JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Estimation of probable maximum precipitation: a case study for Bilate sub river basin, Rift Valley Basin, Ethiopia

By

Makiso Lambamo

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

January, 2020

Jimma, Ethiopia

JIMMA UNIVERSITY
SCHOOL OF POSTGRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Estimation of probable maximum precipitation: a case study for Bilate sub river basin, Rift Valley Basin, Ethiopia

By
Makiso Lambamo

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

Advisor: Dr. Zeinu Ahmed (PhD.)

Co-Advisor: Wondmagegn Taye (MSc.)

January, 2020
Jimma, Ethiopia

DECLARATION and COPY RIGHT

I, Makiso Lambamo do here by declare to the senate of Jimma university that this thesis is my original work and all other materials are properly acknowledged. This work has not been presented for a degree in any other university.

Makiso Lambamo	Signature	Date
(MSc. Candidate).	--------------------------	28/01/2020

This thesis has been submitted for examination with my approval as a university supervisor.

Dr. Zeinu Ahmed (PhD).	Signature	Date
Main Advisor	--------------------------	28/01/2020
Wondmagegn Taye (MSc.)	Signature	Date
Co-Advisor	--------------------------	28/01/2020

THESIS APPROVAL SHEET

This is to certify that the thesis entitled "**Estimation of probable maximum precipitation: a case study for Bilate sub river basin, Rift Valley Basin, Ethiopia**" submitted in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering,

Submitted By

Makiso Lambamo	---------------------	28/01/2020
Name of candidate	Signature	Data

As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by: Mr. Makiso Lambamo entitled: Estimation of probable maximum precipitation: a case study for Bilate sub river basin, Rift Valley Basin, Ethiopia. We recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Hydraulic Engineering.

Members of Examining Board

Dr. Kassa Tadele (PhD).	-------------------------	28/01/2020
Name of External Examiner	Signature	Date
Mr. Bekan Chelkeba (MSc).	--------------------------	28/01/2020
Name of Internal Examiner	Signature	Date
Mr. Wondmagegn Taye (MSc).	-------------------------	28/01/2020
Name of Chair Person	Signature	Date

ABSTRACT

Probable maximum precipitation is a basic and fundamental data for determining the probable maximum flood in the design of hydraulic structures. It is defined as theoretically greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year. Developing Isohyetal map was to overcome the problem of inadequate information and to facilitate quick estimation of PMP values for ungauged catchments in the basin. The General objective of this study was to estimate probable maximum precipitation and development of Isohyetal map for bilate sub river basin. It was provided to overcome the problem of inadequate information and to facilitate quick estimation of PMP values for ungauged catchments in the basin. Statistical package for social science20, Global mapper18, Digital Elevation model and MATLAB R2018a were the material used to progress the work. L-moment was a parameter for selection of distribution as candidate distribution. normal, log normal, Gamma, Extreme value type one and General extreme value was used, and values were subjected to goodness of fit tests of chi-square and Kolmogorov-smirnov tests to assess how the data has been the best fits. Diagnostic D-index was used to separate best distribution to predict different year return period rainfall depth from fitted distribution. Accordingly, the minimum D-index value was for General extreme value and parameter of Probability weighting method to station of Angecha with value of 0.024. Isohyetal map over bilate have been generated by means of Arc Map 10.4.1. Estimated value of Probable maximum precipitation was found that from 71.581mm to 128.571mm of stations Durame and Humbo respectively for 1-day duration and the statistical Hershfield Km was estimated as 1.717 to 3.231, belongs to stations of Durame and Hossana with an average value of 2.418 for 1-day duration. the overall monitoring data series at stations are taken into account the Probable maximum precipitation value calculated by statistical method is more suitable.

***Keywords**: Bilate watershed, Isohyetal Map, Probable maximum precipitation, Return Period.*

ACKNOWLEDGMENT

Above all, I would like to thank God for giving me strength to proceed and finish writing this thesis. Next, I would like to express my gratitude to Ethiopian Road Authority for providing such chance to continue my study at Jimma University Institute of Technology and for their cooperative work that made this research possible through financing. I am strongly indebted to my research advisors Dr. Zeinu Ahmed (PhD) helping from inception to the end. I would like to appreciate his intellectual assistance and advice by devoting his precious time and energy to guide me. Secondly I want to thank my Co. Advisor Mr. Wondmagegn Taye (MSc.) for his best comment, kindly advice and suggestions those have great contribution to this work. I would also like to thank the ministry of water, Irrigation and Energy; Department of Hydrology, GIS and Remote sensing for their cooperation in giving all necessary data.

Special thanks to all my friends, Classmates and my relatives for their encouragement, moral support, true friendship and wonderful social atmosphere.

Finally, I want to mention my special thanks and gratitude's to Abebech Mulatu and my families for their never-ending support, encouragement, motivation and care.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

$\bar{x}$	Mean
BRW	Bilate River Watershed
CSA	Central Statistical Agency
Cvn	Coefficient of Variation
DEM	Digital Elevation Model
σn	Standard Deviation
EV1	Extreme Value type one distribution
FOS	Factor of Safety
GEV	General Extreme Value
GIS	Geographical Information System
GoF	Goodness of Fit
HMR	Hydro Meteorological Report
HOR	Highest Observed Rainfall
IDW	Inverse Distance Weighting
Km	Frequency factor
km	Kilometre
K-S	Kolmogorov Smirnov test
LN2	Log normal distribution with two parameters
m.a.s. l	Above mean sea level
MFD	Maximum Flood Discharge

MLM	Maximum Likelihood Method
MMS	Malaysian Meteorological Service
MOM	Method of Moment
M-W	Mann Whitney test
NMSA	National Meteorological Service Agency
NOAA	National Oceanic and Atmospheric Administration
NOR	Normal distribution
NRC	National Research Council
NWS	National Weather Service
PDF	Probability Density Function
PFD	Probable Flow Discharge
PMF	Probable Maximum Flood
PMP	Probable Maximum Perciptation
PWM	Probability Weighting Method
SNNPR	South Nation Nationality People Region
SPSS	Statistical Package forSocial Science
USBR	United States Bureau of Reclamation
USWRC	United States Water Resource Council
WMO	World Meteorological Organization

1. INTRODUCTION

1.1 General Back Ground

Designing hydraulic structures for storm water management encompasses several tasks including watershed morphometric analysis, estimation of the time of concentration, calculation of the design rainfall via frequency analysis, design flow computation, sizing the hydraulic structure and hydraulic modeling to evaluate the structures hydraulic performance under various return periods *(Gonzalez-Alvarez et al., 2019*).

Probable maximum precipitation (PMP) plays an important role as basic and fundamental data for determining the probable maximum flood (PMF) in the design of hydraulic structures like spillways of major dams, canals, barrages, weir and etc. It is obvious that over estimation of PMP would result in added expenditure while under estimation could result in bringing harmful physical and economical failure of the hydraulic structure and living beings (*Fernando and Wickramasuriya, 2011*). Analysis of such rainfall data was absolutely necessary in the context of public safety. The concept of probable maximum precipitation is an attempt made to face this challenge.

It is defined as theoretically greatest depth of precipitation for a given duration that was physically possible over a given size storm area at a particular geographical location at a certain time of the year (*WMO, 2009*). Hydrologist must plan for extreme events. Dams must be built high enough to constrain or limit extreme floods, while bridges must be built high enough to remain above high water mark. Probable maximum precipitation (PMP) study provides rational information in optimal design of dams, reservoir storage capacity and flood carrying structures like spillway and flood carrying tunnel. Hydrologist used the probable maximum precipitation magnitude to calculate the probable maximum flood (PMF) that is helpful in the design of hydraulic and water conservation structures (*Lan et al., 2017*).

Knowing how an extreme rain fall and probable maximum precipitation should be the basis in Engineering practice for designing hydraulic structures and set up measures for reducing extreme natural environmental events, such as floods, rain storms, high winds and droughts have severe effects for human activities and loss of lives*(Garba et al., 2013*).

PMP is the key design rainfall input in computing Probable Maximum Floods (PMF). If a spillway is not able to safely release the PMF, breaching of the dam wall due to overtopping can occur and cause heavy loss of lives and damages to property. Typically, PMP is used to estimate the largest flood that can occur in a given hydrological basin, the so-called probable maximum flood (PMF). In turn PMF is used to determine the design characteristics of flood protection works *(Koutsoyiannis, 1999)*.The PMP approach, which practically assumes a physical upper bound of precipitation amount, was contrary to the probabilistic approach, according to which any amount must be associated with probability of exceedance or return period.

1.2 Statement of the problem

Many site specific studies in the past have produced different PMP values compared to HMR published values *(Singh et al., 2018)*.

There is a need to determine basin specific PMP which can be used for the calculation of PMF. Such PMP can incorporate basin characteristics that are specific to the local topography and climate. Bilate sub river basin has a limiting amount of first class meteorological stations. Developing Isohyetal map was to overcome the problem of inadequate information and to facilitate quick estimation of PMP values for ungauged catchments in the basin. The most important factor to be consideration in the designing Engineering structures are safety, economy and safety for design and risk analysis of hydraulic structures in the basin. this requires estimates of the frequencies of occurrence of rainfall of a given duration. Due to this reason estimation of PMP of basin specified was basic concern of the study area of Bilate sub river basin by using meteorological data of daily annual maximum rainfall in the basin to overcome PMP for ungauged station by developing Isohyetal map, estimation of frequencies of occurrence of rainfall for risk analysis of hydraulic structures.

1.3 Objectives

1.3.1 General Objective

The General Objective of this study is to estimate Probable Maximum Precipitation (PMP) a case study for Bilate sub river basin.

1.3.2 Specific Objective

The specific objectives of this study were planned with the following specific objectives.

1. To estimate the Probable maximum precipitation(PMP) by using Hershfield statistical formula.
2. To estimate point PMPs and their return periods for the considered rain gauge station in the basin.
3. To develop one day PMP, and Frequency factor of Isohyetal map for the study area.

1.4 Research Questions

1. How much the probable maximum precipitation of the stations is estimated by Hershfield statistical formula?
2. What probability of exceedance of a certain observed value is expressed in terms of return period for prediction of PMP?
3. How the PMP, and frequency factor is located over the base map of the basin?

1.5 Significances of the Study

Information on flood magnitudes and their frequencies were needed for design of hydraulic structures such as Dams, Spillways, Railway Bridges, Culverts, Urban drainage system, flood plain zoning, and economic evaluation of flood protection projects. The estimation of peak flows on small and medium sized plains is generally the common application as they are required for the design of conservation works *(Ghosh, 1997)*.

Estimation of probable maximum precipitation which could be an input for estimation of probable maximum flood for water resource planning and designing in the basin where there are no gauging stations. It also provides reliable and quick information on the PMP values in the basin. Hence, this research comes to overcome the problem of inadequate information and to facilitate quick estimation of PMP values for ungauged catchments in the basin.

This study can also create good awareness for Hydrologists and Engineers about how to design economical hydraulic structures in sub-river basin using reliable PMP and helpful to the stakeholders and other researcher to arrive at PMF for planning, design, safety measurement and high-risk assessment of possibility of incurring loss of hydrological structures in the basin. It is also helpful for researchers who have an interest for doing further research on Estimation of PMP using different methods that was appropriate characteristics based of PMP on Ethiopian river basins. Generally, the estimation of PMP for the basin is an important task for various Engineering works such as spillway design for Dams of the highest hazard category.

1.6 Scope of the Study

The study was geographically being limited to Bilate watershed, Rift valley river basin. In general, the study comprises the estimation of probable maximum precipitation of bilate sub river basin and development of Isohyetal maps for PMP, and frequency factor for one-day duration.

The estimation was based on Hershfield statistical formula types of method for the estimation of PMP for Bilate sub river basin or watershed.

1.7 Organization of the thesis

The thesis is organized in five chapters. Chapter one contain an introduction with back ground of the study, problem of the statements, objectives, significance of the study, research questions and scope of the study. In chapter two it has review of literatures about the concept of PMP. Methodology and Data analysis was arranged in chapter three. Chapter four describes result and discussion of estimation of PMP and development of Isohyetal map. Finally, in chapter five conclusion and recommendations were provided.

2. LITERATURE REVIEW

2.1 Historical Back Ground and Definition of PMP and PMF

Early estimates based on the highest recorded rainfall at a specific location (in situ maximization) suffered because of the limited data available and as such, PMP estimates for different locations in the same vicinity differed substantially *(Walland et al., 2003).*

The foundation of PMP estimation lies in observations of rainfall amounts as observed in major storms. It is important to realize that the PMP is a theoretical value that represents a limiting precipitation amount for a particular duration and area, and as such is not a quantity that is expected to be observed.

It is defined as, theoretically the greatest depth of precipitation for a given duration that is physically possible over a given station or area at a particular geographical location at a certain time of year.*(WMO, 2009)*.

PMF is the theoretically maximum flood that poses extremely serious threats to the flood control of a given project in a design watershed. Such a flood could probably or easily occur in a locality at a particular time of year under current meteorological conditions *(WMO, 2009).*

2.4 Methods of PMP Estimation

According to WMO (2009), there were different methods used for PMP estimation which can be categorized as hydro-meteorological and statistical. Common hydro-meteorological methods include: moisture maximization method, maximization and transposition of actual storm method, generalized method, storm separation method and depth-area-duration method.

2.4.1 Empirical Relationships between Variables in a Particular Valley

This approach was convenient in areas with complex topology, such as mountains, and in places where there were limited data for elaborate model studies. Rainfall intensity depends upon inflow velocity, moisture content, and storm mechanisms or convergence factors.

2.4.2 Estimation of PMP by Statistical Method

Statistical method used for estimating extreme rainfall (PMP) at a station or over an area was based upon the assumption that information regarding extreme rainfall was contained in the long rainfall records of that station. Statistical procedure for estimating PMP is normally used whenever sufficient rainfall data are available and is particularly useful for making quick estimates or where other meteorological data, such as dew point and wind records, are lacking. Hershfield (1961), for the first time used the statistical method for estimation of PMP for USA.

If adequate precipitation data is available on the region Statistical method is useful for estimation of PMP because once a statistical model is constructed, its application is simple and fast *(Al-Mamun and Hashim, 2004)*. The statistical method aims at the determination of the point probable maximum precipitation (PMP) for a given gauge position or grid point. Corrections that transform the point PMP to an area rainfall are necessary for determining an area PMP. The statistical approach is often found to be quick and reliable and is therefore often preferred to the physical or empirical approach to the estimation of extreme rainfall.

This method is mainly applicable for watersheds with a collecting area under 1000km^2 and is useful when meteorological data such as dew point temperatures, wind speed, etc., are not easily available but there are large amounts of rainfall data are available. The values of $\bar{x}$, $\bar{x}_{n-1}$, $\sigma n, \bar{x}_{n-1}$, and cv can be estimated using equation 2.2 and 2.3.

The maximum frequency factor (Km) can be estimated for each station using equation (2.4). One-day annual maximum rainfall values of all stations has to be analyzed to extract the station based PMP estimates using equation (2.1).

XPMP=$\bar{x}_n$+KmSn……………..…………………………………………………2.1

Where,

XPMP-PMP- estimatefor a station

$\overline{Xn}$- mean of the annual extreme series

Sn- standard deviation of the annual extreme series

Km- maximum frequency factor

The sample mean ($\overline{xn}$) and standard deviation (Sn) can be computed by:

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} xi$……………………………………………………………………...2.2

$\sigma n=\sqrt{\frac{\sum_{i=1}^{n} (xi-\overline{x})^{2}}{n-1}}$…..2.3

Where,

$\bar{x}$ - mean for the random variable

xi - the i^{th} value of the random variable

σn- sample standard deviation

The maximum frequency factor (Km) can be calculated as (Hershfield, 1961) (Hershfield, 1965)

Km= $\frac{xi-\bar{x}n-1}{\sigma n-1}$…………………………………………………………..…....2.4

Where,

xi - highest observed annual maximum rainfall in the series

$\bar{x}n-1$ - mean of the annual maximum, excluding the highest value in the series

$\sigma n-1$ Standard deviation of the annual maximum, excluding the highest value in the series

PMP is the probable maximum precipitation at the design station, which can be computed with the following formula:

PMP=x_n+kmσ $_{\text{n}}$= $\overline{x}$(1+kmcv_n)……………………………………………....2.5

Where,σ $_{\text{n}}$ and cvn standard deviation and coefficient of variation respectively and

$(cvn = \frac{\sigma_n}{x_n}$…………………………………………………………………...2.6

2.4.3 Storm model approach

In this model precipitation process was expressed in terms of physical parameters like surface dew point, heights of the cells, inflow, outflow, etc. Collier and Hardaker (1996), used this approach to estimate PMP values, using equations of continuity and can adequately represent the meteorological conditions both in space and time.

2.4.4 Maximization and Transposition of Actual Storms

It includes developing Isohyetal maps, mass curves, and estimating moisture change from the representative dew points of the storms by collecting and analyzing data from extreme storms that has occurred over the area being studied. The storm rainfall depths obtained from Isohyetal maps or depth-duration-area curves give PMP estimates for that basin.

2.4.5 Use of Generalized Data

These method was developed by maximizing and translating different storms over a large watershed and involve the classification of storms by calculating the corresponding storm efficiency *(NERC, 1975)*.

2.4.6 Empirical Methods Derived from Depth, Area and Duration

Different empirical formulas were given by different researchers to estimate the world's greatest point PMP value. The general form of empirical equation is given by *(Hansen et al., 1982)* as:

PMP $=aD^b$ ……………………………………………………………..………2.7

Where, D is the rainfall duration and; a and b are dimensionless parameters as a function of the rain gauge station. For example, World Meteorological Organization WMO (2009) as:

P=$422D^{0.475}$ ………………………………………………...…………………2.8

Where, P is precipitation depth (mm) and D the duration hours. In addition, *Linsley et al. (1982)*, present the following equation to calculate world greatest observed point rainfalls as:

$P=417D^{0.48}$…………………………………………………………………….………2.9

Where, P is precipitation depth (mm) and D the duration (hours).

2.5 Development of Frequency Factor (Km) from Hershfield's Chart

Hershfield prepare a curve for estimation of frequency factor by analyzing data from 2700 stations 90% of which were in United States and he found that the maximum observed value of Km was 15. Then, he decided that an estimate of the PMP values can be calculated by using Km= 15, but in 1995 he proposed that the Km value equal to 15 is not compatible for all areas in USA .Therefore, he constructed a chart indicating that Km varies between 5 and 20 depending on the rainfall duration and the mean *(WMO, 2009)*. Different studies show that the frequency factor (Km) found from Hershfield's graphical procedure was overestimate the actual value.

2.6 The magnitude of PMP to maximum observation rainfall ratio

According to Hershfield (1962), the magnitude of point PMP at an individual station should normally not exceed three times the highest observed rainfall from a long period of rainfall data. Dhar *et al.* (1981), at some of the stations over India and Durbude (2008), for southern part of Banswara district of Rajastham state, Desa and Rakhecha (2006), for Malaysia, Dame and Ayalew (2010), for Blue Nile basin in Ethiopia, Regasa (2010), for Benishangul-Gumuz Regional state (Ethiopia), Tesema (2012), for West Shewa Zone, Oromia region (Ethiopia), Gerezihier and Quraishi (2013), for Tigray Region, Ethiopia and Quraishi and Berhane (2014), for Amhara region the ratio of PMP to the HOR for one day rainfall were estimated with average of 1.05, 2.0, 1.9, 1.8, 1.75, 1.11 and 1.75 respectively.

The depth of PMP to the highest observation rainfall ratio or PMP to some known year's design rainfall ratio was an important parameter that could be used in relation to the Factor of Safety (FOS) usually adopted in Engineering practices (e.g. in Structural Engineering generally a FOS of 1.4 - 1.7 and for Geotechnical design FOS of 1.5- 2.0).

2.7 PMP and its application on hydraulic structure

The hydrologic problem typically addressed in Dam safety analysis is the determination of the capacity of the spillway needed to prevent harmful failure of the dam due to over toping. The PMF is general accepted as the design inflow for evaluating the spill way when there is potential loss of life due to dam failure in high hazard situation.

As per the first edition of Dam safety guidelines by the Canadian Dam association Vasquez and Roncal (2009), Dams are classified into four categories. According to the perceived incremental consequences of failure these are very high, high, low and very low Dams. The criteria for the design flood as stated in Vasquez and Roncal (2009), are as follows;

- For very high Dams: The PMF developed as a result of PMP is mandatory.
- For high Dams: the design flood may be selected between PMF and the 1000 years or return period of flood.
- For low Dams: the design flood may be selected between the 1000 year and the 100 year return period of flood.
- For very low Dam: the design flood selected is less than 100 year return period of floods.

The PMF represents an estimated upper bound on the maximum runoff potential for particular watershed. In some sense, the inherent assumption is that a Dam with a spillway designed to pass this flood has zero risk of overtopping.

2.8 Return Period Analysis of the basin

Estimation of rainfall for a desired return period and different durations is often required for design and risk analysis of hydraulic and other structures in a region. Annual maximum rainfall estimates likely to occur for different return periods are very often important inputs for design purposes. These extreme events are also essential in the post commissioning stage, where in the assessment of failure of hydraulic structures needs to be carried out *(Vivekan, 2013).*

The most important factors to be taken into consideration in the designing of Engineering structures are safety, economy and efficiency. This requires estimates of the frequencies of occurrence of rainfall of a given duration and intensity, for analysis of the potential costs and benefits of building adequate controls. These estimates are called return periods.

A comprehensive study of various distributions was made by who found that the Gumbel (EV1) technique, based on the Fisher-Tippet (Type-I) distribution, was the most suitable distribution (if applied to the data of stations in the homogeneous region). This is also the experience of while studying the intensity-duration relationship of South African rainfall. Gumbel's method has been increasingly used in estimating the probability of occurrence of maximum rainfall events.

2.9 Development of Isohyetal map for PMP

Development of isohyets for use in estimating rainfall is one of the commonly used methods of spatial analysis. Yarnell (1935), plotted Isohyetal map for rainfall intensities for desired durations and frequencies from the intensity-frequency diagrams that He developed according rainfall z\values vary throughout the world and storm duration, depth and intensities vary. The prediction of the expected rainfall values at specific locations is necessary in the design of engineering projects Determination of the expected rainfall for a particular rainfall duration and design frequency at a location where there is no recording station is possible and requires spatial analysis of the available rainfall values from the surrounding area Nowadays, Isohyetal line plotting using surface mapping software is mostly based on numerical fitting techniques such as the Inverse Distance Weighting (IDW) can be used to estimate precipitation for the cell in a rectangular grid throughout a watershed, and these values can be arithmetically averaged to obtain a map *(Gerezihier and Quraishi, 2013)*. Each grid cell was characterized by its location; latitude, longitude or rectangular coordinates and elevation *(Zurndorfer, 1986)*.

2.10 Previous Study on PMP in some World

There is little information about the importance of PMP in different world country. Each researcher has recommended their idea in broad concepts depend upon the result found from the given extreme data.

