ESTIMATION AND ANALYSIS OF LOW, HIGH AND MEAN MONTHLY FLOW FOR UNGAUGED MANOHARA RIVER

A

Dissertation Submitted to the Institute of Science and Technology

Central Department of Hydrology and Meteorology

in Partial Fulfillment of the Requirements for the

Degree of Masters in Hydrology and Meteorology

By

Damodar Bagale

September, 2007

Central Department of Hydrology and Meteorology

Tribhuvan University

Kirtipur, Nepal

TRIBHUVAN UNIVERSITY
CENTRAL DEPARTMENT OF HYDROLOGY & METEOROLOGY

Phone No.: 4-331418
P.O.Box No.: 20390 G.P.O
Kathmandu
Office of the Head of Department
Kirtipur, Kathmandu, Nepal
Fax No.: 977-1-4331964

Date: ....

Letter of Recommendation

This is to certify that **Mr. Damodar Bagale** has prepared this dissertation on 'Estimation and Analysis of Low, High and Mean Monthly flow of Manohara River' under my supervision. I certify that he had carried out all his work sincerely with keen interest. I hereby recommend this thesis for approval.

....
Prof. Khadga B. Thapa
(Supervisor)
Head of the Department
Central Department of
Hydrology and Meteorology
Tribhuvan University
Kirtipur

TRIBHUVAN UNIVERSITY
CENTRAL DEPARTMENT OF HYDROLOGY & METEOROLOGY

Phone No.: 4-331418
P.O.Box No.: 20390 G.P.O
Kathmandu
Office of the Head of Department
Kirtipur, Kathmandu, Nepal
Fax No.: 977-1-4331964

Date: ....

23 September 2007

Letter of Approval

This dissertation entitled 'Estimation and Analysis of Low, High and Mean Monthly flow of Manohara River' has been approved as a partial fulfillment for the Master's degree in Science of Meteorology.

DISSERTATION COMMITTEE

Head of Department ....

Supervisor ....

Internal Examiner ....

External ....

Central Department of Hydrology & Meteorology
Tribhuvan University, Kirtipur
Kathmandu

Acknowledgement

It is my great pleasure to express my heartfelt and sincere gratitude to my respected supervisor **Prof. K.B. Thapa**, Head of the Central Department of Hydrology and Meteorology, T.U. for his guidance, constant support and encouragement throughout the course of my dissertation.

I am also grateful to **Lecturer Mr. Deepak Aryal**, **Lecturer Mr. Suresh Maharjan, Lecturer Mr. Tek Bahadur Chhetri** and **Assistant Lecturer Mr. Shakti P.C.** of Central Department of Hydrology and Meteorology, T.U. for their encouragement, constructive suggestions during the study period.

My sincere thanks goes to my class fellows Sunil Acharya, Santosh Regmi, Dibas Shrestha, Yogesh Pant, Sabina Lohani, Sikchya Upadhya, Dinkar Kayastha, Nirajan Sapkota and friend Ramchandra Karki for their suggestions and help during the study period. I would also like to thank Mr. Madan Shrestha for providing me materials during the study period and all the faculty members of CDHM.

I am also grateful to my family members for providing constant support to my student life. Indeed, I am indebted for their belief in me.

Abstract

Manohara River, an important tributary, of Bagmati River has a catchment area of 66.34sq.km. with length and perimeter as 24 km and 47.25 km respectively. The form factor is 0.115, elongation ratio as 0.38, the circulatory ratio as 0.37 and compactness coefficient is 1.5. These statistics relating to the shape of the catchment indicate that the catchment is not symmetrical in shape. It has narrow width at the lower reach and has a fan shape at the upper reach with relatively short river length and high relief of 1038 meters. There is a possibility of flash flood with high intensity of monsoon rain which is frequently experienced. The Manohara River is ungauged and this catchment has fertile agriculture fields supplying vegetables to Kathmandu city in all seasons.

The settlement in this catchment is rapidly growing due to overcrowding of the nearby Kathmandu city. In the near future the agriculture-fields will require irrigation, the growing settlement will require more water supply and more link-roads have to be constructed with many culverts and bridges. Since, no discharge data for Manohara river were available, low flows and high flows have been estimated using transposition data with the help of Cudworth equation, as referred by WECS/DHM method. The discharge data of Bagmati River at Khokana, Chovar and Sundarijal have been transposed for the Manohara River for the estimation of high flows and mean monthly flows. The low flows have been estimated with WECS/DHM method using the catchment area with associated parameters. The monthly minimum low flow for the return period of 2 year has been found to be 1m^3/s. Similarly the monthly minimum flows have been calculated as 72 m^3/s and .56m^3/s for the return periods of 10 and 20 years respectively. The one day minimum low flow value for the return period of 2 years, 10 years and 20 years have been calculated as 1m^3/s, 0.65 m^3/s and 0.5m^3/s. These values are very important for irrigation and domestic water supply projects that are likely to be implemented in the near future for this ungauged river. The flow duration curve has also been constructed for this river with the WECS/DHM method. The flow duration curve indicates that exceedence probability of 100% flow is only 0.14m^3/s. Similarly exceedence probability of 20% and 60% are 10m^3/s and 2m^3/s respectively. These values are also very important for irrigation projects and drinking water projects in near future. Regarding high flood analysis for Manohara River, discharge data were transposed to the Manohara River from Chovar and Khokana and Sundarijal sites. Estimated floods for 5 years, 20 years, 50 years and 100 years have

been calculated as about 201m^3/s, 303 m^3/s, 372 m^3/s and 422 m^3/s respectively. The discharge data of Bagmati River at Chovar and Khokana with transposed data methodology for Manohara River gives reasonable estimated floods agreeing with the values estimated by WECS/DHM method. This is because the bridge site near Pepsi Cola Factory, Chovar site, and Khokana site all are situated in the flood plains of Kathmandu valley, but Sundarijal gauging site is located on the higher elevation near the origin of Bagmati River. The bridge site of Manohara near the Pepsi cola factory, Chovar site and Khokana site have same type of physiographic characteristics but Sundarijal site has completely different physiographic characteristics. Therefore, data from Sundarijal site is not suitable for estimation of high flood for Manohara by data transposition method.

The estimated high floods by transposition method will be useful for designing the bridge near the Pepsi Cola Factory and many link roads with culverts in near future. The results from the discharge data transposition method for ungauged Manohara River which will be useful for water resources project in the near future. Such techniques will also be useful and can be applied for many ungauged catchments in various parts of the country.

Abbreviations

AWI	Average Wetness Index
DHM	Department of Hydrology and Meteorology
GIS	Geographic Information System
GLOF	Glacier Lake Outburst Flood
GBM	Ganga Brahmaputra Meghana
ICIMOD	International Centre for Mountain Development
KW	Kilowatt
MPF	Maximum Probable Flood
MW	Megawatt
MULTR	Multiple Regression Program
NOAA	National Oceanographic and Atmospheric Agency
SPS	Standard Project Storm
UK	United Kingdom
UNEP	United Nations Environmental Programme
US	United Sates
WECS	Water and Energy Commission Secretariat

Mathematical Abbreviations

A	Basin Area
A<3K	Basin area below 3000m
A<5K	Basin area below 5000m
$C_{d,T}$	Constant coefficient for a duration d and return period T
$F_{d,T}$	Coefficient of independent variable for duration d and return period T
g	Skewness coefficient
k_T	Frequency factor
L	Basin Length
Masl	Above mean sea level
r	Coefficient of corelation
R^2	Goodness of Fit
s	Standard normal variate
T	Return Period
y_T	Reduced variate
$\bar{y}_n$	Reduced extremes
Q_2	2 year return period flood discharge
Q_{100}	100 year return period flood discharge
$Q_{d,T}$	Discharge
x_T	Magnitude of flood
σ_n	Standard deviation

List of Tables

List of Figures

List of Annexes

Contents

CHAPTER I

INTRODUCTION

1.1. Background

Water resources can be considered as the most important natural resources because they are not only renewable but also 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 (Berz, 2000). 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 (NOAA, 1994). 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 (Berz, 2000). 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 (Berz, 2000). 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 (Berz, 2000):

- 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. (Scofield and Morgottini, 1999).

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.

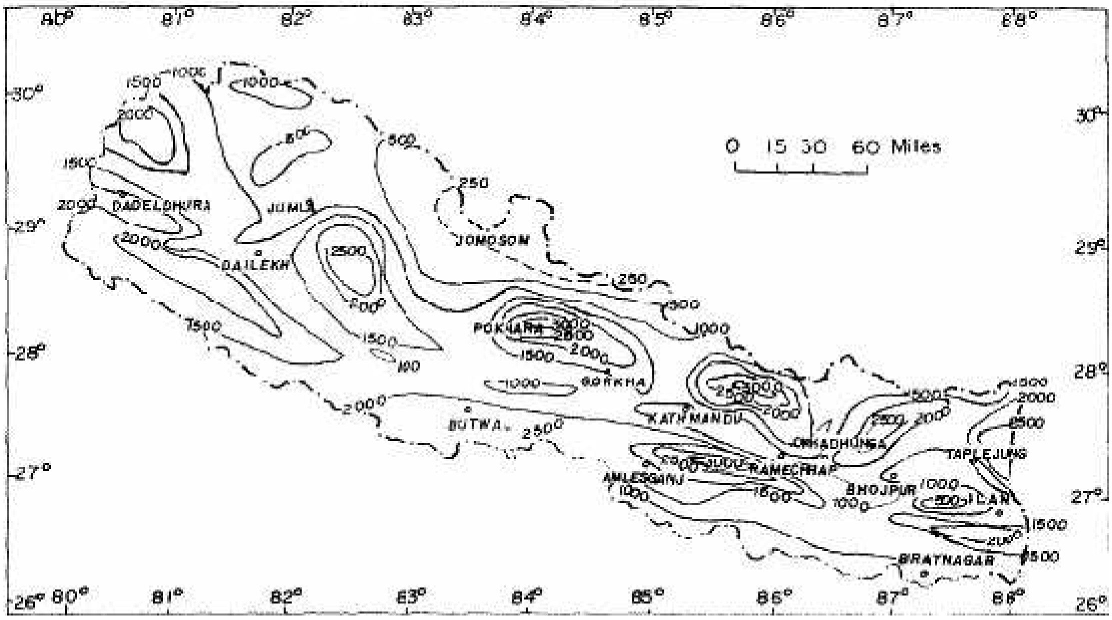
Karnali, Narayani and Koshi are the three major river system of Nepal. These entire rivers originate in Tibet. Although the geographical area of Nepal is 147,181km^2, Nepal drains the discharge from more than 194,000km^2, the additional area being the catchments lying in Tibet. All the river systems 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.

Hydrology of Nepal is primarily dominated by the monsoons characterized by high precipitation during the summer monsoons from June to September. The remaining periods, with western disturbance rain in winter and thunderstorms in summer bring about

20% of the annual precipitation therefore a wide annual variability of water makes the water management issue particularly challenging for a country like Nepal.

Extremities in precipitation pattern are not only limited to temporal variation in precipitation but also on spatial variations. High precipitation in Siwalik region and the increasing precipitation with increasing elevation observed in most of the mountains areas in Nepal illustrate the topographic influence in the high precipitation pattern. Typical example of such variation is illustrated by the distribution of precipitation in Kathmandu valley where the annual precipitation varies from 1400mm in valley floor to more than 2500mm in the higher slopes of Kathmandu area lying in the windward side of the Kathmandu valley.

Another example of strong windward and leeward effect are observed in the Annapurna area, Pokhara located in the windward side of the Annapurna region receives annual precipitation exceeding 3000mm where as the Mustang area in the leeward side receives less than 500mm in a year. The rainfall distribution in Nepal is shown in Fig. 1.1.



Source: DHM

Fig. 1.1. Rainfall Distribution in Nepal. Contours are in mm.

Nepal contains about 2.27% of the world's water resources but most of it remains unexploited (Yogacharya, 1998). Whenever water is viewed with an economic aspect, it can be used for achieving some social benefits, so it can be easily considered as our source. Nepalese rivers carry an annual runoff of 7112 cubic meter per second. Floods from China and 7% or 501 cubic meter per second drains in the frontier river Mahakali from India equivalent to the total runoff of 224 billion cubic meters (Shrestha, 1997). The average annual flow from Himalayas and Maharashtra rivers is 5,511 cubic meter per second. The snow and glacier in Nepal Himalayas spread over large areas of 14,795 sq km. with snow-ice reservoirs with huge amount of water. They account for the higher perennial flows during dry season in major systems. In the context of Nepal, the most important source of water for river is monsoon which occurs in rainfall from in June-September and precipitation from in December-January. About 1500mm rainfall occurs in a year, 10% of total precipitation in the form of snow occurs in northern part of Nepal and 75% of the annual surface runoff occurs during the monsoon period. Due to these phenomena caused by monsoon and snow melt runoff in short period that is, within four months. Nepal is affected by several catastrophic events like floods, landslides etc., so while considering any project near at the river site, detail study of natural events like flood, GLOF, etc., should be properly conducted.

Due to topographical condition of Nepal, the variation of monsoon rainfall has been categorized into three types as macro, meso and micro patterns. The macro scale pattern refers to the precipitation variation across greater Himalayas. The meso scale pattern referred within a defined geographical boundary and the variation within a hill watershed are referred to as micro scale. In the hills, pockets exist where precipitation characteristics, volume, duration and intensity are variable. Since one side of the hill may receives high rainfall while other side of the hill may receives very little or no rainfall. These phenomena can be defined from the windward side and leeward side across the Annapurna range.

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 (Shrestha, H.M. 1997) 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 hydroelectricity power by her water resources in theoretic view (Shrestha, H. M;1984-1985). 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 number of definitions related to floods have been proposed by various organizations and many scientists. Some of these definitions are summarized below. 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. (Scofield and Morgottini, 1999).

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 (Fattorelli et al., 1999). 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.

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.

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.

1.4. 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

Manohara River will require redesigning of the important bridge near Pepsi cola Industry. There are many local bridges that have to be redesigned and also newly constructed. Manohara sub-basin has a wide fertile flood plain and undulating landscape supplying essential vegetables for Kathmandu city. In future the vegetable farmer will require irrigation schemes. The shifting nature of this river inundating the flood plains with important settlements and farms will require river training works. For all these purposes, high and low flows are essential from this ungauged river and therefore appropriate methods are essential for estimation of these extreme flows. Many important rivers in different regions of Nepal are ungauged. Important water resources projects in such river basins will require flood estimation for designing of hydrologic structures and low estimation for irrigation and domestic water supply schemes. Keeping these important aspects in view, Manohara River has been selected because it is not gauged. Manohara basin will definitely emerge out with many important small scale water resources projects. There shall be more settlements in near future in this sub-basin which is adjoining the already overcrowded Kathmandu city.

The main objectives of this study for Manohara River are:

- To analyze the low flow of the river basin.
- To analyze the high flow frequency analysis of the basin.

- To analyze the mean monthly flow of the river basin.
- To analyze the flow duration curve of the river basin.
- To analyze the rainfall distribution pattern with meteorologic stations near by.
- To analyze the temperature distribution pattern with meteorologic stations near by.

