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CHAPTER I

INTRODUCTION

1.1. General Introduction

Nepal is a landlocked independent country of amazing extremes in topography and climate. It lies between 26°22’ and 30°27’ North latitudes and 8004 and 8812 East longitudes covering an area of 147, 181 square kilometres. In the north is Tibet and on the east, south and west is India. The length is about 880 km on an average from Mechi in the east to Mahakali in the west and its north to south is about 193km.

Nepal is a mountainous country with variation in altitude ranging from 60m amsl in south to the highest altitude of 8848 m in north. Hills and mountains cover 80% and the Terai belt covers only 20% of total area. The Terai belt is relatively plain and extends from east to west in the southern part.

Water resources can be considered as the most important natural resources because they are not only renewable but also Water resources abundantly available in Nepal. River runoff is an important component of the hydrologic cycle which is available water resources projects in Nepal. Realizing the importance of monitoring the available water resources, the Government of Nepal started hydrological surveys in Nepal in the early 1960s establishing a permanent institution for this purpose. The institution was initially as a section under the Department of Hydrology and Meteorology (DHM).

Estimation of hydrological extremes and flows during normal conditions are essential for designing water resources and other water related projects. Such estimates are based on the statistical analysis of long term hydrological data collected at project sites and gauging stations on a regular basis. Unfortunately, several water resources projects are identified at locations either without any hydrological measurement or with inadequate information for reliable hydrological analysis. Needs arise in such instances for estimating discharges on the basis of regional hydrological characteristics.

Large river floodplains around the world support heavy population settlements, where development goals are most often for improvement of navigation, enhanced agricultural production and flood protection. Floods are one of the most common devastating natural hazards in the world, claiming more lives and destruction of property than any other natural disaster. Floods are frequent and common features of every year, especially after heavy rains, heavy thunderstorms, winter snow thaws, strong cyclones, and monsoons. Floods can be slow or fast rising depending upon the amount of rains and snow melt, and generally develop over a period of days. Dam failures due to floods are potentially the worst events, often caused by poor design or structural damage due to a major event such as an earthquake.

Flood disasters account for about a third of all natural disasters throughout the world and are responsible for more than half of the fatalities. The trend analyses reveal that major flood disasters and the losses generated by them have increased drastically in recent years. There is a distinct increase with respect to economic losses and the rising numbers of events that attracts the attention of international agencies. Flood losses in the U.S. now exceed US $5 billion in individual years. Flood damage was estimated between US $350-400 million per year in Australia (Smith and Ward, 1998). In the last 10 years, losses amounting to more than US $250billion have been borne by societies all over the world to compensate for the consequences of floods. Flooding in Nepal is frequent enough to be considered as an annual event.

People all over the world have learned to live with floods. However, the population sometimes is taken completely by surprise when a river or the sea rises to an unacceptable level. In this context, three aspects are very important: (i) the dramatic increase in the world's population which creates the necessity to settle in risk prone areas, (ii) the migration of refugees to an unfamiliar environment; and (iii) increased population mobility and the desire of people to live in areas with a good natural environment and certain climate. All these factors bring people into areas whose natural features they do not know. They are not aware of what can happen and they have no idea how to behave if nature strikes. Even if people have experienced a disaster themselves, they tend to forget its lessons within a few years. Economically, floods are a leading cause of losses from natural events. One flood is not only a single disaster event, but creates a cumulative loss from related small and medium sized events. The money spent worldwide on flood control (dykes, reservoirs, barrage, etc.) is far greater than that spent on protection against other impacts from nature.

A comparison of flooding and all other natural hazards in long-term analyses (1988-97) reveals that:

- Floods account for about a third of all natural catastrophes.
- Floods cause more than half of all fatalities.
- Floods are responsible for a third of the overall economic loss.
- Floods' share in insured losses is relatively small, with an average of less than 10%.

A flood is defined as any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream. When a bank overflows, the water spreads over the flood plain and generally becomes a hazard to society. Floods are by and large a function of location, intensity, volume and duration of precipitation. Floods are caused by excessive rainfall, snowmelt or dam failure. The rivers generally originate from mountains. Excessive rainfall or snowmelt in mountainous regions results in flooded rivers. Mountainous regions become more vulnerable to landslides, hyper concentrated flows, debris flow, etc.

In developing countries like Nepal due to water scarcity in lean season, large populations live along the major rivers and as a result the floods are more devastating, killing millions of people and damaging property every few years

1.2. Water Resources of Nepal

Approximately 6000 rivers and rivulets with a total drainage area of about 194,471 km^2 flow through Nepal, 76% of this drainage area is contained within Nepal (Sharma, 1998). The length of all rivers, streams and rivulets exceeds 45,000 kilometers thus the closeness of spacing of river channels as drainage density comes approximately 0.3 km per square kilometer in the scale 1:25,000. The drainage areas lying outside the country are 19% or 37,440 sq km in Tibet of China and 5% or 9,850 sq km in India. Favorable topographic conditions because of high varieties of elevation (from less than100 to more than 8000m) make Nepal one of the richest countries in terms of hydropower potential.

Karnali, Narayani and Koshi are the three major river system of Nepal. These entire rivers originate in Tibet. Although the geographical area of Nepal is 147,181km^2, Nepal drains the discharge from more than 194,000km^2, the additional area being the catchments lying in Tibet. All the river systems of Nepal are the tributaries to the Ganga draining ultimately to the Bay of Bengal. The major tributaries generally flow towards south or southeast direction.

Nepal territory accounts for 14% of the Ganges which means the Nepalese rivers contribute 41% of total runoff and 71% of lean flows of the Ganges, which is as the major sub basin in the Ganga-Bhramaputra -Megana (GBM) drainage system. The nation's total renewable water wealth is 233 billion cubic meters. A study of 1963-66 has shown that theoretically Nepal can produce 83,000MW hydro-electricity power by her water resources in theoretic view. Nepal has 1.5% of world's total hydropower potential. Since the total hydropower potential of the world is about 5,610 million KW. In our context, the hydropower potential of the Sapta Koshi basin is 22,350 MW, the Sapta Gandaki basin is 17,900 MW, the Karnali basin is 34,600MW and rest from other river basins of Nepal. Among them, technically and economically feasible hydroelectricity potential is 25,000MW concerning all these facts. Nepal's greatest national wealth is the water resources. This makes Nepal the second richest country in water resources in the world after Brazil.

1.3. Flood

A flood is defined as "any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream." When a bank overflows, the water spreads over the flood plain and generally becomes a hazard to society. Floods are caused by excessive rainfall, snowmelt or dam failure. The rivers generally originate from mountains. Excessive rainfall or snowmelt in mountainous regions results in flooded rivers. Mountainous regions become more vulnerable to landslides, hyper concentrated flows, debris flow, etc.

A flood is an overflowing of water from rivers onto land. Floods also occur when water levels of lakes, ponds, aquifers and estuaries exceed some critical value and inundate the adjacent land, or when the sea surges on coastal lands much above the average sea level. Nevertheless, floods are a natural phenomenon important to the life cycle of many biota's, not the least of which is mankind. Floods became a problem as humans began establishing farms and cities in the bottomlands of streams and rivers. In doing so, they not only expose their lives and properties to the ravages of floods, but also exacerbate floods by paving the soil and constructing stream channels. Over time, continued urbanization of natural floodplains has caused great annual losses of both wealth and human life. In this way, in many countries and regions of the world, floods are the most deadly hazards in terms of both loss of human lives and material damage. Floods are physical events and natural hazards. Floods can be slow or fast rising depending upon the amount of rains and snow melt, generally developing over a period of days.

Most river floods result directly or indirectly from climatological events such as excessively heavy and/or excessively prolonged rainfall. In cold winter areas, where snowfall accumulates, substantial flooding usually occurs during the period of snowmelt and ice melt in spring and early summer, particularly when melt rates are high. Flooding may also result from the effects of rain falling on an already decaying and melting snow pack. An additional cause of flooding in cold winter areas is the sudden collapse of ice jams, formed during the break-up of river ice.

Of the entire natural hazards flood is by far the most common in causing loss of life, human suffering, inconvenience and widespread damage to buildings, structures, crops and infrastructure. Floods can disrupt personal, economic, and social activities and set back a nation's security and development by destroying roads, buildings and other assets.

Flood is a catastrophic event .It can not be avoided to totally but mitigation can be done by several methods like flood forecasting, constructing flood control reservoirs etc. Flood carries more sediment debris and inundates low land areas by destroying lives, farms and crops. Flood resulting from high intensity rainfall occurring in mountains regions usually overflow the river banks and inundate the surrounding low-lying regions. Kulekhani reservoir can be taken as a current example of sedimentation done by flood of 1993. In such events, real discharge data are not available easily so it should be estimated indirectly. Floods frequently destroy important infra structures, roads, settlements etc. in mountain watersheds.

Most of the natural hazards result from the potential for extreme geophysical events, such as floods, to create an unexpected threat to human life and property (Smith, 1996). When severe floods occur in areas occupied by humans, they can create natural disasters that involve the loss of human life and property plus serious disruption to the ongoing activities of large urban and rural communities. Although the terms 'natural hazards' and 'natural disasters' emphasize the role of the geographical processes involved, these extreme events are increasingly recognized primarily as the 'triggers' of disaster, which often have more complex origins including many social and economic factors.

1.3.1 Causes of floods

Most river floods result directly or indirectly from climatological events such as excessively heavy and/or excessively prolonged rainfall. In cold winter areas, where snowfall accumulates, substantial flooding usually occurs during the period of snowmelt and ice melt in spring and early summer, particularly when melt rates are high. Flooding may also result from the effects of rain falling on an already decaying and melting snow pack. An additional cause of flooding in cold winter areas is the sudden collapse of ice jams, formed during the break-up of river ice.

1.3.2. Problem created by floods

Of the entire natural hazards flood is by far the most common in causing loss of life, human suffering, inconvenience and widespread damage to buildings, structures, crops and infrastructure. Floods can disrupt personal, economic, and social activities and set back a nation's security and development by destroying roads, buildings and other assets.

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1.4. Regional Aspects

One of the major problems in hydrologic analysis is the non-availability of adequate data for a basin where water resources or water related projects are planned .Flood estimations based on the regional hydrological characteristics are required in such cases. Most of the hydrologic design problems require the estimation of peak discharges generated by a river system under specified conditions. Estimations of such flood peaks are made using statistical techniques applied to long-term data. Since long term hydrologic data in Nepal are available only for 49 locations for a period ranging from 11 years to 34 years. Estimate is possible for most of the potential rivers.

1.5. Low Flow

Low flow statistics are essential in water supply planning to determine allowable water transfers and withdraws. Other applications of low flows include water quality management applications, determination of minimum downstream release requirements from water resources projects etc.

1.5.1. Low Flow Characteristics

Significant decrease in low-flow on a stream leads to drought, reduction in reservoir levels, depletion in soil moisture, and depletion of ground water levels. Such conditions lead to scarcity in drinking water, and decline in agriculture production with high consequences on economy and social developments including human miseries. Estimation of low flow status on a river is important for designing a single purpose or multipurpose water resources project considering extreme conditions regarding the availability of adequate water supply. Rivers are mainly recharged by groundwater during minimum flow periods. Hence, the flow pattern is highly influenced by the hydrology of a river basis because of the drawdown of upper aquifers with less water storage during extremely dry years. A potential frequency distribution of low-flow series must, hence, be able to take such problem into account.

In a region affected by continental monsoons, winter and spring seasons are usually dry causing the minimum flow occurring generally in spring season. The period is also highly dependent on the ice and snowmelt situation in spring season. The period is also highly dependent on the ice and snowmelt situation in the headwater areas, lowest flood condition generally occurs throughout the summer in the rivers lacking snowmelt contribution to the river flow. As in the case of flood flow estimates as well as for assessment of low-flow discharges on a river at any location primarily depends on three cases, adequate data, inadequate data and missing data. The well known method of hydrological analogy is an appropriate tool in the case of inadequate hydrometric data. The scope of this method may be wider in respect of the estimation of low flows.

1.6. Objectives of the study

Andhi Khola River has affected rural settlements and agricultural fields in the river valleys and flat areas, high ways and municipality Walling and Putali khet. In future this region will need irrigation schemes, bridge, domestic water supply schemes and dam and the leeves. To construct these schemes engineering and river training work will be needed. For all these purposes, low flow and high flow are essential from this ungauged river and therefore appropriate methods are essential for estimation of these extreme flows. Considering these important aspects, Andhi Khola at Borlangpul has been selected because it is ungauged and many water resources are likely to be implemented in near future. There shall be more settlement in near future in these sub basins which are adjoining the river valley and flat areas.

Borlangpul site on the bank of Andhi Khola has been selected for the hydrologic study, because Borlangpul is easily accessible and I am a resident nearby the site, so that field visits could be made regularly.

The area is very flexible, reasonably populated and rainfall and river fall are ample for water resources projects that are likely to be implemented in near future.

Andhi Khola has been known for its disastrous flash floods in the past that have inflicted loss of life and property. Many fertile agricultural plants, in the flood plains, the highway, and settlements, including Putali khet and the municipality waling have been damaged many times repetitively.

This region gets sample amount of rainfall, and the perennial flow of the Andhi Khola through the surrounding fertile lands in the flood plain and the valley floor favors the growth of agriculture, small scale cottage industries and expansion of the small village towns.

Therefore, water resources projects incorporating irrigation, domestic water supply, electricity supply for towns, industries, mills, ropeways, etc are bound to develop inevitably in future. Besides the infra structure for regional development, river training works also will be necessary for this region.

These aspects will need proper, economical and feasible infrastructures.

The design of these structures will need the characteristic monthly flows, high flows and low flows.

The study area has no gauging station. A small project (Institutional development of DHM/Tahal Consulting Engineers ltd.) had installed a temporary ganging station that operated from June to December in2002 at Borlangpul.

Since there is no hydrologic data at Borlangpul site, data have to be generated with suitable, appropriate hydrologic models.

Water resources development schemes need data for planning management of the project for important growing regional belt in Syangja District data have to be generated because it is not reasonable to wait for collecting data in the next 10 to 15 years and then start the project study.

