JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

ESTIMATION OF PROBABLE MAXIMUM PRECIPITATION AND ISOHYETE MAP IN DIDESSA SUB BASIN, ABBAY BASIN ETHIOPIA

A THESIS SUBMITTED TO THE CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING, JIMMA INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

By: NIGATU NURA DABA

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NIGATU NURA DABA

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Co-advisor: Mr. Chala Hailu (MSc)

DECLARATION

I, the undersigned, declare that this thesis entitled “Estimation of Probable Maximum Precipitation and Isohyetal Map in Didessa Sub Basin, Abbay Basin Ethiopia “is my original work, and has not been presented by any other person for an award of a degree in this or any other University.

Name: Nigatu Nura Daba

Signature:-________________ Date _____/______/_____

APPROVAL

As a member of the board of examiners of the MSc. Thesis open defense examination, we certify that we have read, evaluated the thesis prepared by: Mr. Nigatu Nura entitled Estimation of Probable Maximum Precipitation and Isohyetal Map in Didessa Sub Basin, Abbay Basin Ethiopia

We recommended that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Hydraulic Engineering.

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DEDICATION

I dedicate this work to my Mother

ABSTRACT

Probable Maximum Precipitation (PMP) is theoretically maximum depth of precipitation for a given duration: It is physically possible over a given size storm area at a specific geographical location at a particular time of year. The PMP is used for the design of a hydraulic structure appropriately in the study area. The procedure for estimation of PMP used in the country is based on Hershfield's graphical estimation, but different studies show that the value founded from the chart was not reliable. Therefore, the main objective of this study is to Estimate the Probable Maximum Precipitation and develop Isohyetal Map in Didessa Sub Basin using Hershfield's statical method. Microsoft excel, RAINBOW, Easy fit and Arc GIS software where the materials used for this study Double mass curve is employed for consistency test. The study shows that for 1day, 2and 3day the maximum Frequency factor Km and PMP value obtained by Hershfield's statical method are 5.10 and 255.57mm respectively. Whereas, the computed maximum km and PMP from the chart is 16 and 513.96. The values exhibited deviation about 213.73 for km and 101.10% for PMP. This result confirmed that the value of PMP from chart is over estimated which can leads to uneconomical designs in the Didessa Sub Basin. The ratio of one day rainfall depth for a return period of 2,5,10,25,50,100,200,500,1000,2000,5000 and 10,000 year floods had been estimated and found to vary from minimum 52.69mm to maximum 210.74m. The estimated PMP values to 10,000 years return period founded by Hershfield's statical methods was 1.12, 1.17 and 1.26 times that of 10,000 years return period rainfall depth for 1day 2day and 3day duration respectively in the DSB. Isohyete maps were generated by IDW interpolation method and PMP grid values were varying between 124mm to 167mm. This study clearly indicates that the Hershfield chart gives highest values of PMP due to highest value of Km from the chart. So, further researches should be conducted on the rest of Ethiopian basins for fixing the country's reliable maximum Frequency fator (km).

Key Words: *Didessa Sub Basin, Hershfield Statistical Method, Isohyetal Map, Probable Maximum Precipitation*

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ABBREVIATIONS AND ACRONYMS

AD	Anderson-Darling
CDA	Canadian Dam Association
CDF	Commulative Density Function
CV	Coeffitient of Variation
DEM	Digital Elevation Model
DSB	Didessa Sub Basin
EV1	Extreme Value 1
Etc	Extra
e.g	Example
FOS	Factor of Safety
GIS	Geographical Information System
GOF	Goodness of fit
HMRS	Hydro Meteorology Report
HOR	Highest Observed Rainfall
IDW	Inverse Distance Weighting
ITCZ	Inter Tropical Convergence Zone
KM	Frequency Factor
KS	Kolmogorov-Smirnov
LPT III	Log Pearson Type III
MCMC	Markov Chain Monte Carlo
Masl	Meter Above Sea Level
MLM	Maximum Likelihood Method
MOM	Method Of Moment
MWIE	Ministry of Water Irrigation and Energy
NIPALS	NonLinear Iterative Partial Least Square
NN	Nearest Neighbour