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 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

2.2.1. Selected River Basins

The selected river basin for the study is Manohara River which originates from the Mahabharat Range in north east of Kathmandu Valley.

2.2.2. Data Source

Hydrological data such as discharge data in different years from Khokana and Chovar have been acquired from the Department of Hydrology and Meteorology. Similarly, Meteorological data such as average rainfall and average maximum temperature, average minimum temperature and average temperature have been acquired from the DHM. Maps used have been published from HMG/Nepal, Department of survey. Basins with hydro meteorological data less than 10 years are not used in these studies. The area of the Manohara basin has been calculated from the planimeter with the help of topographical map. The data of the Sundarijal has been taken from Hydrological estimations in Nepal.

2.3. Limitation of Study

For ungauged Manohara River, discharge data of Khokana and Chovar sites were used. Their gauged discharge data of long period were not available. Since the discharge datas of Khokana and Chovar were less than 30 years, Gumbel method was not used on. However, Gumbel method was used for Sundarijal because 30 years data were available. The temperature data for Sankhu and Nagarkot were not available. However, the temperature data of Kathmandu Airport nearby were used to study temperature trend for near by the outlet region of Manohara considered for this study. Sankhu and Nagarkot within the Manohara river basin with limited data of about 13 years have been used to study rainfall trend.

CHAPTER III
THE MANOHARA BASIN

3.1. The Manohara River

The Manohara River is one of the main tributaries of the Bagmati River. The Basin is located in the central part of Nepal and lies on the Bhaktapur district. The basin extends from Latitudes 27°41′05″N to 27°46′50″N and Longitudes 85°21′40″E to 85°31′40″. The total area of the basin is 66.34 sq. km. and the length of the river up to the Bridge (near Pepsi cola Industry) is 24 km. The main tributaries of the Manohara River are Ryale Khola, Ghatte Khola, Kattike Khola, Mahadev Khola, Satghatte Khola and Sali Nadi.

3.2. Description of the Basin.

The lower portion of Manohara basin is narrow and the upper portion is fan shaped. The form factor is defined as the ratio of the basin area to the square of the basin length. The form factor of Manohara basin is 0.115.

The Circulatory Ratio is defined as the ratio of the basin area to the area of the circle whose perimeter is equal to the perimeter of the basin. The Circulatory Ratio is 0.374.

The Compactness coefficient is defined as the ratio of the perimeter of the basin to the perimeter of a circle whose area is equal to the area of the basin. The Compactness coefficient of Manohara Basin is 1.463.

The Elongation Ratio is defined as the ratio of the diameter of a circle whose area is same as the area of the basin to the length of the basin. The Elongation Ratio of Manohara River is 0.383. All these calculated parameters give same indication that basin is not fan shaped strictly.

The Maximum Basin Relief H is the elevation difference between the basin outlet and the highest point on the basin perimeter usually expressed in meters. The highest point near Nagarkot is 2392m and the lowest point near the outlet at Pepsi Cola Industry is 1308. The Basin Relief of Manohara River is 1084 m.

3.3. Topography and Physiography of Manohara Basin

The Bagmati River is the principal river in Kathmandu valley. The length of the Bagmati River from its origin Shivapuri ridge to the Chovar gorge is about 35 kilometers. Because of the relatively flat topography of the Manohara Basin with soft, deep sedimentary deposits, in the lower reach this river has meandering course and, in some areas, wide flood plains. Human settlements and agricultural areas are more in the lower reach. The general lower slope of the basin is located towards the central part and then to the south-west near the outlet. The common feature of the rivers is that during monsoon season they often get flooded and deposit enormous amounts of sand and fine particles over their banks. In the dry season, their water level is unusually low despite the fact that they are perennial.

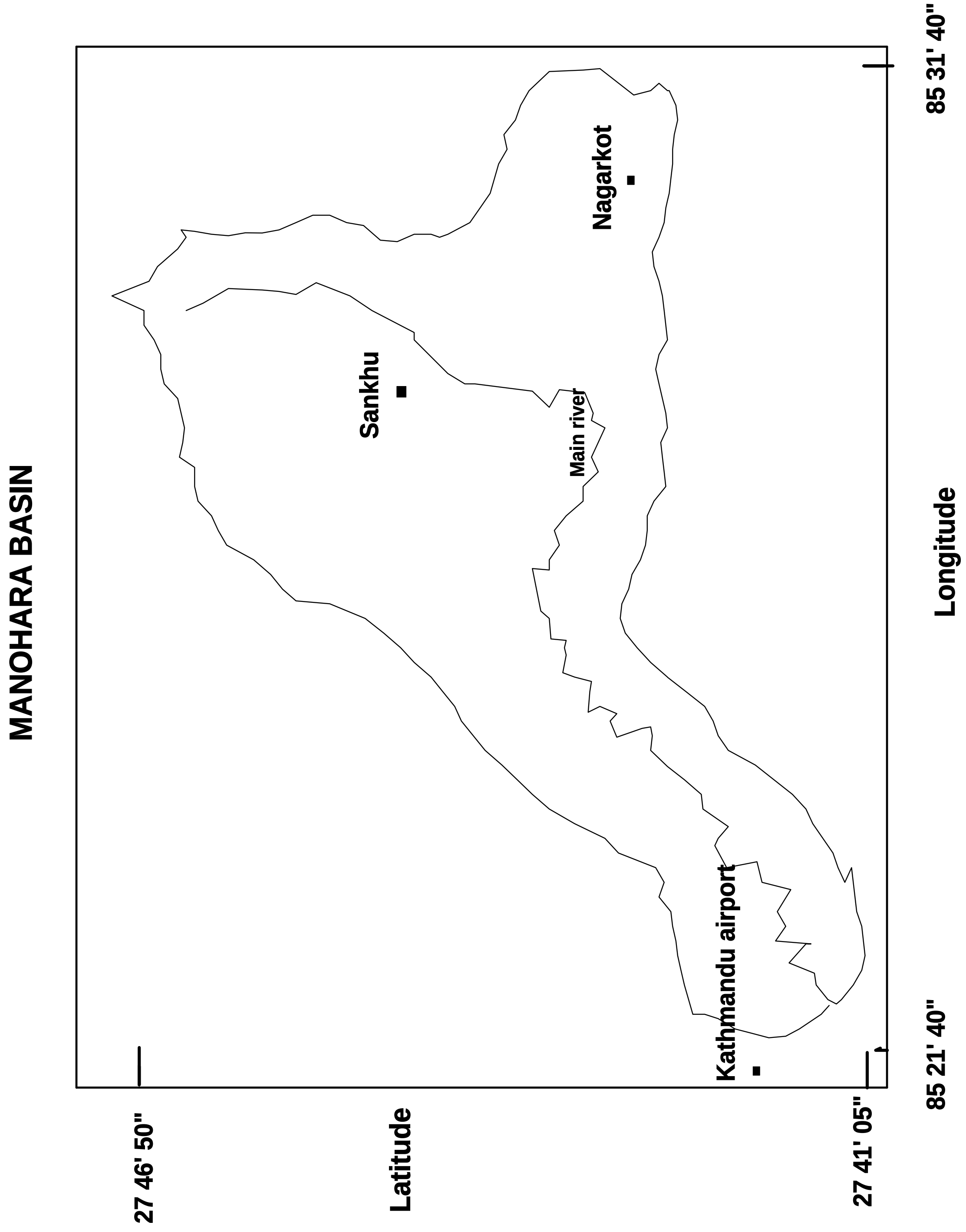


Fig. 3.1. Map of Manohara Basin

3.4. Climate

3.4.1. Rainfall of Nagarkot

Mean monthly rainfall of Nagarkot is shown in Fig (3.2). In July, the maximum rainfall observed is 484mm and 9.2mm is the minimum in November. The rainfall of Nagarkot shows increasing trend from January to July and decreasing trend from August.

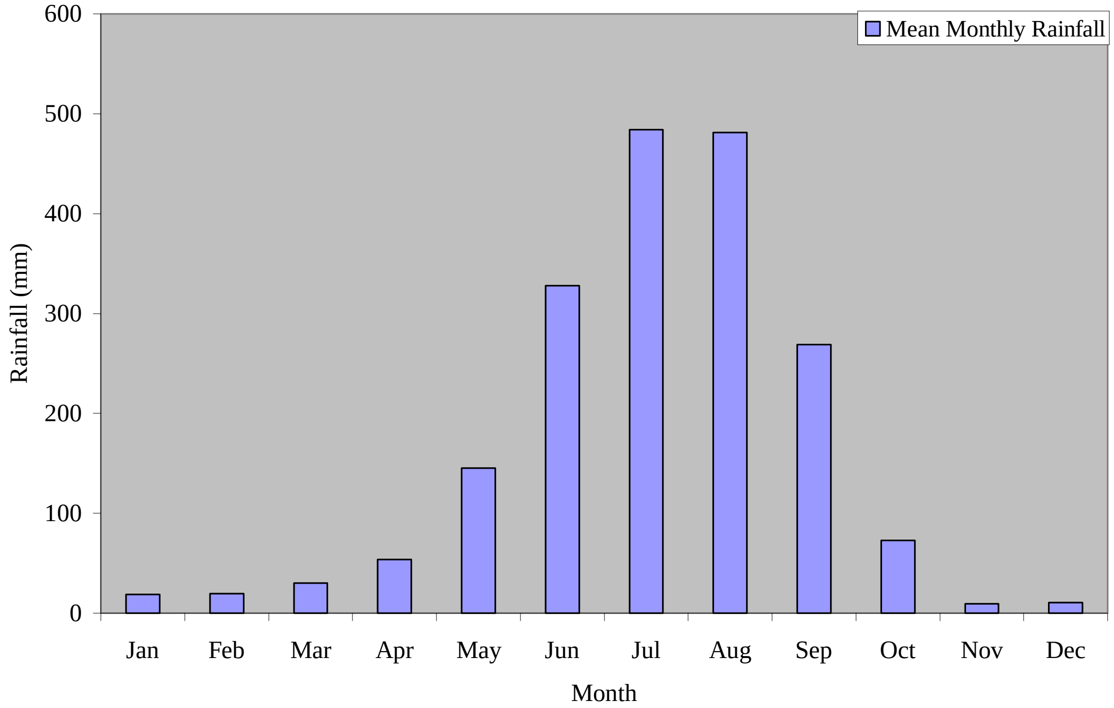


Fig.3.2. Mean Monthly Rainfall of Nagarkot

3.4.2. Rainfall of Sankhu

Mean monthly rainfall of Sankhu is shown in Fig (3.3). In July the maximum rainfall observed is 547mm and in December, the minimum rainfall observed is10mm.

The rainfall of Sankhu Fig (3.3.) shows increasing trend from January to July and decreasing trend from August.

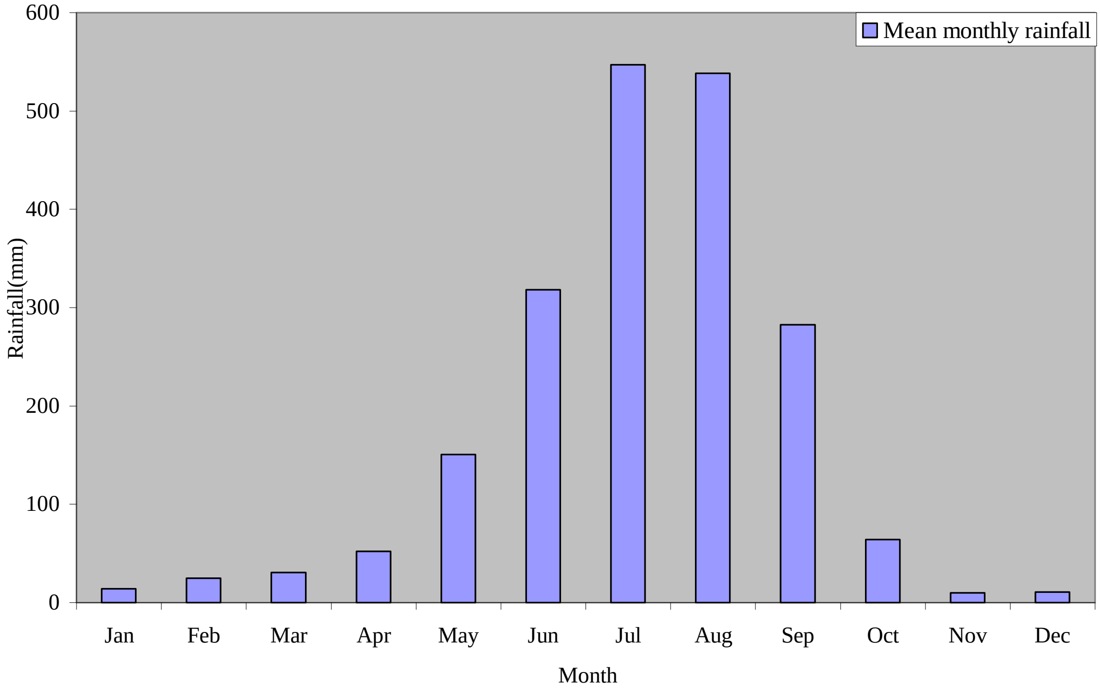


Fig.3.3. Mean Monthly Rainfall of Sankhu

3.4.3. Rainfall and Temperature of Kathmandu Airport

Mean monthly rainfall of Kathmandu Airport is shown in Fig (3.4). In July the maximum rainfall observed is 374.1mm and the minimum in November. The rainfall of Kathmandu Airport shows increasing trend from January to August and decreasing trend from August to December. The average maximum temperature and average minimum temperature of the Kathmandu Airport are observed in June as 28.5°C and in January as 2.1°C. The maximum annual of about 1900mm occurred in 2002 and minimum annual rainfall of about 900mm occurred in 1972 between 1971 and 2004 is shown in Fig (3.7). The mean annual rainfall is about 1900mm. Average minimum temperature of about 25°C occur in May and June, while average minimum temperature of about 2°C occur in Jan (Fig 3.4).