Therefore, this study stresses on the methodologies that will be essential in the generating data for water resources projects for many sites in Nepal. The methodologies ungauged and models are suitable because these have been developed and tested in Nepal. The main objectives of the study are:-

- Construction of flow duration curve of Andhi Khola River at Borlangpul.
- Low flow, high flow analysis of Andhi Khola at Borlangpul.
- To estimate the discharge for ungauged Andhi Khola by WECS/DHM method.

1.7. Statement of the Problem

Nepal is excessively nourished by water resources. There are more than 6000 rivers and streams length of all rivulets amounting to 45,000 kilometres. A study of 1963-1966 has shown that Nepal can produce 83000MW hydroelectricity power (Shrestha H.M, 1997). By proper utilization, this natural gift can indeed uplift our poverty, though, there are many complexities in utilization of this resources with the event like severe storm, complex geology, and varied topography. Hence, the study of hydro-meteorological analysis using long term data is essential for planning water resources in different aspects for example irrigation, hydropower water supply, navigation etc. Due to fragile topographical condition and intense intensity of monsoon precipitation, the occurrence of disastrous floods is common.

There are very few gauged rivers in Nepal, therefore the studies of floods in ungauged rivers are also equally important, because many water resources schemes may have to be implemented in such basins. Such, problem can be solved by transposing the data from gauged station of similar hydrometeorolgical environment to ungauged station. This method will give the estimation of the flood in the ungauged stations. Low flows are also equally important and are estimated with WECS/DHM method.

1.8. Justification of the study

Hydrology of Nepal is primarily dominated by monsoon, characterized by high precipitation from June to September, the remaining period receive only about 20% of the annual precipitation. Such a situation causes a wide annual variability of water making the water management issue particularly challenging for a country like Nepal. There are many ungauged rivers in Nepal, flows in ungauged rivers can be estimated from gauged stations. The study will be useful

- For estimation of low flows in ungauged sub basins in other regions of Nepal for irrigation and water domestic purposes.
- For estimation of high flows in ungauged sub basin for hydraulic structures.

CHAPTER II
LITERATURE REVIEW

2.1. Literature Review

Literature on low flow is limited. The earlier studies on low flows by Riggs (1972) deal with the nature of the low-flow frequency curves presenting a multiple regression approach in regionalization. Few regional studies on low flow found in recent literature include the Low Flow studies in the UK (IH, 1980) in Russia (Artemieva, 1997) and in South Africa (Smakhtin and Hughes, 1997). Multivariate relationship of low flows with climatic and basin characteristics are the basic approach to develop methodologies for ungauged basins. A method developed in 1982 by Sir MacDonald and Partners titled 'Medium Irrigation Project. Design Manual' is based on the data of a single streamflow measurement during a dry period to get long-term characteristics of minimum flows (MacDonald, 1990).

A catchment area acts as a reservoir for precipitation. Hence a catchment area is usually considered as the universal parameter while computing low flows. Besides the catchment area, other parameters have also been considered in the regression analysis for arriving at the best equation for predicting low-flow. A method for assessing low flow characteristics for 1 day ,7 day,30day and monthly duration was developed by the Department of Hydrology and Meteorology and Water and Energy Commission Secretariat in 1980s and was further upgraded and published in 1990 as a report titled 'Methodologies for Estimating Hydrologic Characteristics of Ungauged Locations in Nepal'. This was the first attempt in Nepal for assessing low-flows of different recurrence intervals .The study used data for 44 stations with a period covering from 1963 to 1985. The upgraded study, the 1990 study include: additional data up to 1995, additional stations, and improved physiographic and hypsometric data derived from GIS tools. The study used data from 309 precipitation-gauging stations and 51 hydrometric stations (WECS/DHM, 1990).

Literature on low flow frequency analysis is relatively sparse. Available literature shows that the three- parameter Weibull Distribution, the Log Pearson Type III Distribution and two parameter and three parameter lognormal distribution are the widely used distribution in several parts of the world for the probability distribution analysis of low flows (Riggs, 1982; Stedinger, Vogel & Foufoula-Georgiou, 1992).The extreme value Type III distribution (Weibull Distribution) used in most of the regions of the world, was selected for application in this study. This distribution is particularly suitable for discharge values bounded at the lower and such as the cases of ephemeral rivers. Log Normal Distribution method implies that the logarithmic of basis data to be analyzed are normally distributed. In flood frequency analysis, it is generally necessary to extrapolate the range of the observed events and the idea of normalizing transformation is very attractive. Such transformation is very attractive. Such transformation leads to the log normal distribution.

In 1875, Galton noted that the geometric mean of some types of data series was a better descriptor than the arithmetic mean of logarithms or antilog of such. Concerning this, Hazen in 1930 applied this distribution to flood frequency analysis. Hence this distribution can be known by three names as lognormal or Hazon or Galton distribution.

If the random variable y = logx is normally distributed then x is said to be log normally distributed. If $x = x_1, x_2, \ldots\ldots x_n$ then $y = \log x = \phi \log x_i = \phi y_i$

It was applied in this manner by Ven Te Chow in 1954 to hydrologic variables formed as the products of other variables.

It has advantage over the normal distribution that is bounded ($x>0$) and log transformation tends to reduce the positive skew ness commonly found in hydrologic data. It has only two parameters that it regimes logarithms of the data to be symmetric about their mean, is a drawback of the lognormal method.

United Nations Environment Programme -Division of Early Warning and Assessment (UNEP/DEWA) in a technical report Early Warning, Forecasting and Operational Flood Risk Monitoring in Asia (Bangladesh, China and India) has prepared to develop an operational flood risk monetary system for flood affected developing countries using various factors leading to floods. Through a review of early warning and flood forecasting tools have been used by developed countries this report attempts to assess the gap in knowledge and technology being deployed by developing countries. This report also assists in knowledge transfer related to operational systems for flood risk monitoring using the latest tools and technologies.

Hydro-meteorological studies of River Basins for Applications in Water and Power Resource Projects studied “Hydro meteorological analysis over the Upper Siang basin in Tibet”. Hydro metrological analysis was carried out over the Upper Siang basin in Tibet with area 2,49,186 sq.km. have been conducted using precipitation data of 3 stations (1992-2004) from the National Hydroelectric Corporation (NHPC) ltd., Faridabad, 6 station data (1994-1999)from NASA website and reanalyzed gridded data (1958-1999) (1.875 ×1.875 degree grid size).Using the above data, tentative estimates of mean seasonal, annual precipitation and highest ever-recorded1,2 and 3 day precipitation were made. Estimates of Standard Project Storms (SPS) based on extreme precipitation were also provided.

J.P Chyurlia (1983) stated that non-monsoon precipitation also occurs in Nepal. This precipitation falls during the winter months and is related synoptically to cyclones that originate in the Mediterranean region. It contributes to Nepal’s total annual precipitation by small amount but it is very important at certain locations, specifically in the extreme northwest corner or the Karnali River basin, in the upper regions of the Kali Gandaki catchment, in central Nepal and, also, in western Terai. In the high mountain areas this winter precipitation falls mostly as snow, important for snowmelt runoff.
With the climatology report of DHM for the Far Western Development Region of Nepal isohytel maps of seasonal and/or annual precipitation were prepared. The total annual area-weighted rainfall for Nepal was found to be 1.630mm half Nepal falls with in the 1500mm to 2000mm range (Chyurlia, 1983).

In spite of much work carried out in the modernization of hydrology during the nineteenth century, still the development of quantitative hydrology was immature. The science of hydrology was largely empirical, since the physical processes of hydrology in various fields of hydrology were not well known for solving practical problems by hydrologists and engineers. During the end of the century and following thirty years or so, empiricism in hydrology became more evident as for example hundreds of empirical formula were proposed (Chow, 1962).

Coefficients and parameters had to depend mainly upon judgment and experience. Solutions of practical hydrology problems with these empirical approaches were soon realized to be unsatisfactory. To improve this situation many great hydrologists emerged to make use of rational analysis instead of empiricism to solve hydrological problems. Sherman (1932) came forth with the simple lumped model, the unit hydrograph for translating rainfall excess in runoff hydrograph (1933) initiated the most successful approach in determining the rainfall excess on the basis of infiltration theory. Theis (1935) introduced the non-equilibrium theory revolutionizing the concept of hydraulics of well. Gumbel (1941) proposed the use of the extreme-value distribution for frequency analysis of hydrologic data. Gumbel along with many other revitalized the use of statistics in Hydrology and statistical hydrology was further advocated easier by Hazen (1930). Bernard (1944) linked closely meteorology with hydrology, this marking the beginning of the science of hydrometeorology. Einstein (1950) developed the bed load function with introduced theoretical analysis of sedimentation study. Soon establishments of many hydraulic and hydrologic laboratories through out the world have given more impetus to develop modelling in hydrology.

Example of the theoretical hydrology studies are; linear and non-linear analysis of hydrologic system; the adoption of transient and statistical concepts of ground water hydrodynamics; the application of heat and mass transfer theories to dynamics of soil moisture; the sequential generation of hydrologic data, and the use of operations research in water resources system design.

Many important hydrologic models have been developed these days. Those would indeed be useful to study the inter-disciplinary aspects of environment. The following sections will describe the methodologies to calculate various important parameters and information regarding flood discharge, low-flow frequency, frequency analysis of Manohara River. These will be very valuable for hydrology as well as for other inter-disciplinary studies for these important basins of Nepal.

In case of flood frequency analysis, several studies were carried out by the different persons, agencies etc. Some studies mainly carried out are given below.
Analysis of mean annual flow and flood flow showed that there is no snowmelt contribution and the probability of monsoon floods and sediment concentration is high in Bagmati river basin (Thapa et al.,. 1993). In Nepal, floods are mainly caused by synoptic situations with the depression situated near the foothills of Nepal. For examples, annual and flood discharge analysis for Karnali, Narayani, Bagmati and Sapta Koshi river basins (Gautam, 2000). In Karnali river basin, with data up to 1993 flood peak of 5500 cumec is normal with 23544cumec of floods of 100 years return period (Adhikari, 1997).

2.2. Data Collection

Due to inadequate of data for Station no 415 at Andhi Muhan with only data of 2000 from June to December, the daily discharge data available for Borlangpul from 1964 to May 1991 have been transposed to the site at Borlangpul. The data from 1992 to 1999 are very poor, and is therefore excluded from further study. Daily flow data at Andhi Muhan from January 2000 to May 2000 and at Borlangpul from June 2000 to December 2000 are computed from corresponding developed rating curves. Thus, a total of 28 years of daily flow data (from January 1964 to May 1991) are available for further hydrological studies.

2.3. Limitations of the Study and Data Availability

Data for Borlangpul site is only available from June to December on 2000.
The data of the nearby station no. 415 at Andhimuhan has been used for data transposition to Borlangpul site with the suitable, appropriate methodology developed by DHM.

Data of Andhimuhan with station no. 415 from 1964 to 1991 have been used. Similarly, data from June to December in 2000 at Borlangpul, and the data from 1992 to 1999 at Borlangpul have been used. Borlangpul are very poor so there have been excluded in the analysis. Therefore total of 28 years of data from 1964 to 1991 have been used for the hydrologic studies. Although data of the recent past would be appreciated, older data have been used because of the consistency of the data.

The rainfall in the recent years can change in the Andhi Khola basin due to global warming. This will cause change in the runoff characteristics also.

Nevertheless, 28 years of discharge data will give some important insight of the flow regime of the Andhi Khola at Borlangpul site that will induced be valuable for water resources planning in the Syangja District.

For ungauged Andhi Khola River at Borlangpul discharge data of station at Andhimuhan St. No. 415 were used. The estimation of maximum, minimum and average monthly flow discharge data Andhi Khola were less than 30 years. Discharge and rainfall data could not be collected in the field due to remoteness, financial and time constraints.

CHAPTER III
THE ANDHI KHOLA

3.1. Location

The Andhi Khola is one of the major tributaries of the Kali Gandaki River. The Andhi Khola basin is located in the Syangja district of Gandaki zone in the Western Development Region of Nepal. The basin extends from latitude 28°03′ to 28°14′N and longitude 83°44′ to 83°57′E. (Figure 3.1.) The Andhi Khola basin up to station no. 415 is 195 sq.km. (Table 1.1)

3.2. Major Features

3.2.1 Topography and Physiography

The Andhi Khola basin is bordered by the Harpan Khola in the north, Darung Khola in the south, Saraudi Khola, Dagdi Khola and Baraha Khola in the east, and Modi River basin and Malyangdi Khola in the west. The highest elevation within the basin is 2,509m. Physiographically, 43.6% of the catchment area of the Andhi Khola Basin lies below the 1,000m and the remaining 56.4% lies in between 1,000 and 3,000m. Human settlements are predominantly rural and agricultural activities are more intense in the lower elevation, particularly in river valleys and flat areas. There is no major water resources project in the entire river course except for small irrigation schemes (both farmer managed and agency managed). The basin is oriented north – west to south – east and the main stream of the Andhi Khola flows north – west to south – east for most of its length and then north – east to south – west for some stretch.

3.2.2 Drainage System

The main tributaries of the Andhi Khola are the Sadi Khola, Ranguwa Khola, Bhar Khola and Seta Khola from the north east and many small tributaries from the south – west. None of thes tributaries are gauged. The Andhi Khola originates at an elevation of 2,286m north- west to meet the kali Gandaki at a distance of about 60 km from its origin. For about the first 700m the river is very steep with an average gradient of about 65%.

For the next 800m the river flows with an average gradient of about 12%, for about 11.4 km it decreases to about 2.7% and for a further 14.5 km it flows with an average gradient of 1.1%.

3.3. Climate

Warm temperate climate prevails in the Andhi Khola basin. The Basin temperature varies between 3.1°C to 31.1°C. Annual rainfall varies from 2,390 to 3,695 mm annual as absorbed by 3 rainfall stations inside and in the vicinity of the basin.