The PMP estimates derived from the statistical method depend largely on the frequency factor. Removing or adding any one station can change the shape of the curve which can result in highly uncertain PMP values *(Singh, 2016)*. Historical storms of 1, 3 and 5-day durations from 21 rainfall recording stations operated by Malaysian Meteorological Service (MMS) were identified and analyzed to calculate the PMP values. Maximum rainfall for 1, 3 and 5-day storms in the peninsula were recorded as 809, 1272.9 and 1494mm respectively. The highest calculated point PMP values for 1, 3 and 5-day storms were 1149, 1808 and 2121mm respectively *(Al-Mamun and Hashim, 2004)*.

A basin-scale spatial distribution analysis of Extreme rainfall and PMP in the Yodo river basin at japan is presented. The maximum 24-hour rainfall data of 131 years were used. Highest PMP is observed above 900mm, while the least was below 500mm *(Alias et al., 2013)*. In India over the entire basin, point PMP estimates were found to range from about 5 to 98cm for 1-day, 3 to 137cm for 2-day and 8 to 163cm for 3-day durations. Maximum being estimated at sub basin was 201cm *(Deshpande et al., 2008)*.

2.10.1 Previous Study on PMP in Ethiopia

In an attempt to develop PMP Isohyetal map for a one-day duration, annual daily extreme rainfall series of one day durations at stations in Ethiopia were subjected to statistical analysis using Hershfield formula based on an appropriate maximum frequency factor. Mulugeta (2012), for Benishangul-Gumuz Regional State (Ethiopia) had been considered based on the actual maximum daily rainfall data, the highest value of frequency factors was found 8.1, one-day PMP values varied from 170 mm to 284 mm, and the mean ratio of PMP to HOR was about 1.8. Extreme Value Type-I distribution was fitted to one-day extreme rainfall series and depths of rainfall for various return periods were estimated and found with a return period of $4.9*10^3$ years.

In 2012 Tesema (2012) had attempted to develop PMP Isohyetal map for one-day duration in West Shewa Zone Oromia Region, (Ethiopia) subjected to statistical analysis using Hershfield formula. Based on the actual maximum daily rainfall data of varying record length of the stations, the highest value of frequency factor was found as 6.80 and PMP varying between 105 to 243 mm and the ratio PMP to HOR varied from 1.50 to 2.30 with average of 1.75 *(Gerezihier and Quraishi, 2013)*.

Gerezihier and Quraishi (2013), had attempted to develop PMP and Isohyetal map for Tigray Region. The maximum frequency factors (Km) of individual rain gauge stations were found to vary from 1.91 to 5.91 at an average value of 3.1 and CV 28.2%. The PMP values were found to vary from 70.06 mm and 144.51 mm at an average value of 101.67 mm and CV 19.87%. These values were compared with maximum observations, world enveloping records and previous PMP studies for the same duration. The ratio one-day PMP to highest observed rainfall (HOR) varied from 1.04 to 1.42 with average of 1.11 *(Gebremedhin et al., 2017)*. At Amhara region PMP values were found to vary from 52.83mm to 239.77mm with an average value of 128.75mm and coefficient of variability of 34.57% and the corresponding maximum frequency factor of 5.2 *(Quraishi and Berhane, 2014)*.

Development of one-day probable maximum precipitation and Isohyetal map for bale zone at Oromia region using daily extreme value of 18 stations by statistical method to estimate point PMP and develop one day PMP Isohyetal map has been developed. The frequency factor values varied from 2.24 to 5.09 and PMP varied from 51.43mm to 234.81mm with an average 118.92mm *(Fikre et al., 2016).*

3. MATERIAL AND METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location and General Characteristics

The most logical unit for the water resources planning and optimum utilization of available water resources is the river basin. Accordingly, it is desirable that all major river basins in Ethiopia have an integrated development master plan study, and their potential in term of economic development be known. The Rift valley river basin is one of the Ethiopian River basins; has an area of 52, 739 km^2, covering parts of the Oromia region and SNNPR regions. The basin is endowed with a number of lakes of varying size with high environmental significance. Bilate basin is one of the sub-river basins in Rift valley main River basin.

Bilate River is one of the inland rivers of Ethiopia whose source is located at Gurage Mountains in central Ethiopia. The river drains to the northern watershed of the Lake Abaya-Chamo Drainage Basin. The Bilate River watershed (BRW) covers an area of about 5470 square kilometers and is located in the southern Ethiopian Rift Valley and partly in the western Ethiopian Highlands. The Bilate River catchment includes part of the SNNPRS regional zones which include: Hadiya, Kambata Tambaro, Gurage, Silte, Wolaita, Sidama, and Alaba special woreda and small parts of the south-central Oromia regional states. The Bilate River Watershed stretches across different ecological zones ranging from the mid-south-west Ethiopian Highlands to the lowlands of the Rift Valley. The altitude of the watershed ranges from 1,146 at Lake Abaya to 3,393 meters above sea level at Mt. Ambaricho. Geographically, its location, extends from 6º 36'N 38º00'E at Lake Abaya Wolaita Zone SNNPR to 8º05'N 38 º12'E at Gurage and Silte Zones border, SNNPR; and from 7º18'N 46'E at Kambata Zone to 7º12'N38º22'E Sidama Zone. The Bilate River is the longest river in the Abaya Chamo Basin, with a length of about 255 km and the catchment drains from the north of the Abaya-Chamo Basin to Lake Abaya and constitutes about 38% of Lake Abaya basin. *(Wodaje, 2017)*.

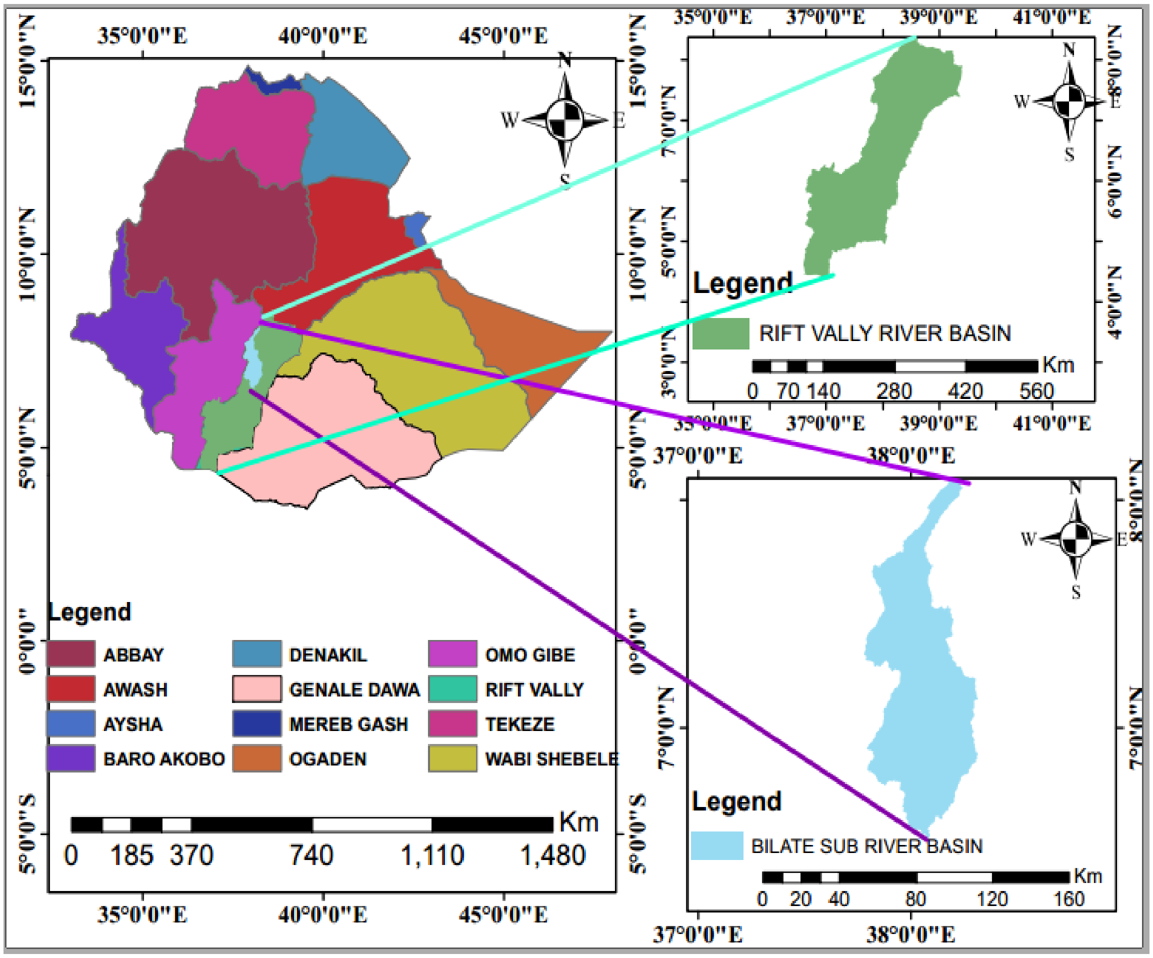

Figure 3.1: Location map of the study area

3.2 Materials used

The following materials were used for this study; but not limited.

- Micro Soft Excel-2016
- Global mapper 18
- DEM (Digital Elevation Model)
- Arc Map 10.4.1 software was used for developing of Isohyetal map and Delineation of study area location map.
- MATLAB R2018a was used for outlier detection.
- SPSS software for interpreting of data for statistical parameters.

3.3 Methods

In world meteorological organization there were various methods of estimating probable maximum precipitation (PMP), for this study, depending upon data availability, Statistical analysis approach (Hershfield method) was used.

3.3.1 Estimation of frequency factor (Km)

The statistical Hershfield method was used to estimate frequency factor that can give certain PMP values for stations in the Bilate sub-river basin for practical application. Daily annual maximum rainfall series of observed values were used for analysis of Km.

3.4 Data Availability and Analysis

3.4.1 Data Availability and Types

There are two general types of data, those are quantitative and qualitative data both were equally important. Both types of data use to demonstrate effectiveness, importance or value.

The methods of collecting primary and secondary data differ since primary data are to be originally collected, while in case of secondary data the nature of data collection work is merely that of compilation. in this study the only data required was meteorological rainfall secondary data.

3.4.2 Source and Types of Data

3.4.2.1 Digital Elevation Model (DEM)

DEM was point elevation data stored in digital computer files which can freely downloaded from internet. This data is downloaded from online source by using Global mapper 18v software. These data consist of X, Y grid locations and point elevation or z-values. It is a commonly used digital elevation source and an important for watershed characterization.

They were generated in a variety of ways for a different map resolutions or scales. Many agencies provided DEM data with different resolutions. But for this specific study resolution or pixel size of 12.5m by 12.5m was used. The elevation of the basin ranges from 1148.34 m.a.s. l to 3355.52m.a.s.l.

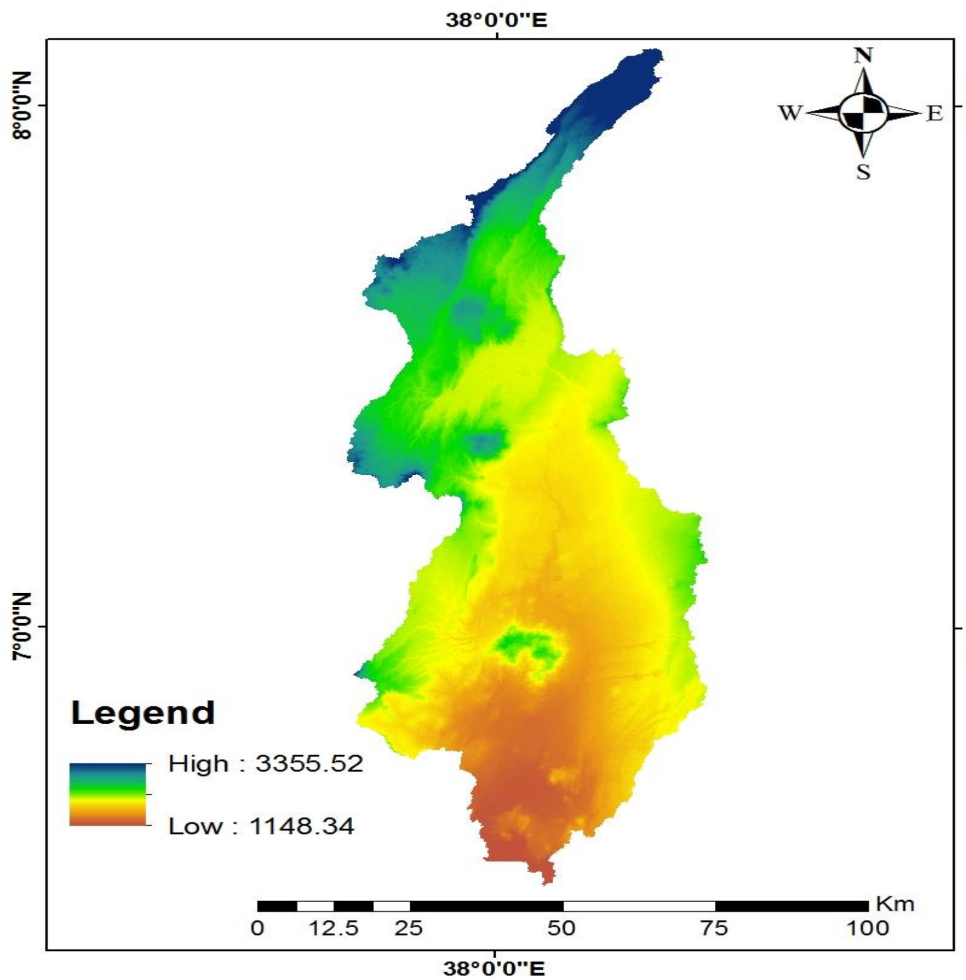

Figure 3.2: DEM map of study area

3.4.2.2 Meteorological Data

Rainfall data was the most important data for estimation of probable maximum precipitations by statistical method. Rainfall data from nearby rain gauge stations which have influence on the basin characteristics and effect of storm flooding were used for the analysis. This data was obtained from National Metrological Service Agency (NMSA) of Ethiopia.

Table 3.1: Meteorological stations of bilate sub river basin

Name of Station	Longitude	Latitude	Elevation(m)
Alaba Kulito	38.094	7.311	1772
Angecha	37.857	7.341	2317
Bedessa	37.936	6.869	1609
Bilate	38.083	6.817	1361
Boditi	37.955	6.954	2043
Butajira	38.367	8.15	2000
Durame	37.95	7.2	2000
Fonko	37.968	7.642	2246
Hossana	37.854	7.567	2307
Humbo	37.759	6.702	1628
Shone	37.953	7.134	1959
Wulbareg	38.12	7.736	1992

The elevation of meteorological station is from 1361m.a.s.l to 2317m.a.s.l.

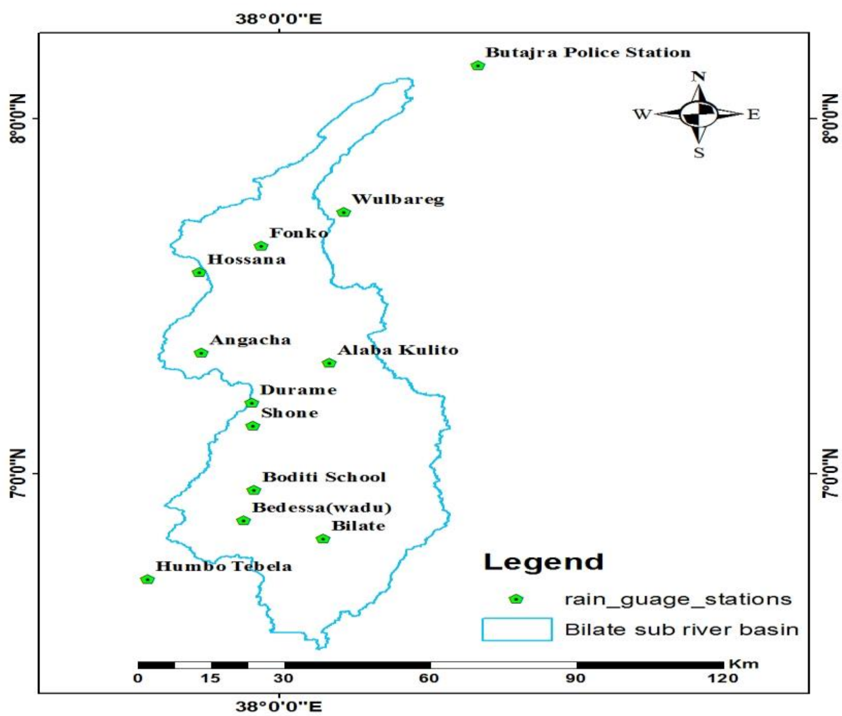

Figure 3.3: Bilate watershed rain gauge distribution

3.5 Data Quality Control

The hydrologic data used for flood frequency analysis should be independent and identically distributed with the hydrologic system producing the phenomenon of rainfall is to be random in nature and independent in space and time *(Vivekanandan, 2015)*.

3.5.1 Filling Missing Data

Missing data, or missing values, occur when no data value is stored for the variable in an observation. Daily rainfall data are one of the basic inputs in hydrological analysis. However, most daily rainfall data series are too short to perform reliable and meaningful analyses and possess significant number of missing records *(Hasan and Croke, 2013)*.

Filling the missed observation can be done through numerous methods. Missing data are a common occurrence and can have a significant effect on the conclusions that can be drawn from the data. Some of the methods to fill missing data are:

1. Station Average Method
2. Normal Ratio Method
3. Regression Method

3.5.1.1 Station Average Method

The missing record is computed as the simple average of the values at the nearby gauges. McCuen (1998), recommends using this method only when the annual precipitation value at each of the neighboring gauges differs by less than 10% from that for the gauge with missing data.

$$P_x = \frac{1}{N}[P_1 + P_2 + \cdots\cdots + P_n] \quad \text{3.0}$$

Where, P_x is the missing precipitation record

$P_1, P_2, \cdots\cdots P_n$ are Precipitation records at the neighboring stations

N is Number of neighboring stations

3.5.1.2 Normal Ratio Method

If the annual precipitations vary considerably by more than 10 %, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighboring stations by the ratios of normal annual precipitations.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots\cdots + \frac{P_n}{N_n}\right] \qquad \text{3.1}$$

Where: N_x = Annual-average precipitation at the gage with missing values

$N_1, N_2, \cdots\cdots N_n$=Annual average precipitation at neighboring gauges

3.5.1.3 Regression Method

A multiple linear regression of the form

$$P_x = a_0 + a_1P_1 + a_2P_2 + \cdots\cdots + a_nP_n \qquad \text{3.2}$$

Where;

$a_1,\ a_2, \cdots\cdots, a_n$; can be calculated by least square method.

The equation can be used to compute rainfall P_x of the missing station. This method is more efficient when digital computer is available at rain gauge site. the annual daily data would be considered as missing if more than 10% of the daily data were missing i.e. the time series almost having 90% of the record is relatively complete to analyze trends in extreme daily precipitation *(Costa and Soares, 2009).*

Based on the criteria given in section equation (3.0) and equation (3.1) their missed day was filled by station average method and normal ratio method. table (3.2) shows the missed stations and percentage of total missed date in number.

Table 3.2: Stations having missing data in percentage

Stations	total observation	observation with missing	observation without missing	Missing in percent (%)	Recorded without missing in percent (%)
Alaba	11687	292	11395	2.499	97.501
Angecha	11322	1227	10095	10.837	89.163
Badessa	11322	423	10899	3.736	96.264
Bilate	11718	383	11335	3.268	96.732
Boditi	11718	377	11341	3.217	96.783
Butajira	11718	1768	9950	15.088	84.912
Durame	11687	694	10993	5.938	94.062
Fonko	11718	433	11285	3.695	96.305
Hossana	11687	710	10977	6.075	93.925
Humbo	11687	894	10793	7.650	92.350
Shone	11322	717	10605	6.333	93.667
Wulbareg	11687	626	11061	5.356	94.644

3.5.2 Test for outliers

Outliers should have to be investigated because they have provided useful information about data or process. According to Javari (2017), several explanations for the occurrences of outliers are:

- Data entry error: Correct the error and reanalyze the data.
- Process issue: Investigate the process to determine the cause of the outliers.
- Missing factor: Determine whether you failed to account for a factor that influences the process.

In this test the upper and lower limits are analyzed by using equations;

$$X_u = \exp(_{\bar{X}} + K_N S) \qquad 3.3$$

$$X_L = \exp(_{\bar{X}} - K_N S) \qquad 3.4$$

$$K_N = -3.62201 + 6.28446N^{1/4} - 2.49835^{1/2} + 0.49146N^{3/4} - 0.037911N \ldots 3.5$$

Where; N is size of sample, $\bar{X}$ mean and S standard deviation.

Box and whisker pilot method is one type of method to identify whether the data has outlier or not in Matlab 2018a and SPSS software.

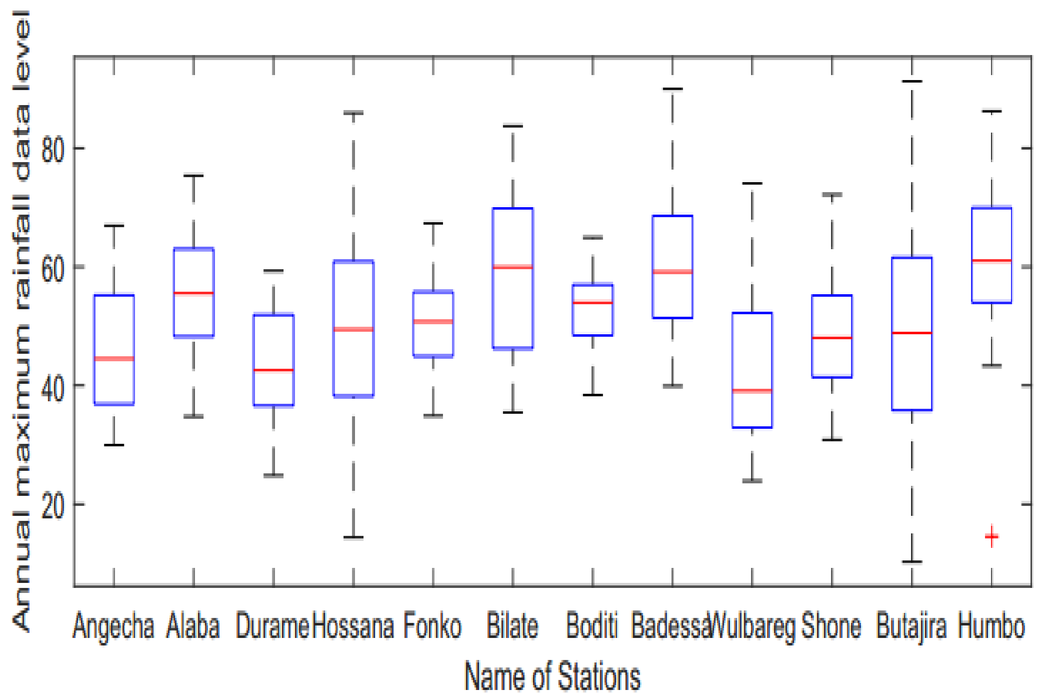

Figure 3.4: Box plot for outlier check of selected stations

Grubbs test was applied to identify the outliers in the data series. The statistical test results for all selected station was presented in table (3.3).