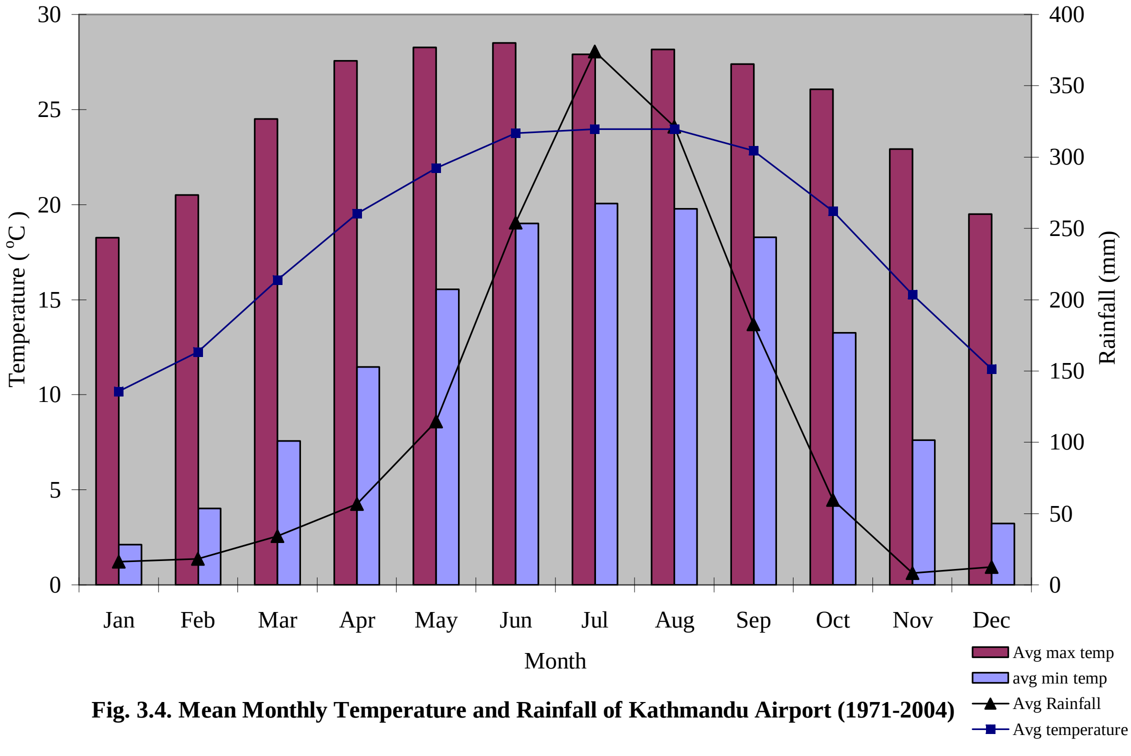


Fig. 3.4. Mean Monthly Temperature and Rainfall of Kathmandu Airport (1971-2004)

Nagarkot and Sankhu being in higher reaches of Manohara Basin get more rainfall than Kathmandu Airport, which is outside and near the outlet of the Manohara Basin at the Pepsi cola bridge. Orography and aspect effect may have caused more rain in Nagarkot and Sankhu, Kathmandu Airport in the near Kathmandu Valley floor.

The rainfall in July and August Fig (3.3.) cause Manohara to flood during monsoon, and low flow during November to May will require water for winter and summer vegetable forms. The maximum annual rainfall of about 3500mm and minimum annual rainfall about 1000mm have occurred in 1978 and 1981 respectively as shown in Fig (3.6). Average annual rainfall at Sankhu is about 2000mm between1971 to 2004.

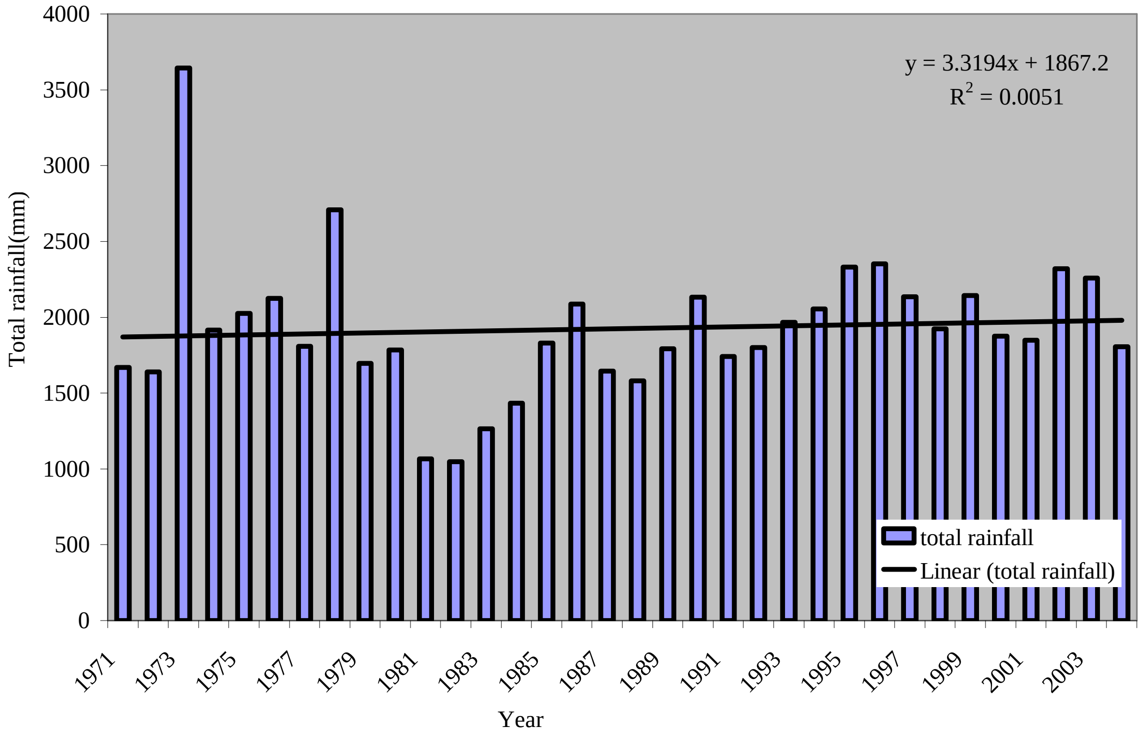


Fig. 3.5. Time Series of Total Annual Rainfall at Nagarkot

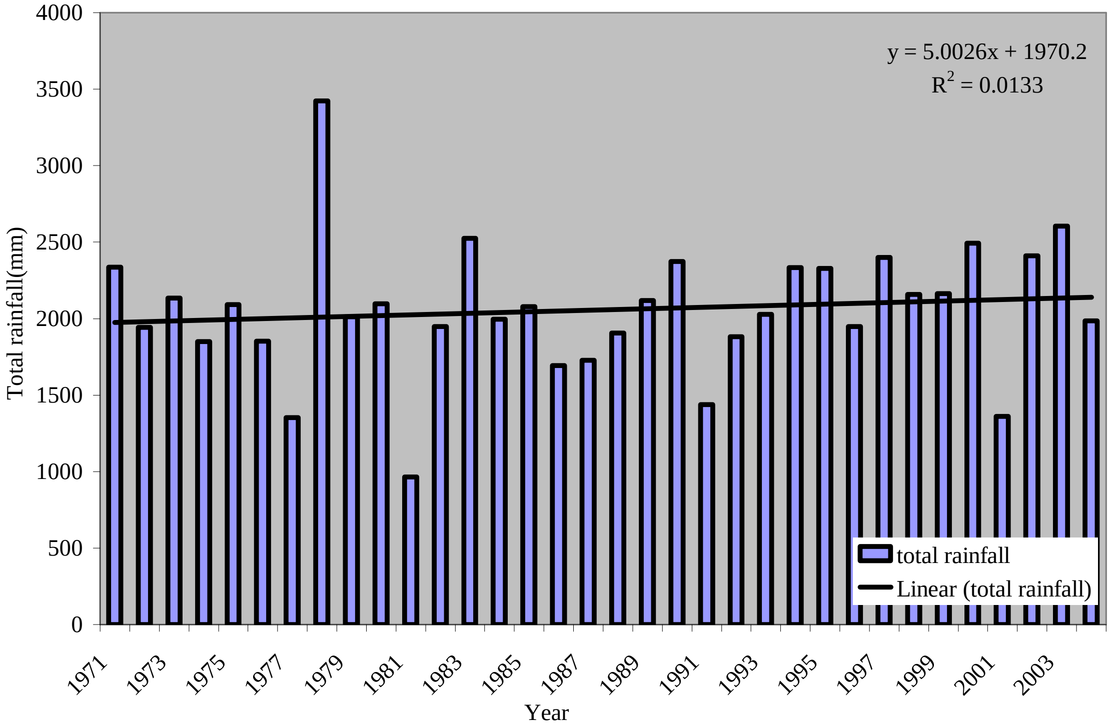


Fig. 3.6. Time Series of Total Annual Rainfall at Sankhu

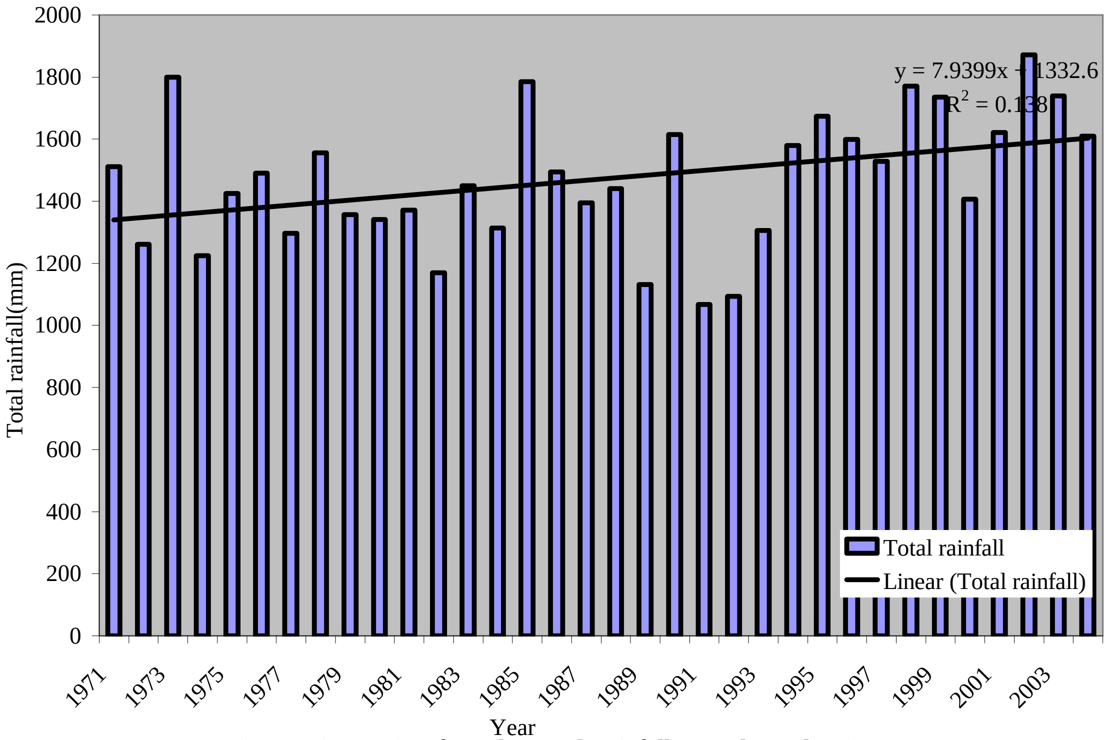


Fig.3.7. Time series of Total Annual Rainfall at Kathmandu Airport

Nagarkot has slightly less rainfall than Sankhu but the rainfall trend Fig (3.2) on monthly basis is similar. Between 1971 to 2004 as shown in Fig (3.5) maximum annual rainfall of about 3600mm and minimum annual rainfall about 1000mm have occurred in 1971 and 2004 respectively.

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. Flood Classification

Among the many classifications of floods, Smith and Ward (1998) classified floods as river floods and coastal floods.

4.2.1. River Flood

- Floods in river valleys occur mostly on floodplains or wash lands as a result of flow exceeding the capacity of the stream channels and over spilling the natural banks or artificial embankments.
- Sometimes inundation of the floodplain, or of other flat areas, occurs in wet conditions when an already shallow water table rises above the level of the ground surface. This type of water table flooding is often an immediate precursor of overspill flooding from the stream channels.
- In very dry conditions, when the ground surface is baked hard or becomes crusted, extensive flat areas may be flooded by heavy rainfall pounding on the surface. This rainwater flooding is typical of arid and semi-arid environments.
- Sheet wash flooding occurs by the unimpeded lateral spread of water moving down a previously dry or nearly dry valley bottom or alluvial fan. This is typical of arid and semi-arid areas where no clearly defined channels exist.
- In urban areas, flooding often results from over spilling or surface pounding, as described above, but may also occur when urban storm water drains become supercharged and overflow (Smith and Ward, 1998).

4.2.2. Coastal Flood

- Floods in low-lying coastal areas, including estuaries and deltas, involve the inundation of land by brackish or saline water. Brackish-water floods result when river water overspills embankments in coastal reaches as normal flow into the sea is impeded by storm-surge conditions, or when large freshwater flood flows are moving down an estuary.
- Direct inundation by saline water floods may occur when exceptionally large wind-generated waves are driven into semi-enclosed bays during severe storm or storm-surge conditions, or when so-called ‘tidal waves’, generated by tectonic activity, move into shallow coastal waters.

4.3. Other Flood Types from a Different Perspective

i. Flash floods

These floods are frequently associated with violent, convective storms of a short duration. Flash flooding can occur in almost any area, but is most common in mountain districts subject to frequent severe thunderstorms. Flash floods are often the result of heavy rains of short duration falling over a small area. This particular type of flooding has been known to wash away roads and bridges, damage houses and drown livestock.

ii. Riverine floods

A riverine flood occurs in the valley of a large river with many tributaries. Usually flooding develops from rainfall lasting for hours, sometimes days, and covering a Wide area of the watershed.

iii. Single event floods

This is the most common type of flooding in which widespread heavy rains of 2 to 3 days duration over a drainage basin results in severe floods. Such heavy rains are associated with cyclonic disturbances, such as storms, slow moving depressions etc., during the summer monsoon season when air moisture content is very high. In India most floods belong to this category.

iv. Multiple event floods

Sometimes heavy rainfall occurs when successive weather disturbances follow each other closely. Floods in the Indo-Gangetic plains and central Indian regions often are caused by the passage of a series of upper air cyclonic circulations, low-pressure areas or depressions from the Bay of Bengal, more or less along the same track.

v. Seasonal floods

These are floods that occur during different seasons. The summer monsoon season experiences a large number of floods, since major storm activity occurs during this season. The southern half of the Indian peninsula experiences floods mostly during the winter monsoon season. These floods are caused by heavy rainfall over a drainage basin. However, floods can also occur due to unusually high water levels of lakes fed by a river. Sometimes flood events are caused by events other than rainfall e.g. coastal floods, floods caused by dam failures and estuarine floods.

4.4. 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.

4.5. 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.

4.5.1. 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.

4.5.2. 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.

4.5.3. 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.

4.5.3. 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.

4.6. 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.

4.6.1. 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 .

4.6.1.1. 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.

4.6.1.2. 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.

4.6.2. 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.

4.6.3 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.

$$Q=CAI \qquad \text{……..………(3.1)}$$

where

C is runoff coefficient.

A is area of the basin.

I is the intensity of rainfall.

In the equation (3.1) 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.

$$Q=2.778\ CAI \qquad \text{…………..…(3.2)}$$

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 (3.1).

Table: 3.1. 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.

4.6.4. 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.

4.6.5. 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.

4.6.6. 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:

Data available for a similar catchment can be transferred to an ungauged location on the basis of drainage area. A relation “fairly accurate for instantaneous peaks" (Cudworth, 1991) takes the following form

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

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.

