well as snowmelt behavior are not similar in different areas. WECS-DHM (1990) method has produced quite low value of flows in dry seasons and erratic in characteristic. It is not also a suitable hydrograph for the basin. WECS-DHM (2004) method has also produced quite low value of flows in dry seasons and peak is sharper that mean peak discharge occurs for very short duration, which is not good for reservoir project. The hydrograph obtained from equation 3.19 is more erratic in characteristic, which is not shown in figure. Transposed from Betrawati produced some low flow in dry season but good in agreement, transposed from Arughat produced some high flow even in dry season also, so here due to similarity of catchment and homogeneous of monsoon pattern we recommend transposed from Arughat Method.

Table 4.12: Comparison of Long Term Monthly Flow. Unit: m^3/s

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(Dam site)Transposed from Betrawati	49.6	43.9	44.0	56.3	101.3	269.2	565.9	645.0	425.4	184.0	91.5	62.3
Regression	54.0	47.1	44.8	55.7	100.8	273.8	663.9	759.3	510.9	219.2	113.1	73.3
(Dam site)Transposed from Arughat	43.9	37.5	43.4	71.4	126.4	274.7	503.6	539.5	388.6	189.0	97.5	60.7
WECS/DHM (1990)	43.9	37.2	35.4	42.2	65.3	58.2	480.6	554.1	411.4	182.9	92.5	59.7
WECS/DHM (2004)	56.7	48.9	35.1	42.4	68.5	229.6	484.0	680.3	437.2	206.4	100.8	70.0

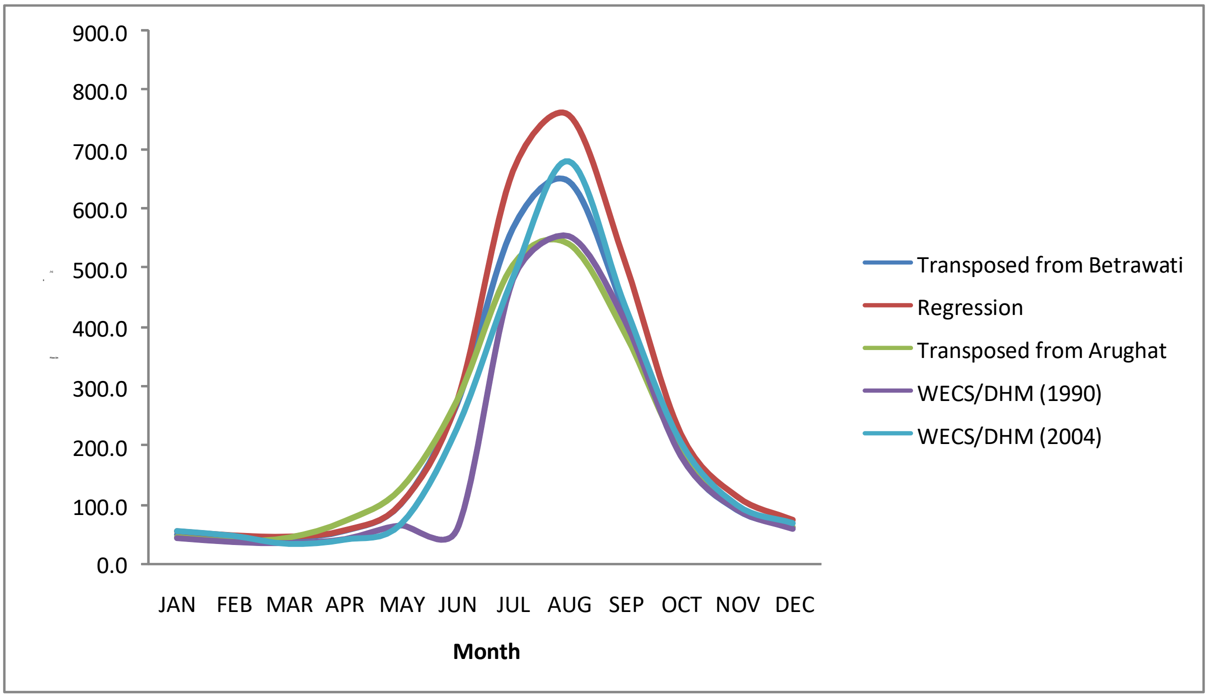


Figure 4.5: Hydrographs of Budhigandaki River at Dam Site by Different Method

4.2.7 Flow Duration Curve

The flow duration curve (FDC) is an exceedance probability-discharge curve which shows the percentage of time when a particular flow is equaled or exceeded. The flow duration curves were prepared using the mean daily flow data (daily discharge of 47 years, total in 7008 days), average of the daily flow data (average discharge of each day of 47 years, total in 366 days) and mean monthly data (average discharge of each month of 47 years, total in 12 month). The flow duration curves, thus obtained are depicted in figure table shows the values of flow for a given probability of exceedance for the dam site. Here mean monthly flow is recommended for both sites.

Table 4.13: Flow Values of Different Probabilities of Exceedance at Arughat

Days	Probability	Daily Flow Method	Long Term Mean Daily	Mean Monthly
18.3	5	482.0	451.40	
36.5	10	418.0	429.30	
54.8	15	368.0	393.46	413.81
73.0	20	325.0	345.25	354.18
91.3	25	267.0	276.53	300.0
109.5	30	206.0	216.79	236.86
127.8	35	159.0	166.43	187.53
146.0	40	129.0	130.49	140.5
164.3	45	106.0	111.14	112.26
182.5	50	88.2	92.35	92.47
200.8	55	73.0	77.45	78.0
219.0	60	61.4	64.79	63.03
237.3	65	52.8	54.85	54.72
255.5	70	46.1	47.72	48.0
273.8	75	41.4	41.83	39.44
292.0	80	37.6	37.62	39.00
310.3	85	34.2	34.56	35.70
328.5	90	31.2	32.84	32.28
346.8	95	28.4	30.92	31.77
361.4	99	20.3	30.16	29

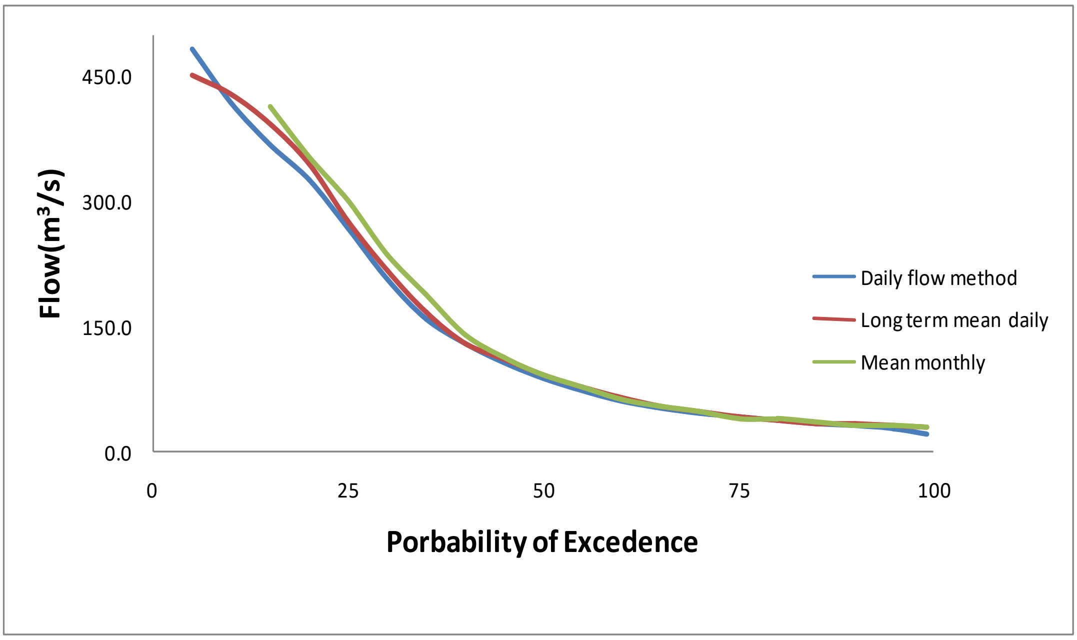


Figure 4.6: Flow Duration Curve at the Arughat

Table 4.14: Flow Values of Different Probabilities of Exceedence at Proposed Dam Site

Days	Probability	Daily Flow Method	Long Term Mean Daily	Mean Monthly
18.3	5	591.9	550.9	540
36.5	10	512.0	523.20	522.0
54.8	15	450.7	479.80	469.76
73.0	20	397.9	411.90	403.40
91.3	25	325.4	335.30	340.0
109.5	30	250.5	258.00	268.69
127.8	35	191.6	199.50	212.51
146.0	40	157.2	158.30	157.0
164.3	45	127.7	132.00	126.64
182.5	50	106.3	110.50	104.00
200.8	55	87.9	93.40	90.0
219.0	60	74.5	77.40	70.86
237.3	65	63.9	66.50	61.51
255.5	70	56.1	58.00	55.0
273.8	75	50.6	50.60	44.48
292.0	80	45.6	45.20	40.47
310.3	85	41.7	42.10	41.0
328.5	90	38.1	39.80	36.50
346.8	95	34.4	37.60	33
361.4	99	24.4	36.40	30