NMSA	National Meteorology Service Agency
NWS	National Weather Service
OK	Ordinary Kriging
PDF	Pobablity Density Function
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PWM	Probability Weighting Method
RAINBOW	Really Absolutely Intelligent Nice Bunch of Wonderful
RCD	Rescaled Cumulative Deviation
SRTM	Shuttle Radar Topogtaphy Mission
UK	United Kingdom
USA	United State of America
USWB	United State Weather Bureau
WMO	World Meteorology Organization
X^2	Chi Square
XT	Extreme Value

1 INTRODUCTION

1.1 Background

According to World Meteorological Organization (WMO,2009). ″Probable Maximum Precipitation (PMP) is theoretically defined as the greatest depth of precipitation for a given duration which is physically possible over a given size storm area at a particular geographical location and at a particular time of year with no allowance made for long term climatic trends’’. 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).

Numerous methods have been developed globally to estimate the PMP. The manual of WMO (2009) describes six methods for estimating the PMP: (1) the local method (local storm maximization model), (2) the transposition method (storm transposition model), (3) the combination method (temporal and spatial maximization of storm), (4) the inferential method (theoretical model), (5) the generalized method, and (6) the statistical method wich is proposed by Hershfield of USA. Hershfield’s Statical method is considerd as convinent, popular and efficient statical tool for estimation of Probable Maximum Precipitation, for those location where sufficiently long precipitation record are available but other meteorological data e.g dew point temperature,wind speed and relative humidity are lacking wich are essential requirnment for other physical methos, such as storm maximization and storm transposition techniques (WMO 2009).

During the past, a number of studies on PMP estimation have been carried out by different researchers at different regions in the world Ghahraman and Sepaskhah (1994). and different countries have reliable frequency factor (Km) the studies show that the frequency factor (Km) found from Hershfields graphical procedure was overestimate the actual value. [India (Srinivas & Chavan, 2015), Iran (Gharaman, 2008) , Spain (Casas, Rudriguez, Prohom, & Gazquez, 2010), Ethiopia (Abenezer & Dereje, 2015), are some examples.

In recent days, Ethiopia is heading with the transformation plan of progressive philosophy. To make this dream true, the country requires tapping and conserving natural resources like land, water and generation of hydro electricity and development of much more water resources to meet the needs in very near future. In the design of major hydraulic structures, hydrologists and hydraulic engineers would like to keep the failure probability as low as possible i.e. virtually zero. In our country as well as in Didessa sub basin there were no developed hydrological procedure in the past that could provide easy, reliable and quick information on the PMP values.The practice of design of dam spillways in Ethiopia is widely employed using the value of Probable Maximum Flood (PMF) obtained from Probable Maximum Precipitation (PMP). The procedure used in the country is based on Hershfield's graphical estimation (WMO, 2009), which is not developed or adapted to our country.

Therefore, the purpose of this study is Estimation of Frequency factor (Km) and PMP value that represent the Didessa sub basin using historical daily rainfall by Hershfield's Statical method and to generate the corresponding Isohyetal map of sub basin.

1.2 Statement of the Problem

The practice of design of dam spillways in Ethiopia is widely employed using the value of Probable Maximum Flood (PMF) obtained from Probable Maximum Precipitation (PMP). The procedure adapted in the country is based on Hershfield's graphical estimation method which is not developed or adapted to the country (WMO 2009).

During the past, a number of studies on PMP estimation have been carried out by different researchers at different regions in the world Ghahraman and Sepaskhah (1994). and different countries have reliable frequency factor (Km) and the studies show that the frequency factor (Km) found from Hershfields graphical procedure was overestimate the actual value.