3.4. Agriculture

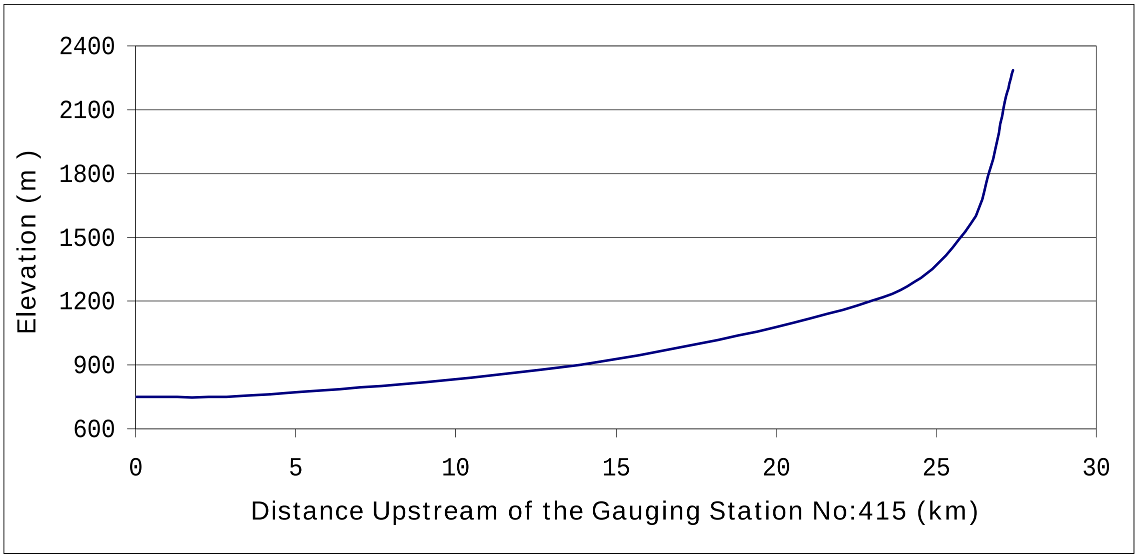
The Andhi Khola basin covers 2% of Parbat and 16% of Syangja districts. It lies in the Middle Mountain Physiographic region. The cultivated areas represent 22% of the catchment. Irrigated cultivation occupies about 35% of the total cultivated area.

The details of the Andhi Khola Basin are presented in Table 3.1. The Andhi Khola is a dynamic river with gradient of 0.056. Maximum area lies between alleviation 3000 to 1000 masl. The river has good carrying capacity of flow and sediment as indicated by the slope and stream order number of 5. This is also supported by drainage density of 1.44 Km^{-}1.

Table No: 3.1. Basin Characteristics

1	Gauging Station No	415	
2	Name of the Stream	Andhi Khola	
3	Relevant Rainfall and Climatological Station Nos.	0613,0804,0805	
4	Location Details		
	Name	Borlangpul	
	Latitude, Longitude, Elevation.	28^0 05' 00" N, 83^0 49' 00"E 749.39m	
5	Physiographic Details:		
	Area Details:		
	Elevation (m)	**Area* (Km^2)**	
	1,000	85	
	3,000	195	
	5,000		
	Total Area(km^2)	195	
	Main Channel Profile Data		
	Total Length of Mainstream Channel “L” = 27.4 km		
	Total Elevation Difference “ΔH”= 1,537.2 m		
	Average Channel Slope = 0.056		
	Weighted Channel Slope= 0.034		
	Time of Concentration T_c = 3 hrs		
	Basin Shape Information		
	Length =	17.0 km	
	Maximum Width	18.3 km	
	Drainage Network Information		
	Channel Order	**Total Number**	**Total Length (Km)**
	1	150	166
	2	33	65
	3	7	25
	4	2	13
	5	1	12.5
		Total	281.5
	Drainage Density (Km/Km^2)		1.444

*The area is that part of the basin which is below the elevation presented.



(Sources : Institutional development of DHM Tech Rep, -7)

Fig.No.3.2. Longitudinal Profile of Andhi Khola River

The Longitudinal profile of the Andhi Khola upstream from the ganging site
No: 415 indicate that most of the river course flows through the valley between 800 to 1200 masl. The head reach of about 8 km is very steep in which the relief changes from about 1200 to 2300 masl. This indicates that there shall be lot of erosion and landslides if the landscape is not properly managed.

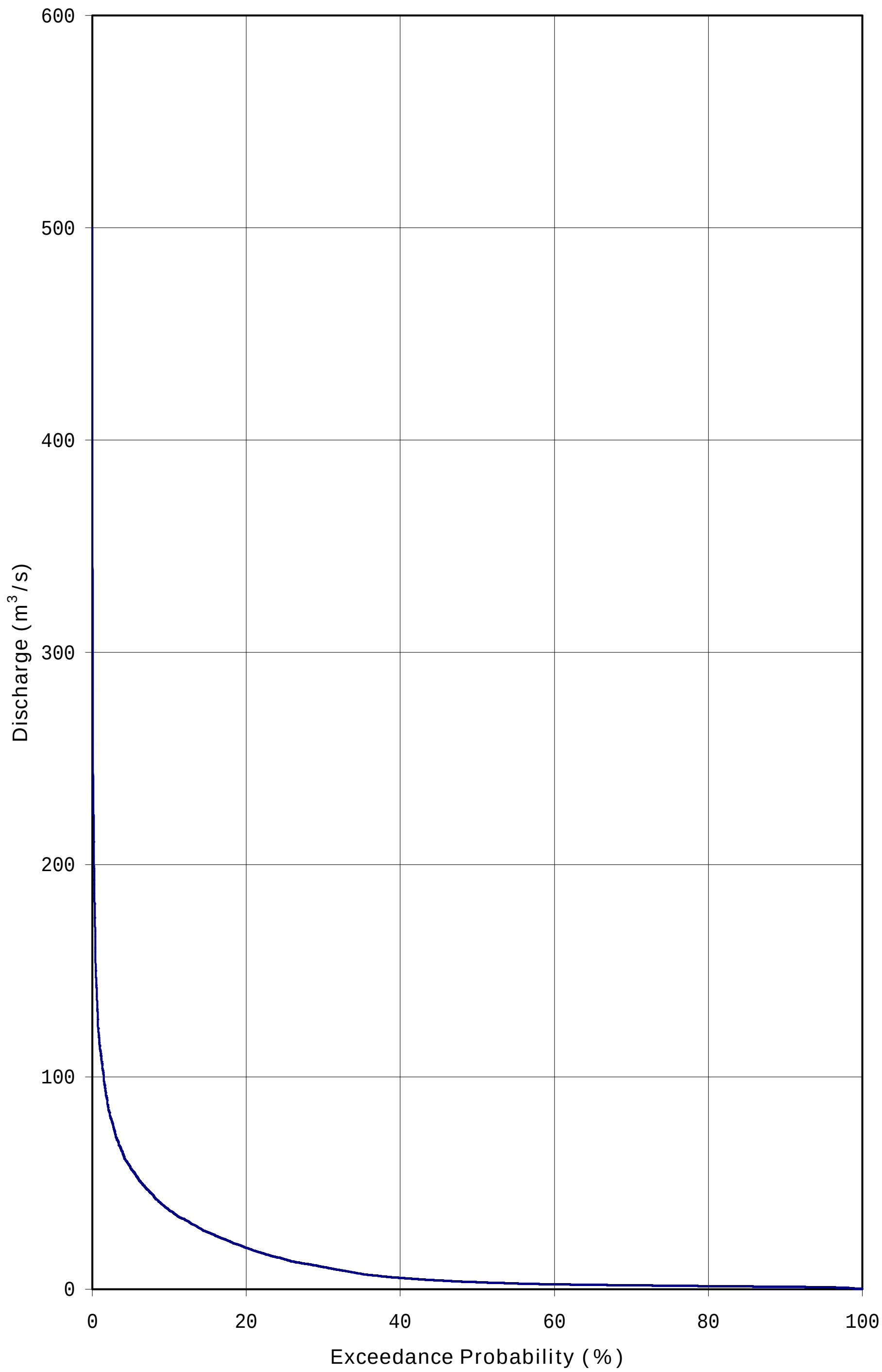
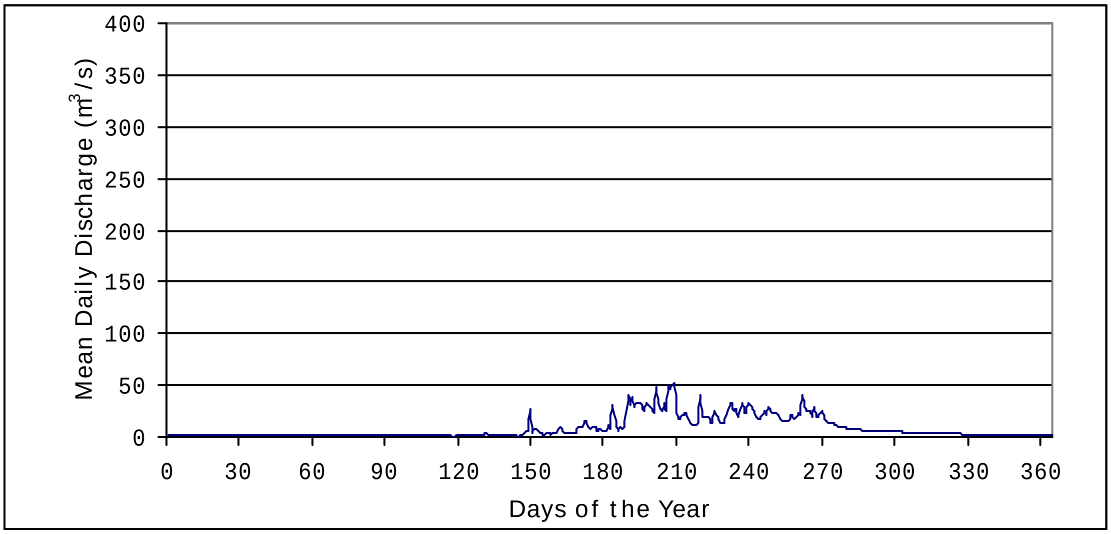


Figure 3.3 : Annual Flow Duration Curve of Andhi Khola at station no.415

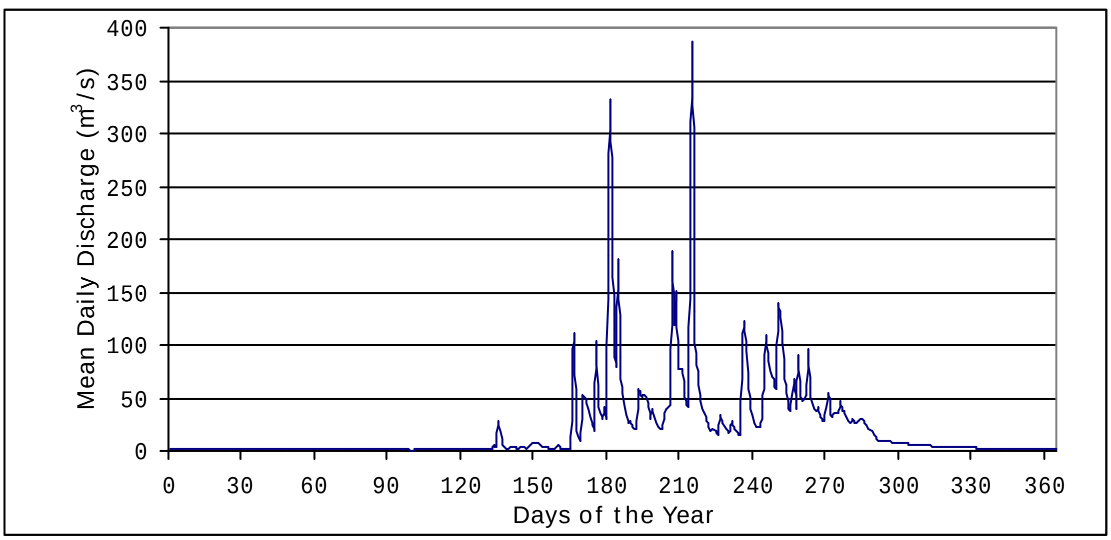
The flow duration curve for the Andhi Khola at station no.415 is shown in Fig. 3.3. The flow for the exceedence probability of 100 % is less than 1 m^3 /s.

From the available discharge data of 28 years, typical dry and wet years are shown in figure 3.4 and 3.5 respectively. The wet years generally indicates double the flow in monsoon season. The average flow characteristic of 1982 is indicated in Fig. 3.6.



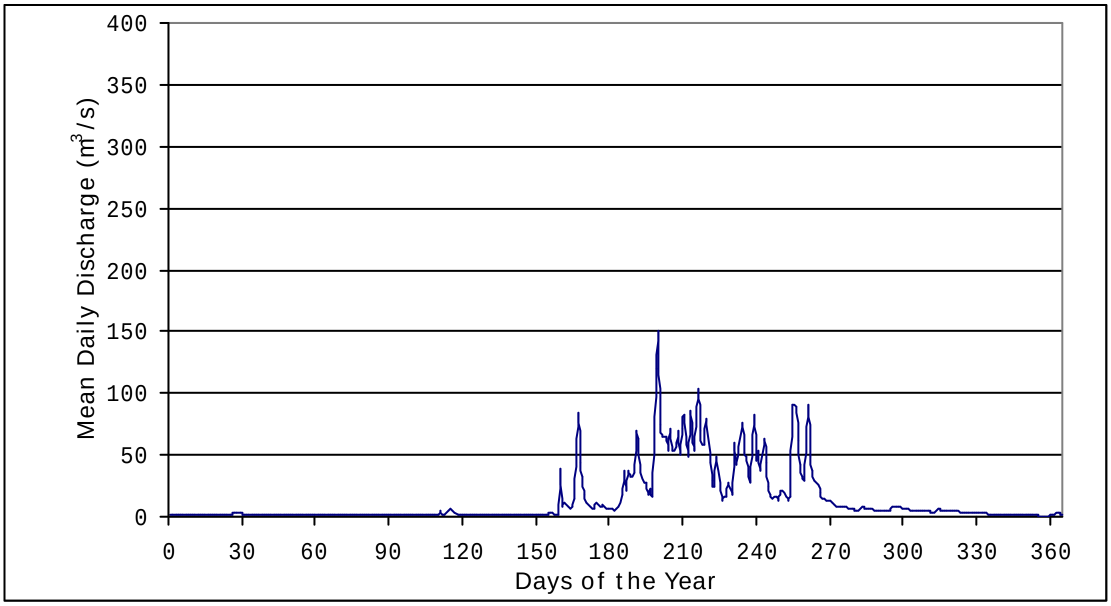
(Sources : Institutional development of DHM Tech Rep, -7)

Fig 3.4: Dry Year Hydrograph of 1969 at Borlangpul



(Sources : Institutional development of DHM Tech Rep, -7)

Fig 3.5: Wet Year Hydrograph of 1975 at Borlangpul



(Sources : Institutional development of DHM Tech Rep, -7)

Fig3.6: Average Year Hydrograph of 1982 at Borlangpul

CHAPTER IV
ESTIMATION OF FLOOD

4.1. Introduction

Estimation of flood is important aspect of hydrologic design .It is equally essential for practical purposes .Flood estimation is the first step in planning for flood regulation protection measures. An estimation of Probable Maximum flood and its corresponding stages are necessary for the design of infrastructures such as irrigation, hydropower, drinking water, flood control etc on a river or in the vicinity of a river. Estimation of flood volumes is required for the design of the flood control reservoirs or retarding basins and for the flood drainage studies.