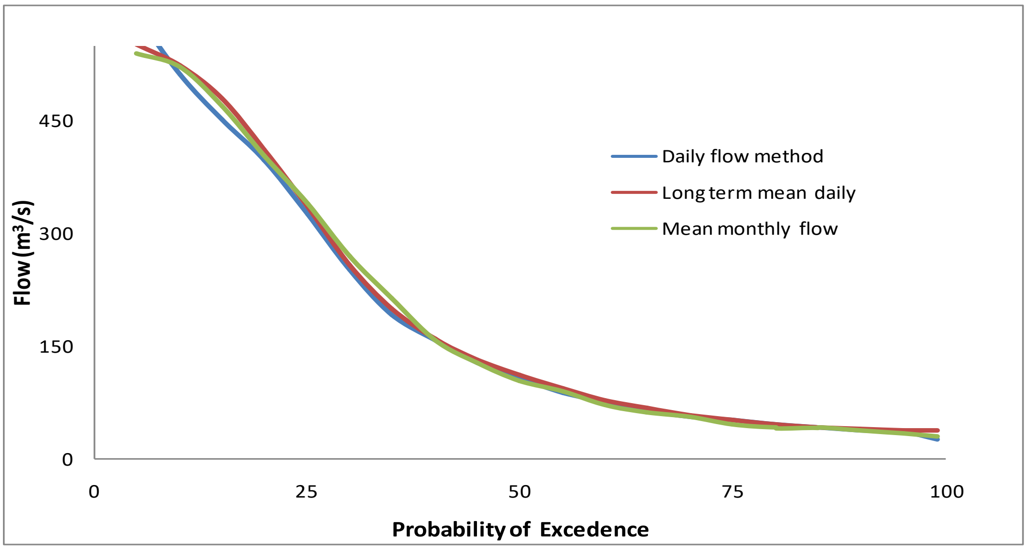


Figure 4.7: Flow Duration Curve for Proposed Dam Site

This is the unregulated flow before construction of reservoir which shows 50% and 90%of flow at Arughat is 92.5 m^3/s and 29 m^3/s. whereas at Dam Site it is 104 m^3/s and 30m^3/s.

4.2.8 Flood Frequency Analysis

A statistical method rather than the usual design storm unit hydrograph approach was used to derive the design flood for the dam site. The analysis of the flood flows for the Budhigandaki at Arughat had been carried out by taking the yearly maximum instantaneous discharge from DHM (1964 to 2010). The flood values were transposed to the Dam Site using equation 3.20, listed in **Table 4.15**. Gumbel, Log Normal and Log Pearson III distribution were, then, fitted, to the observed annual maximum flow data. Of these 47 year floods peaks, the flood of 1968 is the devastating one. On the basic of past years records, the normal high flood line was estimated as the gauge of 5.00 meters. From the flood level at the site by the Roads Department, the difference between the abnormal high flood line and the normal high flood line came out to be 9.61meters on August 2, 1968. Hence, the peak flood on Aug 2, 1968, was plus 9.61, that is 14.61 meter. From the logarithmic extension of the rating curve, the peak discharge of water corresponding to this gauge was 5210 m^3/s; the highest flood ever recorded (Yogacharya K.S, 1969).This was not used in frequency analysis and other statistical test.

Table 4.15: Annual Maximum Flood Series at Arughat and Dam Site

Year	Gauge ht_Arughat	Date	Flow at Arughat	Flow at Dam site (based on Arughat)
1964	4.80	1/9/1964	765	869.75
1965	5.20	12/8/1965	865	983.45
1966	5.50	12/7/1966	940	1068.72
1967	6.25	10/7/1967	1160	1318.84
1968	14.61	2/8/1968	5210	5923.42
1969	4.15	26/07/1969	540	613.94
1970	4.35	6/8/1970	580	659.42
1971	4.40	11/6/1971	590	670.79
1972	4.50	28/07/1972	615	699.21
1973	5.22	17/06/1973	870	989.13
1974	6.80	5/8/1974	1360	1546.23
1975	4.35	3/8/1975	658	748.10
1976	3.80	4/8/1976	540	613.94
1977	4.30	21/7/1977	725	824.28
1978	4.70	3/6/1978	825	937.97
1979	4.30	20/08/79	725	824.28
1980	4.50	8/8/1980	775	881.12
1981	4.80	1/8/1981	600	682.16
1982	4.00	28/08/82	650	739.01
1983	4.15	17/07/83	688	782.21
1984	4.20	18/09/84	700	795.85
1985	3.88	14/07/85	618	702.62
1986	3.90	16/07/86	624	709.45
1987	4.03	3/7/1987	662	752.65
1988	4.30	1/8/1988	744	845.88
1989	3.85	15/07/89	610	693.53
1990	4.67	27/08/90	863	981.17
1991	4.30	8/8/1991	744	845.88
1992	4.80	24/08/92	908	1032.34
1993	4.90	10/8/1993	942	1070.99
1994	4.25	27/07/94	728	827.69
1995	4.96	7/8/1995	964	1096.00
1996	5.00	13/08/96	978	1111.92
1997	4.30	12/8/1997	744	845.88
1998	5.60	11/8/1998	1220	1387.06
1999	7.20	3/7/1999	2060	2342.08
2000	5.25	2/8/2000	1070	1216.52
2001	5.10	3/8/2001	1010	1148.30
2002	4.60	22/08/2002	840	955.02
2003	5.05	31/07/2003	994	1130.11
2004	4.30	20/08/2004	744	845.88
2005	4.10	4/8/2005	683	776.53
2006	4.00	23/07/2006	653	742.42
2007			790.2	898.37
2008			864.1	982.39
2009			778.8	885.44
2010			832.2	946.20

i) **Gumbel Distribution**

The flow of different periods are given in **Table 4.16**

Table 4.16(a): For Arughat

Tr	Y_t	K_t	Q_T
2	0.3665	-0.1563	782
2.33	0.5786	0.0276	830
5	1.4999	0.8261	1037
10	2.2504	1.4765	1205
20	2.9702	2.1004	1367
25	3.1985	2.2983	1418
50	3.9019	2.9079	1576
100	4.6001	3.5130	1733
200	5.2958	4.1160	1889
500	6.2136	4.9114	2095
1000	6.9073	5.5126	2251
2000	7.6007	6.1136	2407
5000	8.5171	6.9079	2613
10000	9.2103	7.5087	2768

Table 4.16(b): For Dam site

Tr	Y_t	K_t	Q_T
2	0.3665	-0.1563	960
2.33	0.5786	0.0276	1019
5	1.4999	0.8261	1273
10	2.2504	1.4765	1480
20	2.9702	2.1004	1678
25	3.1985	2.2983	1741
50	3.9019	2.9079	1935
100	4.6001	3.5130	2128
200	5.2958	4.1160	2320
500	6.2136	4.9114	2573
1000	6.9073	5.5126	2764
2000	7.6007	6.1136	2955
5000	8.5171	6.9079	3208
10000	9.2103	7.5087	3399

For N = 46	Average	822.59 (Arughat) & 1010.09(Dam site)
Y_n = 0.5468	Standard Deviation	259.14 (Arughat) & 318.21 (Dam site)
S_n= 1.1538		

ii) **Log Normal Distribution**

The flows for different return period are given in **Table 4.17**

Table 4.17 (a): For Arughat

Tr	CS=0	$\bar{Y}_t$	Q_T
2	0	2.899	793.21
2.33	0.093	2.910	812.36
5	0.842	2.994	985.29
10	1.282	3.043	1103.51
20	1.595	3.078	1196.05
25	1.751	3.095	1245.19
50	2.054	3.129	1346.25
100	2.326	3.160	1443.93
200	2.576	3.188	1539.96
500	2.769	3.209	1618.33
1000	3.09	3.245	1757.92

Table 4.17 (b): For Dam site

Tr	CS=0	$\bar{Y}_t$	Q_T
2	0	2.989	974.01
2.33	0.093	2.999	997.53
5	0.842	3.083	1209.88
10	1.282	3.132	1355.05
20	1.595	3.167	1468.67
25	1.751	3.184	1529.01
50	2.054	3.218	1653.11
100	2.326	3.249	1773.06
200	2.576	3.277	1890.97
500	2.769	3.298	1987.21
1000	3.090	3.334	2158.62