In our country also Hershfield's graphical procedure is not well tested, The researches on Blue Nile River basin (Alemayehu & Semu , 2010) and (Abenezer & Dereje, 2015) confirm that for our country Hershfield's graphical procedure is not well tested due to this reason it is big challenge to design and construct large dams in Ethiopian, and they recommended that like other country, further researches should be conducted on the rest basins of Ethiopia for fixing the country's reliable Frequency factor(Km). Therefore, the main purpose of this study is estimation of the Probable Maximum Precipitation of the stations in the Didessa sub basin for 1day, 2day and 3day duration using Hershfield's statistical methods using historical daily rainfall data and Hershfield's Graphical methods, and to develop corresponding isohyets map in sub basin.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this study is Estimation of Probable Maximum Precipitation (PMP) in Didessa sub basin, Abbay River Basin, Ethiopia.

1.3.2 Specific Objectives

- To Estimate the Frequency factor Km and PMP value using Hershfield's statistical formula and compare the result with the Hershfield's Graphical method in Didessa sub basin.
- To distinguish the best fit probability distribution function for stations in Didessa sub basin
- To Estimate Probable Maximum Precipitation PMP values with in different return period in Didessa sub basin.
- To develop Point Probable Maximum Precipitation (PMP) Isohyetal map in Didessa sub basin.

1.4 Research Questions

- How frequency factor is estimated by Hershfield Graphical and statistical method?
- How PMP Value is estimated with in different return periods in Didessa sub basin by Hershfield's statical method?
- Which Probability distribution function is best fitted for Didessa sub basin stations?
- What is spatial distribution of PMP over the base map of the basin?

1.5 Significances of the Study

Information on flood magnitudes and their frequencies is 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).

The purpose of hydrologic design is to estimate maximum average or minimum flood which the structure is expected to handle. Hence, for designing the hydraulic structure knowledge is necessary about the maximum intensity of the critical flood or the design flood an estimate of the Probable Maximum Precipitation (PMP) depth is used to determine the Probable Maximum Flood (PMF) for that location.

This study helps the Hydrologists and Engineers about how to design economical hydraulic structures in sub basin using reliable value of Probable Maximum Precipitation and helpful to the stakeholders and other researcher to arrive at Probable Maximum Flood (PMF) for planning, design, safety measurement and high risk assessment of hydraulic structures in the sub basin. It is also helpful for researchers who have an interest for doing further research on Estimation of Probable Maximum Precipitation (PMP) using Hershfield’s statical methods.

1.6 Scope of The Study

The scope of the research is Estimation of Probable Maximum Precipitation of Didessa sub basin and development of Isohyetal maps. The study was geographically being limited to Didessa sub basin, Abbay river basin. The estimation is based on Hershfield graphical method and Hershfield statistical method.

1.7 Organization of the thesis

This study presents Estimation of Probable Maximum Precipitation of Didessa sub basin and development of Isohyetal maps. The study is organized in five chapters. Chapter one includes an introduction with back ground of the study, Statements of the problem,Objectives,Significance of the study, Research questions and Scope of the study.Chapter two contains review of literatures pertinent to estimation of Probable Maximum Precipitation(PMP). General descriptions of the study area, 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, chapter five comes up with a conclusion and recommendations of the study.

2 LITERATURE REVIEW

2.1 Definition of Probable Maximum Precipitation and Probable Maximum Flood

According to the World Meteorological Organization (WMO), the Probable Maximum Precipitation (PMP) is the theoretical maximum precipitation for a given duration under modern meteorological conditions (WMO 2009). The Probable Maximum Precipitation helps design a civil structure properly in the study area the PMP approach has been widely used to estimate extreme precipitation, providing disaster risk management procedures including emergency preparedness. Particularly, over the last few decades, estimated PMP values have allowed for the design, operation, and risk assessment of large hydraulic infrastructures, such as dams, levees, and urban drainage (Rakhecha, 2009).

However, these issues remain difficult to solve because many global disasters are caused by heavy precipitation and floods. Also, a future projection based on global circulation models shows that water vapor concentrations will increase worldwide during the 21st century, which, in turn, will result in an increase in PMP (Kunkel *et.,al* 2013).