Table 3.3: Statistical outlier test result for selected stations of one 1-day

Outlier test of all Stations for 1-days of Corrected data						
			Data Range		Limiting value	
Name of stations	Mean	standard deviation	Maximum	Minimum	Upper limit	Lower limit
Alaba Kulito	55.991	12.410	86.000	34.800	89.235	27.125
Angecha	46.007	11.025	67.000	30.000	81.250	11.250
Badessa	61.929	14.929	100.400	39.900	102.300	25.713
Boditi school	53.403	7.697	69.800	38.400	70.638	35.938
Butajira	48.696	23.199	91.300	10.215	98.400	-1.200
Durame	43.228	9.949	59.300	24.800	74.363	14.263
Fonko	50.955	8.630	67.400	34.900	70.100	30.900
Hossana	50.684	15.854	66.800	14.408	90.200	7.000
Humbo Tebela	62.656	15.809	103.600	14.580	105.075	31.188
Shone	49.310	10.615	72.200	30.900	75.400	21.000
Wulbareg	42.777	14.049	74.100	23.900	77.800	7.000
Bilate	58.731	14.211	83.800	35.500	102.924	12.325

However, the data values given in the table (3.3) was waited to be confirmed by the next step. Grubbs (1950), test was applied to identify the outliers in the data series.

3.5.3 Homogeneity test

Homogeneity is an important issue to detect the variability of the data. In general, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments*(Kang and Yusof, 2012)*.

In this test two samples of size p and q are compared. Set of data combined to size N=p+q is ranked into ascending order. The *(Mann and Whitney, 1947)*; (M-W) test considered the quantities v and w in equation below;

$$V=N-\frac{(p(p-1))}{2} \quad \text{...3.6}$$

$W=pq-V$……………………………………………………………….…………3.7

N is the sum of the ranks of the elements of the first sample size p in the combined series size N. and V and w are calculated from N, p, and q. v represents the number of times an item in sample one follows an item in sample two in the ranking. Similarly, w can be computed for sample two following sample one.

The m-w statistic u is defined by the smaller of v and w. when N>20 and p, q>3 and under the null hypothesis that the two samples came from the same population is approximately normally distributed with mean.

Umean= $\frac{p+q}{2}$……………………………………………………………...……3.8

Variance var (u)

Var (U) =$(\frac{pq}{N(N-1)})\ (\frac{N^3-N}{12}-\sum T)$……………………………………………………3.9

And T= $J^3-\frac{J}{12}$………………………………………………………………3.10

Where J is the number of observations tied in a given rank.

T is summed overall groups of tied observation in both samples of size p and q.

Ustat= $\frac{(U-Umean)}{(var(u))^{1/2}}$…………………………………………………………………..3.11

Equation (3.11) is used to test the hypothesis of homogeneity at significance level 5%.

For no trend in the data series this value should be within the limit of ± 1.96 at the significance level of 5%. The test by mann-Kendal showed that no significant trend in the annual maximum rainfall values exists at all stations. table (3.4) shows the homogeneity test of M-W test result for Bilate station.

Table 3.4: Mann-Whitney test to homogeneity of all selected station

Name of Station	Sample size N	var (U)	stat (U)	standard value	Remark
Alaba	32	697.223	0.606	1.96	Homogenous
Angecha	29	509.978	0.642	1.96	Homogenous
Badessa	28	467.209	0.648	1.96	Homogenous
Bilate	32	701.014	0.604	1.96	Homogenous
Boditi	30	567.746	0.630	1.96	Homogenous
Butajira	31	637.979	0.614	1.96	Homogenous
Durame	32	695.209	0.607	1.96	Homogenous
Fonko	29	524.763	0.633	1.96	Homogenous
Hossana	31	635.957	0.615	1.96	Homogenous
Humbo Tebela	30	567.746	0.630	1.96	Homogenous
Shone	31	637.979	0.614	1.96	Homogenous
Wulbareg	31	639.763	0.613	1.96	Homogenous

As the result shown at table (3.4) the standard test for all station with significance level of 5% was found to be less than the critical value of $\pm$1.96. Therefore, there was no significance trend in the annual maximum observed values.

3.5.4 Test for consistency of Data

In order to check the consistency of the data, Searcy and Hardison (1960), used double mass analysis as consistency tool of rainfall data in the watershed. Cumulative of mean annual precipitation data of the stations was used as a pattern for testing the individual station records.

3.5.4.1 Double mass curve test

The slope of the line will represent the constant of proportionality between the quantities. the theory of the double mass curve was based on the fact that a graph of the cumulative of one quantity against the cumulative of another quantity during the same period has plot as a straight line so long as the data are proportional; the slope of the line represented the constant of proportionality between the quantities *(Searcy and Hardison, 1960).*

If a break in slope is observed, then the data of the station is adjusted by multiplying it with the ratio of the two slopes. Therefore, there is a need for correction of slope of double mass curve, for adjusting inconsistency record of data.

$$Pa = \frac{Ma}{Mo} * Po \qquad (3.12)$$

Where:

Pa; adjusted rainfall

Po; observed rainfall

Ma; the slope of graph to which records are adjusted

Mo; the slope of graph at time Mo was observed.

The double mass curves have been plotted between the rainfall data for Bilate station for the period of 1986-2017. All of the stations were consistent with Bilate rainfall data in double mass curve plots. The plot figure (3.5) shows that the Bilate rainfall data was consistent with the other rainfall stations.

The double mass curve shown as below with linearly fitting value and equation of double mass curve.

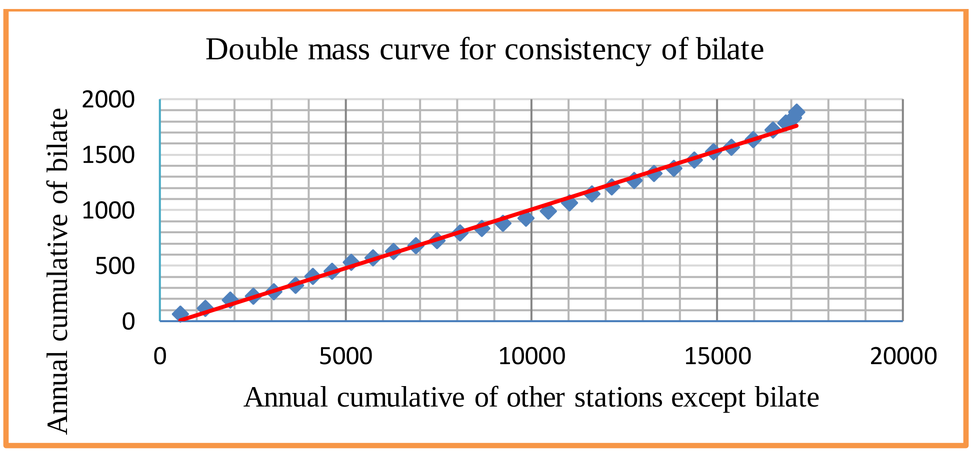

Figure 3.5: Double mass curve for consistency of Bilate station

The consistency of other stations' double mass curve was presented in Annex B list of Figure (1-11) and their linear fitting equation shown in table (3.5).

Table 3.5: Consistency Test Equations for double mass curve of all stations

S.No	Name of stations	Fitted Equation type	fitted Equation	R^2 value
1	Alaba Kulito	Linear Equation	y= 0.0983x+35.247	0.9975
2	Angecha	Linear Equation	y= 0.0778x-8.3436	0.9976
3	Badessa	Linear Equation	y= 0.109x-12.828	0.9972
4	Bilate	Linear Equation	y= 0.1057x-50.91	0.9945
5	Boditi	Linear Equation	y= 0.0942x-11.854	0.9997
6	Butajira	Linear Equation	y= 0.0884x+68.462	0.991
7	Durame	Linear Equation	y= 0.0733x-37.518	0.9904
8	Fonko	Linear Equation	y= 0.0877x-9.0818	0.9994
9	Hossana	Linear Equation	y= 0.0889x+9.0274	0.9987
10	Humbo	Linear Equation	y= 0.1164x-86.993	0.9992
11	Shone	Linear Equation	y= 0.0848x+40.93	0.996
12	Wulbareg	Linear Equation	y= 0.0749x+23.176	0.9973

3.6 Method of Data Analysis

For each station, daily maximum rainfall was selected and an array of annual daily maximum values of rainfall has been formed. All the annual daily and annual total rainfall data of the stations was arranged in Excel-2016, MATLAB R2018a, SPSS software has been used for data analysis and interpretation. In additional to this to develop PMP Isohyetal map, Global mapper 18 and Arc Map 10.4.1 software has been used.

3.7 Fitting Data to the Probability Distribution Function

Frequency analysis techniques were employed to analyze the annual daily maximum rainfall data *(Gebremedhin et al., 2017)*. Fitting the theoretical probability distribution to the observed data is done by applying corresponding plotting position given in table (3.6).

3.7.1 Plotting position

The purpose of the frequency analysis of an annual maximum series is to obtain a relation between the magnitude of the event and its probability of exceedance *(Subramanya, 2013)*.

Table 3.6: Different plotting positions formulae

Plotting Positions Formulae	Formulae
Hazen (1930)	$\frac{(m-0.5)}{n}$
Weibull (1939)	$(\frac{m}{n+1})$
Gringorton (1963), Heo *et al.* (2008)	$\frac{(m-0.375)}{n+0.25}$
Cunnane (1978)	$\frac{m-0.4}{n+0.2}$
California (1923)	$\frac{m}{n}$
Blom (1958)	$\frac{m-0.44}{n+0.12}$
Chegodajev (1955)	$\frac{m-0.3}{n+0.4}$

3.7.2 L-moment for selection of probability distribution

Khan *et al.* (2017), showed that L-moment is used to detect homogenous region to select suitable regional frequency distribution and to predict extreme precipitation quantiles at region of interest.

L-moments are analogous to method of moments but are estimated by linear combination of an ordered set, namely L-statistics.

The following L-moments are defined by *(Cunnane, 1989)*.

λ1 =L1=M100………………………………………………………………….3.13

λ2=L2=2M110−M100……………………………………………………...….3.14

λ3=L3=6M120−6M110+M100……………………………………………..…3.15

λ4=L4=20M130−30M120+12M110−M100…………………………………..…3.16

Hosking (1986), Defined L-moment; as linear combinations of the PWM. Hosking (1986) used L-moment ratio diagram to identify underlying parent distribution and L-moment ratios for testing hypothesis about suitability of different probability distribution in a potentially homogenous region.

The dimensionless L-moment ratios are defined by Hosking (1986), as:

$\tau 2 = \lambda 2/\lambda 1$ (L-variation coefficient, L-Cv)

$\tau 3 = \lambda 3/\lambda 2$ (L-skewness coefficient, L-Cs)

$\tau 4 = \lambda 4/\lambda 2$ (L-kurtosis coefficient, L-Ck)

3.7.3 Method of Parameter Estimation

A number of methods can be used for parameter estimation. Three of the more commonly used methods are considered here.

1. Method of moment (MOM)
2. Maximum likelihood method (MLM)
3. Probability weighting method (PWM)

1. Method of moment (MOM)

The method of moment (MOM) is a natural and relatively easy parameter estimation method. However, MOM estimates are usually inferior in quality and generally are not as efficient as the MLM estimates, especially for distributions with large number of parameters (three or more), because higher order moments are more likely to be highly biased in relatively small samples.

2. Maximum likelihood method (MLM

The MLM method requires higher computational efforts, but with increased use of high speed personal computers, this is no longer a significant problem *(Duckstein et al., 1991)*.

3. Probability weighting method (PWM)

The PWM method *(Hosking, 1986)* gives parameter estimates comparable to the MLM estimates, yet in some cases the estimation procedures are much less complicated and the computations are simpler. Parameter estimates from small samples using PWM are sometimes more accurate than the MLM estimates *(Landwehr et al., 1979)*.

3.8 Selection of the appropriate probability distribution

Hosking (1986) proposed approaches to select the distribution that fitted best the given annual maximum rainfall data; the L-moment ratio Diagram. The L-moments ratio Diagram is a plot of the computed values L-C_s and L-C_k of the distribution function. Figure (11-18) indicated the selected L-moment ratio diagram for selected stations

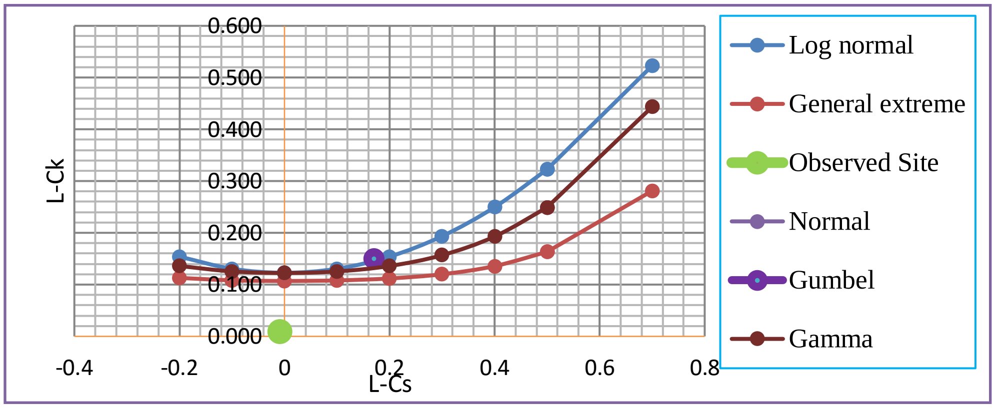

Figure 3.6: L-moment ratio diagram for Bilate station

3.9 Probability Distribution for Hydrologic Variables

The distribution models which were suggested by WMO (2009), for annual maximum data series are listed below *(Cunnane, 1989)*:

3.9.1 Normal Distribution

The normal distribution arise from the central limit theorem, which states that if the sequence of random variables, X i are independently and identically distributed with mean μ and variance σ^2 , then the distribution of the sum of n such random variables y= $\sum_{i=1}^{n} x_i$ tends towards the normal distribution with mean nμ and variance nδ^2 as n becomes large. The main limitation of the normal distribution for describing hydrologic variables are that it varies over a continuous range [−∞,∞], while most hydrologic variables are non-negative and that it is symmetric about the mean, while hydrologic data are skewed.

The probability density function of the normal distribution, a familiar bell-shaped curve, is represented by:

$F(x)= \frac{1}{\delta\sqrt{2\pi}} exp[-(\frac{(x-\mu)^2}{2\delta^2}]$……………………………………………………....3.17

Where μ and δ are parameters, this function is simplified as $z= \frac{x-\mu}{\delta}$

The corresponding standard normal distribution has probability density function

$F(x)= \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}}$; $-\infty \leq z \leq \infty$…………………………………………………3.18

Plotting Probability was estimated using Weibull method Table (3.6), value of Extreme value (X_T) and standard normal deviate (Z) were estimated using equation 3.19 and 3.20 respectively.

$x_{T=}\ \bar{x} + $ δnKT. …………………………………………..…………….....3.19

$K_T = \frac{X_{T-}\bar{X}}{sn}$ ……………………………………..……………………....3.20

Where $x_{T,}\ \bar{x}$, and sn are variates of a given sample data.

3.9.2 Lognormal Distribution (LN2)

If the random variable $y_i = log_{xi}$ is normally distributed, then x_i is said to be log normally distributed. The distribution was applicable to hydrological variables formed as product of other variables*(Chow Ven et al., 1988)*. The log normal distribution has the advantage over the normal distribution that it is bound (x>0) that the log transformation tends to reduce the positive skewness commonly found in hydrologic data.

The probability density function of log normal distribution is given by:

$F(x)= \frac{1}{x\delta\sqrt{2\pi}} \exp[-\frac{(y-\mu y)^2}{2\delta y^2}]$…………………………………………….…..3.21

Where y= $\log_x$ and x>0

After re-arranging the annual daily maximum values in the descending order of magnitude, values of the Z and *w* were estimated using equation (3.22) and (3.23) respectively *(Gebremedhin et al., 2017).*

$$Z = K_{T=}w - \left(\frac{2.516+0.82028W+0.0103W^2}{1+1.4328W+0.1893W+0.0013W^2}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.22$$

Where, w is intermediate variable which is calculated using the formula:

$$w=\left[ln\frac{1}{p^2}\right]^{\frac{1}{2}} \; 0<p<0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.23$$

Where, p is probability of exceedance.

Table 3.7: Expressions used to estimate parameters of Log normal distribution

Parameter Formula	Formula
$logX_T$	$\mu + K_T\sigma$
X_T	$e^{(\mu y - u*\sigma y)}$
K_T	$\frac{(e^{u*\sigma y - \frac{\sigma y^2}{2}} - 1)}{(e^{\sigma y^2} - 1)^{1/2}}$

3.9.3 Gamma Distribution

The two-parameter gamma (G2) distribution parameter is given in equation 3.24 of the probability distribution function as;

$$F(x)=\frac{1}{\alpha^{\beta}\Gamma(\beta)}x^{\beta-1}e^{-(\frac{x}{\alpha})}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.24$$

The time taken for a number of β of events to occur in a poison process is described by the gamma distribution, which is a distribution of a sum of β independent and identical exponentially distributed random variable. The gamma distribution involves the gamma function Γ(β) which is given by Γ(β)=(β−1)!=(β-1)(β-2)…3.2.1 for positive integer β and in general by

$$\Gamma(\beta)=\int_0^{\infty} u^{\beta-1} e^{-u}du\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.25$$

Thus, the probability density function of gamma distribution is given as

$$F(x)=\frac{\lambda^{\beta}x^{\beta-1}e^{-\lambda x}}{\Gamma(\beta)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.26$$

Where Γ is a gamma function and x ≥ 0 and $\lambda = \frac{\bar{x}}{Sx^2}$

The T year quantiles are then calculated by using equation

$$x_T = \alpha\beta + K_T\sqrt{\alpha^2\beta} \quad \text{......3.27}$$

Where K_T is calculated by using appropriate formula by Wilson-Hilferty transformation. Hosking (1986) the Wilson-Hilferty approximation is quite accurate for $c_s \leq 1$ and may be sufficiently accurate for $c_s$as high as 2. Then the value of K_T is given as;

$$K_T = \frac{2}{C_s}[\{\frac{C_s}{6}\left(u - \frac{C_s}{6}\right) +\}^3 - 1], C_s > 0 \quad \text{......3.28}$$

3.9.4 Extreme value Distribution (EV1)

Extreme values are selected maximum or minimum values of sets of data.

The study of extreme hydrologic events involves the selection of a sequence of the largest or smallest observations from sets of data. As such the Gumbel's extreme value distribution *(Gumbel, 1941)* as modified by Chow Ven *et al.* (1988), has been used in this report for computations of return period values for 25, 50, 100,500, and l000 year periods for duration of 1-day durations using Data Available rainfall Station's in and around the bilate basin.

The extreme value Type I (EVI) probability distribution function is

$$F(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right] \quad -\infty \leq x \leq \infty \quad \text{......3.29}$$

The parameters are estimated as

$$\alpha = \frac{\sqrt{6}S}{\pi} \quad \text{......3.30}$$

Where s is standard deviation of sample

$$u = \bar{x} - 0.5772\alpha \quad \text{......3.31}$$

Where the parameter u is the mode of the distribution (point of maximum probability density). A reduced variate y can be defined as

$y=\frac{x-u}{\alpha}$……………………………………………………………………...……3.32

Substituting the reduced variate into equation (3.29) yields

$F(x)=\exp[-\exp(-y)]$……………………………………………………..3.33

Solving for y

$y=-ln[\ln(\frac{1}{F(x)})]$…………………………………………………………3.34

(Chow Ven *et al.*, 1988).

This extreme value distribution was introduced by Chow Ven *et al.* (1988), and is commonly known as Gumbel's distribution. According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value *x*o is

$p(x \geq xo)=1-e^{-e^{-y}}$ ……………………………………………………..3.35

In which y is a dimensionless variable and given by

$y=a(x-a)$ ………………………………………..……………………………3.36

Where $a=\bar{x}-0.45005$, and $a=\frac{1.2825}{sn}$

Thus $y=\frac{1.285(x-\bar{x})}{sn}+0.577$ ……………………………………………………..3.37

Where $\bar{x}$ and Sn are mean and standard deviation of the variate x. In practice it was a value of x for a given P that is required and the above equation is transposed as

$y_P=-\ln(-\ln(1-P)$ ……………………………………………………………3.38

But; $T=\frac{1}{P}$ where, T is return period.

This distribution is achieved by plotting the ranked annual maximum rainfalls values and exceedance probability is estimated. the reduced variate (YT) can be calculated using equation (3.38).

$y_T = -\ln[\ln(\frac{T}{T-1})]$ ……………………………………………………………..3.39

Where y_T is reduced variate for given T.

And T is return period.

Frequency factor KT can be derived from Yn and Sn obtained from the reduced y_n and s_n variate.

$K_T = \frac{Y_{T-\overline{yn}}}{sn}$…………………………………………………………………..3.40

Finally, XT = $\bar{X}$+ KT*S…………………………………………………………….3.41

This is the extreme value.

3.9.5 Generalized Extreme Value(GEV)Distribution

The probability density function of the GEV distribution is given as

f(x)= $\frac{1}{\sigma}[1-k(\frac{X-\mu}{\sigma})]^{1/k-1} e^{-[1-k(\frac{X-\mu}{\sigma})]^{1/k}}$…………………...………..….……………….3.42

where σ, μ and k is shape, scale and location parameters. The range of variable x depends upon the sign of parameters.

The value of k is given by *(Hosking, 1986)*.

k= $\frac{3+\tau_3}{2}$,where τ_3 is L-skewness coefficient calculated from ratio of equation (3.15) to (3.14)

the distribution function of x given by equation 3.42 can be written in the inverse form of;

$x = \mu + \frac{\sigma}{k}\{1-(-logF)^k\}$………………………..………………...……..……3.43

by substituting F =1$-\frac{1}{T}$,the T-year quantile is estimated as

$$X_T = \mu + \frac{\sigma}{k}[1 - \{-\log\left(1 - \frac{1}{T}\right)\}^k] \text{..3.44}$$

Where T is return period.

3.10 Testing the Goodness of Fit of Data to Probability Distribution

In order to determine the best-fit model at each station, probability distribution models were subjected to three goodness of fit tests, chi-square test (x^2), Kolmogorov-Smirnov test and Diagnostic test (D-index).

Goodness of test are essential for checking the adequacy of probability distribution to the recorded series of annual probable flow discharge (PFD) for estimation of PFD.