Average	2.90 (Arughat) & 2.99 (Dam Site)
Standard Deviation	0.11 (Arughat) & 0.11 (Dam Site)

iii) Log Pearson Type III

The flow of different period are given in **Table 4.18**

Table 4.18(a): For Arughat

Tr	Kz	$\bar{Y}_t$	Q_T
2	-0.209	2.876	752
2.33	-0.106	2.887	772
5	0.720	2.980	955
10	1.339	3.049	1120
20	1.850	3.106	1277
25	2.105	3.135	1364
50	2.662	3.197	1574
100	3.204	3.258	1810
200	3.736	3.317	2076
500	4.192	3.368	2335
1000	4.951	3.453	2839

Table 4.18(b): For Dam Site

Tr	Kz	$\bar{Y}_t$	Q_T
2	-0.209	2.965	923
2.33	-0.106	2.977	948
5	0.720	3.069	1172
10	1.339	3.138	1375
20	1.850	3.195	1568
25	2.105	3.224	1675
50	2.662	3.286	1933
100	3.180	3.344	2209
200	3.736	3.406	2549
500	4.192	3.457	2867
1000	4.951	3.542	3486

Average	2.90 (Arughat) & 2.99 (Dam site)
Standard Deviation	0.11 (Arughat) & 0.11 (Dam site)
Skewness Coefficient	1.29 (Arughat) & 1.29 (Dam site)

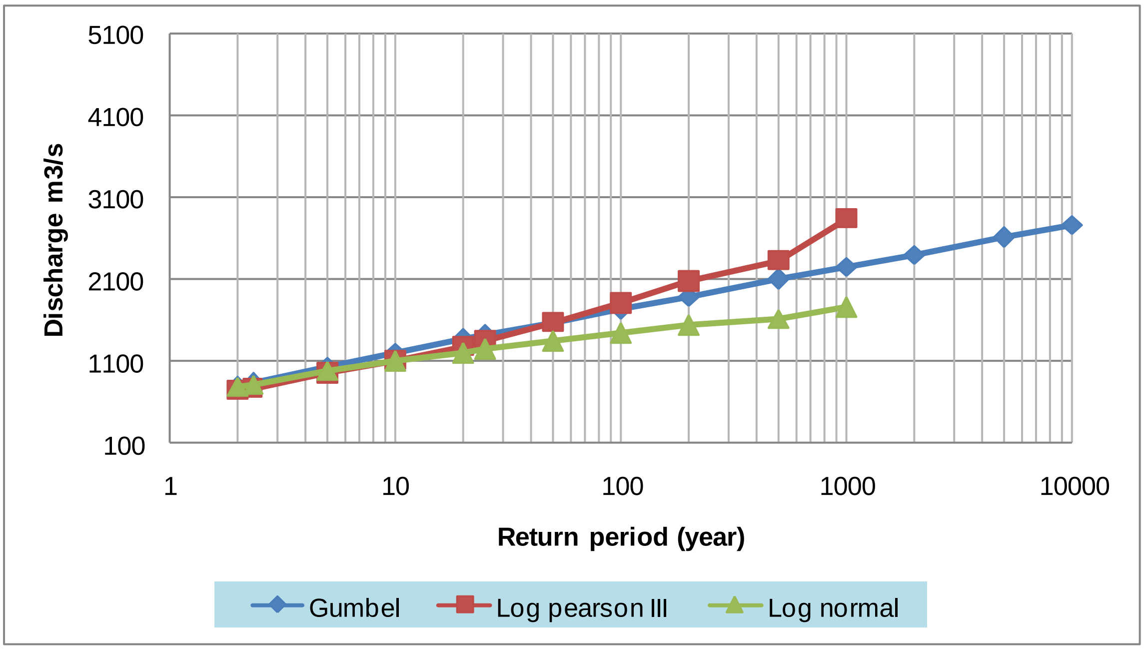


Figure 4.8: Flood Frequency for Budigandki River at Arughat

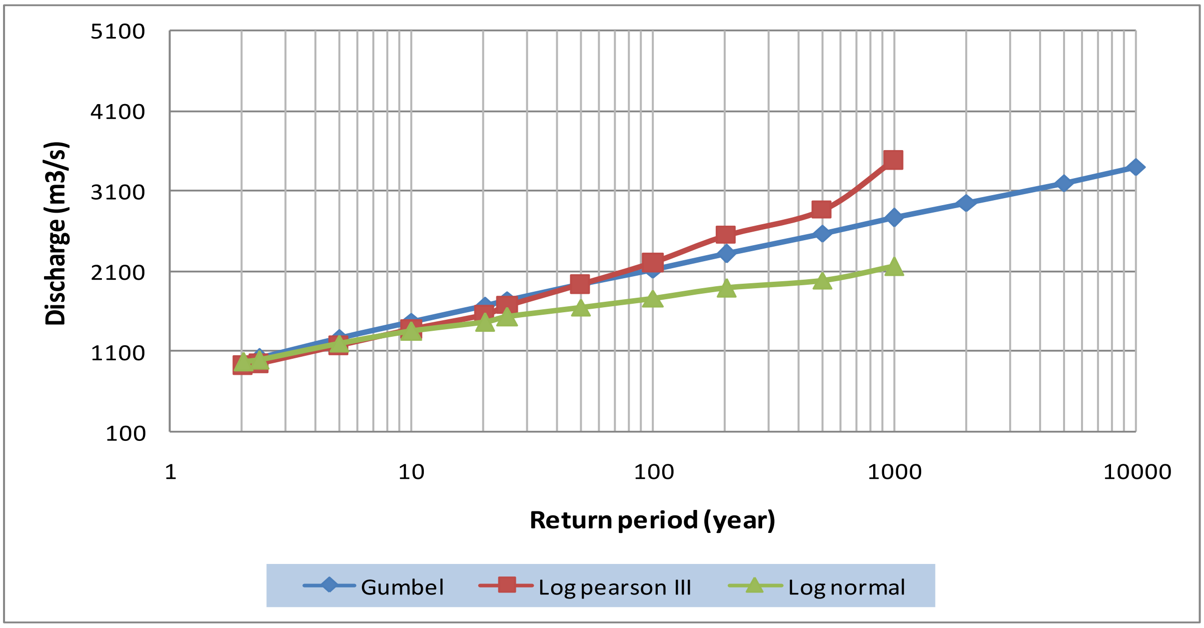


Figure 4.9: Flood Frequency for Budhigandaki at Dam Site Based upon Arughat Data

4.2.9 Goodness of Fit Test of Budhigandaki River

For the selection of best distribution, goodness of fit tests is required. Generally, Chi square and Kolmogorov-Smirnov statistical tools are used for the goodness of fit test. Here, Chi square test was done for the flood frequency distributions of Arughat. The Gumbel, Log Normal, Log Pearson for Chi-square test is calculated in **Appendix-B** Using equation (3.6) observed and expected value was calculated for three distributions, depicted in **Table 4.19.**

Table 4.19: Chi Square Test

S.N	Lower Limit	Upper Limit	Oi	Gumbel		log-Normal		log-Pearson-III	
				Ei	χ2	Ei	χ2	Ei	χ2
1	0	206	0	0	0	0	0	0	0.00
2	206	412	0	1	1.00	0	0	0	0.00
3	412	618	7	10	0.90	7	0	6	0.17
4	618	824	20	15	1.67	19	0.05	24	0.67
5	824	1030	14	11	0.82	13	0.08	10	1.6
6	1030	1236	3	5	0.80	6	1.50	4	0
7	1236	1442	1	3	1.33	1	0	1	0
8	1442	1648	0	1	1.00	0	0	1	0
9	1648	1854	0	0	0	0	0	0	0
10	1854	2060	1	0	0	0	0	0	0
		Total	46	46	7.518	46	1.629555	46	2.433333

At significance level of 0.05, and d.f. of 7 (=10-2-1),	At 0.01
Chi-square value from Table = 14.067	18.475

Chi-square values of all the three distributions have less than the table value, and hence, the null hypothesis for the test is that the proposed probability distributions fit the data adequately. But since the lognormal distribution has the lowest Chi-squared value, it is clearly seen that lognormal distribution fits better.

4.2.10 Diversion Flood

Hydropower project diverting the flow through a part of the channel and proceeding works in the dry section of the channel. Hence it is required to design the diversion channel through which it is by passed downstream. Construction is usually done during the dry season of the year i.e. from November to May. Thus, the annual maximum series was obtained using the daily discharge data of this period of the year and used for frequency analysis using the Gumbel Method. The results the analysis is presented in **Table 4.20**. The construction/diversion flood corresponding to 20 years return period is generally used (i.e., 419 m^3/s). But it is a huge project (i.e., 600 MW); it takes 7 to 8 years to commission. For safe side the construction/diversion flood is taken as 50 year return period; is 495 m^3/s.