Flood adopted for the design purpose is known by design flood. During a flood design, very high value chosen will make the structure costly causing unnecessary investment. Similarly, low value chosen for design will bring high risk for the structure and safety of person and property located at downstream. Hence, while estimating a design flood, the economical aspects of the flood value chosen for the design must not be forgotten. Regarding this while designing any important structure, provision must be made for the flood that is likely to occur during the life time of the particular structure.

Depending upon the magnitude, the floods can be mostly classified into these three classes.

a) Ordinary floods
b) Standard project flood (SPF)and
c) Probable maximum flood (PMF).

Flood estimation can be done by using various methods. Some of them are based on characteristics of drainage basin; others are based on theory of probabilities by using the previous known flood data, and still others are based on a study of rainfall and runoff data.

4.2. Floods Depending upon magnitude

Floods depending on the magnitude are classified as:

i. **Ordinary flood:**

Ordinary flood is that flood which is equalled in magnitude or more in the life period of the project.

ii. **Annual flood:**

The highest flood discharge in water year is the annual flood which has been equalled or once each year on the average.

iii. **Maximum observed flood:**

The highest of the recorded floods at a site of a stream during a specified period is the maximum observed flood. The period may be weak, a month, a year, or even the entire period of record.

iv. **Mean annual maximum flood:**

The mean annual maximum flood is that flood which normally occurs once in every two years or on average.

v. **Maximum probable flood:**

Maximum Probable flood is defined as that flood estimated to result from the most critical combination of severe meteorological and hydrological conditions in the region.

vi. **Standard project flood:**

Standard project flood is defined as flood volume that is likely to occur, from the most severe combination of hydrological and meteorological condition of watershed, equal to 80%.of maximum probable flood.

vii. Design Flood:

Design flood is the flood adopted for the design purposes based upon the standard probable flood or probable maximum flood or a flood corresponding to some desired frequency of occurrence depending upon the type of structure to face the flood for the purpose of the project.

4.3. Measurable Features of Flood.

Floods may be measured related to height, peak discharge, volume of flow and area inundated with water. The height of flow is required to those planning to build structures along or across streams. The peak discharge is of interest to those designing spillways bridges, culverts and flood channels. The volume of flow is essential to those designing storage works for irrigation, water supply and flood control etc. The area inundated is of interest to those planning to occupy in any manner the flood plains adjacent to a stream. The area inundated is measured by outlying the edge of water on a map. Often this area is defined by developing flood profiles along each bank.

4.3.1. Flood elevation.

The elevation of flood peak is most used fact of all flood data. It is not as simple a measurement as it at first may appear. A natural stream in flood does not produce a smooth surface waves and surges cause fluctuations of a foot or more, these fluctuations must be considered when recording a flood height.

4.3.2. Flood discharge.

The measurement of flood discharge can be made most satisfactory by the current meter. In that condition, when current meter is not able to measure flood discharges, indirect methods such as slope area method and hydraulic methods can be used. Beyond these, flood discharge can also be determined by analysis of hydrologic data or by formulae developed empirically. These methods may consider precipitation, land use, the size, shape and slope of basin and other parameters believed to be important by the designer of the method. In computing discharges, the hydrologic methods are widely used for the design of spillways, reservoirs, urban drainage systems, culverts and other structures draining large as well as small basins.

4.3.3. Flood volume.

The volume of flow during a flood period can be computed from a record of daily discharges. A measure of the flow can be easily obtained at a reservoir, especially if the reservoir capacity is large in relation to the volume. The volume of the flood flow is given by the difference in storage at the beginning and end of the flood plus the volume of flow passing the dam during the same time interval.

4.3.4. Duration of floods.

The time that a stream remains at flood stage is important in many instances. A high peak of short duration usually has a relatively small volume of flow and thus may be completely controlled by a reservoir. A lower peak of long duration and large volume will not be controlled by a reservoir of the same size. Hence the design of storage reservoir must be consider for the volume of such flood flow.

Main roads are built across flood plains on low embankments considering only the height of the flood peak. Therefore it is important to know, how long the road will be flooded. The duration of flood varies widely since some rise and recede within hours while other remains at a high stage for days.

In context of Nepal, the calculation of duration of flood is very essential because many roads are constructed across floodplains on low embankments.

4.4. Flood Discharge Determining Methods

Usually, to estimate flood discharge, the following methods are used.

i. Statistical or Probability Method,
ii. Empirical Formula Method,
iii. Rational Method, and
iv. Unit Hydrograph Method.

4.4.1. Statistical or Probability Method

These methods can predict future floods by the available records of past floods. These methods are also able to determine maximum flood which is expected on a river, with a given frequency i.e. return period of the flood. Hence, for the success of these methods, sufficient past flood records must be available.

There are various statistical or probability distributions suggested by investigations for flood frequency. Among them, some important and popular methods are given as,

A. California Method.
   i. Modified California Method.
   ii. Modern Clifornia Method.
B. Ven Te Chow Method .

4.4.1.1. California method

The recurrence interval [T] can be defined by using this method as,

T=N/m and P=1/T. where, N is total number of flood records, m is the serial number of descending flood magnitude, and P is probability of the occurrence.

For the prediction of future floods, a graph between frequency and discharge can be drawn.

i. Modified California Method

This method is widely used in France. Wajen in 1930 proposed that the flood frequency 'f' in 100 years is based upon the following conditions as,

$$f = \frac{100(2m-1)}{2n}$$

where m is number of years during the records of flood which are equaled or exceeded and n is the total number of years of record.

ii. Modern California method

$$f = \frac{100\ m}{(n+1)}$$

where m is number of years during the records of flood which are equaled or exceeded and n is the total number of years of record.

This method is widely used in U.S.A. and Russia.

4.4.1.2. Ven Te Chow Method

Frequency factor is introduced in this method which is,

$$Y_T = a + b\, k_T$$

where

$$k_T = \text{Log}\left(\text{Log}\ \frac{T}{T-1}\right)$$

Here, T is return period in years, and

a and b are estimated parameters by the method of moments from the observed data.

In this technique, each value y_T is arranged in descending order of magnitude. For example, if rank of y_T for a particular year is m, its plotting position is n +1/m. where n is total number of years of flood records.

4.4.2. Empirical Formulae

Empirical Formulae can be applied to the areas for which they were specifically derived. Several flood-producing factors are considered on empirical formulae such as area of the basin, rainfall characteristics, and recurrence interval either explicitly or implicitly. Some of these commonly used formulae are given below.

(i). Dickens Formula (1865).

$$Q=CA^{3/4}$$

where Q is peak discharge in cumec (m^3/s), A is the basin area in square kilometers, and C is a coefficient, which is 11.42 for areas with annual rainfall range of 600mm to 1250mm.

(ii). Ryve's Formula (1884).

It is almost similar to Dicken's formula except value of the constant C. That is,

$$Q=CA^{2/3}$$

where Q is peak discharge in cumec(m^3/s), A is basin area in sq.km and C is a constant. The value of C is 6.75 for areas with in 80km off the coast, 8.45 the area with in 80km to 2400km off the coast and 10 for limited area near hills.

(iii). Inglis Formula(1930).

It is mostly applicable to far shaped catchment

$$Q = \frac{124\ A}{A^{0.5}+10.4}$$

where Q is the peak discharge in m^3/s, A is the basin area in sq. km.

(iv). Ali Nawaj Jung Bahadar Formula

It is widely used in small basins.

$$Q = CA\left(0.993 - \frac{1}{14\log A}\right)$$

where Q is in m^3/s and A is the catchment area in km^2 and C is a constant whose value lies between 48 to 60.

(v). Craig's Formula

It is given by

$$Q = 10KBI\ Ln\left(\frac{4.97\ L^2}{B}\right)$$

where

Q is maximum flood discharge in cumec.

L is the greatest length of catchment in km.

B is the average width of catchment in km.

K is the coefficient of runoff.

(vi). Lillie's Formula.

This formula was developed by dividing the basin area into series of triangles expressing its apical angle θ, and its vertical length L.

Thus,

$$Q = 0.058VRK\sum\theta.\ L$$

where

Q is peak discharge in cumec .

K is coefficient (0.8934+LogL)

C is a constant usually 0.436

W is average width of basin in km .

R is rainfall coefficient given by .

$$R = 2 + \frac{p}{38.1}$$

(vii). Rhind's Formula

$$Q = 0.098CSR(0.386A)^{P}$$

where

Q is peak discharge in cumec.

S is the average fall of the last 5km of the river above the basin outlet in m/km

R is the greatest average annual rainfall in cm.

P is a variable index.

C is a co-efficient depends on the ratio R/L

L is the greatest length of the catchment in km.

(viii). Chamiers Formula

$$Q=3.5IRA^{3/4}$$

where

Q is peak discharge in cumec.

I is average rate of rainfall cm/hr

K is a runoff coefficient

A is basin area in sq km.

(ix). Iszkowski's Formula

$$Q=0.03171CMHA$$

where

Q is peak discharge in cumec.

A is basin area in sq. km.

H is annual rainfall in meters.

C is co-efficient of runoff

M is a coefficient with a range of 0.17m to0.8.

(x). Fullers Formula

$$Q = CA^{0.8}$$

$$Q = Qav(1+0.8\log T_r)$$

$$Qmax = Q(1+2.66A^{-0.3})$$

where

Q is maximum 24 hour flood

A is basin area in sq.km.

Tr is return period in years and

C is a coefficient which varies from 0.026to 2.77.

(xi). Horton's Formula

$$Q = \frac{114\ T_r^{0.25}}{A}$$

where

Q is flood discharge in cumec,

A is basin area in sq.km, and

Tr is return period in years.

(xii). Pettis Formula

$$Q = C\ (P\overline{B}\ )^{5/4}$$

where

Q is the flood discharge with return periods of 100 years in cumec.

C is a co-efficient varying from 1.51 in humid areas to 0.195 in desert areas.

P is the one day rainfall with 100 years return period in cm

B is the average width of the basin in km.

This formula is generally applicable to basin area ranging from 1,600 to 16,000 sq.km. with no storage effect and uniform width.

(xiii).W. P. Creager's Formula

$$Q=C.A_1^{0.894A1-\ 0.048.}$$

where

Q is peak discharge in m^3/s

A is the catchment area in square kilometers) and

C is a constant whose value lies between 40 to 130.

(xiv). Jarvis Formula.

$$Q=C\sqrt{A}$$

where

Q is peak discharge in cumec,

A is the catchment area in square kilometers and

C is a constant whose value varies between 1.77 and 177.

(xv). Modified Myer's Formula

$$Q=177PA^{1/2.}$$

where

Q is the peak discharge in cumec,

A is basin area in sq km,

P is a factor which depends upon the drainage factor and frequency of floods. It varies from 0.002 to 1 and usually taken as 1.

(xvi). Davis and Wilson Formula.

$$Q=KP_{av}A^{2/3}$$

Where

Q is peak discharge in cumec.

A is basin area in sq km

P_{av} is the maximum rainfall in cm, and

K is a coefficient, its value lies between 0.6to1.2.

(xvii). Waitt FWF Formula.

$$Q = \frac{176\ A}{0.8+A^{0.5}}$$

where

Q is peak discharge in cumec and

A is basin area in sq km.

(xviii). Austraila Formula

$$Q = \frac{5100\ A}{(277+A)^{0.9}}$$

where

Q is peak discharge in cumec and

A is basin area sq km.

(xix). J. Dredge and Burge Formula

$$Q = \frac{19.6\ A}{(L)^{2/3}}$$

Where

Q is peak discharge in cumec,

A is basin area in sq. km. and

L is length of drainage basin in kilometer.

If B is average width of the basin, then A=BL i.e. $Q=19.6BL^{2/3}$. Hence the formula becomes the 1day rainfall with 100 years return period in cm.

4.4.3 Rational Method

In this method, it is assumed that the maximum flood flow is produced by a certain rainfall intensity, which lasts for a time equal to or greater than the period of concentration time. This concentration time is nothing but the time required for the surface runoff from the remotest part of the catchment area to reach the basin outlet. When a storm continues beyond concentration time, every part of the catchment would be contributing to the runoff at outlet and therefore, it represents condition of peak runoff. The peak value of runoff (Q) is given by.

$$Q=CAI \qquad \text{………………(4.1)}$$

where

C is runoff coefficient.

A is area of the basin.

I is the intensity of rainfall.

In the equation (4.1) A and I are substituted in units of acres and inches/h, the runoff is obtained in cusecs (ft^3/s). Without requiring any conversion factor, Equation (4.1) is called the rational formula. However, in SI system of units when A is in km^2 and I is in cm/h, the flow rate is given by.

$$Q=2.778\ CAI \qquad \text{……………(4.2)}$$

Here, the intensity of rainfall (I) depends on duration of time and desired return period. Hence after obtaining rainfall intensity and basin area; the peak flood can be estimated from equation (4.1) and (4.2) using appropriate runoff coefficient C given in Table (4.1).

Table: 4.1. Runoff coefficient C for different soil and land use conditions.