$Q_f = \exp(\mathrm{Ln}Q_2 + S\exists_1)$ …………(5.4)

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

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

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	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,

$Y = a + b(X_1) + c(X_2) + d(X_3)$ ....(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,

$$P = \frac{m}{n + 1} \qquad \ldots\ldots\ldots\ldots (1)$$

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,

$$P = \frac{1}{T_r} \qquad \ldots\ldots\ldots\ldots (2)$$

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

5.3.3. Gumbel distribution

Let x_1, x_2, x_3, ………..x_n be n independent random variables and let each of these variables have a distribution whose right tail is unbounded and of exponential type. Let x be another random variable which is the largest of these n random variables.

Then it is shown that in the limiting base as n becomes large, the variable x follows the extreme value type-III distribution whose p.d.f. is given by

$$f(x) = \Im\, e^{-\Im (x - \wp) - e^{-\Im(x - \wp)}}$$

where $\Im$ and $\wp$ are called the parameters of the distribution. The C.D.F. is given by

$$F(x) = e^{-e^{-\Im(x-\wp)}} = e^{-e^{-y}}$$

Where $y = \Im(x-\wp)$ is called the reduced variate. The mean and standard deviation of the variable $\Uparrow$ and $\exists$ are related to its parameters through the following equations.

$$\Im = \frac{1.28255}{\exists}$$

$$\wp = \Uparrow - 0.450056$$

It may be noted that $\wp$ is the mode of the distribution.

The use of Gumbel distribution to describe the annual peak discharge is justified on the following assumptions.

a. The daily discharge follows an exponential type of distribution.

b. The original number of elements (365 daily discharge) from which the peak value is taken is sufficiently large.

c. The daily discharge is independent.

Although the last assumption is strictly not valid, experience has shown that extreme value distribution is a good fit for the annual peak discharges and therefore it is extensively used all over the world.

If x_1', x_2' …… x_n' are extreme value of floods (in descending order), the probability of occurrence (P) that any of the n extreme will be less than or equal to X is given by

$$P\,(x \mid x_0) = 1- e^{-e^{-y}}$$

The exceedence probability is given by

$$P = 1- e^{-e^{-y}} = \frac{1}{T_r} \qquad \text{……………..…… (1)}$$

Where, y is called the reduced variate given by

$$y = a\,(x - x_f) \qquad \text{……………..... (2)}$$

where a and x_f are the parameters of the distribution which can be obtained from sample statistics through the method of moments. When the sample size is large, say n > 200 they are given by

$$a = \frac{1.28255}{S_x} \qquad \text{……………..… (3)}$$

$$x_f = \bar{x} - 0.45005\, S_x \qquad \text{…………..…… (4)}$$

where $\bar{x}$ and S_x are the mean and standard deviation of the sample respectively. However, for small samples, the parameters a and x_f are to be estimated using the following equations given by Gumbel.

$$a = \frac{\exists_n}{S_x} \qquad \text{……………...… (5)}$$

$$x_f = \bar{x} - \frac{\bar{y}_n}{\exists_n} S_x \qquad \ldots\ldots\ldots\ldots (6)$$

where $\exists_n$ and $\bar{y}_n$ are called the standard deviation and mean of the reduced extremes which depend on the sample size n as given in table.

Let y_T be the reduced variate corresponding to a return period of T_r.

Thus, noting that $P = \frac{1}{T_r}$ from eqn (1)

We have, $P = 1 - e^{-e^{-y}} = \frac{1}{T_r}$

$$e^{-e^{-Y_T}} = 1 - P = \frac{T_r - 1}{T_r}$$

Taking logarithms on both sides to the naperian base twice

$$y_T = -\,Ln \left[-Ln \left(\frac{T_r-1}{T_r} \right) \right]$$

$$y_T = -\,Ln \left[-Ln \left(\frac{T_r}{T_{r-1}} \right) \right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots... (7)$$

Let x_T denote the magnitude of the flood with a return period of T_r years.

Then from eqn (2) we have

$$y_T = a\,(x_T - x_f) \qquad \ldots\ldots\ldots\ldots\ldots (8)$$

Substituting equations (5) and (6) in eqn (8) and simplifying, we obtain

$$x_T = \bar{x} + \frac{y_T - \bar{y}_n}{\exists_n} S_x$$

$$x_T = \bar{x} + k_T S_x \qquad \ldots\ldots\ldots\ldots (9)$$

where k_T is known as the frequency factor given by

$$k_T = \frac{y_T - \bar{y}_n}{\exists_n} \qquad \ldots\ldots\ldots\ldots... (10)$$

The frequency factor k_T depends on the type of distribution and the return period.

Eqn (9) is the final eqn the Gumbel method.

Fit of this distribution can be tested by plotting the descending order of flood magnitude and its reduce variate on an ordinary graph paper. If straight line appears then it concluded that the Gumbel's distribution is good fit for the data.

CHAPTER VI
ESTIMATION AND ANALYSIS

6.1. Introduction

Nepal being very rich in water resources have not been able 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 flows, mean monthly discharge and other relevant data are essential for the multipurpose projects 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 flows for designing the hydraulic structures associated with the objectives of the project .Keeping this in view the Manohara river basin which is a very important sub basin in Kathmandu valley has been selected for the study. This sub basin has very important agricultural landscape providing vegetables for the Kathmandu city which requires irrigation during the dry season from March to May. People are now migrating and settling in Manohara basin from the already over crowded Kathmandu city .Therefore, the new coming up settlement will require more water supply. More roads have to be built within this basin as it progresses with different developing schemes. For the construction of these roads, culverts and bridges high flows have to be estimated. However, more parameters and pitched roads will reduce infiltration and give more surface runoff. This will require careful designing of the local drainage systems. Therefore flow estimation are carried out with suitable methodologies applicable to Manohara environment. The techniques applied for these various kinds of flow estimation are described in the following articles below.

WECS/DHM method was applied in order to find the Low flow frequency, High flow frequency, and Average monthly flow and flow duration curve analysis for Manohara River. The basin area of the Manohara river basin was delineated by drawing the boundary with district map of 1:25,000 scale and measured with the graph paper. The catchment area of the Manohara Basin is 66.375 sq. km. The average elevation of basin is

1850m.The average wetness index (AWI) was taken from the book (Hydrological Estimations in Nepal, 2004) as 1800mm.

6.2. The Low Flow Estimation

Low flows are necessary for Manohara basin for irrigation purposes and for domestic water supply in near future. The low flows have been estimated with the help of methodologies developed by WECS/DHM method (Keshav et al., 2004) for low flow characteristics. 1day, 7day, 30day and monthly duration has been conducted given in Table. 6.1. The detailed calculation of these low flows are presented in Annex. 1. 20 years return period with monthly low flow of 0.65m^3/s will give rise to irrigation and domestic water supply.

Table. 6.1. Low Flow Frequency Analysis for Manohara River

Return period	Discharge in m^3/s			
	1day	7day	30day	monthly
2	0.77	0.83	1.00	1.08
10	0.46	0.49	0.65	0.72
20	0.41	0.43	0.59	0.65

Low flow frequency analysis from Table.6.1. shows that the monthly minimum value for the return period of 2 year was found 1.08 m^3/s. Similarly the monthly minimum value was found 0.72m^3/s and 0.65m^3/s for the return period of 10 and 20 years respectively. The one day minimum value for the return period of 2 years, 10 years and 20 years are 0.77m^3/s, 0.46m^3/s and 0.41m^3/s. The 30 day minimum value for the return period of 2 years, 10 years, and 20 years are 1.00 m^3/s, 0.65 m^3/s, and 0.59m^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. and graphically represented in Fig. 6.1.

During monsoon the Manohara catchment gets heavy rainfall as indicated by the Nagarkot and Sankhu stations of about 480mm in July and 540mm in August respectively. For occasion of high monsoon rains that generate peak flows, it is observed that the return periods of 2 years, 10 years, 20 years and 50 years are 84m^3/s, 205m^3/s, 265m^3/s and 350m^3/s respectively. It is to be remarked that the hydrologic structures like culverts, bridges etc. have to face such high floods. The Manohara River flowing in the flood plains as it approaches the Pepsicola Bridge near the Pepsi cola Industry and also near the Kathmandu International Airport starts to meander and has a shifting nature. This will require river training works like constructing levees or embankments.

Table.6.2. High Flow Frequency Analysis for Manohara River.

Return period	Discharge(m^3/s)
2	84.48
5	151.54
10	205.66
20	264.58
50	351.42
100	424.43

The high flow frequency analysis from Table.6.2.shows that the high flow frequency for the return periods of 2yr and 100yr are calculated as 84.48m^3/s and 424.43m^3/s respectively. Similarly the discharges for return periods for 5yr, 10yr, 20yr, 20yr and 50 yr were 151.54m^3/s, 205.66m^3/s, 264.58 m^3/s and 351.43m^3/s respectively.

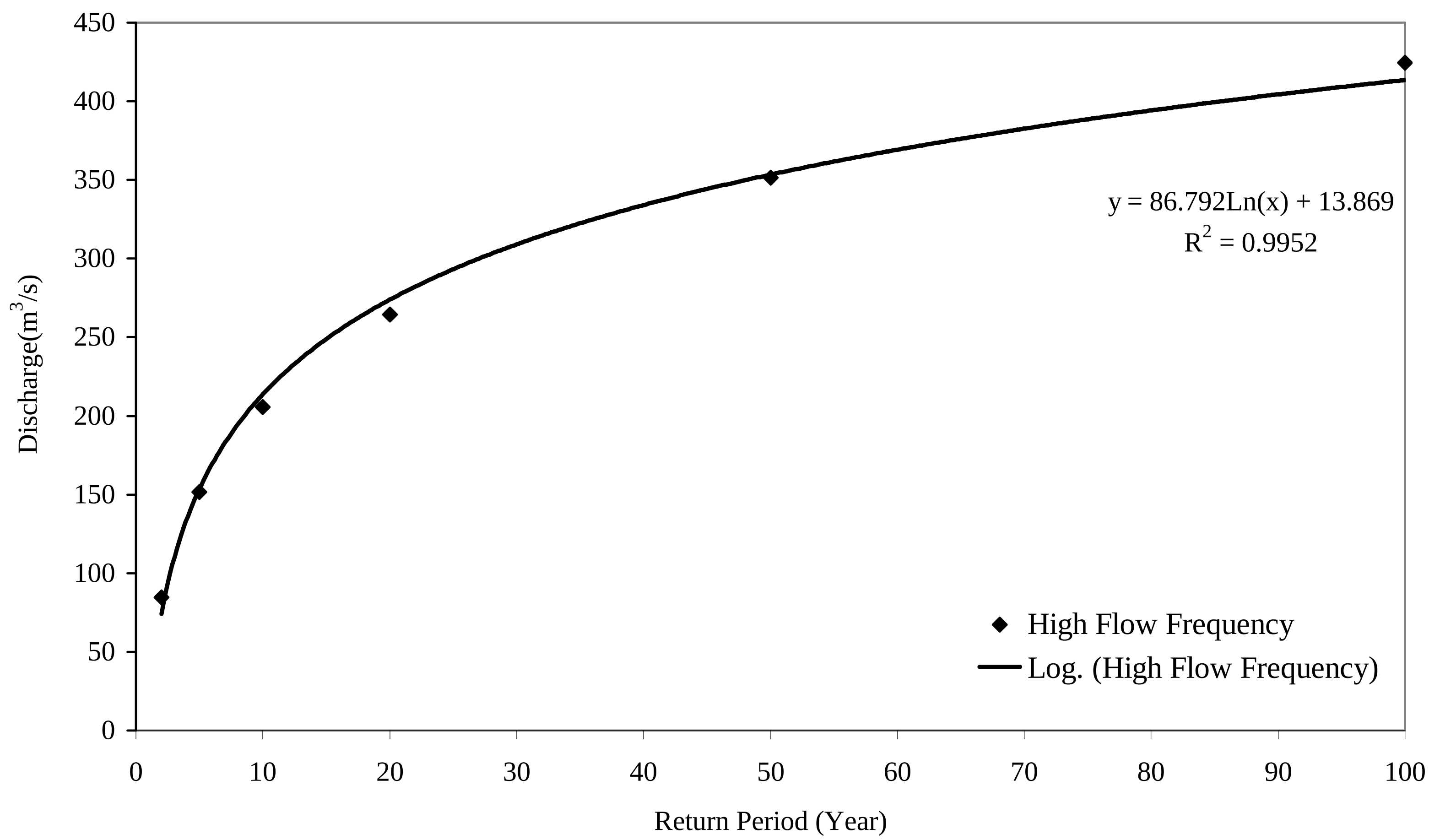


Fig. 6.1. High Flow Frequency of Manohara River (Estimated)

6.4. Mean Monthly Flow Estimation

Mean monthly flow of Manohara River are necessary for water supply and other purposes like irrigation in different months except during the monsoon season. The 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 1m^3/s and during monsoon for the month of August the flow is about 19m^3/s.The groundwater is recharged due to the monsoon rains and Manohara river discharge ranges from about 6m^3/s for October up to about 1.4m^3/s for the month of February.

Table. 6.3. Average Monthly Flow of Manohara River.

Months	Mean monthly flow(m^3/s)	R^2
January	1.64	0.971
February	1.37	0.968
March	1.27	0.966
April	1.06	0.962
May	1.23	0.946
June	4.88	0.941
July	13.15	0.958
August	19.01	0.964
September	13.61	0.977
October	6.36	0.963
November	2.91	0.953
December	1.98	0.966

The average monthly flow for Manohara was calculated from WECS/DHM methodology. The value of goodness of fit R^2 was obtained from the Table. 6.3. The mean monthly flow 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 mean monsoon months (Table 6.3).