The theoretical description of GoF tests statistic are as follows;

3.10.1 Chi Square (x^2)

The chi square (x^2) Statistic is given as;

$$x^2 = \sum_{i=1}^{k} \frac{(O_j(Q) - E_j(Q))^2}{E_j(Q)} \text{...3.45}$$

Where, $E_j(Q)$ is the expected frequency value of j^{th} Class.

$(O_j(Q)$ Is the observed frequency value of j^{th} class and

K is the number of frequency classes.

The rejection region of x^2 statistic at the described significance level α is given by $x^2 \geq \ {x^2}_{1-\alpha,k-m-1}$. Here m denotes the number of parameters of the distribution and ${x^2}_c$ is computed value of x^2 statistic by PDF (probability density function).

This test was performed at the significant level (α= 0.05) for choosing the best fit probability distribution

3.10.2 Kolmogorov smirnov test

KS statistic is given as;

KS= $\sum_{i=1}^{N}(Max(F_e(Q_i) - F_d(Q_i))$...3.46

Where; $F_e(Q_i)$ is the empirical CDF of Q_i and

$F_d(Q_i)$ is the computed CDF of Q_i; If the computed values of GoF test statistic given by the distribution are less than that of the theoretical values at the desired significance level, then the distribution is considered to be acceptable for estimation of MFD (maximum flood discharge).

This test was performed at the significant level (α= 0.05) for choosing the best fit probability distribution

3.10.3 Diagnostic test (D-index)

The selection of a suitable probability distribution for estimation of MFD is carried out through D-index, which is defined as

D-index= $\frac{1}{\bar{X}}\sum_{i=1}^{6}[X_i - X^*{}_i]$..3.47

Where is $\bar{X}$ the average (mean) of the recorded or observed annual maximum rainfall, Q_i's (i=1 to 6) are the first highest sample values in the series and $X^*{}_i$ is the estimated value by PDF. The distribution having the least D-index is better and suited distribution in comparison with the other distribution for estimation of MFD *(USWRC, 1981)*, and *(Vivekanandan, 2015)*.

Test criteria; If the computed values of GoF tests statistic given by the distribution are less than that of the theoretical values at the desired significance level then the distribution is found to be acceptable for modeling the series of annual peak flood discharge (PFD)*(Vivekanandan, 2012).*

3.11 Estimation of Return Period Values for PMP

Equation ($T = \frac{1}{1-F}$) along with the estimated location and scale parameters using different equations are used for the computation of return period values corresponding to estimated PMP value for durations of one day for all stations.

3.12 Development of Isohyetal map

The Isohyetal maps are helpful in estimating the rainfall depth for any location in the study area considered more easily and faster without having to go through the rigor of fitting probability distribution models all over again. These are very useful for design and planning purposes *(Parvez and Inayathulla, 2019)*.

The Isohyetal maps were generated for Bilate sub river basin considering 12 stations with 28 to 32 years' data, for various selected return periods such as 25, 50, 75, 100, 200, 500,1000 and 10000 years based on design requirements. Considering lower return periods might not be appropriate considering the fact that, generally the life of a structure is more than 25 years.

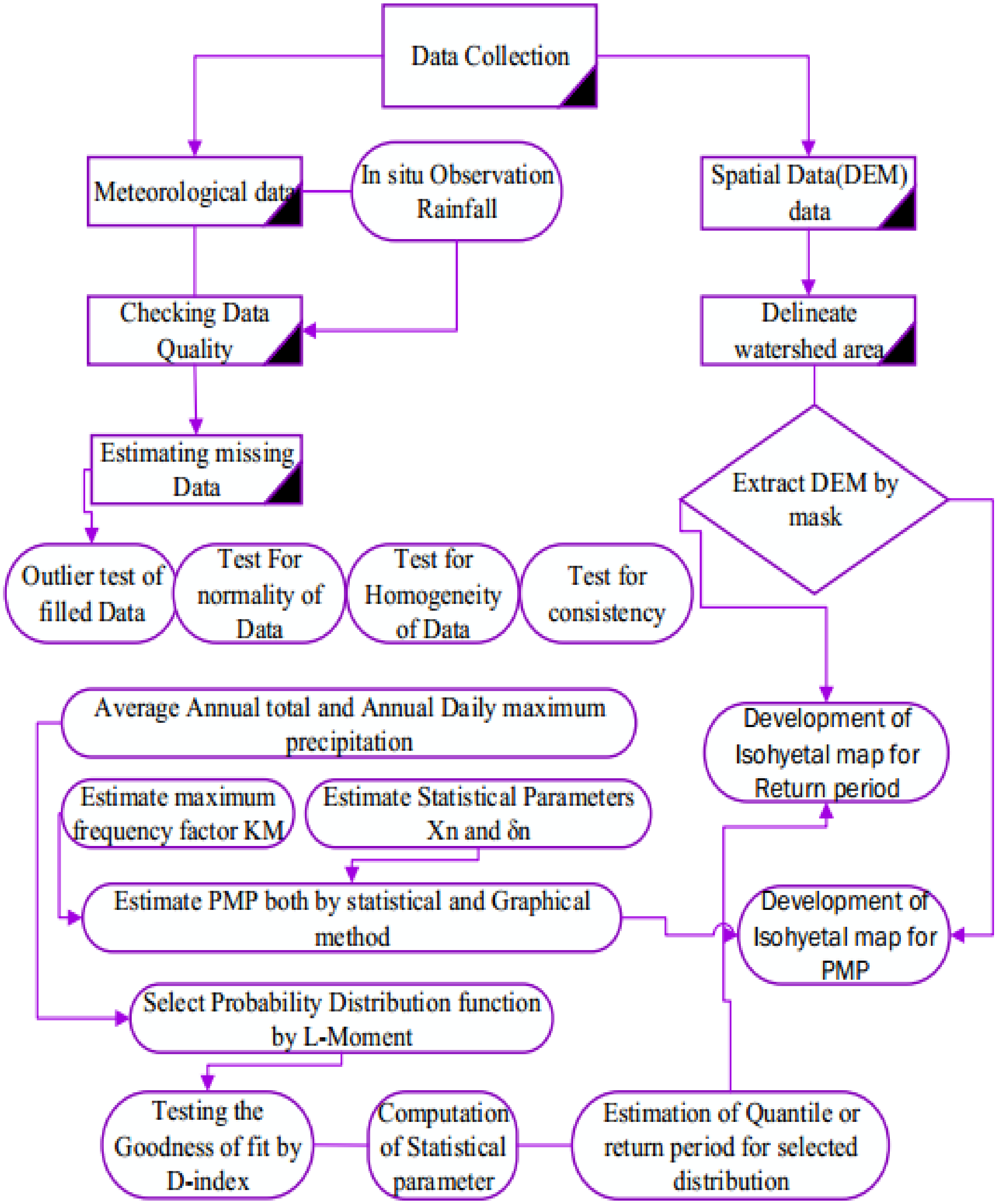

Figure 3.7: Conceptual frame work for the study.

4. RESULTS AND DISCUSSIONS

4.1 Estimation of frequency factor (Km)

The statistical Hershfield method was used to estimate frequency factor that can give certain PMP values for stations in the Bilate sub-river basin for practical application. This value was calculated from Hershfield statistical formula given in equation (2.4).

The maximum statistical Hershfield frequency factors of individual rain gauge stations were found to vary from 1.717 to 3.231, belongs to stations of Durame and Hossana with an average value of 2.418 and coefficient of variation 20.468% for 1-day duration.

Table (4.1) shows the maximum frequency factor (Km) calculated value for 1-day duration of each station.

Table 4.1: Derivation of Km for 1-day duration

Stations	HOR	Xn-1	Sn-1	Km
Alaba	86.000	55.023	11.321	2.736
Angecha	67.000	45.257	10.448	2.081
Badessa	100.400	60.504	13.131	3.038
Bilate	83.800	57.923	13.676	1.892
Boditi	69.800	52.838	7.172	2.365
Butajira	91.300	47.276	22.183	1.985
Durame	59.300	42.710	9.664	1.717
Fonko	67.400	50.368	8.177	2.083
Hossana	94.100	49.237	13.887	3.231
Humbo	103.600	61.244	14.033	3.018
Shone	72.200	48.547	9.894	2.391
Wulbareg	74.100	41.733	13.009	2.488
Mean				2.418

As indicated in table, the values of maximum frequency factor were between 2 and 3(50%), only three values (25%),3.231 for Hossana,3.038 for Badessa and 3.018 for Humbo Tebela were greater than three. The frequency table for Km was formed and the most frequency interval was found between 2 and 3.the corresponding frequency factor 3.231 was chosen as extremely high Km value for one-day duration.

Table 4.2 Estimated frequency factor with account of intervals

No	Km interval	frequency	frequency in(%)
1	1.5≤Km≤2	3	25%
2	2<Km≤3	6	50%
3	Km>3	3	25%

Plots were for the estimated maximum frequency factor(Km) against highest observed annual daily maximum rainfall depths to obtain the trend.as observed from figure (4.1) the trend line shows a direct relation. The value of Km was generally increasing for increased mean and standard deviation of annual daily maximum rain fall.

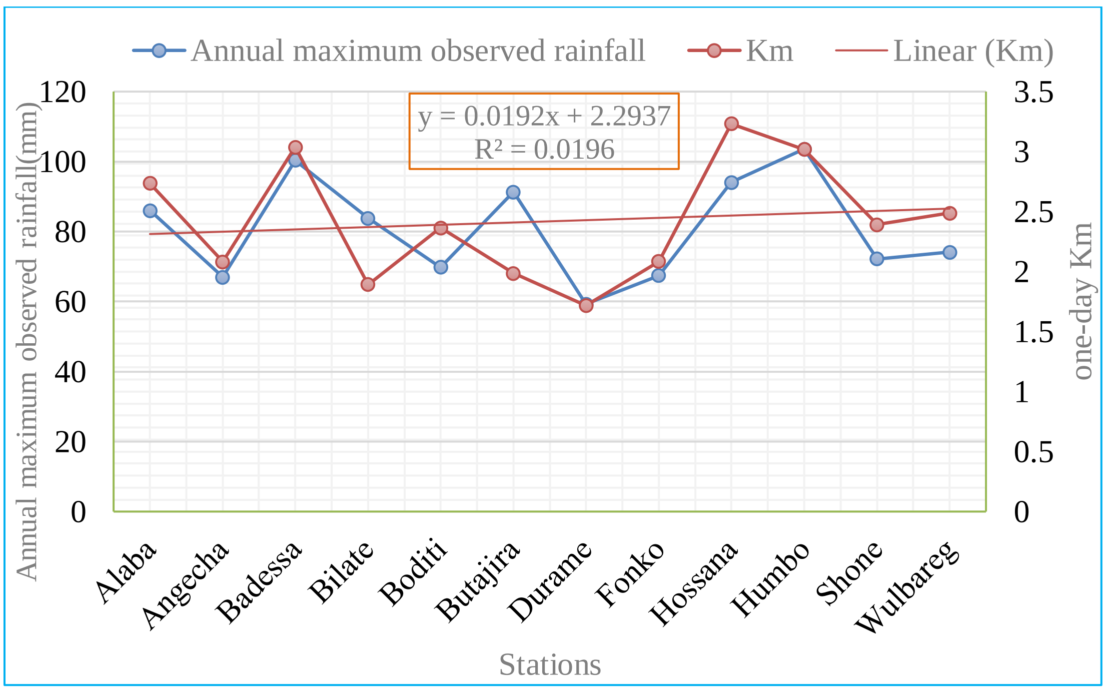

figure 4.1 Km and annual daily maximum rainfall and Its Km trends

4.1.1 Comparisons of Km with the previous studies

The observed enveloping Km (3.231) has 78.46%, 62.86%, 66.34%, 64.1%, 60.59%, 52.48%, 45.32%, 37.86%, and 36.52% change from largest Km (Largest Hershfield frequency factor, Humid regions of Malaysia, Dry Atrak watershed, Iran, Blue Nile River Basin, Ethiopia, Benshangul Gumuz, Ethiopia, West Shewa zone Oromia, Ethiopia, Tigray region, Ethiopia, North Shewa zone Amhara region, Ethiopia, and Bale zone Oromia region, Ethiopia respectively.

The 78.46% change of the estimated Km from Hershfield largest frequency factor implies that, considering Km=15, for estimation of PMP will give an over estimated value for value for PMP in the Bilate sub river basin.

Table 4.3 The maximum frequency factors for different basins or regions

Frequency factor of some region/basins			
Region/basins	K-envelope	$\left(\frac{K_{envelope}-3.231}{K_{envelop}}\right)$*100	Source
Largest Hershfield frequency factor	15	78.46	*(Hershfield, 1962)*
Humid regions of Malaysia	8.7	62.86	*(Desa and Rakhecha, 2006)*
Dry Atrak watershed, Iran	9.6	66.34	*(Ghahraman, 2008)*
Blue Nile River Basin, Ethiopia	9.00	64.1	*(Dame and Ayalew, 2010)*
Benshangul Gumuz, Ethiopia	8.20	60.59	*(Regasa, 2010)*
West Shewa zone Oromia, Ethiopia	6.8	52.48	*(Tesema, 2012)*
Tigray region, Ethiopia	5.91	45.32	*(Gebremedhin et al., 2017), (Gerezihier and Quraishi, 2013)*
North Shewa zone Amhara region, Ethiopia	5.2	37.86	*(Quraishi and Berhane, 2014)*
Bale zone Oromia region, Ethiopia	5.09	36.52	*(Fikre et al., 2016)*

4.2 Estimation of PMP using Hershfield statistical method

For Hershfield method the parameter was computed from series of annual maximum observed rainfall and used to estimation of PMP. Their estimated value of PMP was found that from 71.581mm to 128.571mm of stations Durame and Humbo with an average value of 97.852mm and coefficient of variation 16.610% respectively for 1-day duration. Table (4.4) gives the computed values of the parameters used to estimate PMP for the selected stations under study area. The result indicated as the computed PMP values were greater than the observed annual maximum rainfall and has no rainfall variability in the basin. figure (4.2) indicates plots were made for relation of PMP with that of HOR for indication of rainfall variability and its trends of rainfall changes over time.

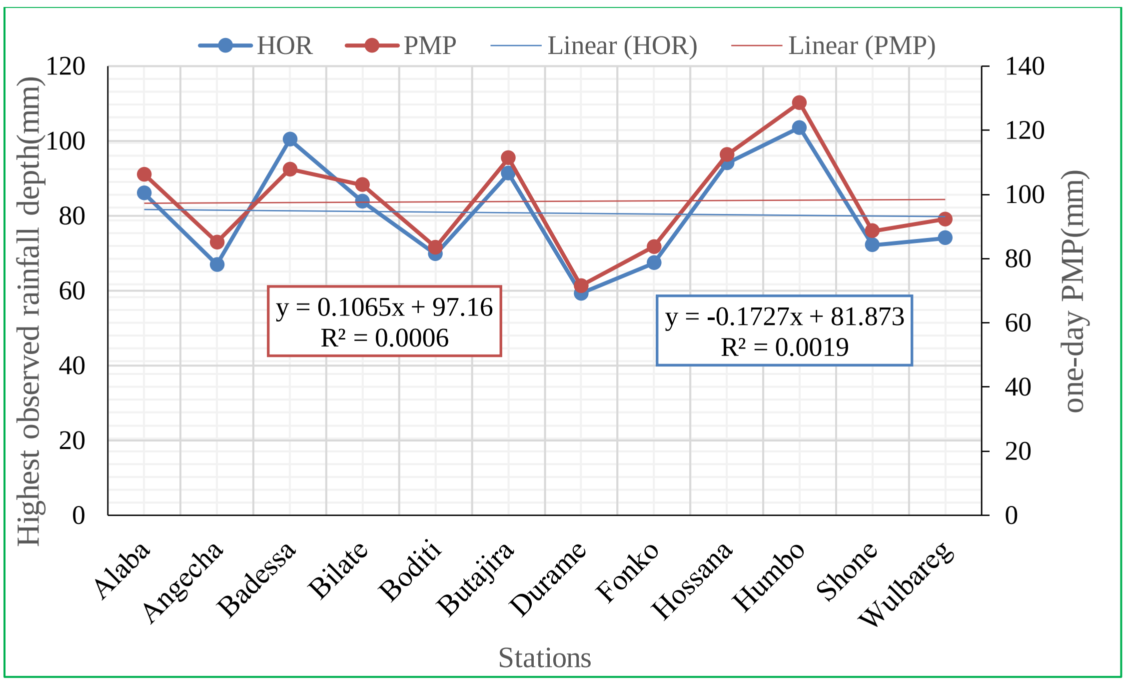

figure 4.2 trend relation between PMP and HOR of the basin

Table 4.4: Derivation of parameter and its calculated PMP value for 1-Day

stations	Xn	Sn	Km	Fixed time interval	PMP
Alaba	55.991	12.410	2.736	1.130	106.230
Angecha	46.007	11.025	2.081	1.130	85.110
Badessa	61.929	14.929	3.038	1.130	107.842
Bilate	58.731	14.211	1.892	1.130	103.013
Boditi	53.403	7.697	2.365	1.130	83.559
Butajira	48.696	23.199	1.985	1.130	111.392
Durame	43.228	9.949	1.717	1.130	71.581
Fonko	50.955	8.630	2.083	1.130	83.710
Hossana	50.684	15.854	3.231	1.130	112.323
Humbo	62.656	15.809	3.018	1.130	128.571
Shone	49.310	10.615	2.391	1.130	88.620
Wulbareg	42.777	14.049	2.488	1.130	92.283
Average					97.852

4.2.1 The magnitude of PMP to maximum observation rainfall ratio

According to Hershfield (1962), the magnitude of point PMP at an individual station should normally not exceed three times the highest observed rainfall from a long period of rainfall data. PMP to HOR was discussed in table (4.5). This ratio was found to vary from 1.074 to 1.270 Badessa and Angecha respectively with an average value of 1.215 for 1-day duration. So, the result for this study confirmed *(Hershfield, 1962)*.Therefore, the predicted PMP values for this study were neither overestimated nor underestimated. The estimated PMP values represent the best estimation with available knowledge, technique and data support. This variation originates from stations with different micro-climate, different record length of the observation and number of meteorological stations Hershfield (1962).

Table 4.5: Derivation of the ratio of PMP to HOR for 1-day

Stations	PMP	HOR	PMP:HOR
Alaba	106.230	86.000	1.235
Angecha	85.110	67.000	1.270
Badessa	107.842	100.400	1.074
Bilate	103.013	83.800	1.229
Boditi	83.559	69.800	1.197
Butajira	111.392	91.300	1.220
Durame	71.581	59.300	1.207
Fonko	83.710	67.400	1.242
Hossana	112.323	94.100	1.194
Humbo	128.571	103.600	1.241
Shone	88.620	72.200	1.227
Wulbareg	92.283	74.100	1.245
Mean			1.215

4.2.2 Comparisons of PMP to HOR ratio with previous studies

The estimated values of PMP: HOR ratios were much smaller than the ratios obtained for dry Atrak watershed, approach to Bale Zone Oromia region, Ethiopia; North Shewa zone Amhara region, Ethiopa, West Shewa zone Oromia region, Ethiopia and Tigray region, Ethiopa with average values of 2.5, 1.13, 1.52,1.75 and 1.11 respectively. The observed ratio was nearly similar between the ratio of 1.11 and 1.52 for Tigray region, Ethiopia and North Shewa zone Amhara region, Ethiopia. This result indicated that the relative homogeneity of rainfall in climatic conditions of the areas.

Table 4.6: PMP to HOR ratio of some selected regions or Basins

PMP to HOR ratios of some region/basins			
Region/basins	1-Day PMP	PMP:HOR	Source
Humid regions of Malaysia	400-1000	2.0	*(Desa and Rakhecha, 2006)*
Dry Atrak watershed, Iran	97-296	2.5	*(Ghahraman, 2008)*
southern Banswar District, India	350	1.05	*(Durbude, 2008)*
Blue Nile River Basin, Ethiopia	180-420	1.9	*(Dame and Ayalew, 2010)*
Benshangul Gumuz, Ethiopia	170-284	1.8	*(Regasa, 2010)*
West Shewa zone Oromia, Ethiopia	105-243	1.75	*(Tesema, 2012)*
Tigray region, Ethiopia	70.06-144	1.11	*(Gebremedhin et al., 2017), (Gerezihier and Quraishi, 2013)*
North Shewa zone Amhara region, Ethiopia	52.83-239.77	1.52	*(Quraishi and Berhane, 2014)*
Bale zone Oromia region, Ethiopia	51.43-234.81	1.13	*(Fikre et al., 2016)*

4.3 Parameter selection and their quantile estimation

Quantiles of different return periods were estimated using the parameters with smallest Diagnostic D-index values for the best distribution. The best fitted candidate distribution was selected by L-moment and the method of parameters and quantile estimator for selected distribution for Bilate station is shown in table (4.8). The parameters and quantile estimator for remain stations are presented in Annex A table (3-4).

Table 4.7: The frequency distribution estimated parameters for Bilate station

Station	Parameters	NOR	LN2	Gamma	EV1	GEV
Bilate	MOM	μ=58.731 σ=3.769	μy=1.756 δy=0.157	α=694.337 β=0.084	α=11.085 β=52.336	μ=48.871 σ=27.247
	MLM	μ=58.731 σ=3.769	μy=1.757 δy=0.425	α=3.471 β=16.919	α=11.081 β=52.336	μ=53.462 σ=14.538
	PWM	μ=58.731 σ=14.714	μy=1.737 δy=0.249	α=85.008 β=0.691	α=11.979 β=51.816	μ=53.467 σ=14.545

4.3.1 Probability distribution

The distribution models which were selected by L-moment for annual maximum data series are:

Normal distribution (NOR), Log normal distribution (LN2), Gamma distribution (GAMMA2), Extreme value type one (Gumbel) distribution (EV1) and General extreme value distribution (GEV)

Hershfield (1961), method was used to estimate the probable maximum precipitation (PMP) and GEV (54.54%), LN2 (27.27%) and Gamma (18.2%) probability distributions were used to compute one day maximum rainfall for different return period for the study area. The Diagnostic D-index was used to select best distribution to the basin rather than the chi square and K-S test by percent (%) of coverage. The goodness of fit test called chi square and K-S tests were mainly powerful on hypothesis of best fit distribution. Table (4.9) show that the selected distribution for Bilate station by D-index value. The selected distribution is interpreted at annex A table (15-24) by Diagnostic D-index test. Table (4.8) shows the expected extreme rainfall for one-day duration for Bilate stations. The expected extreme rainfall for other stations is tabulated at Annex A, table (5-14).