Traditionally, PMP estimates have relied chiefly on statistical and hydro meteorological approaches. Early estimates based on the highest recorded rainfall at a specific location or 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). A statistical method is preferred in those areas where meteorology parameters such as daily relative humidity, dew point temperature and wind speed data are unavailable (Rakhecha, 1994).

PMF is the theoretical maximum flood that poses extremely serious threats to the flood control of a given project in a design watershed. Such a flood could plausibly occur in a locality at a particular time of year under current meteorological conditions (WMO, 2009). Or the Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. Estimates of extreme floods have long been used to design the flood-handling facilities of major dams whose failure might cause loss of life or extensive property damage.

2.2 Probable Maximum Precipitation (PMP) Estimation Methods

According to manual of WMO (2009), there are 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 and generalized method. Methods of PMP estimation currently exist; such as Empirical relationships between variables in a particular valley, Statistical methods, Storm model approach, Maximization and transposition of actual storms and use of generalized data.

2.2.1 Empirical Relationships between Variables in a Particular Valley

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

2.2.2 Statistical Method

The statistical method was proposed by Hershfield of the United States. PMP is derived from data from numerous gauge stations in a meteorologically homogeneous zone, using the hydrological frequency analysis method together with the regional generalized method. Statistical method involves statistical analysis of station observations on extreme rainfall, which can be employed wherever sufficient precipitation data are available, and are particularly useful where other meteorological data such as dew point and wind records are not available, also statistical method is useful for estimation of PMP because once a statistical model is constructed; its application is simple and fast. This technique mostly used for small areas of watershed up to 1000 km^2 and also used for much larger areas and one does not have to be a meteorologist to use it (WMO, 2009).

2.2.3 Storm model approach

In this model precipitation process is expressed in terms of physical parameters like surface dew point, heights of the cells, inflow, outflow, 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.

2.2.4 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.

2.2.5 Use of Generalized Data

The generalized method is used to estimate PMP for a large, meteorologically homogeneous zone. The procedure involves grouping the observed rainfall of a storm into convergence and orographic rainfall. Convergence rain, which is the rainfall created through atmospheric convergence and rising induced by a passing weather system, is assumed to occur anywhere in meteorologically homogeneous zones. Orographic rain is the rainfall created through orographic rising (WMO, 2009)

2.3 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 the rest for other parts of the world) Based on the data analysis, Hershfield found that the value of Km varied in the range 1.00–14.99 and that K ranged between 13.00 and 14.49 for only four stations. Consequently, he suggested utilizing the value of K = 15 for estimating the PMP. but in 1995 Hershfield 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).

2.4 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), Desa 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 is an important parameter that could be used in relation to the Factor of Safety (FOS) usually adopted in Engineering practices For example in Structural Engineering generally a FOS of 1.4 - 1.7 and for Geotechnical design FOS of 1.5- 2.0. The estimated PMP values could have a factor of safety that is equal to the ratio that is further used for suggesting whether the estimated PMP value, which is very uncertain, is reasonable or not for the design purpose.

2.5 Estimation of Return Period Values for PMP

Return period or recurrence interval is the average interval of time within which an extreme event of a given magnitude will be equaled or exceeded at least once. Return period is calculated by Weibull's plotting position formula (Chow, 1964) by arranging one-day maximum daily rainfall in descending order giving their respective rank as:

$$T = \frac{n+1}{R} \quad (1)$$

Where, N is the total number of years of record and R is the rank of observed rainfall values arranged in descending order and T is the Return period.

2.6 Fitting Data to the Probability Distribution Functions

Frequency analysis techniques (Tao *et al*, 2002) were employed to analyze the annual daily maximum rainfall data. Fitting the theoretical probability distribution to the observed data was done by applying the corresponding plotting position given in Table 2.1.