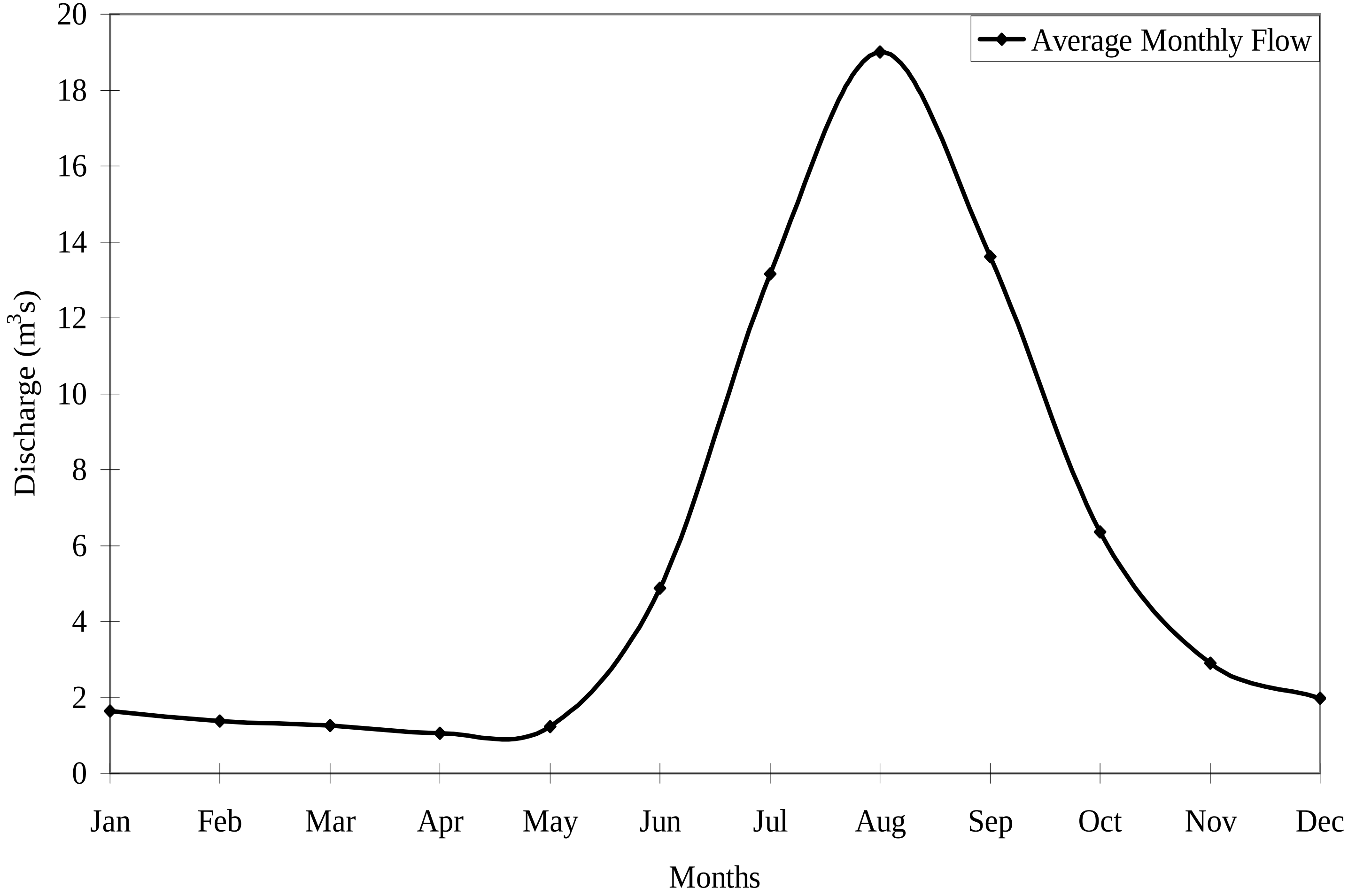


Fig.6.2. Average Monthly Flow of Manohara River (Estimated)

6.5. Flow Duration Curve

Flow duration curve is estimated with the help of WECS/DHM method. A flow duration curve gives evaluation 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% the flow is only $0.14m^3/s$. This means that the flow expected to be exceeded 100% of the time is $0.14m^3/s$. Similarly exceedence probability of 20% and 60% are about $10m^3/s$ and $2m^3/s$ respectively. These indicated values are very important for irrigation projects and drinking water projects.

Table. 6.4. Flow Duration Curve of Manohara River.

Exceedence P(%)	Discharge(m^3/s)	R^2
0	52.59	0.906
5	19.14	0.963
20	9.92	0.967
40	3.36	0.95
60	1.79	0.96
80	1.27	0.963
95	0.86	0.965
100	0.14	0.945

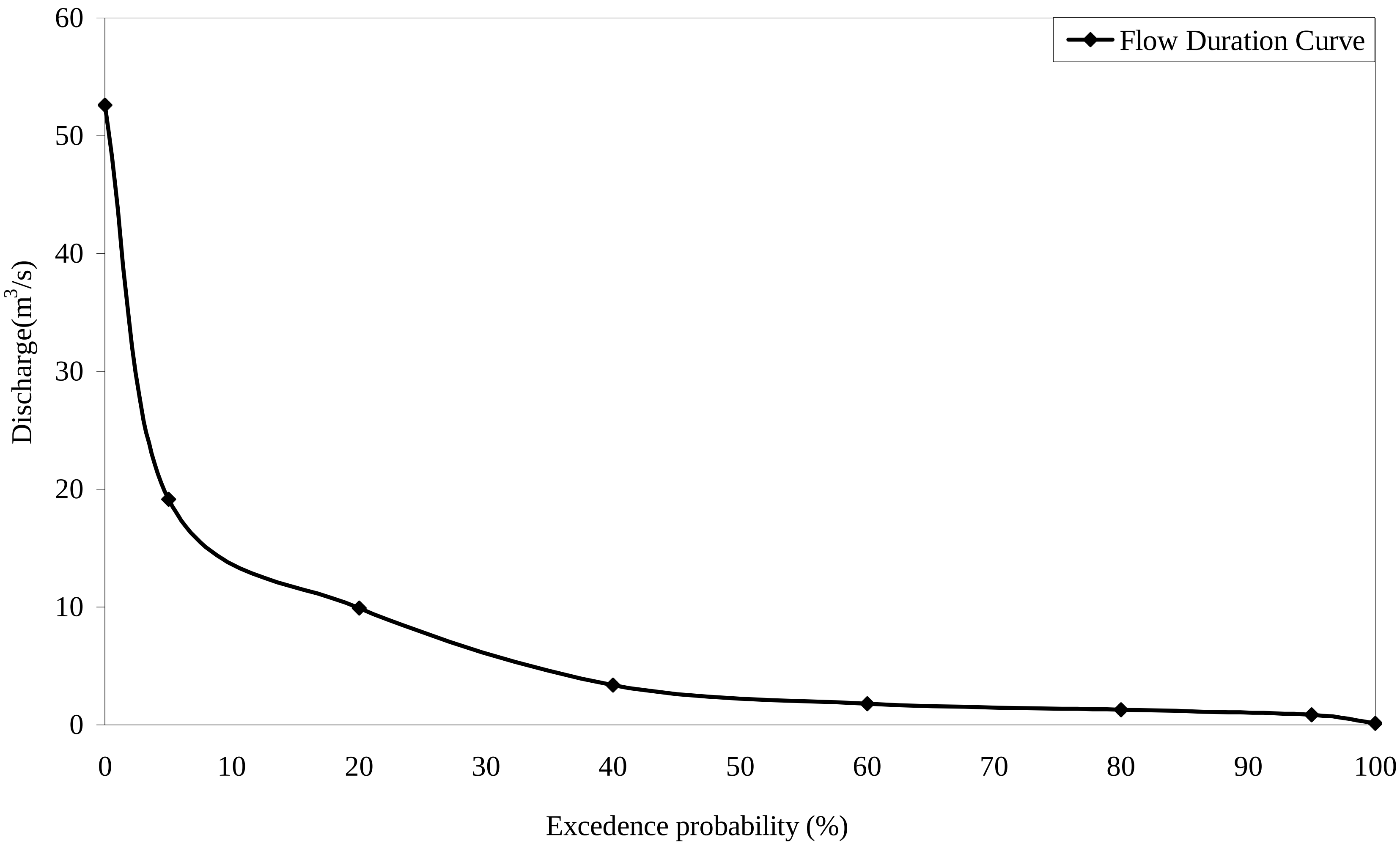


Fig.6.3. Flow Duration Curve of Manohara River (Estimated)

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 Manohara River are calculated as given in Table 6.7. with the help of discharge data at Sundarijal gauging site. The data was transposed to Manohara River. This transposed discharge data were used to get the flood for various return periods.

I.a. By Transposition of Data from Sundarijal to Manohara.

Table 6.5. and Fig.6.4. indicate the flood frequency analysis for Manohara River with the help of transposition of discharge data from Sundarijal station.

Similarly, Table 6.6. indicates the average monthly flow of Manohara River with the help of transposition of discharge data from Sundarijal station.

Table. 6.5. Flood Frequency Analysis of Manohara River with Transposition of Data from Sundarijal.

Return Period	Discharge m^3/s
2	22.57
5	54.88
10	79.33
20	103.77
50	136.77
100	160.54

Table. 6.6. Average Monthly Flow of Manohara River with Transposition of Data from Sundarijal.

Months	Mean Monthly Flow(m^3/s)
January	0.65
February	0.53
March	0.49
April	0.49
May	0.61
June	1.82
July	5.41
August	7.67
September	6.20
October	2.73
November	1.30
December	0.87

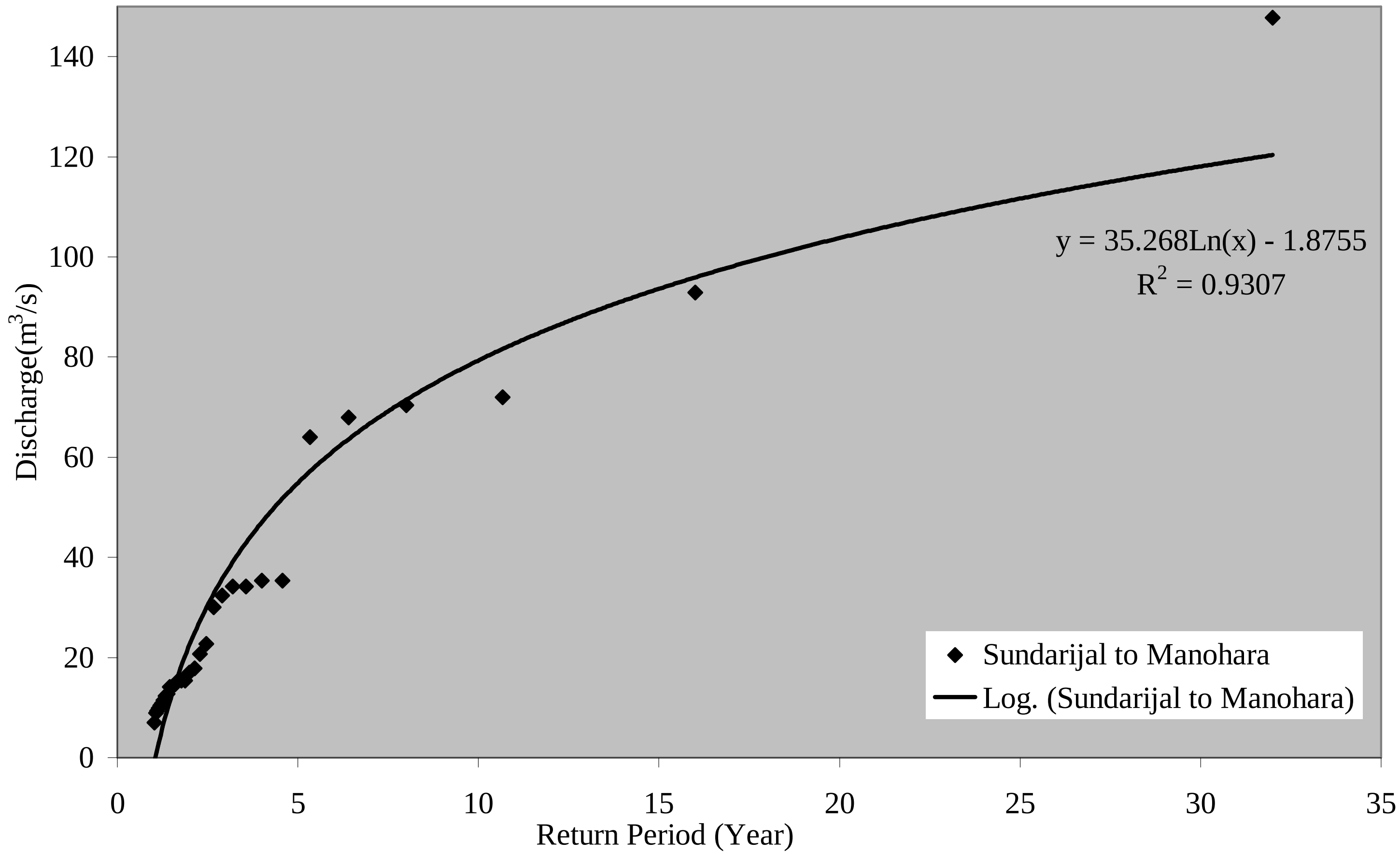


Fig:6.4. Flood Frequency Analysis of Manohara River (Transposition from Sundarijal)

I.b. Gumbel Method applied to Sundarijal

The transposed discharge data from Sundarijal to Manohara were used to get the flood for various return periods using Gumbel method as given in Table 6.7. and is shown in Fig. 6.5. It is observed that the flood for these various return periods, indicated in Table. 6.7. for the Manohara River are varying widely. Therefore estimation of high flows transposed from Sundarijal discharge data for Manohara River is not suitable.

Table.6.7. Comparison between WECS/DHM and Transposition (Cudworth) Method.

Return period	Flood Peak(m^3/s)		
	Transposition		WECS/DHM
	Weibul's	Gumbel's	
2	22.57	26.74	84.48
5	54.88	58.42	151.54
10	79.33	79.39	205.66
20	103.77	99.51	264.58
50	136.09	125.56	351.42
100	160.53	145.07	424.43

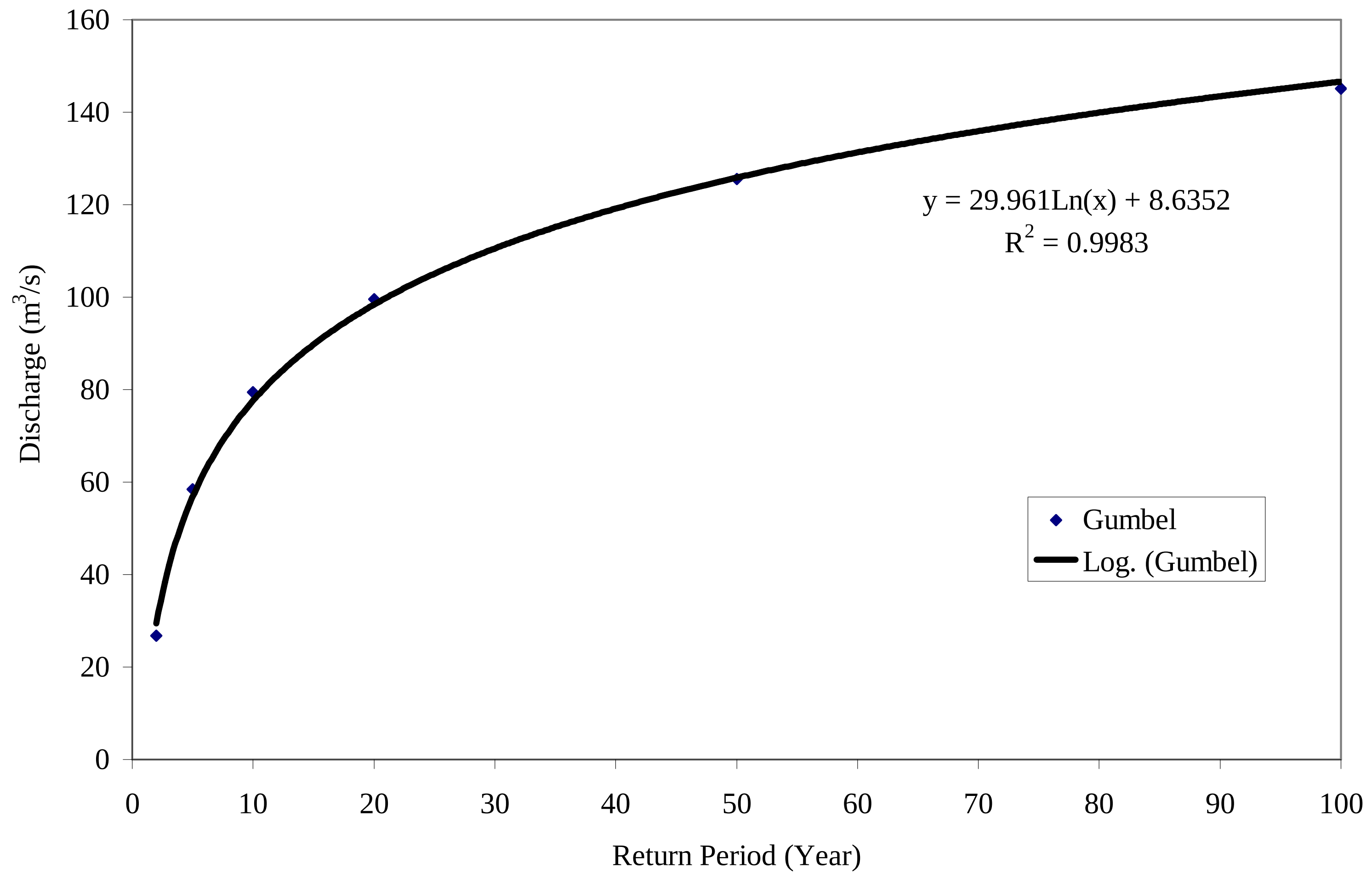


Fig 6.5. Flood Frequency Analysis from Gumbel Method(Transposition of Data)

II). By Transposition of Data from Khokana to Manohara.