Table 4.8: Expected extreme rainfall of Bilate station for one-day duration

Bilate		1 Day Expected Extreme rain fall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/PWM	Gamma/MLM	EV1/MOM	GEV/PWM
1	83.800	86.346	89.467	85.687	90.926	86.351
2	79.900	81.538	82.674	80.951	83.068	81.895
3	79.200	78.380	78.504	77.847	78.394	78.812
4	77.600	75.933	75.422	75.446	75.020	76.360
5	77.200	73.886	72.941	73.441	72.357	74.278
6	75.100	72.097	70.841	71.690	70.140	72.439
7	72.600	70.486	69.004	70.115	68.230	70.773
8	71.799	69.005	67.359	68.669	66.541	69.235
9	68.000	67.622	65.860	67.319	65.021	67.795
10	67.500	66.313	64.473	66.043	63.630	66.431
11	65.500	65.063	63.176	64.824	62.343	65.126
12	65.200	63.856	61.951	63.649	61.139	63.868
13	64.300	62.684	60.784	62.509	60.002	62.647
14	63.900	61.537	59.664	61.393	58.921	61.454
15	60.400	60.407	58.583	60.296	57.886	60.281
16	60.000	59.289	57.532	59.209	56.887	59.121
17	59.900	58.174	56.504	58.128	55.917	57.968
18	57.400	57.055	55.492	57.043	54.971	56.816
19	55.700	55.925	54.490	55.948	54.041	55.659
20	53.200	54.778	53.491	54.837	53.122	54.489
21	50.000	53.606	52.490	53.703	52.208	53.299
22	48.400	52.400	51.481	52.536	51.293	52.082
23	47.900	51.149	50.456	51.328	50.371	50.827
24	46.400	49.840	49.407	50.064	49.433	49.522
25	46.000	48.457	48.323	48.730	48.471	48.152
26	45.400	46.976	47.190	47.302	47.473	46.696
27	44.100	45.366	45.990	45.751	46.423	45.125
28	43.800	43.577	44.694	44.029	45.296	43.396
29	40.500	41.530	43.259	42.062	44.057	41.438
30	36.800	39.082	41.608	39.713	42.640	39.126
31	36.400	35.924	39.575	36.688	40.909	36.191
32	35.500	31.116	36.682	32.092	38.459	31.822

4.4 Goodness of fit test (GoF)

The goodness of fit tests including chi square (x^2) and Kolmogorov-smirnov (K-S) test were selected to check whether the hypothesized distribution function fitted the sample data.

4.4.1 Chi square test

For chi square test, ${x^2}_{calculated} < {x^2}_{critical}$.

The calculated x^2 were compared with tabulated critical value at 5% significance level with degree of freedom. The calculated x^2 resulted to be less than the critical value; the value x^2 was selected as the best fit hypothesis model. According to result shown for bilate station; selected distributions have been fit the hypotheses distribution. Gamma and LN2 not fit for stations of Hossana, Angecha, Durame and Badessa; GEV and Gamma for Wulbareg and LN2 for shone.

4.4.2 Kolmogorov-smirnov test

The calculated K-S maximum values were compared to that of critical value from d table; the calculated K-S resulted to be greater than the critical K-S value; the value K-S was selected as best fit model regarding to K-S test. The both test result for Bilate River was estimated at table (4.9). Accordingly, the result shown for Bilate station; selected distributions have been fit the hypotheses distribution. The K-S test result supported the use of five distributions for remain other stations have been fit the hypothesis distribution. The K-S result for other stations presented in Annex A table (39-41).

Table 4.9: Goodness of fit test for Bilate station

Goodness of fit test for Bilate					
Bilate					
Distributions	x^2test	K-S test	critical for x^2	critical for K-S	Remark
NOR	1.0000	0.949	43.924>all calculated x^2 values	0.231<all calculated K-S values	accepted hypothesis for x^2 and K-S for selected distribution
LN2	0.0500	0.924			
Gamma	0.0001	0.948			
EV1	0.1210	0.912			
GEV	0.3640	0.946			

4.4.3 Diagnostic test (D-index) test

The distribution having the least D-index was identified as better and suited distribution in comparison with the other distribution for estimation of MFD *(USWRC, 1981)*. For the selection of a suitable probability distribution-index values of the distributions were computed by Equation (3.47) from the given result; D-index values given by GEV distribution for Bilate, Shone, Wulbareg, Badessa, Angecha and Alaba stations comparatively minimum when compared to other distribution. i.e. about 54.54% covered by GEV distribution with parameter of PWM.

For the selection of the best suitable distribution for estimation of annual maximum flood discharge, the D-index value and the selected distribution is presented in Table (4.10).

Table 4.10: Best selected distribution by diagnostic D-index test for Bilate station

	Bilate			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.545	PWM	
	MLM	1.545		
	PWM	0.079		
LN2	MOM	0.072	PWM	
	MLM	0.056		
	PWM	0.050		
Gamma	MOM	25.082	MLM	
	MLM	0.132		
	PWM	7.443		
EV1	MOM	0.049	MOM	
	MLM	5.613		
	PWM	0.112		
GEV	MOM	1.705	PWM	GEV/PWM*
	MLM	0.047		
	PWM	0.045		
*Selected Distribution				

4.5 Selection of best fit probability distribution by L-moment

L-moment were used to select best fit distribution as candidate distribution for frequency distribution and to predict extreme precipitation quantiles at region of interest. annex B figure (14-20) presented the selected parent distribution of the selected station.

4.5.1 Comparison of L-moment ratio and D-index for selected distribution

L-moment is used to select suitable regional frequency distribution and to predict extreme precipitation quantiles at region of interest. L-moment ratio diagram is one of the selection method of best fit distribution. table (4.11) shows the kurtosis values of observed point and selected distributions to separate best fit from the selected distribution. The difference of L-ck of observed point and distribution for selection of best fit by L-moment is presented at table (4.12)

Table 4.11 L-moment Kurtosis value of sample and selected distribution

	observed site	GEV	EV1	LN2	NOR	Gamma
Station	L-ck sample	L-ck distribution	L-ck distribution	L-ck distribution	L-ck distribution	L-ck distribution
Alaba	0.149	0.107	0.150	0.130	0.122	0.126
Angecha	-0.004	0.107	0.150	0.123	0.122	0.122
Badessa	0.172	0.113	0.150	0.154	0.122	0.134
Bilate	0.009	0.107	0.150	0.123	0.123	0.122
Boditi	0.157	0.107	0.150	0.122	0.122	0.122
Butajira	0.128	0.108	0.150	0.130	0.122	0.122
Durame	0.055	0.107	0.150	0.122	0.122	0.122
Fonko	0.138	0.107	0.150	0.123	0.122	0.122
Hossana	0.137	0.147	0.150	0.130	0.122	0.125
Humbo	0.260	0.107	0.150	0.122	0.122	0.122
Shone	0.140	0.107	0.150	0.130	0.122	0.125
Wulbareg	0.114	0.113	0.150	0.157	0.122	0.137

Table 4.12 difference of L-ck observed point and distribution for best fit selection

	observed sample	Difference of L-ck sample and L-ck distribution					best fit distribution
Station	L-ck sample	GEV	EV1	LN2	NOR	Gamma	
Alaba	0.149	0.042	-0.001	0.019	0.027	0.023	EV1
Angecha	-0.004	-0.111	-0.154	-0.127	-0.126	-0.126	GEV
Badessa	0.172	0.059	0.022	0.018	0.050	0.038	LN2
Bilate	0.009	-0.098	-0.141	-0.114	-0.114	-0.113	GEV
Boditi	0.157	0.050	0.007	0.035	0.035	0.035	EV1
Butajira	0.128	0.020	-0.022	-0.002	0.006	0.006	LN2
Durame	0.055	-0.052	-0.095	-0.067	-0.067	-0.067	GEV
Fonko	0.138	0.031	-0.012	0.015	0.016	0.016	EV1
Hossana	0.137	-0.010	-0.013	0.007	0.015	0.012	GEV
Humbo	0.260	0.153	0.110	0.138	0.138	0.138	EV1
Shone	0.140	0.033	-0.010	0.010	0.018	0.015	EV1
Wulbareg	0.114	0.001	-0.036	-0.043	-0.008	-0.023	GEV

Accordingly, to the result of L-moment selected distribution 41.67% occupied by GEV,41.67% by EV1 and 16.66% was occupied by LN2.this result is approximately similar to that of D-index. From D-index 54.54% for GEV,27.27% for LN2 and 18.18% for Gamma. therefore, GEV occupy most stations for both D-index and L-moment ratio.

4.6 Estimation of Various Return Period Rainfall Depth for estimated PMP

For the annual rainfall data of the stations with 28 to 32 with an average 30 years of record, the maximum 24-hour rainfall frequencies of 2,5, 10, 50, 100, 1000 and 10,000 rainfall amounts have been estimated for the comparison with the estimated period developed by GEV types of distribution. In depth of the rainfall for 2,5, 10, 50, 100, 1000, and 10,000 return periods table (4.13) were found to vary between 39.88 mm and 168.46mm. the depth of 10,000 years was limited between 80.76mm and 168.46mm while depths of 1000 years were between 77.63mm and 138.42 mm and the depths for 5, 10, 50 and 100 years were between 71.86mm and 112.76 mm the minimum rainfall was found at return period of 2 years at Wulbareg station and the maximum rainfall depth estimated at 10000 year return period of Wulbareg station. table (4.13) presented different return period and corresponding depth of rainfall.

Table 4.13: Different return period and corresponding depth of rainfall

recurrence interval (return period)/year for 1-day duration										
Name of Station	2	5	10	25	50	100	200	500	1000	10000
Alaba	55.15	66.43	72.74	79.61	84.02	87.88	91.29	95.18	97.74	104.28
Angecha	45.83	55.84	60.99	66.20	69.30	71.86	73.98	76.25	77.63	80.76
Badessa	59.42	73.14	82.22	93.69	102.19	110.61	119.01	130.07	138.42	166.12
Bilate	58.54	71.42	78.03	84.68	88.62	91.86	94.54	97.39	99.13	103.03
Boditi	52.48	59.35	63.57	68.60	72.17	75.62	78.99	83.37	86.64	97.41
Butajira	47.60	69.73	81.95	95.46	104.47	112.76	120.49	130.08	136.93	157.91
Durame	41.49	50.35	56.22	63.64	69.17	74.71	80.29	87.80	93.59	113.74
Fonko	49.76	57.48	62.33	68.23	72.48	76.64	80.74	86.11	90.18	103.79
Hossana	49.39	63.82	72.14	81.63	88.10	94.15	99.89	107.11	112.34	128.73
Shone	48.37	58.12	63.78	70.13	74.32	78.09	81.50	85.52	88.23	95.56
Wulbareg	39.88	52.73	61.74	73.74	83.11	92.81	102.90	116.89	128.00	168.46

4.6.1 Estimation of PMP Value to Various Return Period Rainfall Depth

The estimated PMP values to various return period rainfall depth ratios were computed and presented in table (4.14).

Table 4.14: Ratio of PMP to different return period rainfall depth

Ratio of PMP to Different year return period rainfall depth (FOS)										
	2	5	10	25	50	100	200	500	1000	10000
Name of Station	year	Year	Year	year	year	year	year	year	year	year
Alaba	1.93	1.60	1.46	1.33	1.26	1.21	1.16	1.12	1.09	1.02
Angecha	1.86	1.52	1.40	1.29	1.23	1.18	1.15	1.12	1.10	1.05
Badessa	1.82	1.47	1.31	1.15	1.06	0.97	0.91	0.83	0.78	0.65
Bilate	1.76	1.44	1.32	1.22	1.16	1.12	1.09	1.06	1.04	1.00
Boditi	1.59	1.41	1.31	1.22	1.16	1.10	1.06	1.00	0.96	0.86
Butajira	2.34	1.60	1.36	1.17	1.07	0.99	0.92	0.86	0.81	0.71
Durame	1.73	1.42	1.27	1.12	1.03	0.96	0.89	0.82	0.76	0.63
Fonko	1.68	1.46	1.34	1.23	1.15	1.09	1.04	0.97	0.93	0.81
Hossana	2.27	1.76	1.56	1.38	1.28	1.19	1.12	1.05	1.00	0.87
Shone	1.83	1.52	1.39	1.26	1.19	1.13	1.09	1.04	1.00	0.93
Wulbareg	2.31	1.75	1.49	1.25	1.11	0.99	0.90	0.79	0.72	0.55

This ratio was found between 2.34 to 0.55 (2 years and 10000 year) return period for stations occurred at Butajira and Wulbareg respectively. The estimated PMP ratio to depth of different return period rainfall called factor of safety (FOS). According to Al-Mamun and Hashim (2004), this ratio can be used in relation to the factor. To give conclusions that whether PMP values are reasonable for designing hydraulic structures or not usually the adopted factor of safety value for Engineering practices in structural Engineering is between 1.4 and 1.7 and for geotechnical design between 1.5 and 2. accordingly it can be concluded that the estimated PMP which is very uncertain values for 100, 1000 and 10000 years and reasonable for designing of hydraulic structures for return periods in the orders of 5 and 50 years. However, the use of PMP for 5 years of return periods for hydraulic structures will be stable but relatively costly. Therefore, PMP approach could solve the limitations of common probabilistic approach.

This uncertainty of large return period was occurring when the number of observation data was minimum.

4.7 Development of spatial and Isohyetal map for Hershfield statistical PMP

The Isohyetal maps for Hershfield statistical PMP were generated for Bilate sub river basin considering 12 stations with each station's year of recorded data, for 1-day. Isohyetal lines of contour maps were prepared for estimation of design rainfall for ungauged stations at the given catchment or far apart stations to minimize gap of rain gauge by interpolation techniques at arc map 10.4.1 GIS software by IDW method. Based on this result of Isohyetal map show that the spatial distribution of 1-day PMP values in the Bilate sub river basin was developed. PMP grid values were varying between 76mm to 112mm at contour interval of 2mm. The maximum PMP Isohyetal point values were observed to upper Bilate river basin to Hossana and lower Bilate river basin around Humbo tebela and decrease to central or middle Bilate river basin belong to Alaba Kulito, Durame and some part of Hossana near to Fonko Stations.

The IDW Isohyetal and its contour maps is shown as figure(4.3) for 1-day duration.

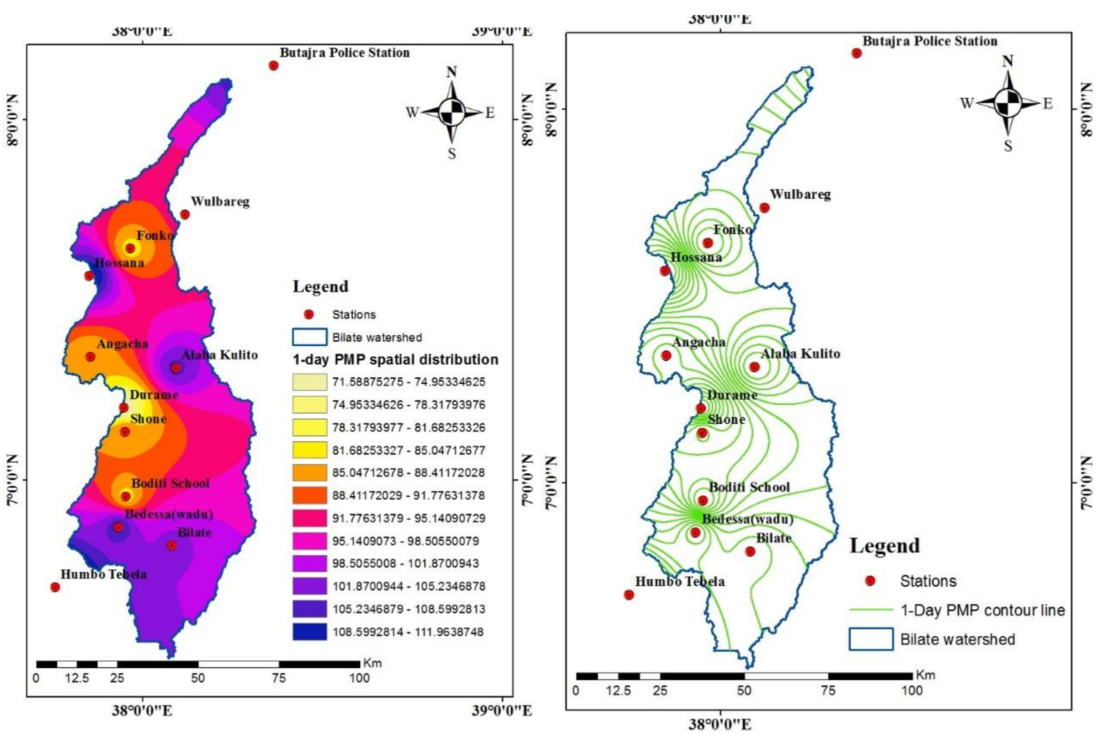

figure 4.3 one-day PMP spatial distribution and Isohyetal contour map

4.7.1 Development of spatial and contour map for frequency factor

The Km grid values were varying between 1.9 to 3.3 at contour interval of 0.1. The maximum Km Isohyetal point values were observed to upper Bilate river basin to Hossana and lower Bilate river basin Badessa and decrease to central or middle Bilate river basin belong to Durame and lower Bilate river basin of Bilate stations.

The IDW Isohyetal and its contour maps were shown as figure (4.5) for 1-day duration.

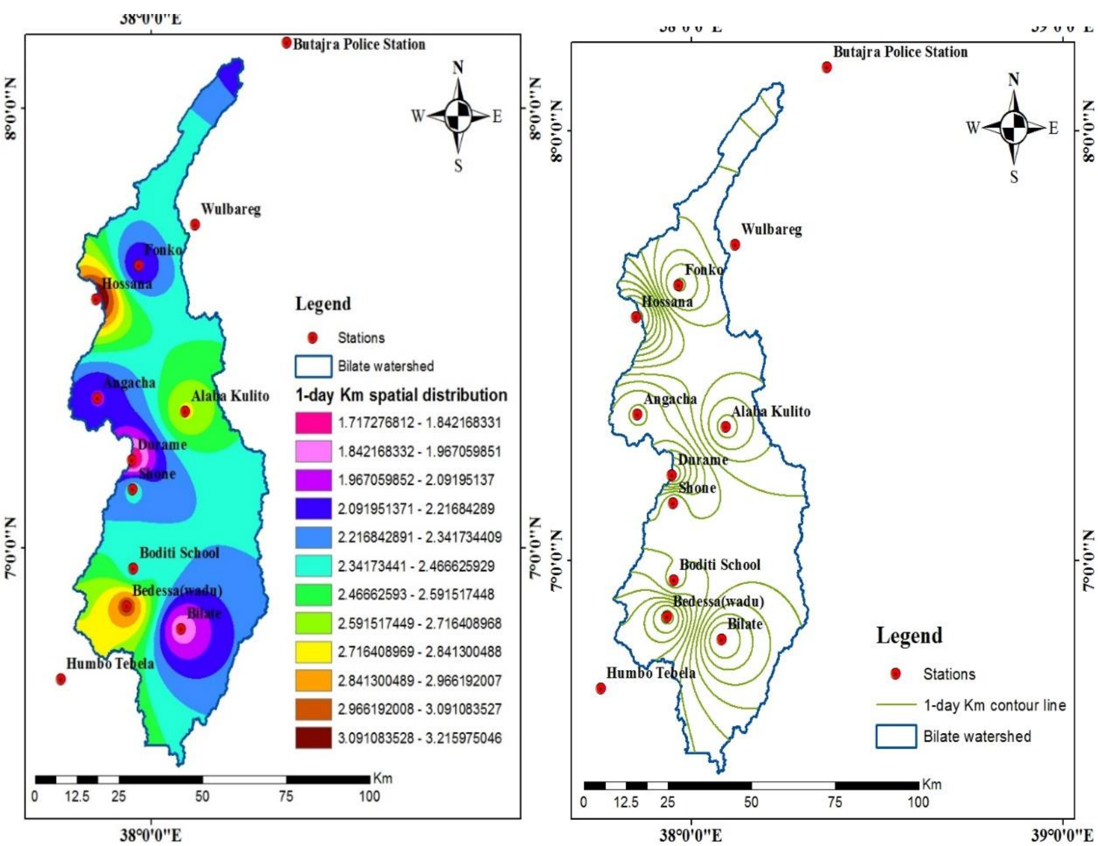

figure 4.4 one-day Km spatial distribution and Km contour map

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

1.2 Statement of the problem

Determine basin specific PMP and was basic concern of the study area of Bilate sub river basin. Developing Isohyetal map was to overcome the problem of inadequate information and to facilitate quick estimation of PMP values for ungauged catchments in the basin.

Estimate the Probable maximum precipitation(PMP), develop one day PMP and its return period was the main specific objectives of the study.

The PMP estimates were mainly derived from statistical Hershfield method depend upon the frequency factor. The maximum statistical Hershfield frequency factors of individual rain gauge stations were found to vary from 1.717 to 3.231, belongs to stations of Durame and Hossana with an average value of 2.418 and coefficient of variation 20.468% for 1-day duration.

The corresponding frequency factor 3.231 was chosen as extremely high Km value for one-day duration.

Frequency factor depends upon the statistical distribution of rainfall series, numbers of years of record, and return period of occurrences.

By using Hershfield statistical method the 1-day PMP for each selected station was computed as minimum and maximum value between the stations. The minimum PMP value indicated as 71.581mm which was belongs to Durame station and the maximum PMP value was 128.571mm for Humbo tebela station.

Hershfield statistical method can approximate the PMP values should be given to use the specific precipitation data for the study area.

As can be seen from the study the PMP values derived from the Hershfield statistical method should be given higher priority than Hershfield's graphical method or the published HMR documents PMP's.

Frequency analysis was done using 5 probability distributions which were selected by L-moment ratio diagram as a candidate distribution. The analysis was performed for selected station of 1-day duration was GEV, LN2 and Gamma distribution as the best frequency distribution. From this GEV (54. 54%). LN2 (27.27%) and Gamma (18.2%) total percentile occupies from selected distribution. By using D-index test the greater percent of coverage indicated that the GEV distribution was the best fit and selected distribution for determine different years return period depth of rainfall. The shape parameter of the GEV distribution governs the behavior of the distribution.

The PMP return period values were derived by using GEV type of distribution.

5.2 Recommendation

The distribution functions suitable for extreme hydrological value series analysis should have parameters; of shape, location and scale parameters.in this study the result show that EV1 does not have the best fit through hypothesized goodness of fit and diagnostic D-index test. GEV should be more suitable universal distribution model for the prediction of annual daily maximum rainfall to verify the ensuring result of PMP. since this distribution chooses EV1, EV2, and EV3 depend upon the shape parameter. Therefore, recommended that the value of shape parameter is equal to zero then the distribution converted to EV1.

There are a limited number of stations with first class recording in the Bilate sub river basin. So, establishment of additional first class stations for the study area is very essential to compare other type of methods of PMP estimation.

According to the result given from the study frequency factor for all stations was less than the recommended value of 5. So, increasing observation and station number would give the better result of Km value to approach to standardized value greater than 5.