Table 2.1 Different plotting positions formula

Plotting Positions	Formula
Hazen (1930)	$\frac{m-0.5}{n}$
Weibull(1939)	$m/_{n} + 1$
Gringorton(1963)	$m - 0.375/_{n} + 0.25$
Cunnane (1978)	$m - 0.4/_{n} + 0.2$
California (1923)	$m/_{n}$
Blom (1958)	$m - 0.44/_{n} + 0.12$
Chegodajev(1955)	$m - 0.3/_{n} + 0.4$

2.6.1 Normal Distribution:

Plotting Probability was estimated using the Weibull method (Table 2.1), the value of Extreme value *(X_T)*,and standard normal deviate *(Z)* were estimated using equation (2 and 3) respectively. The standard normal deviate *(Z)* values for exceedance probability other than the equation 2.2

were interpolated.

$$XT = \bar{x} + \sigma kT \quad (2)$$

$$kt = \frac{XT + \bar{x}}{Sn} \quad (3)$$

Where XT is the variant $\bar{X}$ is the mean and *Sn* is the standard deviation of the sample data, kt is Frequency factor

2.6.2 Log Normal Distribution:

After rearranging the annual daily maximum values in the descending order of magnitude and assigning a rank' with '1'for the highest value (Table 2.1), values of the 'Z' and 'W' were estimated using equation (4 and 5) respectively and the other parameters will be estimated using equations given in Table 2.2.

$$Z = KT = W - \left[\frac{(2.156 + 0.8028w + 0.0103w^2)}{1 + 1.4328w + 0.1893w^2 + 0.0013w^3}\right] \quad (4)$$

Where W *is* an intermediate variable which is calculated using the formula:

$$W = \left[ln \frac{1}{P^2}\right]^{1/2} \quad (0<p\leq 0.5) \quad (5)$$

Where *P*is the probability of exceedance, and *P>0.5*, *1-P is* substituted for *P*and the value of *Z* which is computed is given a negative sign

Table 2.2. Expressions Used to Estimated Parameters of Log-Normal Probability Distribution

Parameters	Formula
YT	$\bar{y}n + KTSy$
XT	10^{yT}

2.6.3 Log Pearson Type-III Distribution

The procedure for fitting the LPT-III distribution is similar to that for the normal and log-normal. For making LPT-III analyses the following steps were used given by Raghunath (2006) as;

- A logarithmic transformation was made for all events of the series (Yi = log Xi)
- The probability plotting positions were calculated using the Hazen formula (Table 2.1)

mean ($\bar{y}$), standard deviation (Sn), and standardized skew (Cs) of the logarithms were computed using equations (6, 7 and 8) respectively,

$$\bar{y} = \frac{\sum y}{n} \quad (6)$$

$$sy = \sqrt{\frac{\sum(y-\bar{y})2}{n-1}} \quad (7)$$

The coefficient of skewness (Cs) is estimated given by Apipattanavis et al. (2005) as:

$$cs = \frac{n\sum(y-y)3}{[(n-1)(n-2)sy^3]} \quad (8)$$

- ✓ K_T and K were calculated using equation (9) and (10) respectively

$$KT = Z + (z^2 - 1)k + \frac{1}{3(z^3-6z)k^2} + zk^4 + \frac{1}{3k^5} \quad (9)$$

Where,

$$K = \frac{Cs}{6} \quad (10)$$

2.6.4 Gamble Extreme Value Type-I

Distribution: this distribution was achieved by plotting the ranked annual maximum rainfall values and exceedance probability was estimated. The following steps were followed for the derivation of extreme value, given by Raghunath (2006); the reduced variate (YT) was calculated using equation (11)

$$YT = -ln\left[ln\left(\frac{T}{T-1}\right)\right] \quad (11)$$

The value of the return period was obtained by taking the inverse of the probability plotting position which was obtained by using the Weibull method

Frequency factor KT was derived (where Yn and Sn were obtained from the reduced variate) using equation (12),

$$\mathrm{KT} = \frac{\mathrm{YT}-\bar{\mathrm{y}}\mathrm{n}}{\mathrm{sn}} \quad (12)$$