Table 4.20: Diversion/Construction Floods at Dam Site

Tr	Y_t	K_t	Q_T
2	0.3665	-0.1564	206
2.33	0.5786	0.0271	223
5	1.4999	0.8243	299
10	2.2504	1.4736	360
20	2.9702	2.0965	**419**
25	3.1985	2.2941	438
50	3.9019	2.9027	**495**
100	4.6001	3.5068	**552**

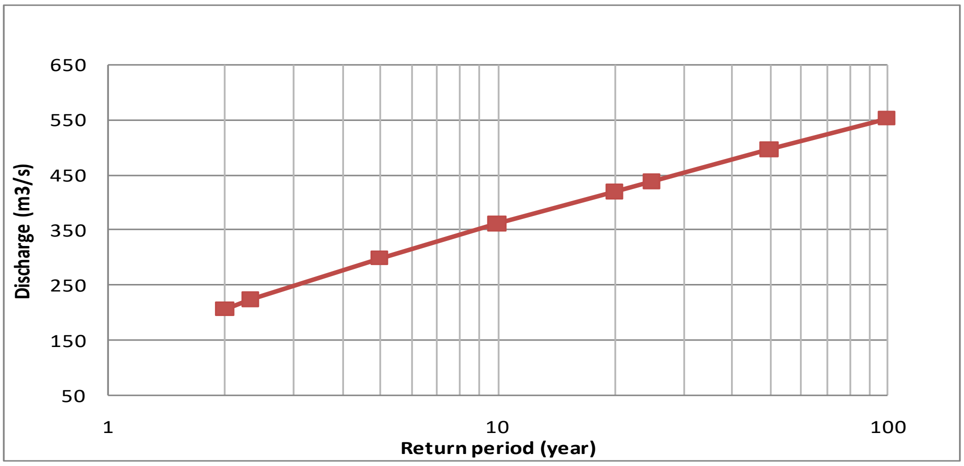


Figure 4.10: Construction Flood of the Study Area

4.2.11 Probable Maximum Flood (PMF)

Since the 10,000 year flood is 3,399 m^3/s, the PMF thus, comes to be 6,798.8 m^3/s

From Hersfield's Technique the PMF (i.e., equation 3.9) is estimated as;

PMF = $\overline{Q}$ +K*σ

Where;

$\overline{Q}$ = mean of the instantaneous maximum

σ= standard deviation of the instantaneous maximum

K = coefficient (6 to 30)

K value is generally taken as 18. (i.e., mean of 36)

By this method PMF came to be 6,737.8 m^3/s

To be in safe side, PMF for this project is considered to be 6,800 m^3/s

4.2.12 Hydrological Risk Analysis

Generally design of permanent structures has to consider the 1 in 100 years to 1 in 10,000 years flood events depending on the risk involved. Temporary structures like the cofferdams will be designed to resist flood events with a rather short recurrence interval, of 10 to 50 years.

The selection of design flood involves the following considerations as given below:

- Effect of overtopping on the structure
- Cost of structure for reconstruction
- Potential loss of life and cost of downstream damage
- Cost of loss of revenue while the structure is out of commission

In order to understand the risk associated with a given return period, it is expressed as the probability of a given flood being equaled or exceeded at least once in 'N' consecutive years (where 'N' is often gives as the expected service life of the structure). The relationship is expressed by the following equation:

$$R = 100\,[1-(1-1/T)^{N}] \quad (4.1)$$

Where,

R = probability in percent of exceeding a flow with a return period T once in N years

T = return period in years

N = service life in number of consecutive years

The risk associated with a certain life span (35 years) of the hydraulic structure for different return period flood and for a given return period flood (2,000 years) for different life span of the structure has been given in **Table 4.21**.

Table 4.21: Risk Associate with the Life Span of the Structure

Return period (T) years	Life Span (N) years	Risk (R) %
100	35	29.6
500	35	6.8
1000	35	3.4
2000	35	1.7
5000	35	0.7
10000	35	0.3

Return period (T) years	Life Span (N) Years	Risk (R) %
2000	35	1.7
2000	50	2.5
2000	65	3.2
2000	80	3.9

Hence, during the service life period of 50 years, the risk involved for a structure design for a 1 in 2000 year flood event would be 2.5%.

4.2.13 Elevation - Area- Volume Curve

The elevation storage capacity characteristic is an important characteristic of the basin that assists in determining the available storage capacity of the reservoir at different dam heights. The curve is useful in determining the storage capacity of the reservoir for a given dam height. This curve is also known as Elevation-Storage-Capacity curve. Here we generated the data (Area& Volume) from Hec-GeoRAS and draw the elevation- Area- Volume curve on Excel; depicted in **Table 4.22** and in **Figure 4.11.**

Table 4.22: Data for Elevation-Area-Volume Curve.

Elevation (masl)	Area (KM^2)	Volume (MCM)
320	0	0
340	0.55	3.8
360	1.82	24.1
380	4.91	88.5
400	7.81	214.4
420	11.13	400.8
440	15.06	661.0
460	19.96	1008.8
480	24.68	1455.4
500	29.07	1996.1
520	32.87	2615.7

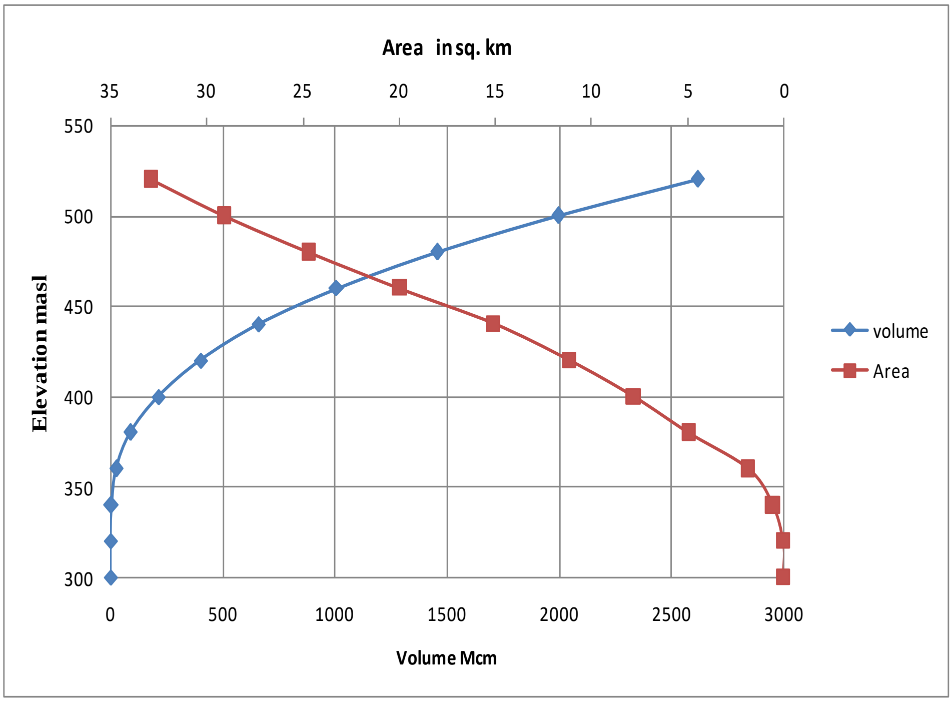


Figure 4.11: Elevation-Area-Volume Curve.

4.3 Compensation flow

Environmental regulations require a minimum flow to be released downstream of the Dam all the time. It will be based on the minimum depth for the survival of the aquatic life found in the river and will be decided during the environmental impact study. Hydropower policy (1996) reveals that 10% of the minimum flow as compensation flow. However, 20.2m^3/s is the minimum flow ever recorded (from instantaneous low flow data of the 1964 to 2010). So compensation flow for downstream release is 2.02 m^3/s.

4.4 Review of Sediment Analysis

Sediment measurement is very essential during pre monsoon, monsoon and post monsoon period rather than in dry and lean season, however it is also equally important if flooding and debris flow occur in the river even in dry season. There are hardly half a dozen and have been in operation for a very short period, and are confined only to suspended load. There are four sediment load measuring stations are functioning which are at Betrawati on Trishuli, Phoolbari on Seti river, Goplingghat on Marsyangdi river and Narayanghat on Narayani river. The sediment data of the first two stations are operated and analysed by DHM. Sediment loads calculated in Trishuli and Seti rivers are 660 m^3/km^2/yr. and 3300 m^3/km^2/yr respectively.

Budhigandaki (storage) HEP, by its name is water storage and utilize type project. It traps the water from Budhigandaki near Benighat with the help of 225 m high dam. Up to design level (525 masl), the gross capacity at FSWL is 3320 million cubic meters. The effective storage capacity is assumed to be 2755 million cubic meters (NEA, 2011). This means that total space of 565 million cubic meters is left for the storage of sediment. So it is necessary to decide whether this provided volume is sufficient or not to fulfill the projects goal and its sustainability in future.