Development of Isohyetal map provides point PMP and Km estimations; hence to get better reliable area estimations, minimize cost of rain gauges, minimize error of gauge stations and easily distribute the calculated PMP to ungauged stations to determine areal precipitation of the basin having far-off rain gauges are better consideration to different methods of PMP of the basin.

Considering maximum observed length of rain fall data will give better results regarding to return period and reliable factor of safety for maximum year of return periods.

By using rainfall runoff hydrologic model, it is possible to convert this PMP to PMF to estimate design discharge.

REFERENCES

Al-Mamun A. and Hashim A. (2004). Generalised Long Duration Probable Maximum Precipitation (PMP) Isohyetal Map for Peninsular Malaysia *Journal of Spatial Hydrology* 4.

Alias N E., Luo P. and and Takara K. (2013). Probable maximum precipitation using statistical method for the Yodo river basin *Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering)* 69 PP I_157-I_62.

Chow Ven T, Te C V and and Ar B 1988 *Applied Hydrology*: McGraw-Hill Book Company)

Collier C and Hardaker P (1996). Estimating probable maximum precipitation using a storm model approach *Journal of hydrology* 183 PP 277-306.

Costa A, C. and Soares A. (2009). Trends in extreme precipitation indices derived from a daily rainfall database for the South of Portugal *International Journal of Climatology: A Journal of the Royal Meteorological Society* 29 1956-75.

Cunnane C. (1978). Unbiased plotting positionsâ€"a review *Journal of hydrology* 37 205-22.

Cunnane C. (1989). Statistical distributions for flood frequency analysis *Operational hydrology report (WMO).*

Dame A. and Ayalew S. (2010). Development of regional probable maximum precipitation for probable maximum flood development and application in design of flood hydrograph: case study of Blue Nile basin, Ethiopia. In: *The 2010 Conference on Water Resources in Ethiopia. Addis Ababa*, pp 12-6.

Desa M, M. and Rakhecha P. (2006). Deriving the highest persisting monthly 24-hour dew points in Malaysia for the estimation of PMP *IAHS PUBLICATION* 308 287.

Deshpande N, Kulkarni B, Verma A. and and Mandal B. (2008). Extreme rainfall analysis and estimation of Probable Maximum Precipitation (PMP) by statistical methods over the Indus river basin in India *Journal of Spatial Hydrology* 8.

Dhar O, Kulkarni A. and and Rakhecha P. (1981). Probable maximum point rainfall estimation for the southern half of the Indian peninsula *Proceedings of the Indian Academy of Sciences-Earth and Planetary Sciences* 90 PP 39-46.

Duckstein L, Bobee B. and and Ashkar F. (1991). A Multiple Criteria Decision Modelling approach to selection of estimation techniques for fitting extreme floods *Stochastic Hydrology and Hydraulics* 5 PP 227-38.

Durbude D, G. (2008). Estimation of probable maximum precipitation for planning of soil and water conservation structures *Journal of soil and water conservation* **7** 31-5.

Fernando W. and Wickramasuriya S. (2011). The hydro meteorological estimation of probable maximum precipitation under varying scenarios in Sri Lanka *International Journal of Climatology* 31 668-76.

Fikre A, Quraishi S. and and Bezabih B. (2016). Development of One Day Probable Maximum Precipitation (PMP) and Isohyetal Map for Bale Zone, Oromiya Region, Ethiopia *Civil and Environmental Research* 8.

Garba H, Ismail A. and Tsoho U. (2013). Fitting probability distribution functions to discharge variability of Kaduna River *International Journal of Modern Engineering Research* 3 2848-52.

Gebremedhin Y G, Quraishi S. and and Itefa H. (2017). Development of one day probable maximum precipitation (PMP) and isohyetal map for Tigray Region, Ethiopia *Global Journal of Science Frontier Research: H Environment & Earth Science* 17.

Gerezihier Y. and Quraishi S. (2013). Development of One Day Probable Maximum Precipitation and Isohyetal Map for Tigray Region, Ethiopia. Haramaya University.

Ghahraman B. (2008). The estimation of one day duration probable maximum precipitation over Atrak watershed in Iran *Iranian Journal of Science and Technology* 32 175.

Ghosh S, N. (1997). *Flood control and drainage engineering*: CRC Press.

Gonzalez-Alvarez A l, Viloria-Marimon O M, Coronado-Hernandez O E, Vaolez-Pereira A M, Tesfagiorgis K. and Coronado-Hernandez a J R. (2019). Isohyetal

Maps of Daily Maximum Rainfall for Different Return Periods for the Colombian Caribbean Region *Water* 11 358.

Grubbs F, E. (1950). Sample criteria for testing outlying observations *The annals of mathematical statistics* 21 27-58.

Gumbel E, J. (1941a). Probability interpretation of the observed return periods of floods *Eos, Transactions American Geophysical Union* 22 836-50.

Hansen E M, Schreiner L, C. and and Miller J, F. (1982). Application of probable maximum precipitation estimates: United States east of the 105th meridian

Hasan M M and Croke B 2013 Filling gaps in daily rainfall data: a statistical approach PP 380-6

Hazen A 1930 *Flood flows: a study of frequencies and magnitudes*: John Wiley & Sons)

Heo J-H, Kho Y W, Shin H, Kim S and and Kim T 2008 Regression equations of probability plot correlation coefficient test statistics from several probability distributions *Journal of hydrology* 355 1-15

Hershfield D M 1961 Estimating the probable maximum precipitation *Journal of the hydraulics Division* 87 PP 99-116

Hershfield D M 1962 Extreme rainfall relationships *Journal of the hydraulics Division* 88 73-92

Hershfield D M 1965 Method for estimating probable maximum rainfall *Journal of American Water Works Association* 57 965-72

Hosking J R 1986 *The theory of probability weighted moments*: IBM Research Division, TJ Watson Research Center)

Javari M 2017 Spatial variability of rainfall trends in Iran *Arabian Journal of Geosciences* 10 78

Kang H M and Yusof F 2012 Homogeneity tests on daily rainfall series *Int. J. Contemp. Math. Sciences* **7** 9-22

Khan S A, Hussain I, Hussain T, Faisal M, Muhammad Y S and and Mohamd Shoukry A 2017 Regional frequency analysis of extremes precipitation using L-moments and partial L-moments *Advances in Meteorology* 2017

Koutsoyiannis D 1999 A probabilistic view of Hershfield's method for estimating probable maximum precipitation *Water Resources Research* 35 PP 1313-22

Lan P, Lin B, Zhang Y and Chen a H 2017 Probable Maximum Precipitation Estimation Using the Revised K m-Value Method in Hong Kong *Journal of Hydrologic Engineering* 22 PP 1-8

Landwehr J M, Matalas N and and Wallis J 1979 Probability weighted moments compared with some traditional techniques in estimating Gumbel parameters and quantiles *Water Resources Research* **15** PP 1055-64

Linsley R, Kohler M A and and Paulhus J 1982 Hydrology for Engineers *McGraw-Hill Series in Water Resources and Environmental Engineering (PP. 508): McGraw-Hill, Inc*

Mann H B and Whitney D R 1947 On a test of whether one of two random variables is stochastically larger than the other *The annals of mathematical statistics* 50-60

McCuen R 1998 Hydrologic design and analysis *Prince Hall, New Jersey* 814

NERC 1975 Flood studies report. Natural Environment Research Council, London)

Quraishi S and Berhane M 2014 Development of One Day Probable Maximum Precipitation and Isohyetal Map for North Shewa Zone of Amhara Region, Ethiopia. Haramaya University)

Regasa M 2010 Development of one day probable maximum precipitation isohyetal map for Benishangul Gumuz regional state. In: *MSc thesis Presented to the School of Graduate Studies.*, (Ethiopia: Haramaya University)

Searcy J K and Hardison C H 1960 *Double-mass curves*: US Government Printing Office)

Singh A 2016 Computation of Probable Maximum Precipitation (PMP) and Its Uncertainty.

Singh A, Singh B and and Ar B 2018 Risk analysis of probable maximum precipitation estimates *Int. J. Hydrol* 2 PP 411-22

Subramanya K 2013 *Engineering Hydrology, 4th edition*: Tata McGraw-Hill Education)

Tesema M 2012 Development of one day probable maximum precipitation isohyetal map for Westshewa zone, Ethiopia. In: *MSc thesis Presented to the School of Graduate Studies of Haramaya University,*

USWRC 1981 *Guidelines for determining flood flow frequency* vol 29: US Water Resources Council,Hydrology Committee)

Vasquez J A and Roncal J J 2009 Testing River2D and Flow-3D for sudden dam-break flow simulations. In: *Proc., CDA 2009 Annual Conf,* pp 3-8

Vivekan N 2013 Assessment of probable maximum precipitation using Gumbel distribution and Hershfield method *Bonfring International Journal of Data Mining* **3** PP 01-5

Vivekanandan N 2012 Assessing Adequacy of a Probability Distribution for Estimation of Design Flood *Bonfring International Journal of Industrial Engineering and Management Science* **2** 22-

Vivekanandan N 2015c Estimation of probable maximum precipitation using statistical methods *World Journal of Research and Review* 1 PP 13-6

Walland D, Meighen J, Xuereb K, Beesley C and and Hoang T 2003 Revision of the generalised tropical storm method for estimating probable maximum precipitation *Hydrology Report Series*

WMO 2009 *Manual on estimation of probable maximum precipitation (PMP)*: World Meteorological Organization)

Wodaje G G 2017 Local adaptation practice in response to climate change in the Bilate River Basin, Southern Ethiopia.

Yarnell D L 1935 Rainfall intensity-frequency data. Mise Pub *US Dept. Agric*

Zurndorfer E 1986 *Probable maximum and TVA precipitation estimates with areal distribution for Tennessee River drainages less that 3,000 Mi square in area*: US Dept. of Commerce, National Oceanic and Atmospheric Administration(NOAA)

ANNEXES

Annex A

Table 1: The Mann-Whitney test result for homogeneity test of all stations

Name of Station	Sample size N	var (U)	stat (U)	standard value	Remark
Alaba	32	697.223	0.606	1.96	Homogenous
Angecha	29	509.978	0.642	1.96	Homogenous
Badessa	28	467.209	0.648	1.96	Homogenous
Boditi	30	567.746	0.630	1.96	Homogenous
Butajira	31	637.979	0.614	1.96	Homogenous
Durame	32	695.209	0.607	1.96	Homogenous
Fonko	29	524.763	0.633	1.96	Homogenous
Hossana	31	635.957	0.615	1.96	Homogenous
Humbo Tebela	30	567.746	0.630	1.96	Homogenous
Shone	31	637.979	0.614	1.96	Homogenous
Wulbareg	31	639.763	0.613	1.96	Homogenous

Table 2: Descriptive statistics of the stations

Station Name	N	Mean		Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error
Angecha	29	46.01	2.047	.045	.434	-1.153	.845
Alaba	32	55.99	2.194	.334	.414	-.141	.809
Durame	32	43.23	1.759	-.073	.414	-.854	.809
Hossana	31	50.68	2.847	.481	.421	.949	.821
Fonko	29	50.96	1.603	.030	.434	-.432	.845
Bilate	32	58.73	2.512	.026	.414	-1.142	.809
Boditi	30	53.40	1.405	-.039	.427	-.251	.833
Bedessa	28	61.93	2.821	.788	.441	.470	.858
Wulbareg	31	42.78	2.523	.816	.421	-.201	.821
Shone	31	49.31	1.906	.346	.421	-.205	.821
Butajira	31	48.70	4.167	.259	.421	-.411	.821
Humbo Tebela	30	62.66	2.886	-.305	.427	2.810	.833

Table 3: The frequency distribution estimator parameters for listed five stations

Types of selected distribution and parameters						
Name of stations	parameters	NOR	LN2	Gamma	EV1	GEV
Butajira	MOM	μ=48.695 σ=4.816	μy=1.643 δy=0.298	α=11.052 β=4.405	α=3.757 β=46.528	μ=27.977 σ=49.991
	MLM	μ=48.695 σ=4.816	μy=1.625 δy=0.774	α=13.314 β=3.657	α=18.089 β=38.255	μ=39.461 σ=22.250
	PWM	μ=48.695 σ=23.552	μy=1.566 δy=0.493	α=12.120 β=4.017	α=44.152 β=23.210	μ=39.469 σ=22.262
Fonko	MOM	μ=50.955 σ=2.937	μy=1.701 δy=0.111	α=1.461 β=34.862	α=2.292 β=49.633	μ=45.165 σ=16.320
	MLM	μ=50.955 σ=2.937	μy=1.700 δy=0.288	α=1.449 β=35.156	α=6.729 β=47.071	μ=47.843 σ=8.759
	PWM	μ=50.955 σ=8.813	μy=1.692 δy=0.173	α=1.535 β=33.179	α=16.521 β=41.419	μ=47.846 σ=8.762
Shone	MOM	μ=49.309 σ=3.258	μy=1.683 δy=0.140	α=2.285 β=21.580	α=2.541 β=47.843	μ=48.550 σ=1.674
	MLM	μ=49.309 σ=3.258	μy=1.683 δy=0.362	α=2.220 β=22.217	α=8.276 β=44.532	μ=44.856 σ=9.797
	PWM	μ=49.309 σ=10.742	μy=1.699 δy=0.218	α=2.368 β=20.818	α=20.138 β=37.685	μ=44.864 σ=9.801
Badessa	MOM	μ=61.928 σ=3.864	μy=1.780 δy=0.156	α=3.599 β=17.207	α=3.014 β=60.189	μ=61.928 σ=2.310
	MLM	μ=61.928 σ=3.865	μy=1.780 δy=0.429	α=3.288 β=18.834	α=11.641 β=55.201	μ=54.974 σ=12.123
	PWM	μ=61.928 σ=14.841	μy=1.763 δy=0.240	α=3.609 β=17.161	α=27.821 β=45.869	μ=61.928 σ=2.325
Wulbareg	MOM	μ=42.777 σ=3.748	μy=1.609 δy=0.211	α=4.614 β=9.270	α=2.924 β=41.090	μ=36.339 σ=10.034
	MLM	μ=42.777 σ=3.748	μy=1.609 δy=0.529	α=4.139 β=10.334	α=10.954 β=36.454	μ=35.914 σ=10.703
	PWM	μ=42.777 σ=13.954	μy=1.577 δy=0.329	α=4.678 β=9.144	α=26.160 β=27.677	μ=35.912 σ=10.699

Table 4: The frequency distribution estimator parameters for listed five stations

Types of selected distribution and parameters						
Name of stations	parameters	NOR	LN2	Gamma	EV1	GEV
Alaba	MOM	μ=55.99 σ=3.523	μy=1.738 δy=0.144	α=2.750 β=20.355	α=2.748 β=54.405	μ=53.444 σ=5.972
	MLM	μ=55.99 σ=3.523	μy=1.738 δy=0.385	α=2.681 β=20.879	α=9.676 β=50.405	μ=50.995 σ=11.701
	PWM	μ=55.99 σ=12.517	μy=1.723 δy=0.224	α=2.833 β=19.758	α=23.465 β=42.446	μ=50.999 σ=11.707
Angecha	MOM	μ=46.007 σ=3.320	μy=1.650 δy=0.156	α=2.642 β=17.412	α=2.590 β=44.512	μ=43.577 σ=6.656
	MLM	μ=46.007 σ=3.321	μy=1.651 δy=0.395	α=2.643 β=17.403	α=8.596 β=41.045	μ=41.896 σ=11.246
	PWM	μ=46.007 σ=11.411	μy=1.631 δy=0.248	α=2.875 β=16.002	α=21.392 β=33.658	μ=41.900 σ=11.252
Durame	MOM	μ=43.228 σ=3.154	μy=1.624 δy=0.149	α=2.289 β=18.877	α=2.460 β=41.808	μ=36.969 σ=18.344
	MLM	μ=43.228 σ=3.154	μy=1.623 δy=0.373	α=2.367 β=18.265	α=7.757 β=38.751	μ=39.708 σ=10.30
	PWM	μ=43.228 σ=10.251	μy=1.607 δy=0.238	α=2.465 β=17.531	α=19.217 β=32.135	μ=39.712 σ=10.304
Hossana	MOM	μ=50.684 σ=3.981	μy=1.684 δy=0.201	α=4.959 β=10.221	α=3.106 β=48.891	μ=43.191 σ=26.464
	MLM	μ=50.684 σ=3.981	μy=1.682 δy=0.526	α=5.207 β=9.734	α=12.361 β=43.549	μ=43.882 σ=13.792
	PWM	μ=50.684 σ=19.182	μy=1.631 δy=0.382	α=7.534 β=6.726	α=29.927 β=35.960	μ=44.983 σ=20.136
Boditi	MOM	μ=53.403 σ=2.774	μy=1.723 δy=0.094	α=1.109 β=48.132	α=2.16 β=52.154	μ=48.942 σ=13.765
	MLM	μ=53.403 σ=2.774	μy=1.723 δy=0.248	α=1.101 β=48.490	α=6.002 β=49.939	μ=50.825 σ=7.945
	PWM	μ=53.403 σ=7.801	μy=1.717 δy=0.146	α=1.146 β=46.607	α=14.625 β=44.961	μ=50.827 σ=7.950

Table 5: Expected extreme rainfall of Alaba station for one-day duration

Alaba		1 Day Expected extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MLM	Gamma/PWM	EV1/MLM	GEV/PWM
1	86.000	79.482	84.325	81.335	84.089	81.450
2	75.400	75.392	77.304	76.424	77.230	76.667
3	74.700	72.705	73.151	73.286	73.150	73.525
4	73.700	70.623	70.160	70.902	70.205	71.107
5	71.800	68.882	67.802	68.940	67.880	69.105
6	68.000	67.360	65.842	67.249	65.946	67.373
7	68.000	65.990	64.154	65.745	64.278	65.830
8	64.000	64.730	62.664	64.377	62.805	64.426
9	62.000	63.554	61.323	63.113	61.477	63.130
10	60.300	62.441	60.098	61.929	60.263	61.916
11	59.000	61.376	58.966	60.808	59.140	60.769
12	57.000	60.350	57.909	59.737	58.089	59.674
13	56.700	59.353	56.913	58.705	57.097	58.621
14	56.400	58.377	55.968	57.704	56.153	57.602
15	55.700	57.417	55.065	56.726	55.249	56.609
16	55.700	56.465	54.196	55.766	54.377	55.635
17	55.400	55.516	53.355	54.818	53.531	54.676
18	55.300	54.565	52.535	53.874	52.705	53.724
19	55.000	53.604	51.732	52.929	51.893	52.775
20	53.800	52.628	50.940	51.979	51.091	51.824
21	52.400	51.631	50.155	51.015	50.293	50.864
22	51.400	50.605	49.371	50.033	49.495	49.889
23	51.300	49.541	48.585	49.025	48.690	48.891
24	48.400	48.428	47.789	47.980	47.872	47.862
25	48.200	47.251	46.977	46.887	47.032	46.790
26	45.400	45.991	46.140	45.730	46.161	45.660
27	41.400	44.621	45.265	44.488	45.244	44.451
28	40.300	43.099	44.336	43.126	44.260	43.132
29	38.500	41.358	43.325	41.592	43.179	41.654
30	37.900	39.276	42.185	39.791	41.942	39.928
31	37.800	36.589	40.818	37.520	40.431	37.764
32	34.800	32.499	38.943	34.175	38.293	34.600

Table 6: Expected extreme rainfall of Badessa station for one day duration

Badessa		1 Day				
		Expected Extreme rainfall for the selected distribution				
S.No	Observed Annual max	NOR/PWM	LN2/PWM	Gamma/PWM	EV1/MLM	GEV/MLM
1	100.400	88.925	92.801	93.165	94.202	95.516
2	90.000	83.950	85.672	85.952	85.924	86.920
3	85.700	80.662	81.267	81.471	80.988	81.792
4	81.900	78.101	77.993	78.134	77.416	78.079
5	75.800	75.947	75.344	75.431	74.587	75.139
6	72.900	74.054	73.091	73.130	72.226	72.683
7	70.500	72.341	71.110	71.107	70.184	70.559
8	69.200	70.756	69.326	69.287	68.373	68.675
9	68.100	69.267	67.691	67.619	66.734	66.970
10	64.600	67.848	66.170	66.070	65.229	65.404
11	63.200	66.483	64.738	64.613	63.828	63.947
12	60.500	65.155	63.376	63.229	62.511	62.575
13	60.000	63.854	62.069	61.904	61.259	61.273
14	59.500	62.568	60.805	60.624	60.060	60.024
15	58.800	77.336	77.042	77.164	58.901	58.818
16	57.700	76.052	75.471	75.561	57.773	57.643
17	57.200	74.753	73.915	73.971	56.666	56.491
18	56.800	73.431	72.364	72.388	55.572	55.351
19	55.700	72.075	70.808	70.799	54.480	54.214
20	54.400	70.675	69.236	69.195	53.382	53.070
21	52.600	69.213	67.633	67.560	52.265	51.907
22	50.200	67.670	65.981	65.877	51.117	50.710
23	49.400	66.017	64.256	64.124	49.919	49.462
24	49.400	64.210	62.424	62.264	48.644	48.134
25	48.300	62.180	60.429	60.244	47.253	46.684
26	41.400	59.803	58.173	57.970	45.675	45.039
27	39.900	56.811	55.454	55.245	43.761	43.044
28	39.900	52.401	51.681	51.502	41.078	40.246

Table 7: Expected extreme rainfall of Boditi station for one day duration

	Boditi	1 Day Expected Extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MLM	Gamma/PWM	EV1/MLM	GEV/PWM
1	69.800	67.828	69.723	67.744	70.451	67.152
2	65.000	65.248	66.029	65.213	66.190	65.083
3	64.500	63.548	63.756	63.540	63.652	63.602
4	64.200	62.227	62.073	62.236	61.819	62.395
5	62.500	61.120	60.716	61.141	60.369	61.353
6	59.000	60.150	59.566	60.180	59.161	60.418
7	58.200	59.274	58.557	59.311	58.118	59.560
8	57.000	58.467	57.652	58.509	57.195	58.758
9	57.000	57.710	56.825	57.757	56.362	57.999
10	56.500	56.993	56.058	57.042	55.598	57.273
11	56.000	56.304	55.339	56.355	54.890	56.571
12	55.000	55.638	54.658	55.690	54.226	55.888
13	55.000	54.988	54.008	55.041	53.597	55.218
14	55.000	54.350	53.382	54.402	52.997	54.557
15	54.500	53.718	52.774	53.769	52.420	53.900
16	53.500	61.525	61.207	61.542	51.861	53.244
17	53.500	60.893	60.444	60.917	51.316	52.585
18	53.200	60.256	59.690	60.285	50.781	51.918
19	52.000	59.608	58.939	59.643	50.253	51.239
20	51.700	58.946	58.187	58.986	49.726	50.544
21	51.200	58.265	57.430	58.309	49.198	49.826
22	48.800	57.559	56.662	57.606	48.664	49.078
23	48.500	56.820	55.877	56.870	48.118	48.291
24	48.000	56.037	55.065	56.089	47.553	47.453
25	45.400	55.196	54.214	55.248	46.962	46.546
26	44.000	54.274	53.308	54.326	46.330	45.544
27	43.300	53.234	52.318	53.285	45.637	44.405
28	41.200	52.014	51.196	52.059	44.849	43.054
29	40.200	50.472	49.840	50.507	43.888	41.328
30	38.400	48.191	47.953	48.206	42.535	38.738