Table. 6.8. indicates the flood frequency analysis of Manohara River with the help of transposition of discharge data from Khokana station for Bagmati River.

Similarly, Table.6.9. gives the average monthly flow of Manohara River with the help of transposition discharge data from Khokana site of Bagmati River.

Table. 6.8. Flood Frequency Analysis of Manohara River with transposition of data from Khokana.

Return period	Discharge (m^3/s)
2	132.09
5	225.16
10	295.56
20	365.96
50	459.03
100	529.43

Table. 6.9. Average Monthly Flow of Manohara River with transposition of data from Khokana.

Months	Mean monthly flow(m^3/s)
January	1.96
February	1.60
March	1.24
April	1.26
May	2.29
June	5.56
July	17.00
August	21.53
September	12.14
October	5.36
November	3.27
December	2.42

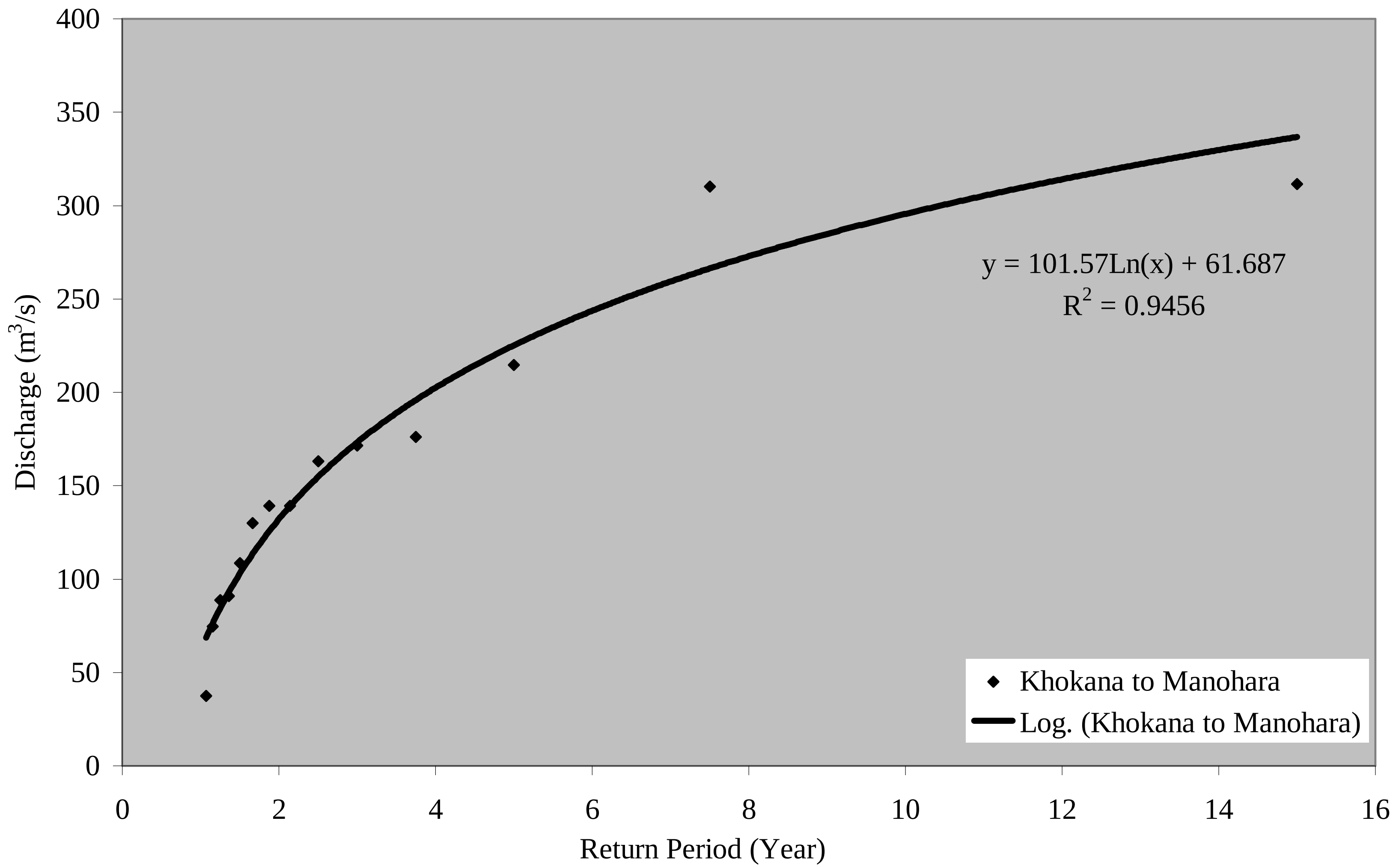


Fig. 6.6. Flood Frequency Analysis of Manohara River(Transposition from Khokana)

III). By Transposition of data from Chovar to Manohara.

Table 6.10. and Fig.6.7. indicate transposition of the flood frequency analysis for Manohara River with the help of transposition of discharge data from Chovar.

Similarly, Table 6.11. indicates the average monthly flow of Manohara River with the help of transposition of discharge data from Chovar station.

Table.6.10. Flood Frequency Analysis of Manohara River with transposition of data from Chovar

Return period	Discharge (m^3/s)
2	134.127
5	201.610
10	252.659
20	303.708
50	371.191
100	422.240

Table. 6.11. Average Monthly Flow of Manohara River with transposition of data from Chovar

Months	Mean monthly flow(m^3/s)
January	0.85
February	0.62
March	0.52
April	0.60
May	0.83
June	4.88
July	15.29
August	17.99
September	11.92
October	5.52
November	2.35
December	1.31

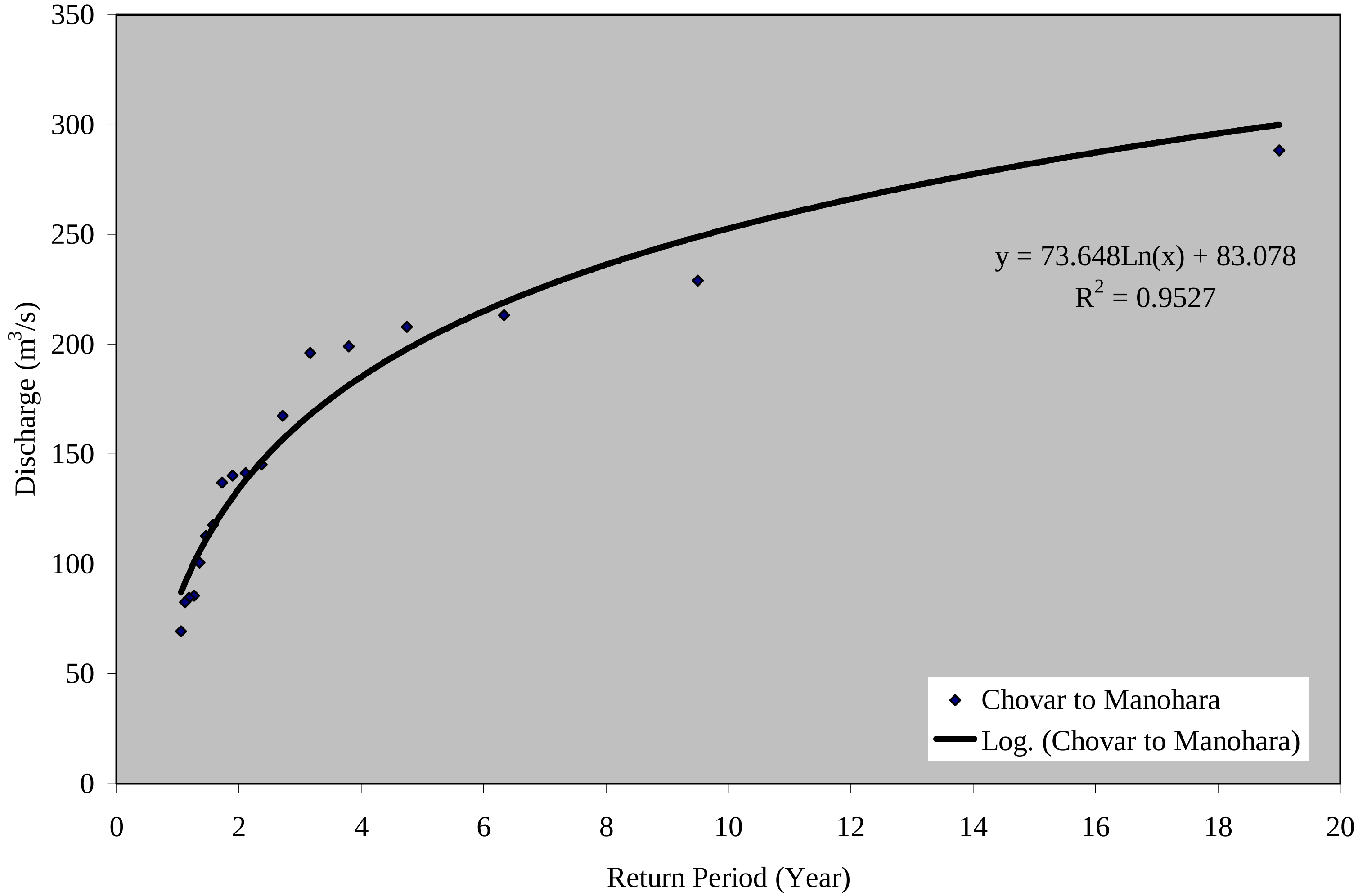


Fig.6.7. Flood Frequency Analysis of Manohara River (Transposition from Chovar)

6.7. Comparison of Estimated High Flows of Manohara River with WECS/DHM and transposition method.

The estimated high flows of Manohara River have been obtained with WECS/DHM method and with transposition method with the discharge data at Khokana, Chovar and Sundarijal. These estimated data are given in Table (6.12) and graphically represented in Fig (6.8) 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 Bagmati River at Chovar station. However, the curve for Manohara River obtained from transposition discharge data from Bagmati river at Khokana lies above the estimated discharge data curves from WECS/DHM method and transposition method using discharge data at Chovar. The estimated discharge data obtained from the transposition discharge data of Bagmati River at Sundarijal station is much below the estimated curve of Manohara River by using WECS/DHM method. The discharge data of Bagmati River at Chovar and Khokana with transposed data methodology for Manohara River gives reasonable high flows estimated agreeing with WECS/DHM method. This is because the Pepsicola bridge site, Chovar site and Khokana site are all situated in the flood places or valley flow of Kathmandu valley. However, Sundarijal gauging site is located on the higher elevation near origin of Bagmati River. The bridge of Manohara site, Chovar site and Khokana site have more or less the same kind of physiographic characteristics but Sundarijal site has completely different physiographic characteristics.

Table. 6.12. Comparison of Flood Frequency Analysis of Manohara River.

Return period	WECS/DHM	Transposition of data from		
		Khokana	Chovar	Sundarijal
2	84.48	132.09	134.13	22.57
5	151.54	225.16	201.61	54.89
10	205.66	295.56	252.66	79.33
20	264.58	365.96	303.71	103.78
50	351.43	459.03	371.19	136.09
100	424.44	529.43	422.24	160.54

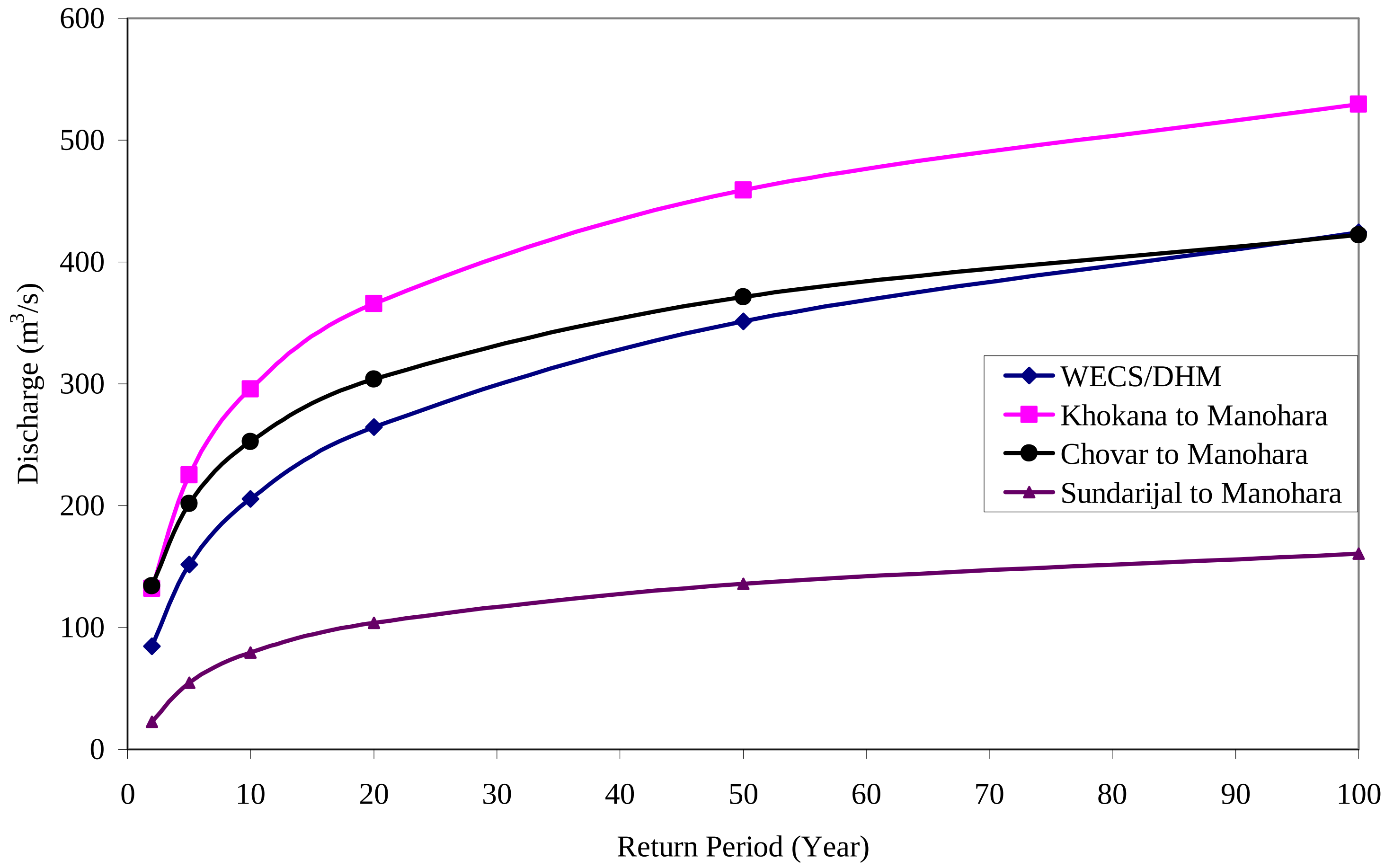


Fig. 6.8. Comparison of Flood Frequency of Manohara River

6.8. Comparison of Estimated Mean Monthly Flows of Manohara River with WECS/DHM and transposition method.

The estimated mean monthly flows of Manohara River have been obtained with WECS/DHM method and with transposition method with the discharge data at Khokana, Chovar and Sundarijal. These estimated data are given in Table 6.13 and graphically represented in Fig 6.9. indicates the comparison of the mean monthly flows with these methods.