4.4.1 Sediment yield of Nepalese Rivers from FAO

Sediment yields of some of the Nepalese river basins are presented in **Table 4.23**. These values should be taken as indicative of average basin yields, and little or no inference can be drawn on the spatial and temporal variation of sediment concentrations. However, the values can be taken for comparison in the light of measurements taken during Feasibility Study in 1997-98 and the more recent measurements of 2008.

Table 4.23: Sediment yields of Nepalese Rivers

River	Location	Catchment Area (km^2)	Runoff (mm/year)	Sediment Yield ($t/km^2/y$)
Arun	Tribeni	36533		1430
Bagamati	Kathmandu	585		4552
Kali Gangaki	Setibeni	7130	1062	4173
Kankai Mai	Mainachuli	1148	1593	4840
Karnali	Chisapani (#280)	42890		5130
Lothar Khola	Lothar (# 470)	169	1866	3640
Narayani	Narayan Ghat (#450)	31100	1622	5684
Phewa	Chankapur	85		985
Rapti	Jalkundi (Site 360)	5150	845	2800
Seti	Banga near Belgaon (# 260)	7460	1230	2802
Small streams	Kathmandu Valley	177		2199
Sun Koshi	Tribeni	19230		3950
Tamur	Tribeni	5900		8210
Tamur	Mulghat (# 690)	5640	1756	10205
Trisuli	Betrawati (#447)	4850		1852
			max	10205
			min	985
			average	4163
			STD	2501

Source: FAO Website- http://www.fao.org/AG/AGL/aglw/sediment

NEA carried out the sedimentation program during 2012 monsoon season at the Dam site, has great value. A total of about 61 samples were collected during the period of 15 July to 15 September. Based on these field works, the maximum sediment load was calculated to be 9926 ppm (410830 tons/day) and average sediment was 3225 ppm (278640 tons/day).

4.4.2 Assessment of Sediment Load at the Dam Site

The average total sediment load for Himalayan Rivers averaged from 21 rivers is given as 2638 $m^3/km^2/yr$. Kulekhani I reservoir was designed for total sediment load of 700 $m^3/km^2/year$, Whereas from another literature Sapta Koshi yields 2,670 $t/km^2/year$. In the preliminary information given in the prefeasibility study report (April 1984) due to the similarity of Marsyangdi River's catchment the average sediment yield of Budhigandaki also assume as 2500 $m^3/km^2/yr$. The component of bed load is considered to be 15% of the total load (Suresh R, 1993). So that approximate sediment load transported by the river at the dam site would be the range of 13.43×10^6 to 15.04×10^6 m^3 per year and it will take about 50 years to fill up the dead storage volume approximately751.8×10^6 m^3 or (565 million cubic meters).

4.5 Result from HEC-GeoRAS

Result from the hydraulic analysis using HEC-RAS and HEC-GeoRAS have been presented in this section. Based on the information from this analysis profile plot of different return periods, flood inundation map is prepared. The most important output from this analysis is Elevation-Area-Volume curve.

Initially, the model was run to calculate the water surface profiles at steady state condition for the discharges of different return periods. Total 92 river station were drawn for the longitudinal profile of reservoir; **Figure 4.13.**

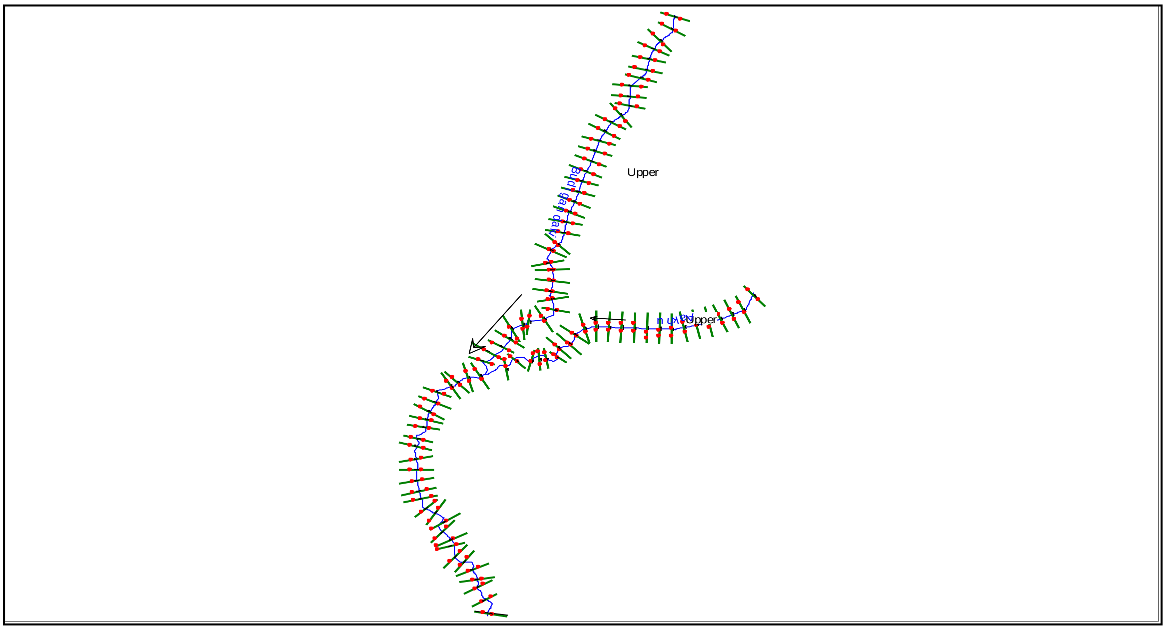


Figure 4.12: Cross-sectional profile of Budhigandaki River

(Note: green lines denote the cross-sections for analysis; the numbers are the chainages from the d/s point; blue line is the stream centerline; red dots are the bank points; arrow shows the flow direction and the lowest boundary is the dam site).

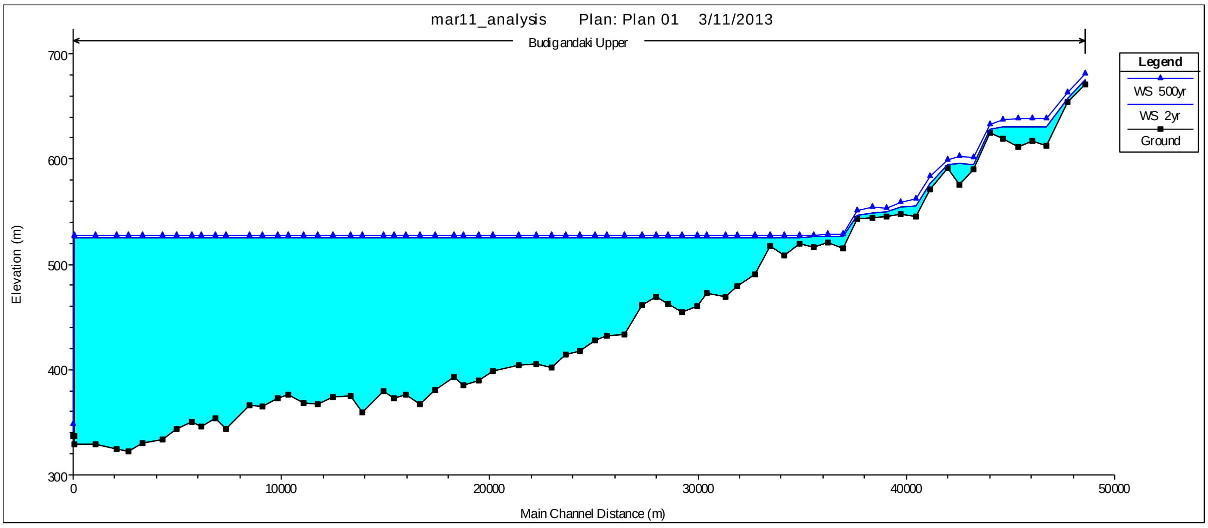
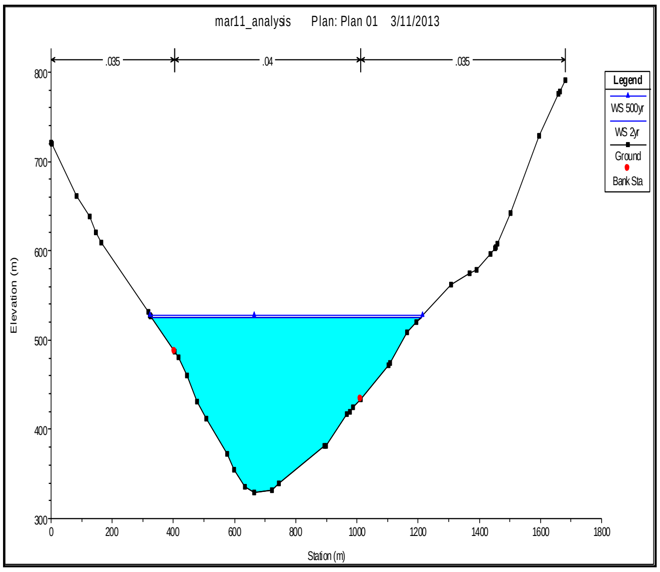
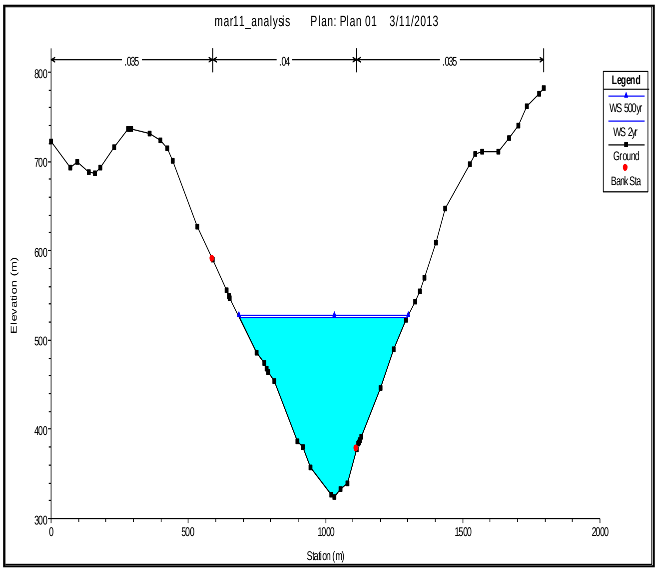