Table 8: Expected extreme rainfall of Butajira station for one day duration

	Butajira	1 Day Expected Extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MOM	Gamma2/MLM	EV1/MLM	GEV/PWM
1	91.300	92.577	99.448	98.769	73.061	95.572
2	90.200	84.835	87.608	89.162	65.904	86.867
3	90.000	79.742	80.429	82.980	61.644	81.093
4	90.000	75.791	75.168	78.258	58.568	76.621
5	75.000	72.483	70.962	74.354	56.138	72.897
6	67.200	69.587	67.422	70.975	54.114	69.661
7	65.000	66.977	64.341	67.958	52.369	66.768
8	62.100	64.574	61.593	65.206	50.825	64.128
9	60.000	62.327	59.097	62.652	49.433	61.679
10	58.700	60.198	56.797	60.252	48.159	59.381
11	56.000	58.159	54.652	57.971	46.978	57.200
12	52.100	56.190	52.632	55.784	45.872	55.112
13	50.600	54.273	50.713	53.669	44.827	53.099
14	50.200	52.393	48.877	51.610	43.832	51.142
15	50.000	50.538	47.106	49.591	42.876	49.230
16	48.900	74.161	73.074	76.329	41.953	47.348
17	47.300	72.322	70.762	74.166	41.055	45.485
18	43.500	70.469	68.487	72.000	40.175	43.630
19	41.800	68.593	66.237	69.823	39.309	41.773
20	40.500	66.684	64.001	67.621	38.450	39.900
21	39.000	64.730	61.769	65.384	37.593	37.999
22	38.000	62.717	59.525	63.094	36.730	36.056
23	36.800	60.626	57.255	60.733	35.855	34.052
24	35.500	58.434	54.938	58.277	34.960	31.964
25	28.700	56.109	52.550	55.694	34.032	29.765
26	28.200	53.606	50.057	52.937	33.057	27.412
27	23.000	50.860	47.410	49.940	32.014	24.844
28	16.500	47.761	44.533	46.595	30.869	21.966
29	12.897	44.115	41.288	42.707	29.562	18.603
30	10.361	39.503	37.393	37.865	27.966	14.383
31	10.215	32.672	32.025	30.843	25.715	8.205

Table 9: Expected extreme rainfall of Durame station for one day duration

Durame		1 Day				
		Expected Extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MLM	Gamma/PWM	EV1/MLM	GEV/PWM
1	59.300	62.467	65.856	62.920	65.755	61.944
2	58.400	59.117	60.301	59.405	60.256	59.087
3	58.200	56.917	57.004	57.111	56.985	57.076
4	56.800	55.212	54.625	55.341	54.624	55.457
5	55.200	53.786	52.746	53.867	52.760	54.070
6	54.700	52.540	51.181	52.582	51.209	52.836
7	54.000	51.417	49.832	51.428	49.872	51.712
8	52.200	50.386	48.640	50.370	48.691	50.669
9	51.700	49.422	47.566	49.385	47.627	49.688
10	49.500	48.510	46.584	48.454	46.654	48.754
11	47.600	47.639	45.676	47.566	45.753	47.858
12	47.600	46.799	44.826	46.712	44.910	46.991
13	47.300	45.982	44.026	45.884	44.115	46.146
14	43.800	45.183	43.265	45.075	43.359	45.318
15	43.100	44.396	42.537	44.279	42.634	44.501
16	43.100	43.616	41.836	43.493	41.935	43.692
17	42.000	53.924	52.924	54.009	41.256	42.885
18	41.400	53.146	51.933	53.206	40.594	42.076
19	40.500	52.360	50.962	52.397	39.943	41.261
20	38.900	51.563	50.004	51.578	39.300	40.435
21	38.700	50.751	49.057	50.744	38.661	39.593
22	38.400	49.918	48.114	49.892	38.020	38.729
23	38.000	49.059	47.171	49.014	37.375	37.836
24	37.000	48.165	46.221	48.102	36.719	36.905
25	36.200	47.227	45.256	47.148	36.046	35.925
26	34.700	46.231	44.267	46.136	35.347	34.880
27	34.500	45.157	43.241	45.049	34.612	33.750
28	32.800	43.977	42.158	43.857	33.824	32.502
29	30.600	42.644	40.990	42.514	32.957	31.084
30	27.500	41.073	39.684	40.938	31.965	29.403
31	24.800	39.084	38.134	38.950	30.754	27.258
32	24.800	36.132	36.032	36.018	29.040	24.048

Table 10: Expected extreme rainfall of Fonko station for one-day duration

	Fonko	1 Day Expected Extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MLM	Gamma/PWM	EV1/MOM	GEV/PWM
1	67.400	67.121	69.359	67.285	69.843	67.018
2	66.800	64.187	64.993	64.291	65.062	64.345
3	63.900	62.251	62.333	62.321	62.213	62.480
4	62.100	60.745	60.377	60.792	60.153	60.987
5	59.600	59.480	58.808	59.509	58.523	59.713
6	58.400	58.371	57.483	58.386	57.164	58.581
7	57.000	57.368	56.326	57.371	55.989	57.551
8	55.400	56.442	55.292	56.436	54.948	56.594
9	55.200	55.573	54.349	55.559	54.008	55.694
10	54.800	54.747	53.477	54.726	53.145	54.837
11	54.200	53.954	52.661	53.926	52.344	54.012
12	52.700	53.184	51.890	53.152	51.591	53.213
13	51.000	52.432	51.155	52.395	50.877	52.431
14	50.900	51.691	50.447	51.650	50.195	51.661
15	50.800	60.484	60.048	60.527	49.537	50.899
16	50.700	59.750	59.137	59.782	48.899	50.138
17	50.400	59.009	58.240	59.032	48.274	49.375
18	49.400	58.259	57.352	58.272	47.659	48.603
19	49.000	57.493	56.469	57.498	47.049	47.818
20	48.600	56.707	55.584	56.703	46.438	47.011
21	47.700	55.893	54.692	55.881	45.822	46.177
22	45.600	55.042	53.785	55.023	45.194	45.304
23	42.800	54.142	52.853	54.116	44.546	44.380
24	42.500	53.177	51.882	53.144	43.869	43.386
25	41.900	52.120	50.855	52.081	43.147	42.296
26	39.500	50.931	49.740	50.887	42.357	41.065
27	38.500	49.536	48.487	49.488	41.459	39.615
28	36.000	47.777	46.985	47.727	40.368	37.779
29	34.900	45.180	44.921	45.134	38.834	35.055

Table 11: Expected extreme rainfall of Hossana station for one-day duration

	Hossana	1-DAY Expected Extreme rainfall for the selected distribution				
S.No	Observed Annual max	NOR/PWM	LN2/PWM	Gamma/MLM	EV1/MLM	GEV/PWM
1	94.100	86.424	86.454	83.987	86.193	82.774
2	77.000	80.118	77.508	77.171	77.424	78.589
3	73.900	75.970	72.208	72.859	72.206	75.477
4	67.100	72.752	68.387	69.605	68.437	72.881
5	66.800	70.058	65.371	66.943	65.460	70.595
6	62.800	67.699	62.862	64.657	62.980	68.518
7	62.300	65.573	60.698	62.634	60.841	66.588
8	61.200	63.617	58.787	60.800	58.950	64.766
9	60.000	61.786	57.065	59.112	57.244	63.026
10	59.000	60.052	55.490	57.534	55.683	61.348
11	59.000	58.392	54.033	56.045	54.237	59.715
12	54.600	56.788	52.671	54.625	52.882	58.116
13	52.200	55.226	51.385	53.260	51.601	56.539
14	51.300	53.695	50.163	51.939	50.382	54.975
15	50.400	52.185	48.993	50.652	49.211	53.415
16	49.500	71.425	66.881	68.287	48.079	51.850
17	47.800	69.927	65.229	66.815	46.979	50.273
18	46.900	68.417	63.613	65.349	45.902	48.674
19	45.000	66.890	62.027	63.883	44.841	47.044
20	42.300	65.335	60.461	62.409	43.788	45.371
21	40.600	63.744	58.909	60.919	42.738	43.644
22	39.400	62.104	57.359	59.403	41.681	41.846
23	39.400	60.401	55.803	57.850	40.609	39.960
24	37.800	58.615	54.227	56.244	39.511	37.959
25	37.600	56.722	52.615	54.567	38.375	35.811
26	37.200	54.684	50.948	52.790	37.181	33.469
27	37.100	52.447	49.194	50.874	35.903	30.860
28	35.600	49.923	47.307	48.755	34.500	27.870
29	35.400	46.953	45.204	46.319	32.898	24.287
30	33.500	43.197	42.718	43.325	30.943	19.658
31	14.408	37.633	39.360	39.067	28.185	12.609

Table 12: Expected extreme rainfall of Shone station for one-day duration

Shone		1 Day Expected Extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/MLM	Gamma/PWM	EV1/MLM	GEV/PWM
1	72.200	69.325	73.098	70.925	73.084	71.674
2	70.100	65.793	67.245	66.668	67.213	67.166
3	67.300	63.471	63.758	63.947	63.719	64.263
4	61.900	61.668	61.234	61.879	61.196	62.058
5	61.300	60.159	59.236	60.177	59.202	60.247
6	60.300	58.839	57.569	58.708	57.542	58.692
7	57.300	57.648	56.128	57.401	56.110	57.315
8	55.400	56.552	54.853	56.212	54.843	56.068
9	54.600	55.527	53.701	55.112	53.702	54.922
10	54.400	54.556	52.646	54.081	52.656	53.853
11	53.600	53.626	51.668	53.103	51.688	52.845
12	52.400	52.728	50.752	52.167	50.781	51.886
13	49.100	51.853	49.887	51.265	49.923	50.966
14	48.300	50.996	49.063	50.389	49.107	50.077
15	48.300	50.150	48.272	49.532	48.323	49.212
16	48.100	60.925	60.237	61.037	47.565	48.366
17	47.800	60.086	59.142	60.095	46.829	47.532
18	47.400	59.241	58.069	59.153	46.107	46.705
19	46.500	58.385	57.014	58.208	45.397	45.881
20	46.200	57.514	55.970	57.255	44.692	45.054
21	44.900	56.623	54.934	56.289	43.989	44.218
22	43.200	55.705	53.898	55.302	43.281	43.367
23	41.400	54.751	52.856	54.287	42.564	42.494
24	41.400	53.751	51.798	53.234	41.829	41.588
25	41.200	52.691	50.715	52.129	41.068	40.639
26	40.300	51.550	49.592	50.954	40.268	39.628
27	40.100	50.297	48.408	49.680	39.412	38.531
28	38.900	48.883	47.130	48.263	38.473	37.308
29	32.300	47.220	45.703	46.623	37.401	35.887
30	31.500	45.117	44.009	44.592	36.092	34.119
31	30.900	42.001	41.711	41.668	34.245	31.556

Table 13: Expected extreme rainfall of Wulbareg station for one-day duration

	Wulbareg	1 Day Expected extreme rainfall for the selected distribution				
S.No	Observed annual max	NOR/PWM	LN2/PWM	Gamma/PWM	EV1/MLM	GEV/MLM
1	74.100	68.777	73.883	73.398	74.244	77.041
2	71.500	64.190	66.438	66.561	66.473	67.858
3	67.700	61.173	61.961	62.335	61.849	62.580
4	67.000	58.831	58.700	59.199	58.509	58.853
5	59.400	56.871	56.105	56.669	55.871	55.957
6	55.800	55.155	53.930	54.524	53.673	53.578
7	54.600	53.609	52.043	52.646	51.778	51.549
8	53.300	52.185	50.366	50.962	50.102	49.772
9	49.200	50.854	48.847	49.426	48.590	48.185
10	47.600	49.592	47.452	48.005	47.207	46.744
11	45.600	48.385	46.154	46.676	45.925	45.418
12	42.300	47.218	44.935	45.420	44.724	44.185
13	40.300	46.082	43.780	44.224	43.590	43.028
14	39.600	44.968	42.677	43.076	42.509	41.932
15	39.500	43.869	41.616	41.967	41.471	40.886
16	39.100	57.866	57.407	57.942	40.469	39.881
17	38.200	56.776	55.982	56.548	39.494	38.909
18	37.600	55.678	54.583	55.171	38.539	37.963
19	37.400	54.567	53.203	53.803	37.599	37.036
20	37.200	53.436	51.836	52.438	36.666	36.121
21	35.600	52.278	50.473	51.070	35.735	35.213
22	35.300	51.085	49.107	49.690	34.798	34.304
23	34.800	49.846	47.729	48.288	33.849	33.387
24	32.300	48.547	46.327	46.853	32.876	32.453
25	29.700	47.170	44.885	45.369	31.869	31.491
26	29.200	45.687	43.386	43.814	30.810	30.486
27	28.800	44.060	41.798	42.158	29.678	29.417
28	27.900	42.223	40.079	40.351	28.435	28.252
29	27.300	40.063	38.150	38.309	27.015	26.931
30	24.300	37.331	35.845	35.852	25.283	25.334
31	23.900	33.283	32.693	32.463	22.839	23.106

Table 14: Expected extreme rainfall of Angecha station for one-day duration

	Angecha	1 Day Expected Extreme rainfall for the selected distribution				
S.No	observed annual max	NOR/PWM	LN2/PWM	Gamma/PWM	EV1/MLM	GEV/PWM
1	67.000	66.939	69.143	67.307	70.138	67.074
2	61.300	63.140	63.834	63.382	64.030	63.477
3	61.000	60.633	60.565	60.802	60.390	60.989
4	60.000	58.683	58.143	58.802	57.758	59.009
5	58.500	57.046	56.187	57.126	55.676	57.325
6	57.000	55.609	54.528	55.658	53.939	55.835
7	56.000	54.311	53.072	54.334	52.438	54.483
8	55.000	53.112	51.764	53.114	51.109	53.231
9	53.000	51.987	50.567	51.970	49.907	52.055
10	52.000	50.917	49.456	50.885	48.805	50.937
11	51.000	49.890	48.414	49.843	47.781	49.865
12	50.000	48.893	47.424	48.835	46.819	48.826
13	50.000	47.919	46.477	47.850	45.908	47.812
14	50.000	46.959	45.564	46.881	45.036	46.816
15	44.500	58.345	57.734	58.456	44.196	45.831
16	44.500	57.395	56.598	57.483	43.380	44.850
17	44.000	56.436	55.476	56.502	42.582	43.866
18	42.000	55.464	54.363	55.510	41.797	42.873
19	40.000	54.473	53.251	54.499	41.017	41.863
20	39.500	53.454	52.134	53.462	40.237	40.829
21	39.000	52.400	51.004	52.390	39.449	39.760
22	37.500	51.299	49.850	51.272	38.647	38.643
23	35.000	50.134	48.659	50.090	37.820	37.462
24	32.700	48.883	47.414	48.824	36.954	36.195
25	32.700	47.515	46.090	47.441	36.032	34.806
26	30.500	45.975	44.647	45.888	35.023	33.241
27	30.500	44.169	43.015	44.070	33.875	31.402
28	30.000	41.891	41.047	41.784	32.481	29.078
29	30.000	38.529	38.313	38.422	30.522	25.639

Table 15: Best selected distribution by D-index test for Alaba station

	Alaba			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.535		
	MLM	1.535		
	PWM	0.271	PWM	
LN2	MOM	0.222		
	MLM	0.197	MLM	
	PWM	0.202		
Gamma	MOM	0.232		
	MLM	0.254		
	PWM	0.205	PWM	
EV1	MOM	1.510		
	MLM	0.198	MLM	
	PWM	2.412		
GEV	MOM	1.089		
	MLM	0.187		
	PWM	0.185	PWM	GEV/PWM*
*Selected Distribution				

Table 16: Best selected distribution by D-index test for Angecha station

Angecha				
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.385		
	MLM	1.385		
	PWM	0.060	PWM	
LN2	MOM	0.066		
	MLM	0.065	MLM	
	PWM	0.052	PWM	
Gamma	MOM	0.116		
	MLM	0.115		
	PWM	0.037	PWM	
EV1	MOM	1.367		
	MLM	0.062	MLM	
	PWM	2.717		
GEV	MOM	0.802		
	MLM	0.026		
	PWM	0.024	PWM	GEV/PWM*
*Selected Distribution				

Table 17: Best selected distribution by D-index test for Badessa station

	Badessa			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.719		
	MLM	1.719		
	PWM	0.405	PWM	
LN2	MOM	0.342		
	MLM	0.359		
	PWM	0.332	PWM	
Gamma	MOM	0.316		
	MLM	0.398		
	PWM	0.314	PWM	
EV1	MOM	1.706		
	MLM	0.345	MLM	
	PWM	2.209		
GEV	MOM	1.689		
	MLM	0.268	MLM	GEV/MLM*
	PWM	1.686		
*Selected Distribution				

Table 18: Best selected distribution by D-index test for Boditi station

Boditi				
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	0.812		
	MLM	0.812		
	PWM	0.091	PWM	
LN2	MOM	0.080		
	MLM	0.059	MLM	LN2/MLM*
	PWM	0.070		
Gamma	MOM	0.110		
	MLM	0.115		
	PWM	0.093	PWM	
EV1	MOM	0.796		
	MLM	0.063	MLM	
	PWM	1.584		
GEV	MOM	0.723		
	MLM	0.094		
	PWM	0.094	PWM	
*Selected Distribution				

Table 19: Best selected distribution by D-index test for Durame station

Durame				
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.351		
	MLM	1.351		
	PWM	0.059	PWM	
LN2	MOM	0.046		
	MLM	0.026	MLM	LN2/MLM*
	PWM	0.028		
Gamma	MOM	0.101		
	MLM	0.070		
	PWM	0.032	PWM	
EV1	MOM	1.322		
	MLM	0.023	MLM	
	PWM	2.787		
GEV	MOM	1.414		
	MLM	0.051		
	PWM	0.049	PWM	
*Selected Distribution				

Table 20: Best selected distribution by D-index test for Fonko station

	Fonko			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	0.988		
	MLM	0.988		
	PWM	0.119	PWM	
LN2	MOM	0.114		
	MLM	0.095	MLM	LN2/MLM*
	PWM	0.103		
Gamma	MOM	0.142		
	MLM	0.148		
	PWM	0.110	PWM	
EV1	MOM	0.973		
	MLM	0.103	MLM	
	PWM	1.817		
GEV	MOM	1.041		
	MLM	0.101		
	PWM	0.100	PWM	
*Selected Distribution				

Table 21: Best selected distribution by D-index test for Hossana station

Hossana				
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	2.105		
	MLM	2.105		
	PWM	0.223	PWM	
LN2	MOM	0.183		
	MLM	0.233		
	PWM	0.176	PWM	
Gamma	MOM	0.190		
	MLM	0.128	MLM	Gamma/MLM*
	PWM	0.397		
EV1	MOM	2.077		
	MLM	0.178	MLM	
	PWM	3.730		
GEV	MOM	1.038		
	MLM	1.102		
	PWM	0.141	PWM	GEV/PWM**
*Selected Distribution				

Table 22: Best selected distribution by D-index test for Butajira station

	Butajira			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Selected distribution
NOR	MOM	3.576		
	MLM	3.576		
	PWM	0.589	PWM	
LN2	MOM	0.465	MOM	
	MLM	0.916		
	PWM	0.537		
Gamma	MOM	0.558		
	MLM	0.189	MLM	Gamma/MLM*
	PWM	0.380		
EV1	MOM	3.541		
	MLM	2.757	MLM	
	PWM	5.089		
GEV	MOM	4.443		
	MLM	0.435		
	PWM	0.431	PWM	
*Selected Distribution				

Table 23: Best selected distribution by D-index test for Wulbareg station

Wulbareg				
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	2.565		
	MLM	2.565		
	PWM	0.713	PWM	
LN2	MOM	0.585		
	MLM	2.599		
	PWM	0.572	PWM	
Gamma	MOM	0.552		
	MLM	0.694		
	PWM	0.533	PWM	
EV1	MOM	2.534		
	MLM	0.582	MLM	
	PWM	3.117		
GEV	MOM	0.633		
	MLM	0.459	MLM	GEV/MLM*
	PWM	0.460		
*Selected Distribution				

Table 24: Best selected distribution by D-index test for Shone station

	Shone			
Types of Distribution	Types of parameter	D index Value	Selected parameter	Best fitted distribution
NOR	MOM	1.459		
	MLM	1.459		
	PWM	0.281	PWM	
LN2	MOM	0.245		
	MLM	0.222	MLM	
	PWM	0.227		
Gamma	MOM	0.250		
	MLM	0.275		
	PWM	0.219	PWM	
EV1	MOM	1.436		
	MLM	0.226	MLM	
	PWM	2.277		
GEV	MOM	1.666		
	MLM	0.184		
	PWM	0.183	PWM	GEV/PWM*
* Selected Distribution				

Table 25: Goodness of fit test for Alaba, Angecha, Durame and Badessa Stations

Alaba					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	0.001	0.949	43.924	0.231	accepted hypothesis
LN2	13.072	0.905			Accepted for both
Gamma	11.241	0.939			Accepted for both
EV1	2.202	0.911			Accepted for both
GEV	2.587	0.936			Accepted for both
Angecha					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	0.563	0.954	42.557	0.258	accepted hypothesis
LN2	64.526	0.942			LN2 not for x^2
Gamma	55.773	0.954			Gamma not for x^2
EV1	2.848	0.907			Accepted for both
GEV	2.717	0.94			Accepted for both
Durame					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	5.170	0.957	43.924	0.231	accepted hypothesis
LN2	52.493	0.935			LN2 not for x^2
Gamma	46.638	0.956			Gamma not for x^2
EV1	2.274	0.911			Accepted for both
GEV	4.199	0.948			Accepted for both
Badessa					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	5.631	0.951	41.334	0.253	accepted hypothesis
LN2	85.862	0.939			LN2 not for x^2
Gamma	86.126	0.938			Gamma not for x^2
EV1	3.076	0.905			Accepted for both
GEV	4.853	0.906			Accepted for both

Table 26: Goodness of fit test for Boditi, Butajira, Fonko and Hossana Stations

Boditi					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	3.336	0.955	43.773	0.242	accepted hypothesis
LN2	26.233	0.942			Accepted for both
Gamma	23.317	0.955			Accepted for both
EV1	1.628	0.908			Accepted for both
GEV	2.067	0.947			Accepted for both
Butajira					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	10.936	0.957	43.774	0.224	accepted hypothesis
LN2	25.414	0.942			Accepted for both
Gamma	20.838	0.954			Accepted for both
EV1	4.924	0.911			Accepted for both
GEV	35.222	0.937			Accepted for both
Fonko					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	4.090	0.954	42.557	0.258	accepted hypothesis
LN2	36.102	0.940			Accepted for both
Gamma	32.192	0.954			Accepted for both
EV1	2.031	0.907			Accepted for both
GEV	3.813	0.942			Accepted for both
Hossana					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	7.303	0.957	43.774	0.224	accepted hypothesis
LN2	117.129	0.936			LN2 not for x^2
Gamma	111.363	0.950			Gamma not for x^2
EV1	3.270	0.911			Accepted for both
GEV	0.048	0.953			Accepted for both