Soil type	Cultivated	Pasture	Forest
With above infiltration rates, Usually sandy or gravelly.	0.20	0.15	0.30
With average infiltration rates; clay pans, loams and similar soils.	0.40	0.35	0.30
With below average infiltration rates; Heavy clay soils or soils with a clay pan near the surface; shallow soils above impervious rock.	0.50	0.45	0.40

Source: Reddy, 2002

The Rational Method gives good result for small areas up to about 50 sq.km. Therefore, it is generally used to estimate the peak flood in the design of urban drainage systems, storm sewers, airport drainage and in the design of small culverts and bridges.

4.4.4. Unit hydrograph method.

Unit hydrograph technique was developed by Sherman in 1932. It is widely used for flood estimation and prediction. It is a very useful and a reliable method for computing design flood for a project, provided the basin is small and medium in size, say up to 5,000 sq.km. For a larger basin , the basin will however, have to be subdivided into smaller sub-basins (stream wise) and to complete different unit hydrographs for all these sub-basins will then have to be routed up to the project site by river routing techniques.

The Unit Hydrograph of drainage is a hydrograph of direct runoff resulting from effective rainfall of unit duration generated uniformly over the basin area at a uniform rate. So, when a unit hydrograph is available for the basin under consideration, it can be applied to the design storm to yield the design flood hydrograph. In a case, when the unit hydrograph is not available for the basin, a synthetic unit hydrograph may be developed based on the data of neighboring basins.

The important assumption of unit hydrograph theory is principle of linearity. Hydrograph of direct runoff due to effective rainfall of equal duration have the same time base and the effective rainfall is uniformly distributed throughout the whole area of the drainage basin are the principles of unit hydrograph. Unit hydrograph not only gives flood peak but also the complete flood hydrograph which is essentially required in fixing the spillway capacity after incorporating the effect of storage of the reservoir on flood peak through flood routing .

It has certain limitations such as,

- When infiltration capacity exceeds the rainfall, the unit hydrograph of one day storm can not be obtained.
- This method is not suitable for odd shaped basins particularly long and narrow, which generally have very uneven rainfall distribution.

4.4.5. Envelope Curve Method

Envelope curve is a relationship between maximum flood flow and drainage area in hydro meteorologically homogeneous region and it can be used to calculate maximum flood peaks. J.M. Baird and J.F. Mcillwraith (1951) gave the following equation for the enveloping curve of maximum floods throughout the world.

$$Q = \frac{3010\ A}{(277+A)^{0.78}}$$

where Q is in m^3/s and A is in km^2

This technique is better than empirical formulae because here the selection of coefficients on the basis of judgment is not required. Envelope curves are useful for preliminary estimate of design floods and it can be used for both estimate flood peaks and flood volume. An inherent disadvantage of the envelope curve lies in the fact that it is based on past recorded floods and there is always a possibility that still higher flood may occur in future.

However, envelope curves have certain limitations.

- It is only applicable at hydro meteorologically homogeneous region representing similar types of floods of a basin area.
- It can not tell us future possibilities of floods.
- It gives higher values for the design of minor structures.

4.4.6. Increasing the observed flood.

When the flood data is not available, or when the available data is short , the maximum flood that occurred during the past, and the number of years during which this flood was the highest are found out by local enquiries or from the observation of past records. This is then increased by a certain percentage and adopted as the design flood. The percentage increase naturally depends on the number of years over which the observed flood was maximum. If it is over a longer period the percentage increase may be less and for shorter periods the increased may have to be more. This method is adhoc in nature and has not much theoretical justification and should be resorted to under helpless situations.

CHAPTER V
METHODOLOGY

The methodologies applied in the study are described below:

5.1. Transposition of frequency data:

Instantaneous maximum discharge were not available for the new gauging station at Borlangpul. So, to carry the flood frequency analysis, instantaneous maximum discharges of the old gauging station site with station no. 415 at Adhi Muhan have been transposed to the new gauging station site at Borlangpul by using the following relation:

Cud worth (1991) relation:

$$\frac{Q_1}{Q_2} = \frac{A_1^{0.5}}{A_2^{0.5}} \qquad ....(5.1)$$

Where,

Q_1 is the estimated discharge at an ungauged site.

Q_2 is the available discharge data at the gauged site.

A_1 and A_2 are the drainage area measured at ungauged and gauged locations respectively.

5.2. Estimation of Hydrological parameters at ungauged locations in Nepal by WECS/DHM:

Following relationships derived by WECS/DHM for the ungauged basin are used to calculate high flow, low flow, mean monthly flow and flow duration curve. The estimation is based on statistical models using multiple regression approach. The FORTRAN based multiple regression program (MULTR) was used in WECS/DHM to obtain the best possible equations.

Drainage area below 3000masl is the only one parameter required for the estimation of flood flow. Similarly, low flows are estimated on the basis of the drainage area below 5000masl. Average annual hydrographs at ungauged locations is computed using average basin elevation, average annual precipitation and basin area below 3000masl. Flow duration curve for an ungauged location uses the same variables as in average annual hydrograph besides the basin area below 5000masl.

5.2.1. Multiple regression for high flow at an ungauged location:

The following equations are used to predict the high flow for 2-year and 100-years flood in Nepal.

$Q_2 = 2.29(A<3K)^{0.86}$ n = 49 r = 0.932 ……....(5.2)

$Q_{100} = 20.7(A<3K)^{0.72}$ n = 49 r = 0.879 …...…(5.3)

Where, Q is the flood discharge in m^3/s and A is the basin area in Km^2. The subscripts 2 and 100 indicate 2-year and 100-year flood respectively. Similarly the subscript < 3K indicates area below 3000 m.

Based on the algebraic evaluations of the equations used for lognormal distribution, the following relationships (WECS / DHM 1990) can be used to estimate floods at other return periods.

$Q_f = \exp(LnQ_2 + S\exists_1)$ ...……….(5.4)

Where, $\exists_1 = Ln(Q_{100}/Q_2)/2.326$ ...…...(5.5)

S is the standard normal variate. The values of S are given in table.

Table 5.1: Values of standard normal variate for various return periods.

Return period (T) in years	Standard normal variate (S)
2	0
5	0.842
10	1.282
20	1.645
50	2.054
100	2.326
200	2.576
500	2.878
1000	3.090

5.2.2. Multiple regression for low flow at ungauged location:

The equation which is used for the computation of low flows at an ungauged location is

$$\sqrt{Q_{d,T}} = C_{d,T} + F_{d,T} \sqrt{A<5K} \qquad \ldots\ldots\ldots\ldots(5.6)$$

Where,

$Q_{d,T}$ = Discharge (m^3/s)

d = Duration (day)

T = Return period (year)

$C_{d,T}$ = Constant co-efficient for a duration d and return period T

$F_{d,T}$ = Co-efficient of independent variable for duration d and return period T

A<5K = Area of the basin below 5000 m^2

The values of C and F for different return periods and duration are presented in table below. The table also includes the statistics obtained from the multiple regression analysis of the data.

5.2. Table for low flow estimation equations.

Return period / Year	Day	Constant $C_{d,T}$	Co-efficient $F_{d,T}$	Std Error	R^2
2	1	0.2144	0.0815	0.0033	0.925
	7	0.2362	0.0830	0.0033	0.929
	30	0.3026	0.0854	0.0031	0.938
	Monthly	0.3397	0.860	0.0030	0.940
10	1	0.0859	0.0729	0.0032	0.915
	7	0.0920	0.0748	0.0031	0.921
	30	0.1807	0.0766	0.0030	0.930
	Monthly	0.2138	0.0777	0.0031	0.940
20	1	0.0698	0.0703	0.0031	0.912
	7	0.0662	0.0726	0.0031	0.918
	30	0.1609	0.0742	0.0030	0.927
	Monthly	0.1945	0.0754	0.0031	0.929

Source: Hydrological Estimations in Nepal,2004

5.2.3 Multiple regression analysis for mean monthly flow and flow duration:

Multiple regression assessed with different predictors resulted in the most plausible coefficients for each month as presented in Table 5.3. The coefficient must be substituted in the following equation,

$$Y = a + b (X_1) + c (X_2) + d (X_3) \quad \text{....................(5.7)}$$

Where,

Y is the discharge for a given month after an appropriate transformation as given in column 6 (Table 5.3). Same transformation (column 6) must be applied for all the independent variables X_1, X_2 and X_3 considered in the equation for a particular month. The coefficient "a" is a constant for a given month as presented in column 1 of the table. The coefficients for the independent variables "b", "c" and "d" are appropriately selected for a particular month as given in Table 5.3. from column 2 to column 5.

Table 5.3. shows that the type and number of variables and the mathematical transformation are not the same for all the months. Based on best correlation coefficient, multiple regression with three predictors were adopted January, February and from June to September. On the other hand, only one variable, the area below 5000 m was the dominating predictor during the spring season.

Equation 5.1 can also be used for the computation of duration values for probability of exceedence as given in Table 5.4. which also provides appropriate transformation, constants and coefficient that must be substituted in the equation (5.7) for the computation of flow duration curve.

Table: 5.3. Most Plausible Relationship for the Average Annual Hydrograph.

Month	Const	Coef of ave. elv	Coef of ann ppt	Coef of A<3K	Coef of A<5K	Transfo rmation	Std. error	r^2
	1	2	3	4	5	6	7	10
Jan	-16.7	1.36	0.470	0.820	--	Ln	16.4	0.971
Feb	-17.2	1.42	0.456	0.814	--	Ln	14.7	0.968
Mar	0.384	--	--	--	0.091	Sqrt	15.3	0.966
Apr	0.181	--	--	--	0.104	Sqrt	21.0	0.962
May	0.001	--	--	--	0.136	Sqrt	42.8	0.946
Jun	-19.5	1.61	0.709	0.872	--	Ln	106	0.941
July	-16.3	1.26	0.759	0.884	--	Ln	195	0.954
Aug	-14.7	1.24	0.622	0.871	--	Ln	215	0.964
Sep	-13.7	1.09	0.594	0.872	--	Ln	125	0.977
Oct	-15.3	1.21	0.600	0.846	--	Ln	74.1	0.963
Nov	-16.7	1.36	0.543	0.826	--	Ln	42.5	0.953
Dec	-17.0	1.39	0.504	0.822	--	Ln	23.6	0.966

Source: Hydrological Estimations in Nepal,2004

Table 5.4 : Most plausible Relationship for Different Flow Duration.

Month	Const	Coef of ave. elv	Coef of ann ppt	Coef of A<3K	Coef of A<5K	Transfo rmation	Std. error	r^2
0%	-12.8	0.366	--	0.529	--	Sqrt	527	0.906
5%	-19.6	1.108	0.607	0.874	--	Ln	221	0.963
20%	-17.0	1.359	0.716	0.883	--	Ln	142	0.967
40%	-19.0	1.554	0.656	0.859	--	Ln	68	0.950
60%	-18.3	1.535	0.513	0.832	--	Ln	27	0.960
80%	-19.4	1.589	0.559	0.834	--	Ln	18	0.963
95%	-21.2	1.732	0.598	0.842	--	Ln	14	0.965
100%	-2.18	--	0.48	--	0.077	Ln	13	0.945

Source Hydrological Estimations in Nepal, 2004

The low flow values are significantly correlated with basin area, basin perimeter and river length. Similarly, the minimum flows are significantly related to different hypsometric and land-use areas. Correlation matrices also indicate that the basin areas below 5000 masl are the most influencing area for the low-flows. As indicated by the poor correlation between the low-flow and geographical coordinates, the regional aspect is considered less significant so that the same equation may be applied for the whole country. Caution should; however, be taken while applying the relationship for an ungauged location above 1800 masl in high mountain areas and ungauged location on streams originating in the Siwalik or Terai as no data for these regions were available for developing regression

Analysis of multiple regression showed that the relationship based on the multiple regression of area below 5000 masl or 3000 masl combined with average basin elevation and average basin slope yielded best results avoiding co-linearties. The improvement in goodness of fit by including additional parameters in area below 5000masl however was marginal. Considering the applicability of equation with case, only the relationship of low flow with area below 5000 masl have been recommended for the estimation of low-flows for different durations and frequencies.

5.3. Frequency Analysis

The frequency analysis of hydrologic data gives the magnitude of future extreme events to their frequency of occurrence as indicated by probabilities or return periods.
There are several methods adapted to frequency analysis. Among them, some popular methods are used in this study and are discussed below.

5.3.1. Probability Plotting :

A graph is drawn between the flood magnitude and its return period on simple plane coordinate known as probability plotting. The probability of an event can be obtained by the plotting position.
This method is used when data time series are short.

There are several empirical formulae for plotting position. Among them, Weibull formula is used in this study, since it compromises with more statistical justification. In this formula, the return period for an extreme event can be found out by arranging the flood magnitudes in descending order and assigned rank m, starting from the highest flood. Then exceedence probability P, of an event is obtained as,

$$P = \frac{m}{n + 1} \qquad \text{……….…... (1)}$$

Where m is the rank number and n is the total number of years in the record in which the return period T_r and exceedence probability P are reciprocals to each other as,

$$P = \frac{1}{T_r} \qquad \text{……...…… (2)}$$

5.3.2. Flow Duration Curve:

To characterize the variability of stream flow during a water year, the derivation of flow duration curve is most essential, because it is one of most popular tool for studying the same.

The flow duration curve is derived by plotting the discharge against percent of time, when flow is either equal or greater as abscissa. The derivation procedure is explained as under.

1. Arrange the discharge data in descending order of their magnitude.
2. Compute the rank number to each of the discharge data.
3. Calculate the plotting position of each discharge on interval using the following equation

$$P(\%) = \frac{m}{n+1} \times 100$$

4. Plot the percent probability (P) and corresponding discharge on graph paper and prepare the curve by joining the plotted points. The obtained curve is flow duration curve

CHAPTER VI

Estimation and Analysis

6.1. Introduction

Nepal being very rich in water resources has not been also to harness loss most of its perennial flows. This is basically due to financial constraints, lack of technology and above all lack of discharge data for the development of water resources projects low flows, high flow, mean monthly discharge and other relevant data are essential for the multi purpose project or single purpose projects relating to hydroelectricity power generation, irrigation, domestic water supply and flood absorption. However, in many cases rivers are ungauged and small water resources projects have to be implemented in rural areas. Such situation will demand estimation of low and high flow for designing the hydraulic structures associated with the objectives of the project. Keeping in the view the Andhi Khola river basin which is a very important sub basin of Kali Gandaki river/Walling Bazaar has been selected for the study. This Sub basin has very important Hydro power station agricultural landscape around Jimuba and Asherdi which requires irrigation during the dry season from March to May .People are now migrating and settling in its irrigation area. It is also helpful for the new settlement to supply more water in Walling Bazaar Galyang Bazaar and Putali Bazaar. Therefore flow estimation is carried out with suitable methodologies applicable to Andhi Khola environment. The techniques applied for this various kinds of flow estimation are described in the following articles.