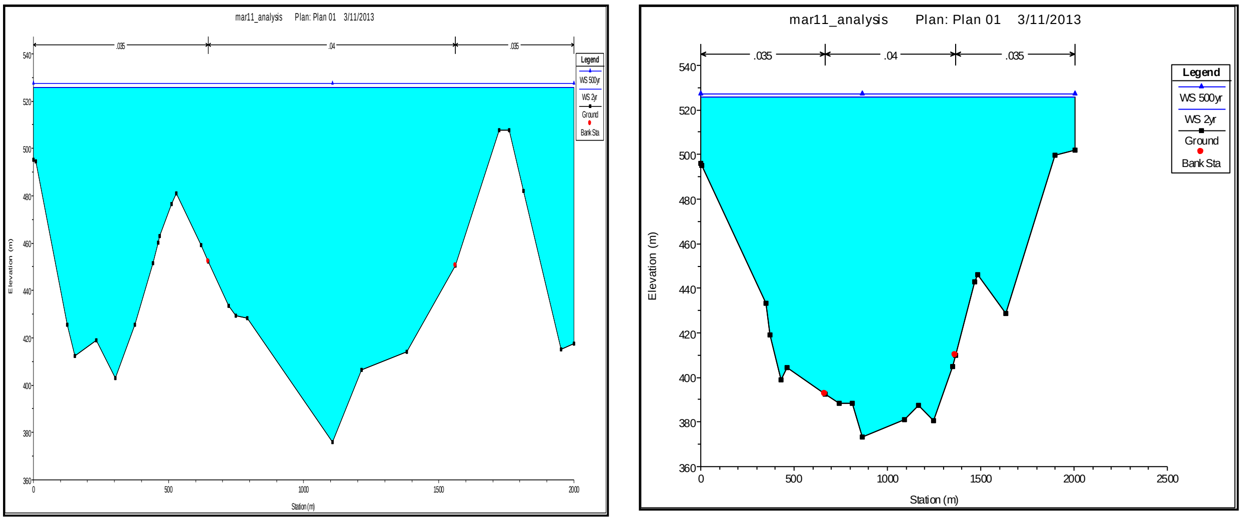
Figure 4.13: Longitudinal Profile of the Reservoir with water Surface Profile for lowest 2 years and greatest 500 year Return Periods Floods.



RS 1227.891



RS 2246.615



RS 16100 **RS 15574.73**

Figure 4.14: Typical Cross-sections of the Reservoir with water Surface Profile for 2 year and 500 year Return Period Floods

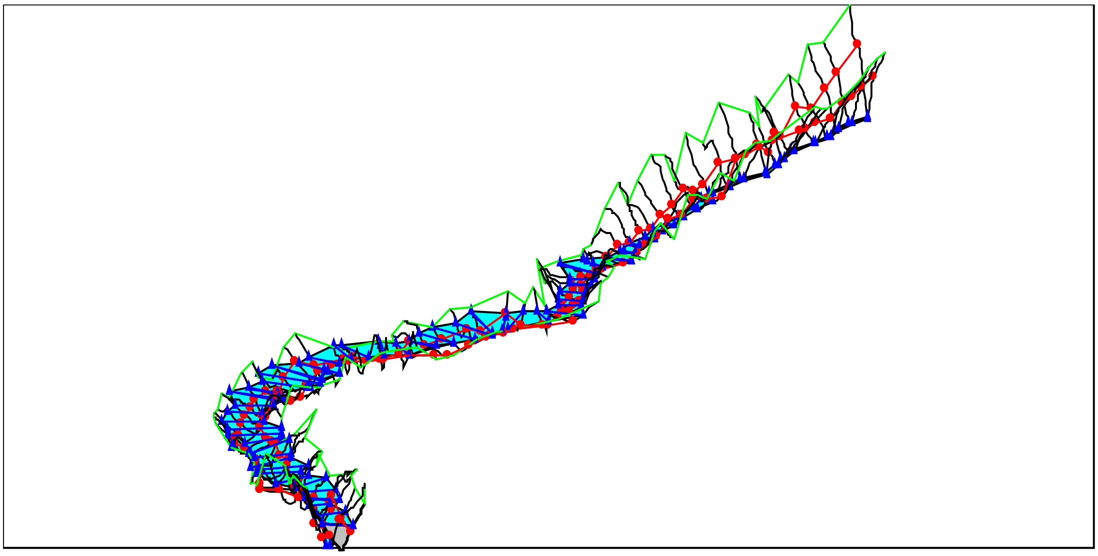
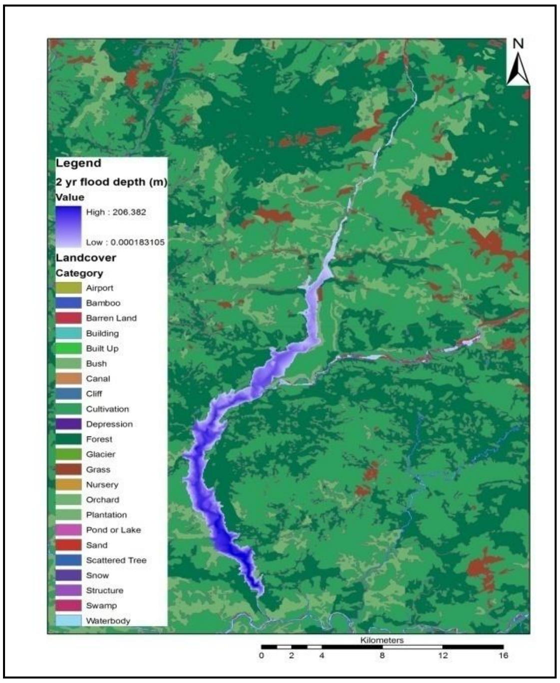


Figure 4.15: 3D view of Reservoir

4.6 Inundation of Different Return Period

Use of HEC-GeoRAS for inundation analysis with the results obtained from HEC-RAS simulation was applied for flood zonation. Consequently, the results derived with the construction of Dam at appropriate location and given dam height (i.e. 225 m). The inundation maps for 2 and 500 year return periods are shown in **Figure 4.16.**



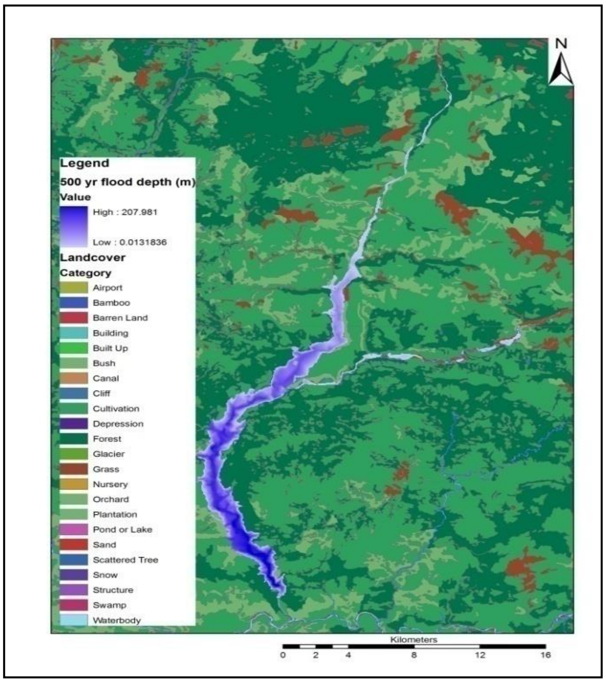


Figure 4.16(a): Inundation Map for 2 year Return Period **Figure 4.16(b):** Inundation Map for 500 year Return Period

CHAPTER V
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the studies carried out on Budhigandaki Storage HEP, some conclusions on study field are interesting. Those points are highlighted in this section. Budhigandaki Storage HEP is only 80 km far from energy load center, so it is very essential to mitigate our energy crisis. The catchment area upstream from dam site was found 5007 km^2; meanwhile upstream of Arughat was 3870 km^2. Average annual flow of Arughat and Dam Site was 161 m^3/s and 198 m^3/s. Similarly in hydrological analysis, the average basin precipitation is found 1457 mm. And for PMP calculation, it is found 430 mm in 24 hour and 173 mm is the 100 year return period precipitation. Evapotranspiration play major role for reservoir simulation which was not calculated in prefeasibility study, meanwhile it came to 1.5 m annually. In this study probable maximum flood found 6798.8 m^3/s. The area of reservoir with the help from HEC GeoRAS was found 32.87 km^2. It is hydrological viable project but socially is major challenging.