Table 27: Goodness of fit test for Wulbareg and Shone Stations

Wulbareg					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	7.610	0.957	43.774	0.224	accepted hypothesis
LN2	8.399	0.940			Accepted for both test
Gamma	101.558	0.944			Gamma not for x^2
EV1	3.416	0.911			Accepted for both test
GEV	58.455	0.899			GEV not for x^2
Shone					
Distributions	x^2 test	K-S test	critical for x^2	critical for K-S	Remark
NOR	5.079	0.957	43.774	0.224	Accepted hypothesis
LN2	54.859	0.937			LN2 not for x^2
Gamma	51.826	0.953			Gamma not for x^2
EV1	2.267	0.911			Accepted for both test
GEV	0.332	0.930			Accepted for both test

Annex B

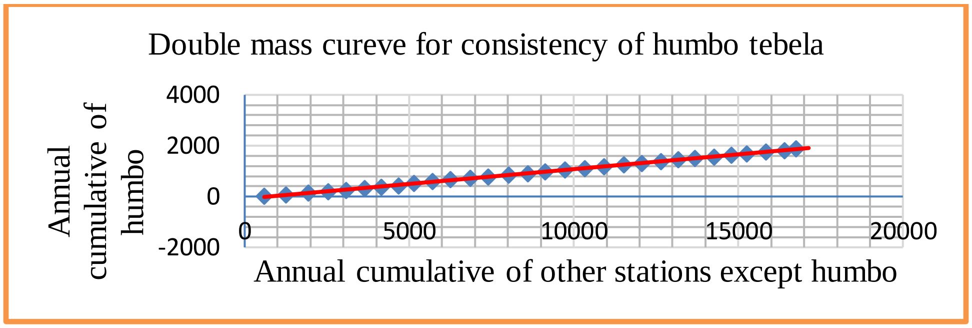

Figure 1: Double mass curve for consistency of data of Humbo

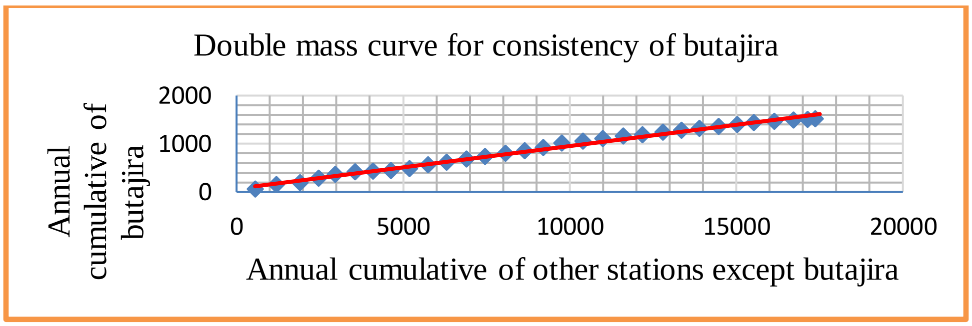

Figure 2: Double mass curve for consistency of Butajira

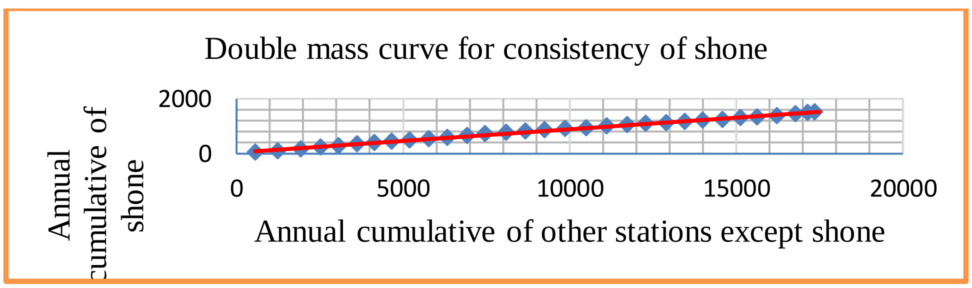

Figure 3: Double mass curve for consistency of Shone

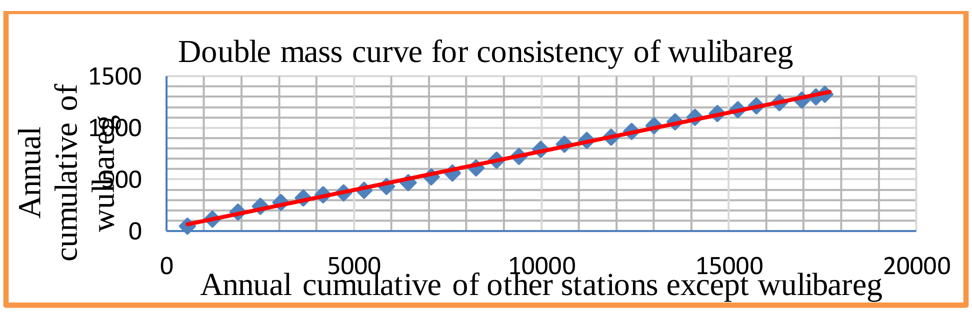

Figure 4: Double mass curve for consistency of Wulbareg

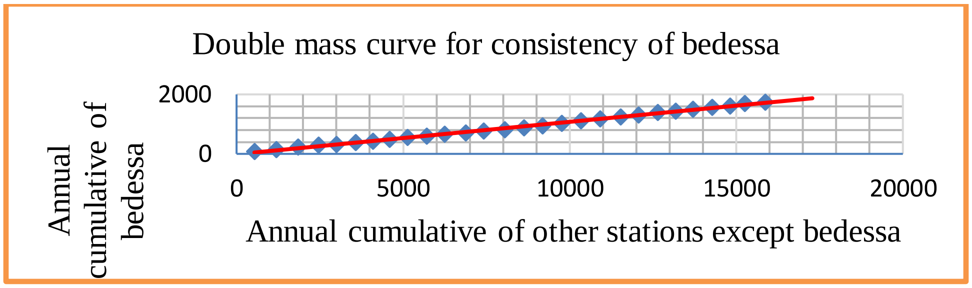

Figure 5: Double mass curve for consistency of Badessa

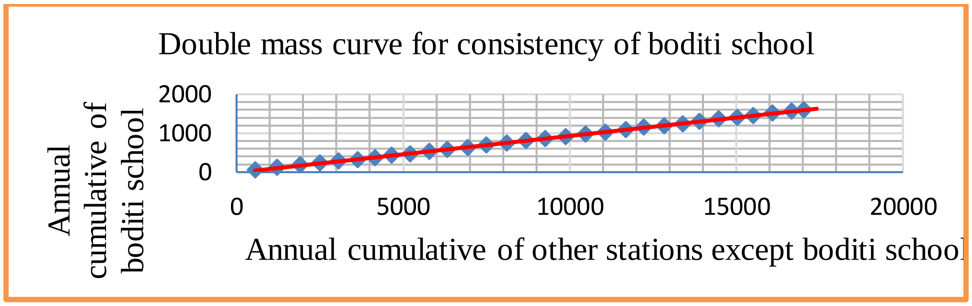

Figure 6: Double mass curve for consistency of Boditi

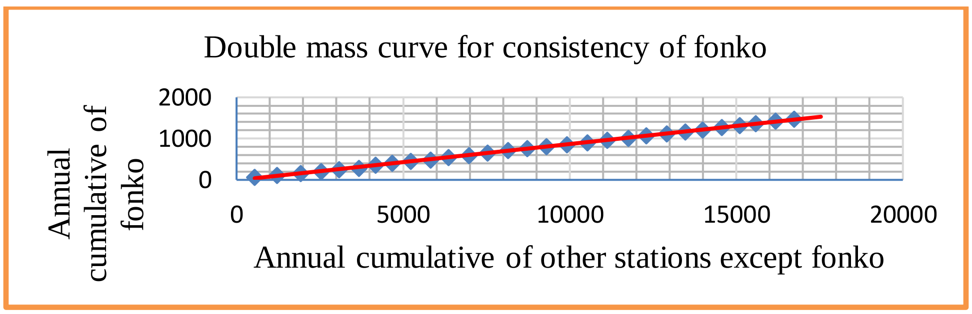

Figure 7: Double mass curve for consistency of Fonko

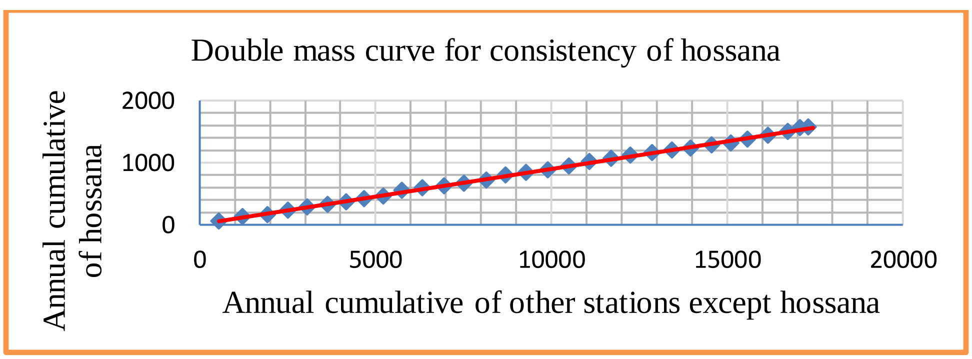

Figure 8: Double mass curve for consistency of Hossana

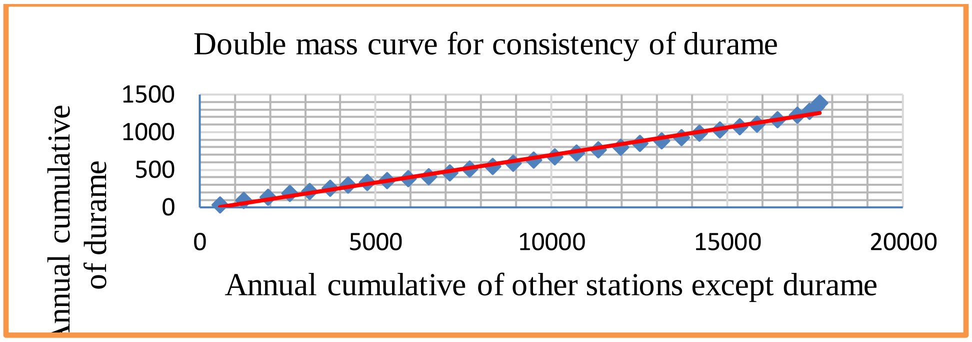

Figure 9: Double mass curve for consistency of Durame

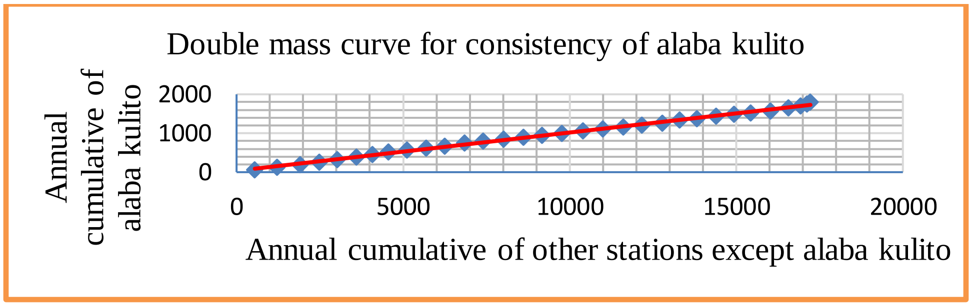

Figure 10: Double mass curve for consistency of Alaba

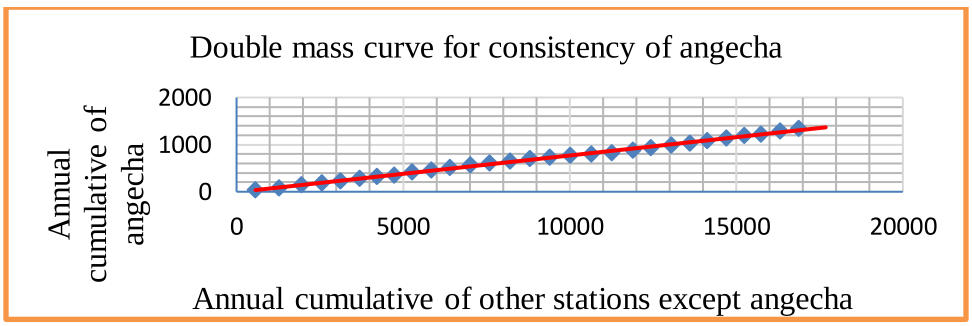

Figure 11: Double mass curve for consistency of Angecha

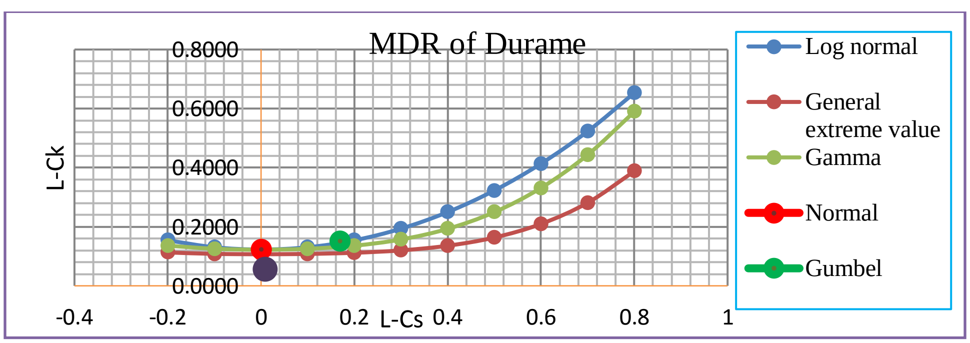

Figure 12 L-moment ratio diagram for Durame

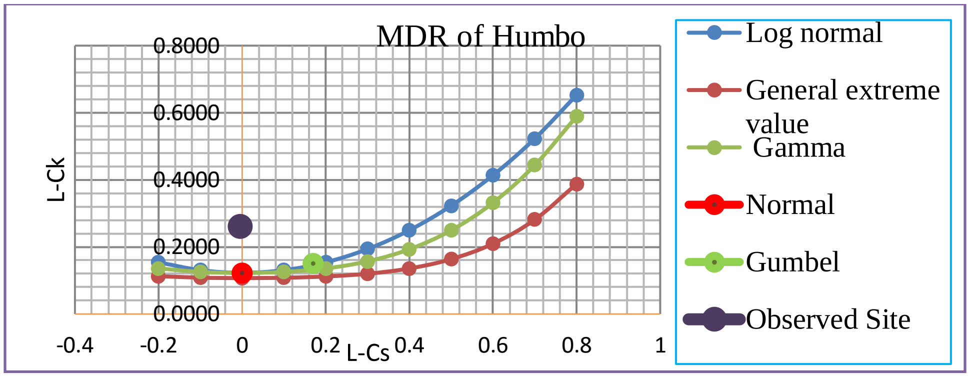

Figure 13 L-moment ratio diagram for Humbo

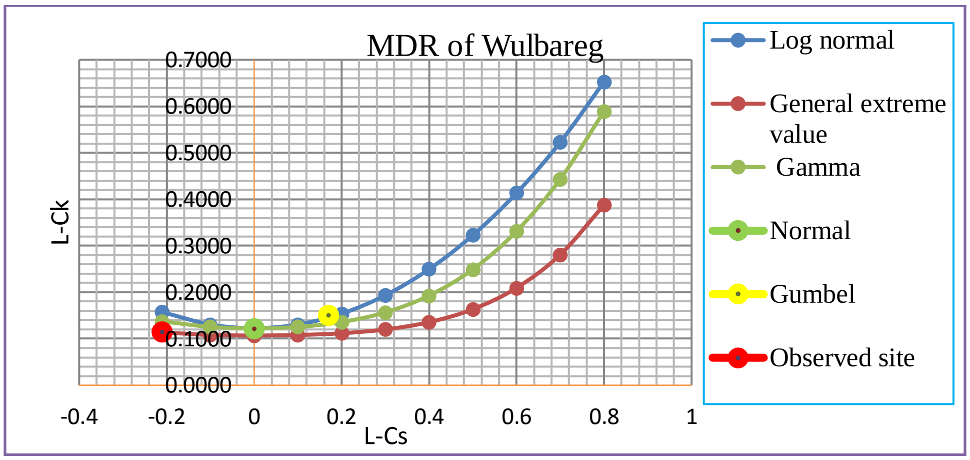

Figure 14 L-moment ratio diagram for Wulbareg

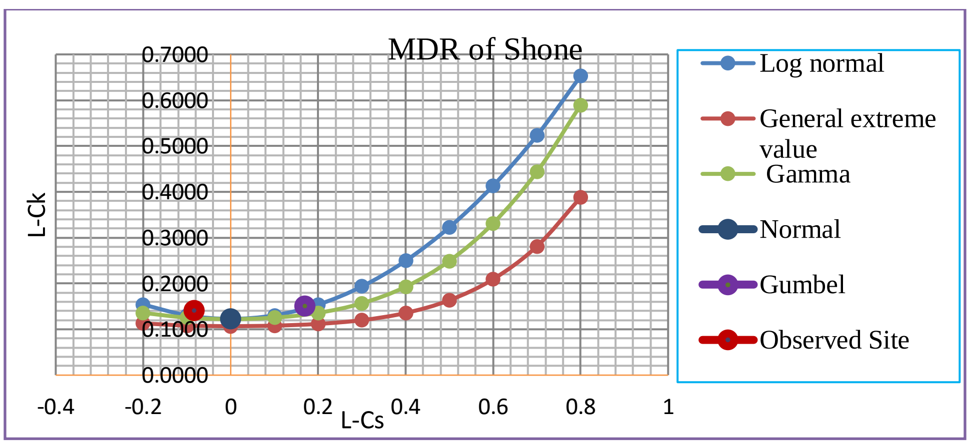

Figure 15 L-moment ratio diagram for Shone

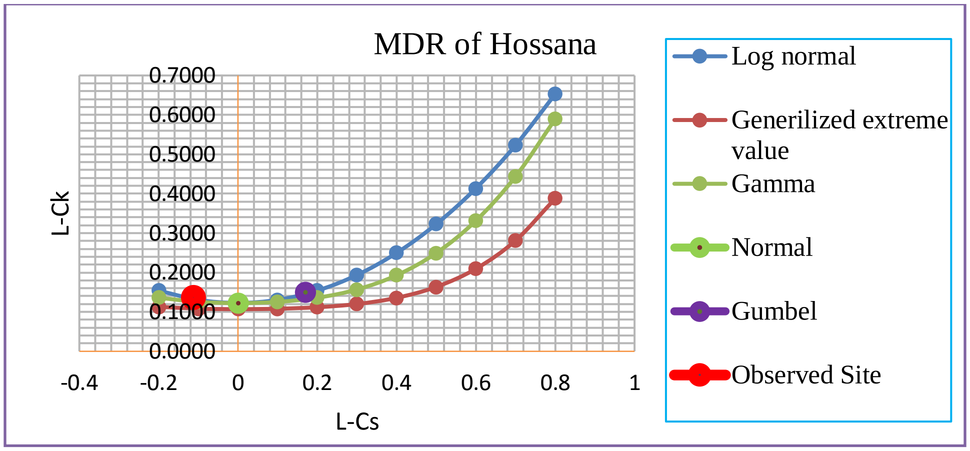

Figure 16 L-moment ratio diagram for Hossana

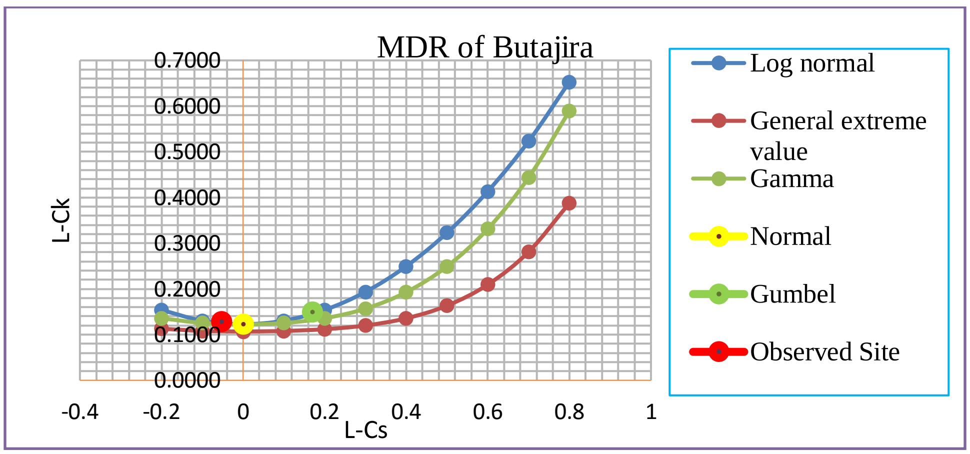

Figure 17 L-moment ratio diagram for Butajira

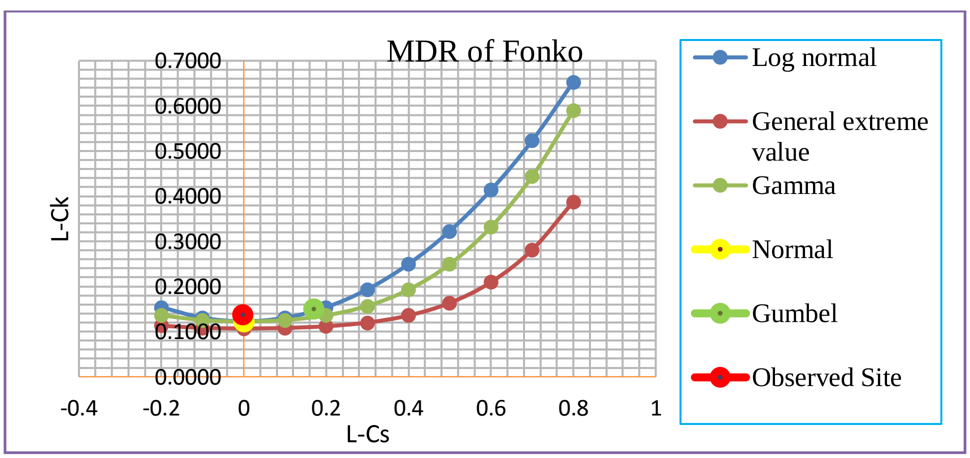

Figure 18 L-moment ratio diagram for Fonko