WECS/DHM method which is applied in order to find the low flow frequency, high flow frequency and average monthly flow and flow duration curve analysis for Andhi Khola river . The basin area of the Andhi Khola river basin was taken from Institutional Development of Department of Hydrology and Meteorology TAHAL Consulting Engineering Ltd scale of Map 1:25000.

6.2. The low flow Estimation

Low flows are necessary for Andhi Khola basin for irrigation purpose, hydropower and water supply in near future. The low flows have been estimated with the help of methodologies developed by WECS/DHM method of Andhi Khola of Borlangpul (Keshav et al, 2004). Low flow characteristics 1 day, 7 day, 30 day, monthly duration has been conducted given in Table 6.1 . The detailed calculation of these low flows is presented in Annex. 1-20 years return period with monthly low flow of 1.56m^3/s will give rise to irrigation and domestic water supply.

Table. 6.1. Low Flow Frequency Analysis for Andhi Khola River at Borlangpul

Return Period (Year)	Discharge m^3/s			
	1day	7day	30day	monthly
2	1.83	1.95	2.24	2.37
10	1.22	1.29	1.56	1.69
20	1.11	1.17	1.43	1.56

Low flow frequency analysis from Table 6.1 show that the monthly minimum value for the return period of 2 years was found 2.37m^3/s. Similarly the month minimum value was found 1.69m^3/s and 1.56m^3/s for the return period of 10 and 20 years respectively. The one day minimum value for the return period of the 2 years, 10 years and 20 years are 1.83 m^3/s, 1.22m^3/s and 1.11 m^3/s.

The 30 day minimum value for the return period of 2 years, 10 years and 20 years are 2.24 m^3/s, 1.56m^3/s and 1.43 m^3/s.

6.3. The High Flow Estimation.

High flows are necessary for designing of bridges, culverts and drainage system for the water logged areas that will be occupied by settlement in future. The high flows are estimated with the help of methodologies by WECS/DHM. It is given in Table 6.2 Borlangpul site and graphically represented in Fig. 6.1. Annual rainfalls vary from 2390 to 3695mm among the three rainfall stations inside and in the vicinity of the basin during monsoon the Andhi Khola catchment. For occasion of high monsoon rain that generate peak flows, it is observed that the return period of 2 years, 10 years, 20 years and 50 years are 213.4m^3/s, 362.5m^3/s, 478.1m^3/s, 600.7m^3/s, 777.1m^3/s and 922.1m^3/s respectively. It is to be remarked that the hydrologic structures like culverts, bridge etc. have to face such high floods. The Andhi Khola River flowing in the flood plains approaches Walling Bazar, Galyang Bazar and Putalikhet Municipality dangerously in Monsoon season. This will require river training work like constructing levees or embankments.

Table 6.2 High Flow Frequency Analysis for Andhi Khola at Borlangpul

High Flow Frequency (Year)	Discharge (m^3/s)
2	213.4
5	362.5
10	478.1
20	600.7
50	777.1
100	922.1

The high flow frequency analysis for Andhi Khola at Borlangpul (Table.6.2.) shows that the high flow frequency for the return periods of 2 years and 100 years are calculated as 213.4m^3/s and 922.1m^3/s respectively. Similarly the discharge for return periods for 5 years, 10 years, 20 years, 30 years and 50 years were 362.5m^3/s, 478.1m^3/s, 600.7m^3/s, 777.1m^3/s and 922.1m^3/s respectively.

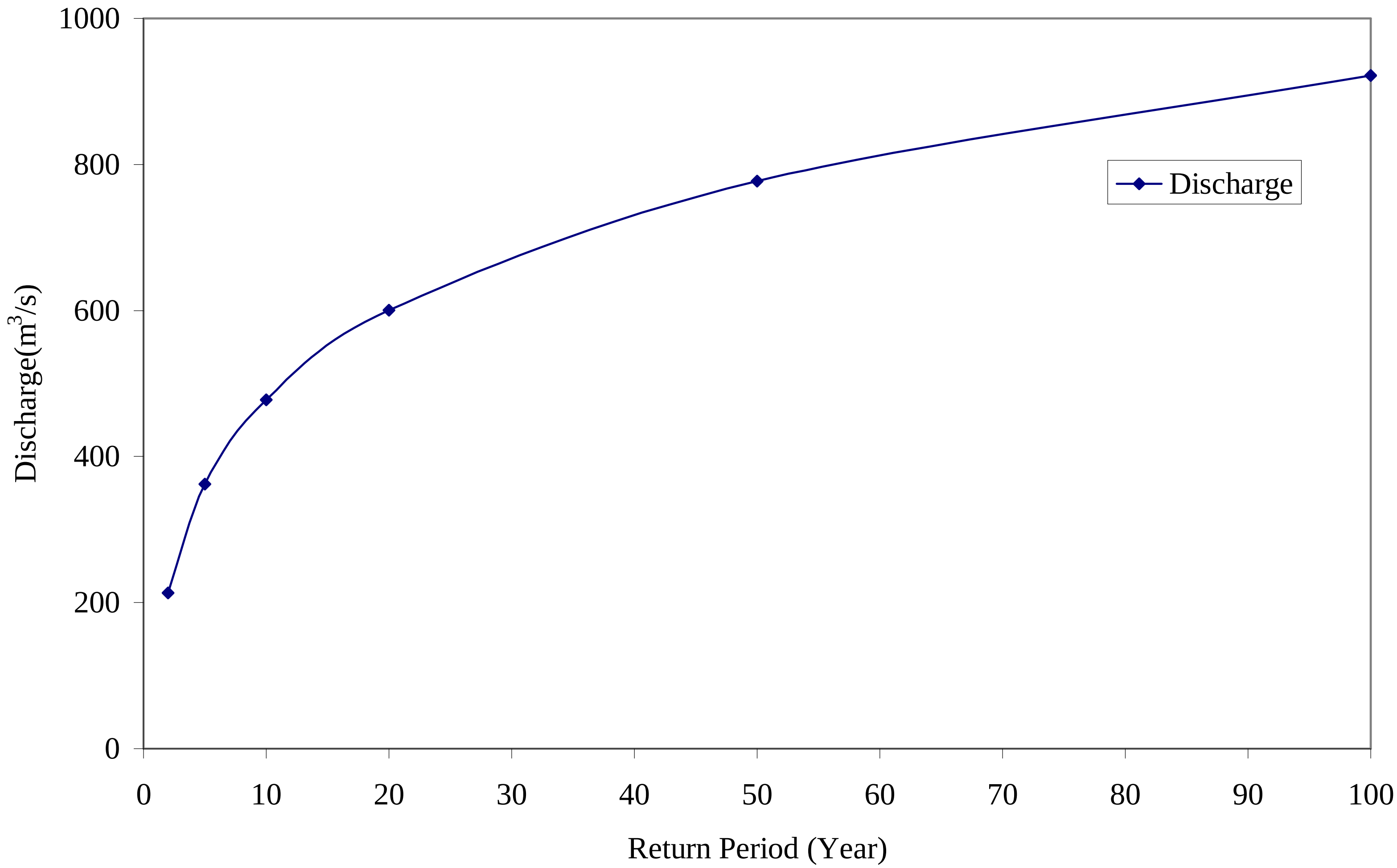


Fig.6.1. High Flow Frequency of Andhi Khola at Borlangpul

6.4. Mean Monthly Flow Estimation

Mean monthly flow of Andhi khola river are necessary for water supply irrigation and hydro power generation in difference month except during the monsoon season. The essential discharge from methodologies by WECS/DHM method are given in Table 6.3 and graphically represented in Fig 6.2. The monthly flow characteristics indicated that during the dry season flow for the month of April is about 2.67m^3/s and during monsoon for the month of August the flow is about 38m^3/s. The ground water is recharged due to the monsoon rains and Andhi Khola river at Borlangpul discharge ranges from about 12.64m^3/s for October about 2.53m^3/s for the month of February. The average monthly flow for Andhi Khola River was calculated from WECS/DHM methodology. The value of goodness of fit R^2 was obtained from formula 5.7. The parameters are different for various months. For monsoon months the flow values were relatively high compared to the monsoon month Table.6.3.

Table 6.3. Average monthly Flow of Andhi Khola River at Borlangpul

Months	Q(Mean Monthly Flow m^3/s)
January	3.08
February	2.53
March	2.74
April	2.67
May	3.61
June	9.26
July	27.00
August	38.62
September	28.46
October	12.64
November	5.50
December	3.71

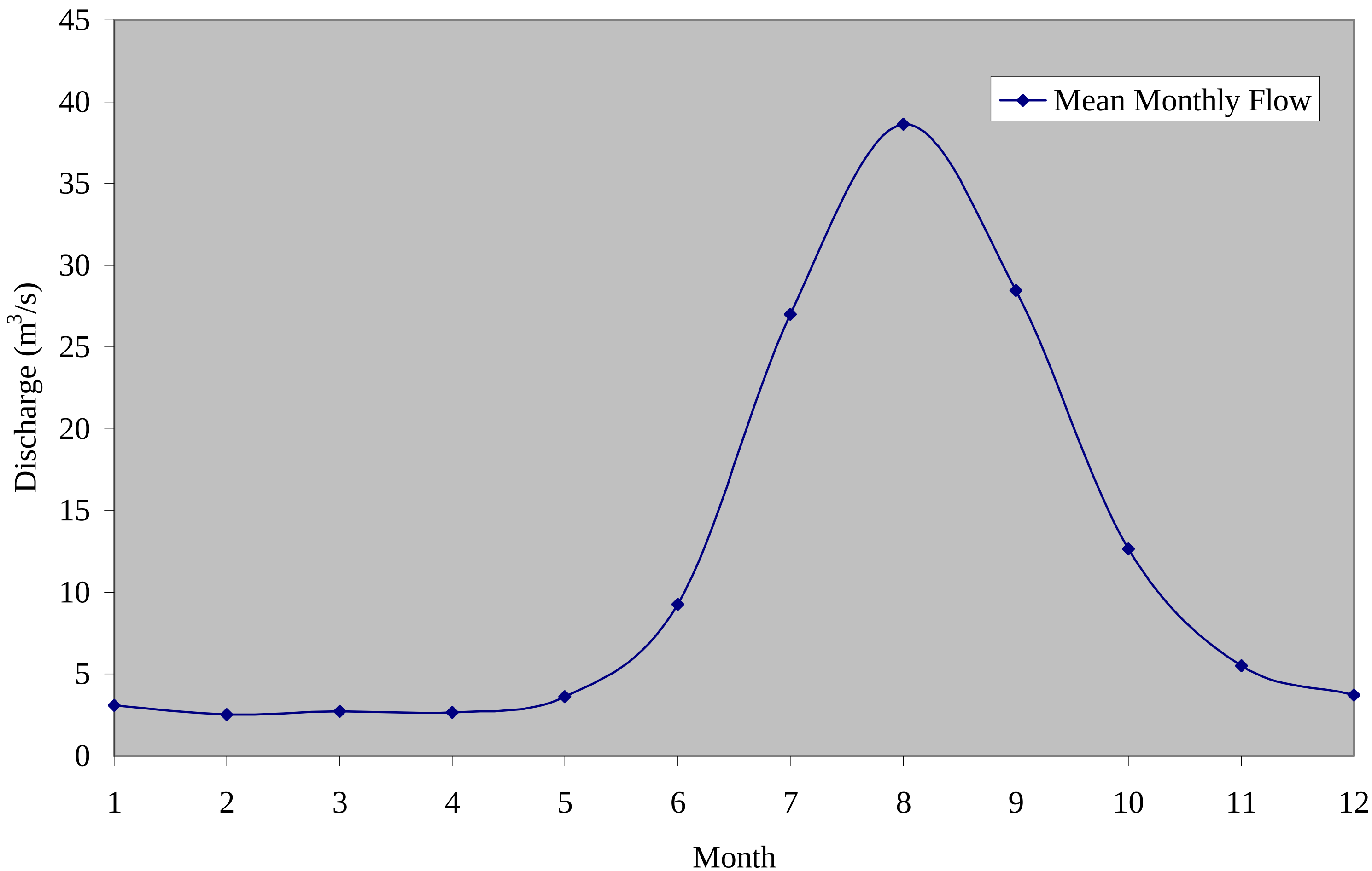


Fig 6.2. Mean Monthly FlowEstimation of Andhi Khola at Borlangpul

6.5. Flow Duration Curve

Flow necessary for duration curve is estimated with the help of WECS/DHM method. A flow duration curve gives elevation of low level flows. The flow duration curve is very useful in planning and designing of water resources projects and is indicated in Table 6.4 and graphically represented in Fig.6.3.

The flow duration curve indicates that for exceedence probability of 100% of the flow is only 0.67 m^3/s. This means that the flow excepted to be exceeded 100% of the time is 0.67 m^3/s.Similarly exceedence probability of 20% and 60% are about 19.98 m3/s and 3.31 m^3/s respectively.

These indicated values are very important for irrigation and drinking water projects.