5.2 Recommendations

The study was based on the available data and relevant assumptions. The study was purely academic fulfillment for thesis level. Following suggestions are made for further improvement of the study as well as project execution.

- There should be sediment study properly.
- Dam should be constructed in stage to minimize sedimentation.
- Regulated flow should be used for irrigation purpose for Chitwan and Nawalparasi.
- Water transport can be used.
- Environment should be management for downstream, for regulated flow.
- It is recommended to study the other meteorological, geological and socio-economical parameter of the basin to get more reliable information that can be the important gear for the further study.

References

B H Khan, 2006: Non-Conventional Energy Resources.

DHM, 2001: Final Report, Institutional Development of Department of Hydrology and Meteorology, Nepal Irrigation Sector Project, Government of Nepal.

Garg, S. K., 1998: Irrigation Engineering and Hydraulic Structures, Khanna Publishers.

ICIMOD, 2001, Mool.P; Bajracharya.S and Joshi S, 2001: Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods, ICIMOD.

ICIMOD, 2011: Glacial Lakes and Glacial Lake Outburst Floods in Nepal.

IIDS, 2000: Water-based Integrated Development of the GBM Region, Institute for Integrated Development Studies Publication, Kathmandu. (Study team members were Yogacharya K.S, Bista R.B, Poudel S.N, Shrestha H.O, Regmi N and Pandey S).

MoE, 2008: Ten Years Task_Force Report Part I, Government of Nepal.

MoE, 2009: Twenty Years Task-Force Report, Government of Nepal.

NEA, 1984: BudhiGandaki Hydroelectric Project Prefeasibility Report, Government of Nepal.

NEA, 2011: Review Report BudhiGandaki,Government of Nepal.

Practical Action, 2009: Temporal and Spatial Variation of Climate Change Over Nepal (1976-2005).

Reddy, P. J. R., 2006: A Text Book of Hydrology, Laxmi Publication.

Sharma K.P and Adhikari N.R, 2004: Hydrological Estimation in Nepal. Department of Hydrology and Meteorology, Government of Nepal.

Subramanya, K., 2008: Engineering Hydrology, Tata McGraw-Hill Education Pvt.

Suresh.R, 1993: Soil and Water Conservation Engineering, Standard Publishers Distributors.

US Army Corps of Engineers, 2002: HEC-GeoRAS An Extension for Support of HEC-RAS Using Arc View, User's Mannual, US Army Corps of Engineers (USACE), Hydrological Engineering Center, Davis, California.

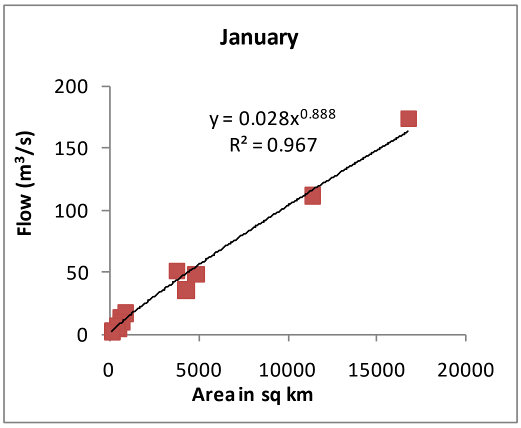
WECS and DHM, 1990: Methodologies for Estimating Hydrologic Characteristic of Ungauged Location in Nepal. Government of Nepal.

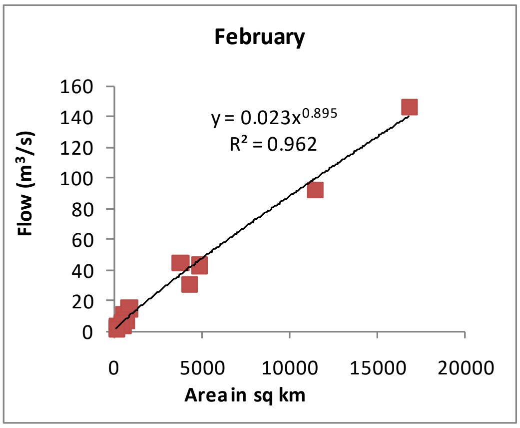
Yogacharya K.S., 1969: Journal of Nepal Engineers Association, Volume 1. Page nos. 47- 49.

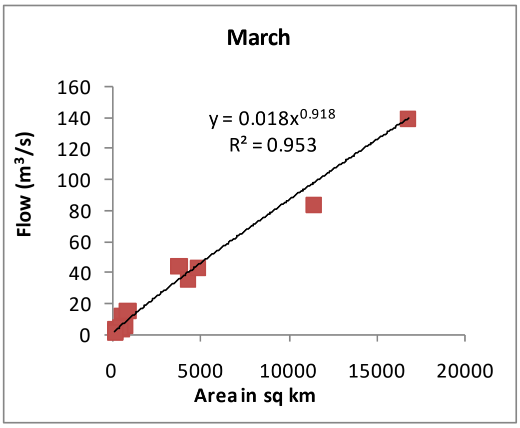
Yogacharya K.S., 2008: A Review on Status of Sediment Studies of Nepal, Society of Hydrology and Meteorology -Nepal, Volume 5. Page nos.77- 90.