The mean monthly estimated flows for Manohara River at the bridge site with WECS/DHM method is agreeing very closely with estimated mean monthly flow for Manohara river with transposed data of Bagmati river at Chovar site. There is reasonable agreement with estimated mean monthly discharge for Manohara River with the estimated river discharge for Manohara with transpose data from Khokana site. The estimated mean monthly flow for Manohara using transposed data from Sundarijal site does not agree with estimated data of Manohara River with WECS/DHM method. The reason behind these results is due to similar physiographic conditions of Manohara bridge site, Chovar site, and Khokana site. Sundarijal has very different physiographic regime from the other three sites.

Table. 6. 13. Comparison of mean monthly flow of Manohara River

Month	WECS/DHM	Transposition of data from		
		Khokana	Chovar	Sundarijal
Jan	1.64	1.96	0.85	0.65
Feb	1.37	1.60	0.62	0.53
Mar	1.27	1.24	0.52	0.49
Apr	1.06	1.26	0.60	0.49
May	1.23	2.29	0.83	0.61
Jun	4.88	5.56	4.88	1.82
Jul	13.15	17.00	15.29	5.41
Aug	19.01	21.53	17.99	7.67
Sep	13.61	12.14	11.92	6.20
Oct	6.36	5.36	5.52	2.73
Nov	2.91	3.27	2.35	1.30
Dec	1.98	2.42	1.31	0.87

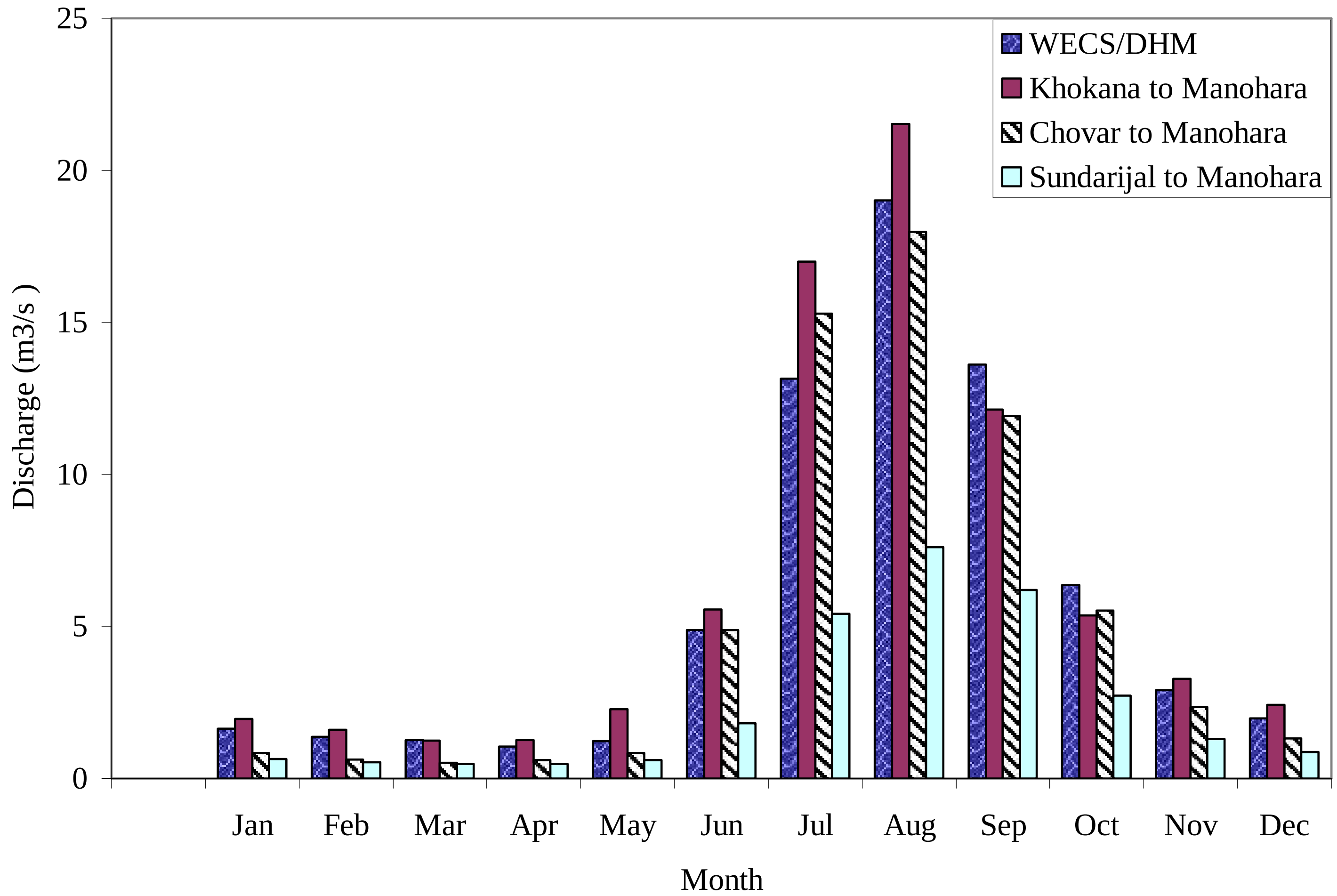


Fig. 6.9. Comparison of Mean Monthly Discharge of Manohara River

6.9. Relationship between mean monthly discharge and rainfall of the study area.

The mean monthly rainfall for July and August for Nagarkot and Sankhu are almost equal above 500mm. The mean monthly rainfall for June for Nagarkot and Sankhu are relatively less up to 350mm. However, the mean monthly rainfall for Kathmandu Airport which is at the middle of the valley floor has more rainfall on July than in August by about 50mm up to July. The soil in the Kathmandu valley gets saturated until July. Most of the rainfall gets abstracted to fulfill the soil moisture. In general the soil moisture capacity for Kathmandu valley is about 250mm per one meter depth of the soil which is mostly comprised of clay and sand. At the end of July the soil gets fully saturated and therefore practically all of the rainfall in August is generated as surface runoff. The runoff of the rivers so considered is more in the month of August than in July.

CHAPTER VII

CONCLUSION AND RECOMMENDATION

7.1. Conclusion

- The area of the Manohara basin is 66.37 sq km, basin length is 24 km and perimeter of the basin is 47.25 km. The form factor is 0.115, circulatory ratio is 0.374, the elongation ratio is 0.383 and compactness coefficient is 1.463. These shape factors indicate that the basin is strictly not symmetrically shaped. The basin is narrow at outlet and wide in upstream.

- Mean monthly rainfall of Kathmandu airport is maximum in July 374.1mm and minimum as 8.2mm in November. Mean monthly rainfall of Sankhu is maximum in July as 547mm and minimum as 10mm in November. Mean monthly rainfall of Nagarkot is maximum in July as 484mm and minimum as 9.2mm in November.

- The average maximum temperature of Kathmandu Airport in June is 28.5°C, and average minimum temperature in January is 2.1°C.

- Low flow frequency analysis shows that the monthly minimum value for the return period of 2 year was found 1.08m^3/s. Similarly the monthly minimum value was found 0.72m^3/s and 0.65m^3/s for the return period of 10 and 20 years respectively. The one day minimum value for the return period of 2 years, 10 years and 20 years are 0.77m^3/s, 0.46m^3/s and 0.41m^3/s. The 30 day minimum value for the return period of 2 years, 10 years, and 20 years are 1.00 m^3/s, 0.65 m^3/s, and 0.59m^3/s.

- From high flow frequency analysis it is found that during the monsoon the Manohara catchment gets heavy rainfall as indicated by Nagarkot and Sankhu stations of about 480mm in July and 540mm in August respectively. For occasion of high monsoon, rains generate peak flows. It is observed that return periods of 2 years, 10 years, 20 years and 50 years are 84m^3/s, 205m^3/s, 265m^3/s and 350m^3/s respectively .It is to be remarked that the hydrologic structures like culverts, bridges etc. have to face such high floods.

- For monsoon months the mean monthly flow estimations were relatively high compared to the non monsoon months.

- The flow duration curve indicates that for exceedence probability of 100% the flow is only 0.14m^3/s, which means that the flow expected to be exceeded 100% of the time is 0.14m^3/s. Similarly exceedence probability of 20% and 60% are about 10m^3/s and 2m^3/s respectively. These indicated values are very important for irrigation projects and drinking water projects in future.

- The flood frequency analysis of Manohara River was conducted with data transposed from Chovar. The flood frequency analysis for the return period of 2yr, 5yr, 10yr, 20yr, 50yr and 100yr was calculated as 134.12m^3/s, 201.61m^3/s, 252.65m^3/s, 303.70m^3/s, 372.19m^3/s, and 422.24m^3/s respectively.

- The discharge data of Bagmati River at Chovar, Khokana and Sundarijal with transposed data methodology for Manohara River give reasonable estimated floods agreeing with WECS/DHM method. This is because the bridge site, Chovar site and Khokana site are all situated in the flood plains or valley floor of Kathmandu valley. However, Sundarijal gauging site is located on the higher elevation near the origin of Bagmati River. The bridge site of Manohara at Pepsi Cola Industry, Chovar site and Khokana site have more or less the same kind of physiographic characteristics but Sundarijal site has completely different physiographic characteristics.

- The mean monthly estimated flows of Manohara River at the bridge site with WECS/DHM method agrees very closely with estimated mean monthly flow for Manohara River with transposed data of Bagmati River at Chovar site. There is reasonable agreement with estimated mean monthly discharge for Manohara River with transposed data from Khokana site. The estimated mean monthly flow for

Manohara using transposed data from Sundarijal site does not agree with estimated data of Manohara River with WECS/DHM method.

- The mean monthly rainfall for July and August for Nagarkot and Sankhu are almost equal above 500mm. The mean monthly rainfall for June for Nagarkot and Sankhu are relatively less up to 350mm. However, the mean monthly rainfall for Kathmandu Airport which is at the middle of the valley floor has more rainfall on July than in August by about 50mm up to July. The soil in the Kathmandu valley gets saturated until July. Most of the rainfall gets abstracted to fulfill the soil moisture. In general the soil moisture capacity for Kathmandu valley is about 250mm per one meter depth of the soil which is mostly comprised of clay and sand. At the end of July the soil gets fully saturated and therefore practically all of the rainfall in August is generated as surface runoff. The runoff of the rivers so considered is more in the month of August than in July.

7.2. Recommendation

- Automatic raingauges and discharge station are essential for meaningful hydro meteorological analysis in Manohara catchment.

- Sediment and flood hazards studies are essential for constructing hydraulic structures like bridges, canals in take, and roads.

- Regular measurement of high flow, low flow and stream flow are required with advanced technologies and to develop models for the study of basin.

- The river training works are to be conducted in the lower reach of the Manohara River, where it meanders. This will save fertile forms and settlements.

BIBLIOGRAPHY

Berz, G. (2000). **Flood disasters: lessons from the past - worries for the future**, Proc. Instn Civ. Engrs. Water & Mar. Engn, Vol. 142, Mar. 3-8, p. 3 - 6.

Central Board of Irrigation and Power. (1979). **Water Resources Research in India**, Publication No 78.(Revised), New Delhi, India.100p

Chow, V. T., Maidment, D. R ., Mays, L. W. (1988). **Applied Hydrology,** McGraw-Hill International Editions.493-530p.

Chyurlia, J.P. (1983). **Land Resources Mapping Project Nepal,** Water Resources Report, Volume I.6-25p.

Cudworth, A. G. (1989). **Flood Hydrology**, Denver.

Garg, S. K. (2002). **Hydrology and Water Resources Engineering,** Khanna Publishers, Twelfth Edition, 334-336,339p

Gautam, N. (2000). **Mean Annual and Flood Discharge Analysis for Karnali, Narayani, Bagmati and Sapta Koshi River Basin**. (M.Sc.Thesis) Central Department of Hydrology and Meteorology, Tribhuvan University, Nepal.

Gupta, S. C., Kapoor, V.K. (1994). **Fundamentals of Mathematical Statistics,** Sultan Chand and Sons, New Delhi.2.1,5.14p.

HMG/N, Department of Hydrology and Meteorology (2004). **Hydrological Estimations in Nepal, Main Report & Appendix I.** Department of Hydrology and Meteorology, Kathmandu.103p

HMG/N, Department of Hydrology and Meteorology. **Climatological Records of Nepal,** 1971 to 2004 series.

IH (1980). **Low flow studies report** (Report No 1 to 4). Institute of Hydrology, Wallingford, UK.

Linsley, R. K. Kohler, M. A. Paulhus, J. L. H. **(**1983). **Applied Hydrology**, Tata McGraw-Hill Company Ltd. New Delhi.243-269p.

Maidment, D. R. (1992). **Hand Book of Hydrology**, McGraw-Hill, Inc.

Meizner, O. (1942). **Meizner Hydrology**, McGraw-Hill Book Company, Inc.

Mutreja, K. N. (1986). **Applied Hydrology.** Tata McGraw-Hill Publishing Company Limited, New Delhi. 722-731p.