Table 6.4. Flow Duration Curve of Andhi Khola river at Borlangpul

Exceedence Probability %	Discharge(m^3/s)
0	53.66
5	39.99
20	19.98
40	6.36
60	3.31
80	2.33
95	1.54
100	0.67

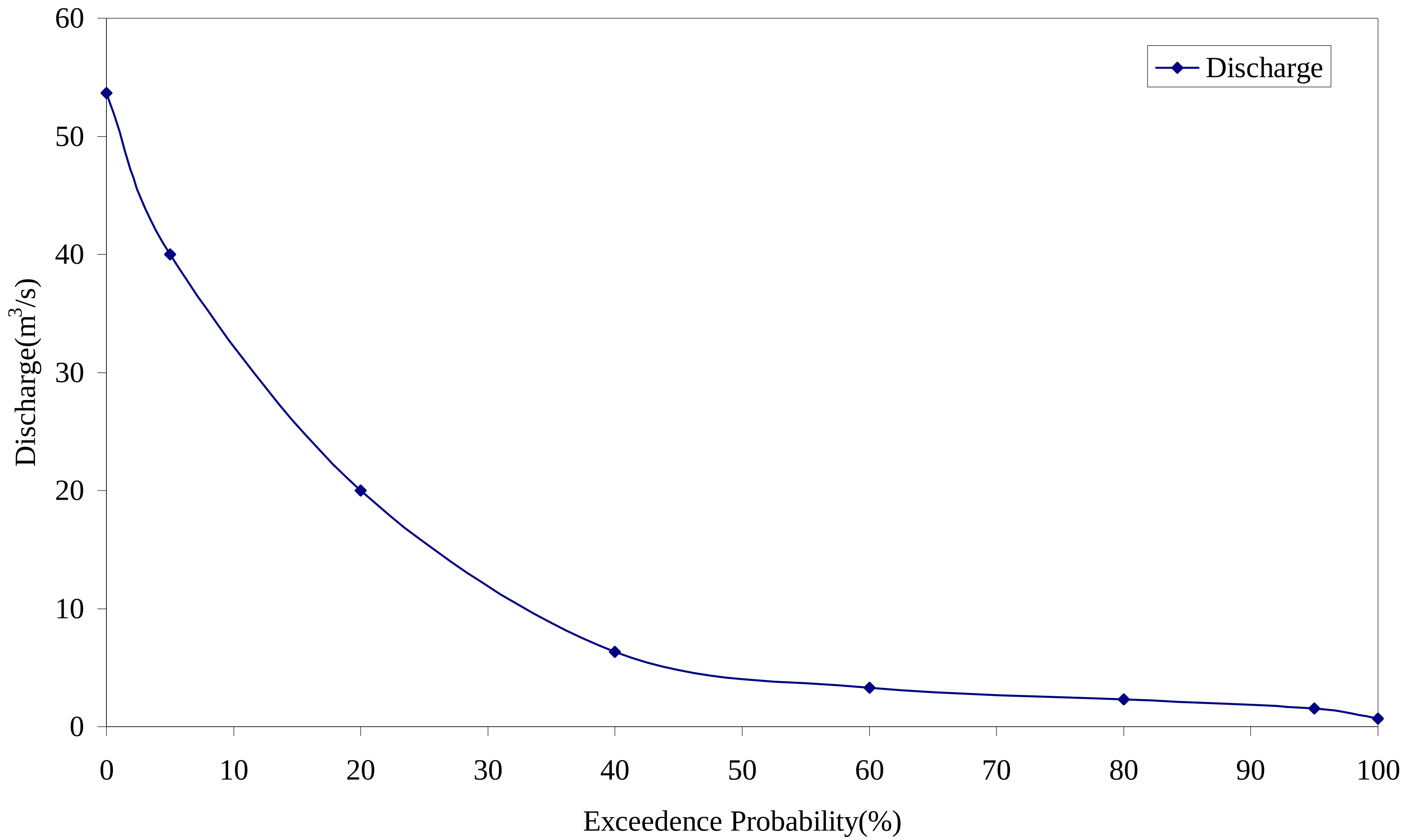


Fig. No.6.3. Flow Duration Curve of Andhi Khola at Borlangpul

6.6. High flow by transposition equation by WECS/DHM method

The transposition is done by Cudworth formula as referred by WECS/DHM method. The floods for various return periods for Andhi Khola at Borlangpul are calculated in Table 6.5 with the help of discharge data at Andhimuhan gauging site. The data was transposed to Andhi Khola at Borlangpul River. This transposed discharge data were used to get the flood for various return periods.

6.6.1. Transposition of data from Andhimuhan to Borlangpul.

Table 6.5 and Figure 6.4 indicate the flood frequency analysis for Andhi Khola at Borlangpul river with the help transposition discharge data from Andhimuhan.
Similarly Table 6.5 indicate the average monthly flow of Borlangpul (Andhi Khola) river with the help transposition discharge data from Andhimuhan.

Table 6.5. Flood Frequency Analysis of Andhi Khola River at Borlangpul with transposition of data from Andhimuhan.

Return Period (Year)	Discharge (m^3/s)	
	Weibuls(Transposition)	WECS/DHM
2	167.2	213.4
5	340.5	362.5
10	471.6	478.1
20	602.7	600.7
50	776.0	777.1
100	907.0	922.1

Table 6.6. Average Monthly Flow of Andhi Khola River with transposition of data from Andhimuhan.

Month	Borlangpul
Jan	1.4
Feb	1.1
Mar	0.9
Apr	0.9
May	2
Jun	10.3
Jul	28.8
Aug	27.6
Sep	19.6
Oct	7.5
Nov	2.8
Dec	1.7

Table 6.6. indicates the average monthly flow of Andhi Khola at Borlangpul with the help of transposition discharge data from Andhi Muhan..Table 6.6 gives the minimum average monthly flow is 0.9 m^3/s and maximum average monthly flow is 28.8 m^3/s.

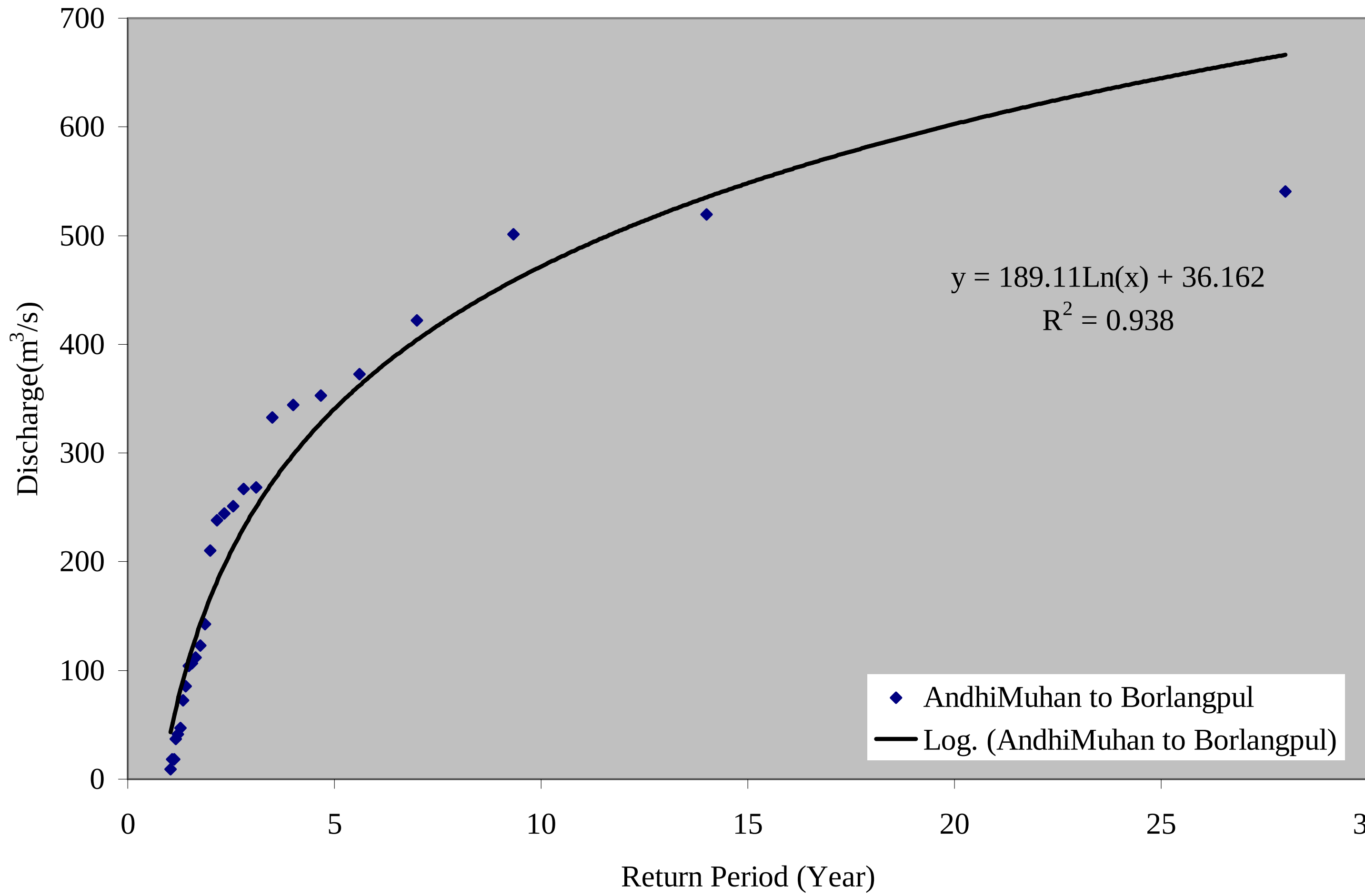


Fig 6.4.Flood Frequency Analysis of Andhi Khola at Borlangpul (Transposed)

6.7 Comparison of Estimated High Flows of Borlangpul (Andhi Khola) River with WECS/DHM and Transposition Method.

The estimated high flows of Andhi Khola at Borlangpul site have been obtained with WECS/DHM method and with transposition methods with the discharge data at Andhimuhan.

These estimated data are given in Table 6.7 and represented in Fig. 6.5. indicates the comparison of the high flows with these methods . It is observed that the curve obtained from WECS/DHM method is closely agreeing with the curve obtained from the transposition discharge data of Andhimuhan.

However, the curve for Borlangpul site obtained from the transposition discharge data from Andhimuhan lies above the estimated discharge data curve from WECS/DHM method using discharge data at Andhimuhan.

Table 6.7. Comparison of Flood Frequency Analysis of Andhi khola River at Borlangpul .

Return Period(Year)	Weibuls(transposition)	WECS/DHM
2	167.2	213.4
5	340.5	362.5
10	471.6	478.1
20	602.7	600.7
50	776.0	777.1
100	907.0	922.1

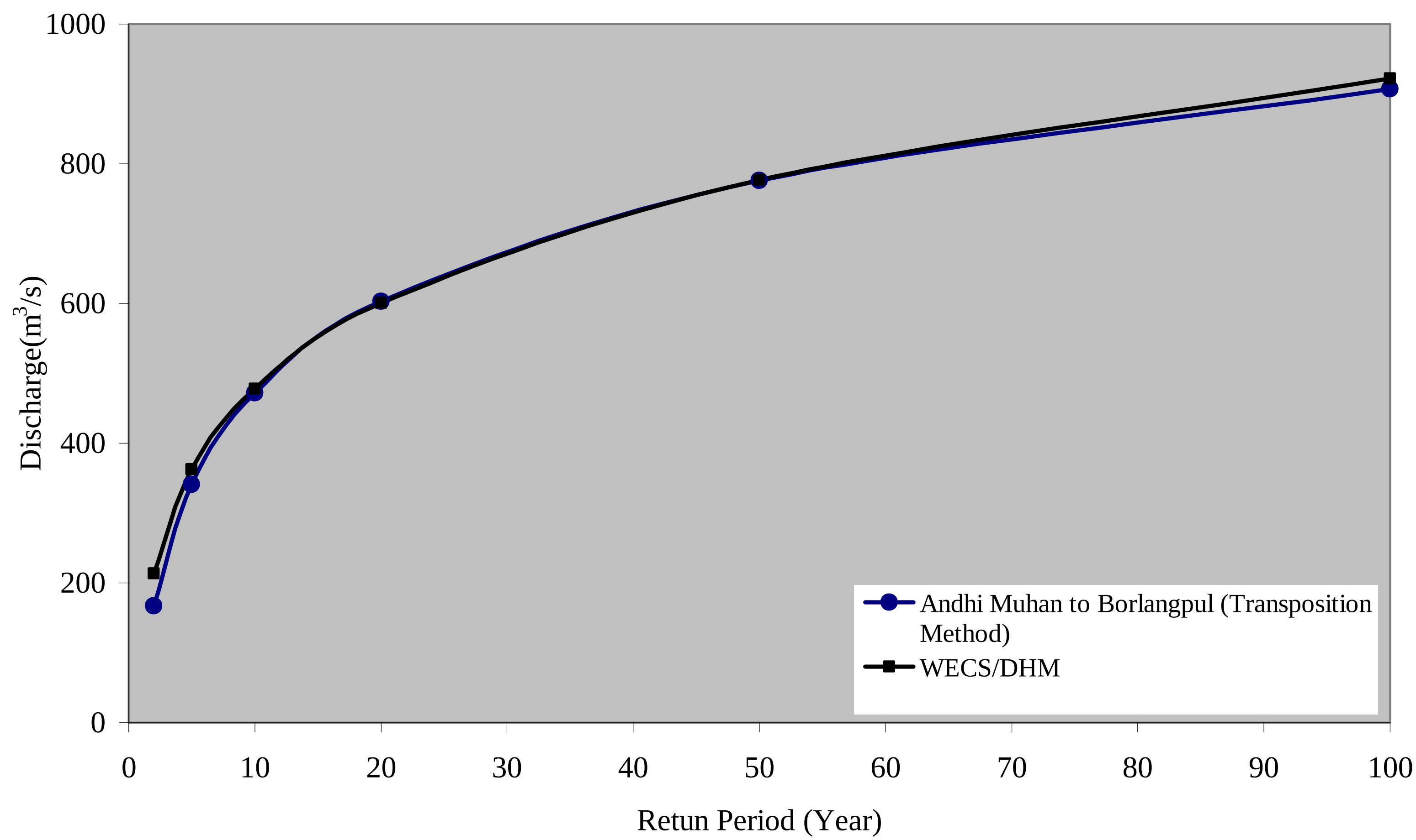


Fig. 6.5. Comparison of Estimated High Flow of Andhi Khola at Borlangpul with WECS/DHM and Transposition Method

6.8. Comparison of Estimated Mean Monthly Flow of Borlangpul with WECS/DHM and Transposition Method

The estimated mean monthly flow of Borlangpul has been obtained with WECS/DHM method and with the discharge data at Andhimuhan. These estimated data are given in Table 6.8 and graphically represented in Fig. 6.6 and are compared.