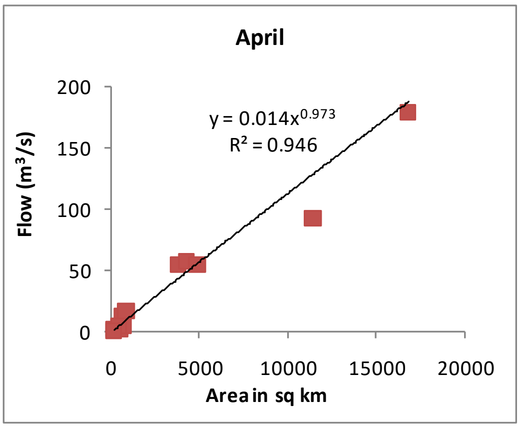
APPENDIX

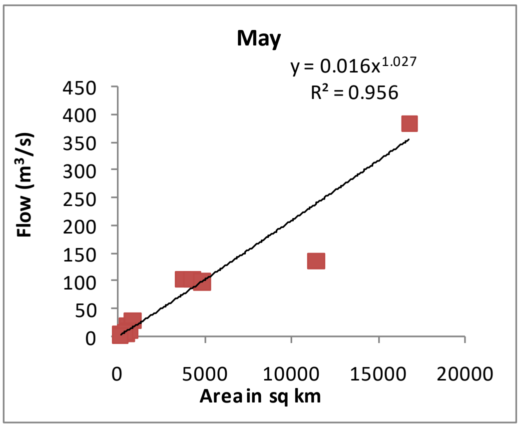
APPENDIX-A

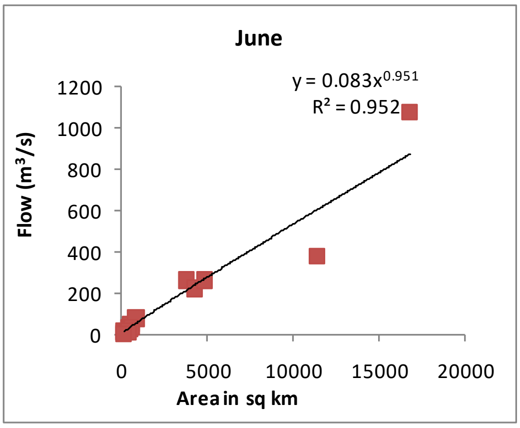


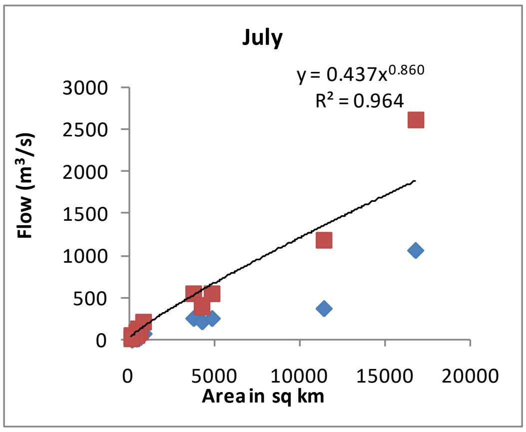


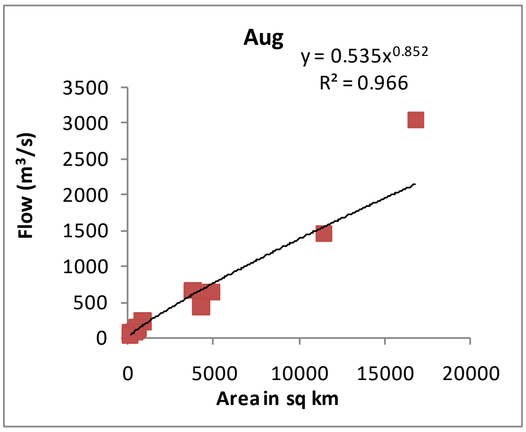


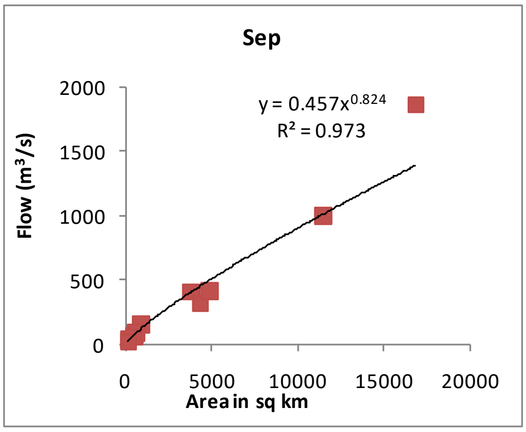


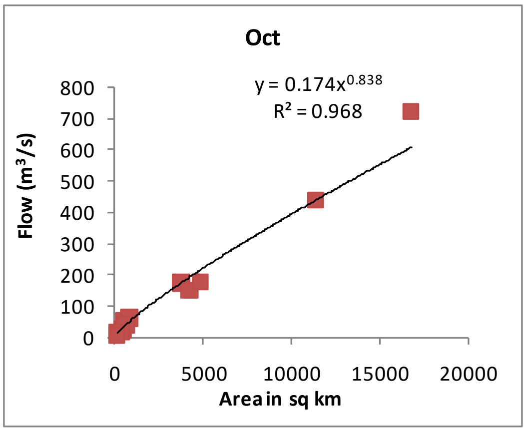


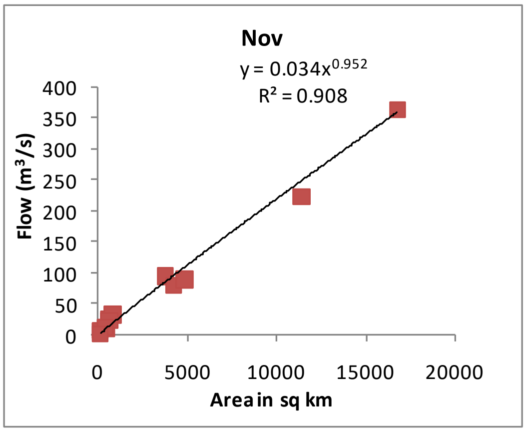


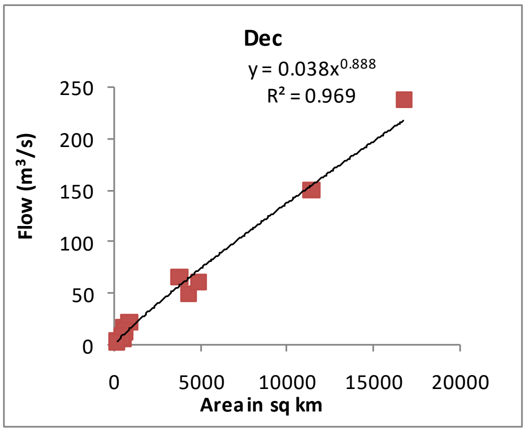

July
y = 0.437x^0.860
R² = 0.964
Flow (m³/s)
Area in sq km
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000


Aug
y = 0.535x^0.852
R² = 0.966
Flow (m³/s)
Area in sq km
3500
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000


Sep
y = 0.457x^0.824
R² = 0.973
Flow (m³/s)
Area in sq km
2000
1500
1000
500
0
0
5000
10000
15000
20000


Oct
y = 0.174x^0.838
R² = 0.968
Flow (m³/s)
Area in sq km
800
700
600
500
400
300
200
100
0
0
5000
10000
15000
20000


Nov
y = 0.034x^0.952
R² = 0.908
Flow (m³/s)
Area in sq km
400
350
300
250
200
150
100
50
0
0
5000
10000
15000
20000


Dec
y = 0.038x^0.888
R² = 0.969
Flow (m³/s)
Area in sq km
250
200
150
100
50
0
0
5000
10000
15000
20000

APPENDIX-B

Rank (m)	Exceedance	Non-Exceedan	T= 1/p	Empirical Q	Gumbel Q	Log-Normal Q	Log-Pearson Q
1	0.021277	0.978723	47.0	2060	1562.1	1327.81	1539.91
2	0.042553	0.957447	23.5	1360	1404.0	1228.68	1334.72
3	0.06383	0.93617	15.7	1220	1310.4	1168.44	1225.50
4	0.085106	0.914894	11.8	1160	1243.2	1124.33	1152.25
5	0.106383	0.893617	9.4	1070	1190.5	1089.12	1097.63
6	0.12766	0.87234	7.8	1010	1146.9	1059.59	1054.30
7	0.148936	0.851064	6.7	994	1109.6	1033.98	1018.50
8	0.170213	0.829787	5.9	978	1076.8	1011.25	988.06
9	0.191489	0.808511	5.2	964	1047.6	990.72	961.61
10	0.212766	0.787234	4.7	942	1021.0	971.92	938.24
11	0.234043	0.765957	4.3	940	996.7	954.52	917.31
12	0.255319	0.744681	3.9	908	974.1	938.27	898.36
13	0.276596	0.723404	3.6	870	953.1	922.97	881.04
14	0.297872	0.702128	3.4	865	933.2	908.48	865.09
15	0.319149	0.680851	3.1	864	914.5	894.67	850.29
16	0.340426	0.659574	2.9	863	896.7	881.44	836.48
17	0.361702	0.638298	2.8	840	879.6	868.72	823.54
18	0.382979	0.617021	2.6	832	863.3	856.44	811.33
19	0.404255	0.595745	2.5	825	847.5	844.53	799.79
20	0.425532	0.574468	2.4	790	832.3	832.94	788.82
21	0.446809	0.553191	2.2	779	817.5	821.63	778.36
22	0.468085	0.531915	2.1	775	803.1	810.56	768.36
23	0.489362	0.510638	2.0	765	789.0	799.70	758.76
24	0.510638	0.489362	2.0	744	775.2	789.00	749.52
25	0.531915	0.468085	1.9	744	761.7	778.42	740.59
26	0.553191	0.446809	1.8	744	748.3	767.93	731.94
27	0.574468	0.425532	1.7	744	735.1	757.51	723.54
28	0.595745	0.404255	1.7	728	722.0	747.11	715.36
29	0.617021	0.382979	1.6	725	709.0	736.72	707.37
30	0.638298	0.361702	1.6	725	696.0	726.30	699.54
31	0.659574	0.340426	1.5	700	683.0	715.82	691.87
32	0.680851	0.319149	1.5	688	669.9	705.24	684.31
33	0.702128	0.297872	1.4	683	656.8	694.52	676.85
34	0.723404	0.276596	1.4	662	643.4	683.61	669.46
35	0.744681	0.255319	1.3	658	629.9	672.47	662.12
36	0.765957	0.234043	1.3	653	616.0	661.02	654.79
37	0.787234	0.212766	1.3	650	601.7	649.18	647.46
38	0.808511	0.191489	1.2	624	586.9	636.87	640.07
39	0.829787	0.170213	1.2	618	571.5	623.94	632.59
40	0.851064	0.148936	1.2	615	555.1	610.22	624.96
41	0.87234	0.12766	1.1	610	537.6	595.48	617.11
42	0.893617	0.106383	1.1	600	518.6	579.33	608.92
43	0.914894	0.085106	1.1	590	497.3	561.19	600.24
44	0.93617	0.06383	1.1	580	472.5	540.00	590.80
45	0.957447	0.042553	1.0	540	441.6	513.52	580.05
46	0.978723	0.021277	1.0	540	397.0	475.19	566.59