Nemec, J. (1973). Engineering Hydrology, Tata McGraw- Hill Publishing Company Ltd. New Delhi.197-291p.

PC, S. (2003). **A study of hydrological regime of Myagadi khola basin.** (M.Sc.Thesis) Central Department of Hydrology and Meteorology, Tribhuvan University, Nepal

Riggs, H.C. (1982). **Low-Flow investigations** (2 ed.). Washington: US Geological Survey.

Raghunath, H. M. (1985). **Hydrology Principles, Analysis**, New Age International Publishers, New Delhi. 230-234p.

Reddi, J.R. (2002). **A Text book of Hydrology**, Laxmi Publications. 471, 476, 479, 480, 79-82p

Seth, S. M. (1985). **Regional flood frequency analysis,** (RN-14). National Institute of Hydrology, Roorkee, India.

Sharma, C. K. (1978). **Natural Resources of Nepal.** Mrs Sangeeta Sharma, Kathmandu, Nepal. 23,28p

Sharma, C. K. (1978). **Partial drought conditions in Nepal,** Ground Water Resources Development Board, Hydrological Sciences Bulletin, des Sciences Hydrologiques. 24, 3, 9/1979.

Smakhtin,V. Y., Hughes, D.A.(1995). **Low-flow studies in South Africa**. In A.V. Rozhdestvensky (Ed.)., International Symposium on Runoff Computation for water projects. UNESCO (pp.23-31).

Smith, K., Ward, R. (1998). **Floods: Physical processes and human impacts**. John Wiley & Sons Ltd, West Sussex, England, pp 3-28.

Subramanya, K. (1984). **Engineering Hydrology,** Tata Mc Graw-Hill Publishing Company, New Delhi.

Suresh, R. (1997). **Watershed Hydrology,** Nem Chand, First Edition. 271,279p

Thapa, K.B., Khanal, N., Dhital, M. R. (1993).**The Role of Extreme Weather Events, Mass Movements and Land Use Change in Increasing Natural Hazard**s, ICIMOD.

UNEP (2002). **Early Warning, Forecasting and Operational Flood Risk Monitoring in Asia (Bangladesh, China and India**), A Technical Report of Project(GT/ 1010-00-04): Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), P.O. Box 30552, Nairobi, Kenya.15-23p.

Varshney, R.S. (1986). **Engineering Hydrology**, Non Chand and Bros, Roorkee.801-837p.

WECS (2002). **Water Resources Strategy Nepal**, Water and Energy Commission, Kathmandu, Nepal. 7p

WECS/DHM (1990). **Methodologies for estimating hydrologic characteristics of ungauged locations in Nepal,** (4/4/240990/1/1 Seq. No. 331). Water and Energy Commission Secretariat and Department of Hydrology and Meteorology, Nepal.

Annex I: Climatological Parameters of Kathmandu Valley

Table 1: Temperature at Kathmandu Airport

Month	Avg max temp	Avg min temp	Avg temp
Jan	18.25	2.11	10.18
Feb	20.51	4.01	12.26
Mar	24.51	7.56	16.04
Apr	27.56	11.46	19.51
May	28.27	15.55	21.91
Jun	28.51	19.00	23.76
Jul	27.89	20.06	23.98
Aug	28.16	19.77	23.97
Sep	27.39	18.28	22.84
Oct	26.07	13.25	19.66
Nov	22.91	7.61	15.26
Dec	19.50	3.23	11.36

Table 2: Mean Monthly Rainfall of Various Stations of Kathmandu Valley

Station/Month	Nagarkot	Sankhu	Kath airport
Jan	18.78	14.14	16.34
Feb	19.47	24.63	18.25
Mar	29.97	30.60	34.19
Apr	53.49	52.08	56.84
May	145.11	150.57	114.64
Jun	327.80	318.22	253.91
Jul	483.97	546.97	374.11
Aug	481.25	538.25	321.23
Sep	268.88	282.79	182.75
Oct	72.88	64.22	59.46
Nov	9.23	9.99	8.19
Dec	10.66	10.72	12.42

Annex II: Rainfall in Sankhu, Nagarkot and Kathmandu Airport from 1971 to 2004

Year	Kath airport	Nagarkot	Sankhu
1971	1511.3	1669.1	2335
1972	1261.4	1640.6	1941.8
1973	1799.8	3644.2	2133
1974	1225.1	1914.8	1849.6
1975	1424.5	2025	2091.6
1976	1490.6	2125.5	1853.4
1977	1297.3	1809.1	1353.5
1978	1556	2707.5	3424.5
1979	1356.4	1697	2013.2
1980	1340.9	1783.4	2097.6
1981	1370.7	1066.2	965.3
1982	1169.2	1046.5	1948.7
1983	1449.6	1264.4	2525.4
1984	1314	1433.3	1996.8
1985	1785.1	1829.8	2079.1
1986	1493.8	2087.6	1694
1987	1395.2	1645.2	1728
1988	1441	1581.2	1905.5
1989	1132	1792.4	2117.2
1990	1614.7	2132	2372.7
1991	1067.9	1741.8	1439
1992	1093.1	1799.1	1883
1993	1306	1967.7	2028.6
1994	1579.2	2055	2333.3
1995	1673.8	2332.1	2328.8
1996	1599.7	2353.2	1948.5
1997	1528.3	2134.7	2398.7
1998	1770.8	1924.2	2158.9
1999	1735.5	2143.8	2164.3
2000	1407	1875	2493.1
2001	1620.9	1849.8	1360.7
2002	1871	2321.2	2411.7
2003	1740	2259.7	2603.7
2004	1609.6	1806.8	1985.6

Annex III: Transposition of Data from Sundarijal to Manohara.

Table 1. Mean Monthly Discharge in m^3/s (Sundarijal to Manohara).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sundarijal	0.33	0.27	0.25	0.25	0.31	0.92	2.74	3.88	3.14	1.38	0.66	0.44
Manohara	0.65	0.53	0.49	0.49	0.61	1.82	5.41	7.67	6.2	2.73	1.3	0.87

Table 2. Maximum Instantaneous Discharge in m^3/s (Sundarijal to Manohara).

Year	Sundarijal	Manohara
1963	17.9	35.37
1964	7.8	15.41
1965	16.4	32.41
1966	47	92.87
1967	36.4	71.92
1968	32.4	64.02
1969	5.8	11.46
1970	35.6	70.34
1971	8.6	16.99
1972	7.22	14.27
1974	4.52	8.93
1975	7.12	14.07
1976	15.2	30.03
1977	17.3	34.18
1978	74.8	147.80
1979	3.53	6.98
1980	10.5	20.75
1981	17.3	34.18
1982	4.74	9.37
1983	34.4	67.97
1984	7.8	15.41
1985	11.5	22.72
1986	6.43	12.71
1987	5.48	10.83
1988	7.4	14.62
1989	9	17.78
1990	4.98	9.84
1992	17.9	35.37
1993	7.8	15.41
1994	6.24	12.33
1995	5.29	10.45

Annex IV: Transposition of Data From Khokana to Manohara

Table 1. Mean Monthly Discharge in m^3/s (Khokana to Manohara).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Khokana	5.92	4.84	3.75	3.81	6.92	16.8	51.4	65.1	36.7	16.2	9.89	7.33
Manohara	1.96	1.6	1.24	1.26	2.29	5.56	17	21.53	12.14	5.36	3.27	2.42

Table 2. Maximum Instantaneous Discharge in m^3/s (Khokana to Manohara).

Year	Khokana	Manohara
1992	113	37.4
1993	938	310.2
1994	533	176.3
1995	393	130.0
1996	328	108.5
1997	493	163.0
1998	649	214.6
1999	421	139.2
2000	519	171.6
2001	275	90.9
2002	942	311.5
2003	421	139.2
2004	268	88.6
2005	226	74.7

Annex V: Transposition of Data from Chovar to Manohara

Table 1. Mean Monthly Discharge in m^3/s (Chovar to Manohara).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chovar	2.51	1.84	1.55	1.78	2.47	14.5	45.4	53.4	35.4	16.4	6.98	3.9
Manohara	0.85	0.62	0.52	0.6	0.83	4.88	15.29	17.99	11.9	5.52	2.35	1.31

Table 2. Maximum Instantaneous Discharge in m^3/s (Chovar to Manohara).

Year	Chovar	Manohara
1963	206	69.39
1964	251	84.55
1965	420	141.47
1966	633	213.22
1967	680	229.05
1968	497	167.41
1969	431	145.18
1970	582	196.04
1971	617	207.83
1972	856	288.34
1973	335	112.84
1974	350	117.89
1975	591	199.07
1976	245	82.53
1977	299	100.72
1978	407	137.09
1979	416	140.13
1980	254	85.56

Annex VI: Estimated Datas

Table 1: High Flow Frequency Estimation

Return Period	lnQ2	Q100/Q2	lnQ100/Q2	sigma1	lnQ2+ssigma1	Qf
2	4.437	5.02	1.61	0.69	4.44	84.48
5	4.437	5.02	1.61	0.69	5.02	151.54
10	4.437	5.02	1.61	0.69	5.33	205.66
20	4.437	5.02	1.61	0.69	5.58	264.58
50	4.437	5.02	1.61	0.69	5.86	351.43
100	4.437	5.02	1.61	0.69	6.05	424.44

Table 2: Average Monthly Flow Estimation

Months	Ln avg elv.	a	ln(AWI)	ln(A<3k)	sqrtA5k	A<3k	A<5k	b	c	d1	d2		Q
Jan	7.52	-16.7	7.50	4.20	8.15	66.38	66.4	1.36	0.47	0.82		0.49	1.64
Feb	7.52	-17.2	7.50	4.20	8.15	66.38	66.4	1.42	0.46	0.81		0.32	1.37
Mar	7.52	0.384	7.50	4.20	8.15	66.38	66.4				0.09		1.27
Apr	7.52	0.181	7.50	4.20	8.15	66.38	66.4				0.1		1.06
May	7.52	0.0001	7.50	4.20	8.15	66.38	66.4				0.14		1.23
Jun	7.52	-19.5	7.50	4.20	8.15	66.38	66.4	1.61	0.71	0.87		1.58	4.88
Jul	7.52	-16.3	7.50	4.20	8.15	66.38	66.4	1.26	0.76	0.88		2.58	13.15
Aug	7.52	-14.7	7.50	4.20	8.15	66.38	66.4	1.24	0.62	0.87		2.94	19.01
Sep	7.52	-13.7	7.50	4.20	8.15	66.38	66.4	1.09	0.59	0.87		2.61	13.61
Oct	7.52	-15.3	7.50	4.20	8.15	66.38	66.4	1.21	0.6	0.85		1.85	6.36
Nov	7.52	-16.7	7.50	4.20	8.15	66.38	66.4	1.36	0.54	0.83		1.07	2.91
Dec	7.52	-17.0	7.50	4.20	8.15	66.38	66.4	1.39	0.5	0.82		0.68	1.98

Table 3: Flow Duration Curve Estimation

Prob of Excedence	Ln avg elv.	ln(AWI)	ln(A<3k)	SqrtA5k	a	b	c	d1	d2		Q
0	7.52	7.50	4.20	8.15	-12.8	0.37	-	0.53		7.25	52.6
5	7.52	7.50	4.20	8.15	-13.6	1.11	0.61	0.87		2.95	19.1
20	7.52	7.50	4.20	8.15	-17	1.36	0.72	0.88		2.29	9.92
40	7.52	7.50	4.20	8.15	-19	1.55	0.66	0.86		1.21	3.36
60	7.52	7.50	4.20	8.15	-18.3	1.54	0.51	0.83		0.58	1.79
80	7.52	7.50	4.20	8.15	-19.4	1.59	0.56	0.83		0.24	1.27
95	7.52	7.50	4.20	8.15	-21.2	1.73	0.60	0.84		-0.2	0.86
100	7.52	7.50	4.20	8.15	-2.18	-	0.05	-	0.08	0.37	0.14

Annex VII: Extreme Flow Data

Table 1: Manohara Data obtained from Cudworth Transposition (Extreme Flow Data from Sundarijal)

Year	Discharge Q	Descending Order	Rank m	Return Period
1963	35.36	147.80	1	32.00
1964	15.41	92.87	2	16.00
1965	32.40	71.92	3	10.67
1966	92.87	70.34	4	8.00
1967	71.92	67.97	5	6.40
1968	64.02	64.02	6	5.33
1969	11.46	35.36	7	4.57
1970	70.34	35.36	8	4.00
1971	16.99	34.18	9	3.56
1972	14.26	34.18	10	3.20
1973	8.93	32.40	11	2.91
1974	14.06	30.03	12	2.67
1975	30.03	22.72	13	2.46
1976	34.18	20.74	14	2.29
1977	147.80	17.78	15	2.13
1978	6.97	16.99	16	2.00
1979	20.74	15.41	17	1.88
1980	34.18	15.41	18	1.78
1981	9.36	15.41	19	1.68
1982	67.97	14.62	20	1.60
1983	15.41	14.26	21	1.52
1984	22.72	14.06	22	1.45
1985	12.70	12.70	23	1.39
1986	10.82	12.32	24	1.33
1987	14.62	11.46	25	1.28
1988	17.78	10.82	26	1.23
1989	9.84	10.45	27	1.19
1990	35.36	9.84	28	1.14
1991	15.41	9.36	29	1.10
1992	12.32	8.93	30	1.07
1993	10.45	6.97	31	1.03

Table 2: Manohara Data obtained from Cudworth Transposition (Extreme Flow Data from Khokana)

Year	Discharge	Descending	Rank	Return period
1992	37.4	311.50	1	15.00
1993	310.2	310.18	2	7.50
1994	176.3	214.61	3	5.00
1995	130.0	176.25	4	3.75
1996	108.5	171.62	5	3.00
1997	163.0	163.03	6	2.50
1998	214.6	139.22	7	2.14
1999	139.2	139.22	8	1.88
2000	171.6	129.96	9	1.67
2001	90.9	108.46	10	1.50
2002	311.5	90.94	11	1.36
2003	139.2	88.62	12	1.25
2004	88.6	74.73	13	1.15
2005	74.7	37.37	14	1.07

Table 2: Manohara Data obtained from Cudworth Transposition (Extreme Flow Data from Chovar)

Year	Discharge	Descending order	Rank(m)	Return period
1963	69.39	288.34	1	19.00
1964	84.55	229.05	2	9.50
1965	141.47	213.22	3	6.33
1966	213.22	207.83	4	4.75
1967	229.05	199.07	5	3.80
1968	167.41	196.04	6	3.17
1969	145.18	167.41	7	2.71
1970	196.04	145.18	8	2.38
1971	207.83	141.47	9	2.11
1972	288.34	140.13	10	1.90
1973	112.84	137.09	11	1.73
1974	117.89	117.89	12	1.58
1975	199.07	112.84	13	1.46
1976	82.53	100.72	14	1.36
1977	100.72	85.56	15	1.27
1978	137.09	84.55	16	1.19
1979	140.13	82.53	17	1.12
1980	85.56	69.39	18	1.06