The mean monthly estimated flows for Borlangpul with WECS/DHM method is not agreed closely with estimated mean monthly flow for Borlangpul with transposed data of Andhimuhan because of very different physiographic regime of the Borlangpul from Andhimuhan.

Table 6.8. Comparison of Mean Monthly Flow of Andhikhola River.

Month	Transposed Data	WECS\DHM
Jan	1.4	3.08
Feb	1.1	2.53
Mar	0.9	2.74
Apr	0.9	2.67
May	2.0	3.61
Jun	10.3	9.26
Jul	28.8	27.00
Aug	27.6	38.62
Sep	19.6	28.46
Oct	7.5	12.64
Nov	2.8	5.50
Dec	1.7	3.71

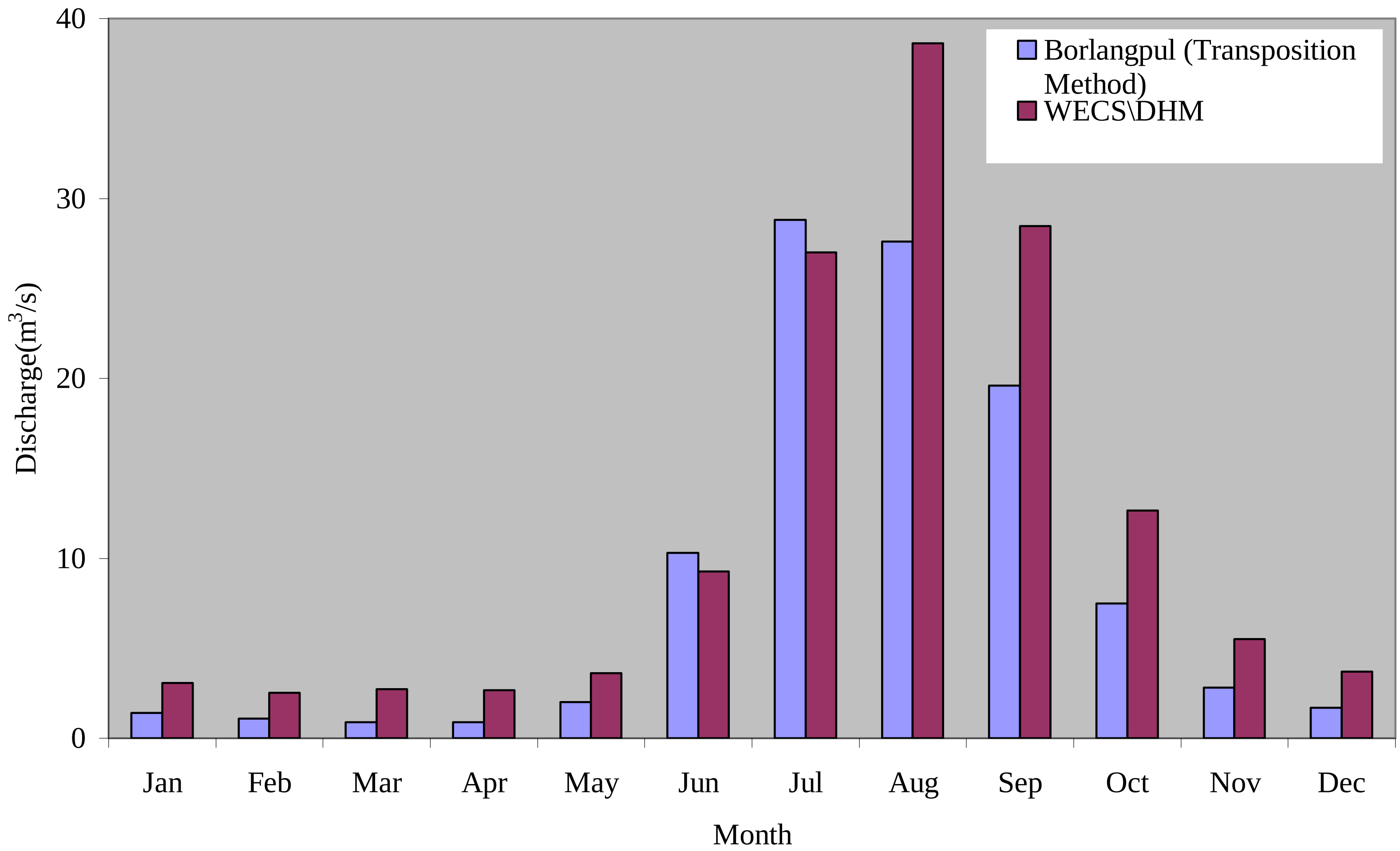


Fig.6.6. Comparison of Mean Montly Discharge of the Transposed Data of Borlangpul and WECS/DHM Method

CHAPTER VII

Conclusion and Recommendation

7.1 Conclusion

- The area of the Andhi Khola basin is 195 sq. km. with stream length of 27.4 km basin length of 17.0 km and maximum width of 18.3 km. The basin extends from latitudes 28.3 to 28.14'N longitudes 83.44' to 83.57'E.
- The highest elevation within the basin is 2509 masl. The Andhi Khola originated at an elevation of 2286 masl north- west to meet the Kali Gandaki at a distance of about 60 km from its origin.
- The first 700 meter reach of the river is very steep with an average gradient of about 65%. The next 800 meter of the river flows has average gradient of about 12.5%. For about 11.4 km downstream it decreases to about 12.5% and for a further 14.5 km downstream it flows with an average gradient of 1.1%.
- The warm temperate climate prevails in the Andhi Khola basin. Basin temperature varies between 3.1°C to 31.1 °C.
- These physical features along with longitudinal profile of the river indicate that Andhi Khola is adgronic river. It can inflict damage by monsoon floods with erosion and landslide problem.
- Low flow frequency analysis shows that the monthly minimum value for the return period of 2 years was found 2.37m^3/s. Similarly the monthly minimum value was found 1.69m^3/s and 1.56m^3/s for the return period of 10 to 20 years respectively. The one day minimum value for the return period of 2 years, 10 years and 20 years are 1.83 m^3/s, 1.22m^3/s and 1.11m^3/s respectively. The 30 day minimum value for the return period of 2 years, 10 years and 20 years are 2.24 m^3/s and 1.43m^3/s. These values will be important for irritation, water supply and hydropower projects.
- For high flow frequency analysis it is found that during the monsoon the Andhi Khola catchment gets heavy rainfall. High monsoon rains generates disastrous peak flows. It is observed that return periods of 2 years, 20 years and 50 years are

213.4 m^3/s, 600.7m^3/s and 777.1 m^3/s respectively. It is to be remarked that the hydrologic structures like bridge, walls side of cultivated areas and cannel etc have to face such high floods. Design of such structure will depend on these values of flood.

- For monsoon month the mean monthly flow estimations were relatively high compared to the non- monsoon months.
- Mean daily discharge of dry year in 1969 and mean daily discharge of wet year from 28 yrs of data indicates that monsoon flow can vary almost by double the amount.
- The flow duration curves indicates that for exceedence probability of 100% the flow is only 0.67 m^3/s which means that the flow excepted to be exceeded 100% of the time is 0.67 m^3/s . Similarly exceedence probability of 20% and 60% are about 19.98m^3/s and 3.31m^3/s respectively. These indicated values are very important for irrigation project and for drinking water project in future.
- Mean monthly estimated flows of Andhi Khola River is very low in February as 2.53 m^3/s.The flows slightly increases in March, April and May. Then it increases in June and rapidly in July, August and September, and then subsequently decreases. The maximum flow is in August as 38.62 m^3/s.
- The mean monthly flow for July is 27m^3/s and August is 38.62m^3/s and September is 28.46m^3/s.
- The Andhi Khola basin has cultivated areas as 22% of the area of catchment and irrigated land as 35% of total cultivated area. Therefore, irrigation will have to be developed in the basin and the result of the flow duration curve will be useful for this purpose.
- The Andhi Khola is used for a hydroelectric plant with 5 KW by Butwal Power Company.
- Comparison between WECS/DHM and transposition discharge is not agreeing to a good extent.
- Mean monthly minimum discharge by WECS/DHM method is found to be 2.53m^3/s in February and transposition method is found to be 0.9m^3/s in March and April.

- Mean monthly maximum discharge WECS/DHM is found Aug. is 38.62m3/s and transposed method is 28.8m3/s.
- Comparison of estimated high flow of Borlangpul with WECS/DHM and transposition method, curve is very close to agree.

Recommendation

- Automatic rain gauges and discharge stations in essential are needed for meaningful hydroelectricity analysis in Andhi Khola catchment with area 195km^2.
- Sediment and flood hazards studies are essential for constructing hydraulic structures like bridge, channel intake and roads and leeves for cultivated areas.
- Regular measurement of high flow, low flow and stream flow are required with advance technologies and to develop models for study of high and low flow.
- Human settlements are predominately in rural areas and agricultural activities are more intense in the lower elevation, particularly in river valleys and flat areas. Feasibility study for small hydro power project, irrigation project and flood hazard studies are essential for the Syangja district.

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Annex I: Estimated Datas

Table 1: High Flow Frequency Estimation

	lnQ2	Q100/Q2	lnQ100/Q2	sigma1	lnQ2+ssigma1	Qf
2	5.363168339	4.320993	1.4635	0.629185	5.3632	213.4
5	5.363168339	4.320993	1.4635	0.629185	5.8929	362.4702787
10	5.363168339	4.320993	1.4635	0.629185	6.1698	478.0828653
20	5.363168339	4.320993	1.4635	0.629185	6.3982	600.7497097
50	5.363168339	4.320993	1.4635	0.629185	6.6555	777.0581893
100	5.363168339	4.320993	1.4635	0.629185	6.8267	922.1

Table 2: Average Monthly Flows Estimation

Months	Ln avg elv.	a	ln(AWI)	ln(A<3k)	sqrtA5k	A<3k	A<5k	b	c	d1	d2		Q
Jan	7.337717859	-16.7	7.4955	6.131226	21.448	460	460	1.36	0.47	0.82		1.8298	6.232682
Feb	7.337717859	-17.2	7.4955	6.131226	21.448	460	460	1.42	0.456	0.814		1.6283	5.095434
Mar	7.337717859	0.384	7.4955	6.131226	21.448	460	460				0.091		5.455647
Apr	7.337717859	0.181	7.4955	6.131226	21.448	460	460				0.104		5.815581
May	7.337717859	0.0001	7.4955	6.131226	21.448	460	460				0.136		8.508743
Jun	7.337717859	-19.5	7.4955	6.131226	21.448	460	460	1.61	0.709	0.872		2.9745	19.57972
Jul	7.337717859	-16.3	7.4955	6.131226	21.448	460	460	1.26	0.759	0.884		4.0546	57.66469
Aug	7.337717859	-14.7	7.4955	6.131226	21.448	460	460	1.24	0.622	0.871		4.4013	81.55646
Sep	7.337717859	-13.7	7.4955	6.131226	21.448	460	460	1.09	0.594	0.872		4.0969	60.15315
Oct	7.337717859	-15.3	7.4955	6.131226	21.448	460	460	1.21	0.6	0.846		3.263	26.12732
Nov	7.337717859	-16.7	7.4955	6.131226	21.448	460	460	1.36	0.543	0.826		2.4138	11.176
Dec	7.337717859	-17	7.4955	6.131226	21.448	460	460	1.39	0.504	0.822		2.017	7.516113

Table3: Flow Duration Curve

bability of ceedence	Ln avg elv.	ln(AWI)	ln(A<3k)	sqrtA5k	a	b	c	d1	d2		Discharge
0	7.337717859	7.495542	5.273	13.96424	-12.8	0.366	0	0.529		-7.3249785	53.66
5	7.337717859	7.495542	5.273	13.96424	-13.6	1.108	0.607	0.874		3.688586962	39.99
20	7.337717859	7.495542	5.273	13.96424	-17	1.359	0.716	0.883		2.994825212	19.98
40	7.337717859	7.495542	5.273	13.96424	-19	1.554	0.656	0.859		1.849395688	6.356
60	7.337717859	7.495542	5.273	13.96424	-18.3	1.535	0.513	0.832		1.195745563	3.306
80	7.337717859	7.495542	5.273	13.96424	-19.4	1.589	0.559	0.834		0.847323256	2.333
95	7.337717859	7.495542	5.273	13.96424	-21.2	1.732	0.598	0.842		0.431127042	1.539
100	7.337717859	7.495542	5.273	13.96424	-2.18	-	0.048	-	0.077	0.817645043	0.669

Annex II: Extreme Flow Data

Table 1: Andhi Khola data obtained from Cudworth Transposition (Extreme Flow Data from Andhimuhan)

Year	Discharge Q	Descending order	Rank(m)	Return Period
1965	501.3	540.4	1.0	28.0
1966	352.9	519.6	2.0	14.0
1967	266.9	501.3	3.0	9.3
1968	421.9	421.9	4.0	7.0
1969	112.0	372.4	5.0	5.6
1970	540.4	352.9	6.0	4.7
1971	46.9	344.4	7.0	4.0
1972	519.6	332.7	8.0	3.5
1973	372.4	268.2	9.0	3.1
1974	142.6	266.9	10.0	2.8
1975	104.2	251.3	11.0	2.5
1976	238.3	244.2	12.0	2.3
1977	210.3	238.3	13.0	2.2
1978	18.4	210.3	14.0	2.0
1979	106.8	142.6	15.0	1.9
1980	72.3	123.1	16.0	1.8
1981	268.2	112.0	17.0	1.6
1982	37.0	106.8	18.0	1.6
1983	251.3	104.2	19.0	1.5
1984	332.7	85.3	20.0	1.4
1985	244.2	72.3	21.0	1.3
1986	344.4	46.9	22.0	1.3
1987	18.4	41.1	23.0	1.2
1988	123.1	37.0	24.0	1.2
1989	41.1	18.4	25.0	1.1
1990	85.3	18.4	26.0	1.1
1991	9.0	9.0	27.0	1.0