Finally, XT = $XT = \bar{X} + KT \times S$ which is the extreme value

2.6.5 Generalized Extreme Value (GEV) Distribution

The probability density function of the GEV distribution is given as

$$\mathrm{f(x)} = \frac{1}{\sigma}[1-\mathrm{k}(\frac{X-\mu}{\sigma})]^{1/k-1} e^{-[1-k(\frac{X-\mu}{\sigma})]^{1/k}} \quad (13)$$

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

the distribution function of x given by equation 13 can be written in the inverse form of;

$$x = \mu + \frac{\sigma}{k}\{1 - (-logF)^k\} \qquad (14)$$

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

$$X_T = \mu + \frac{\sigma}{k}[1 - \{-\log\left(1 - \frac{1}{T}\right)\}^k] \qquad (15)$$

Where T is return period. in this study location parameter k is expressed in terms of σ, μ.(shape and scale parameter as standard deviation and mean of the sample).

2.7 Estimation of Return Period Values for PMP

Return period (T) or recurrence interval is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once.

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 stations.

2.7.1 The Goodness of Fit (GOF) Tests

In easy fit statistical software three goodness of fit tests (GOF), including Kolmogorov-Smirnov test, Anderson Darling test, Chi-square test, were employed to check whether the hypothesized distribution function fitted the sample data. The most common methods are the Kolmogorov-Smirnov and Chi-square test (Chen, 2000).

2.7.1.1 Chi-Square test

Chi-Square (C-S) test is a simple and convenient method for hypothesis test, it is related to the overall fit, the process can be written as follows (Zhang, Luo, 2000):

1, Choosing k-1 numbers: -∞ < t1 < t2 < … < tk-1 < +∞, $k \approx 1.87(n-1)^{0.4}$, and the number axis is partitioned into k intervals, (-∞, t1], (t1, t2], …, (tk-2, tk-1], (tk-1, +∞].

2, Collecting the number of samples dropped into the i-th interval ni, i=1, 2, …, k, and then calculating the probability of the population which obeys alternative PDF fallen into the i-th interval:

$$\begin{cases} p1 = (x \le t1) = Fo(t1) \\ p2 = p(t1 < X \le t2) = Fo(t2) - Fo(t1) \\ \dots\dots. \\ pk-1 = p(tk-2 < X \le tk-1) = Fo(tk-1) - Fo(tk-2) \\ pk = p(tk-1 < X) = 1 - Fo(tk-1) \end{cases} \quad (16)$$

3 Constructing statistics:

$$X^2 = \sum_{i-1}^{K} \frac{ni - npi^2}{npi} \quad (17)$$

Which obeys Chi-square distribution with the degree of freedom m, m=k-1, or m=k-1-r when there are r independent parameters of Fo(x) that need to be estimated by samples. And specifying a significance level α, if p (χ2 ≥ χ2 1-α) ≥ α, then accept the hypothesis, otherwise reject it.

2.7.1.2 Kolmogorov-Smirnov test

Kolmogorov-Smirnov (K-S) test measures the greatest discrepancy between the observed and hypothesized distribution. The process can be summarized as follows (Melo et al., 2009; Wang, Wang, 2010):

(1) Sorting the samples X (x1, x2, …, xn) by ascending order, and storing it to a new vector X′(x′1, x′2, …, x′n), calculating the empirical distribution function:

$$fn(x') = \begin{cases} o, \mathrm{x}' < \mathrm{x1}' \\ \frac{k}{n}, x\mathrm{k}' \le \mathrm{x}' < \mathrm{x}'\mathrm{k}+1 \\ 1, \mathrm{x}' \ge \mathrm{x}'\mathrm{n} \end{cases} \quad (18)$$

Calculating the K-S statistics $D^{(n)}$

$$D^n = max\left|Fn(x') - Fo(x')\right|$$
$$= \max\left\|\frac{i}{n} - Fo(x').\frac{i-j}{n} - Fo(x')\right\| \quad (19)$$

Specifying a significance level α, if p ($D^{(n)} \ge D^{(n)}$(1-α)) ≥ α, then accept the hypothesis, otherwise reject it.

2.7.1.3 Anderson-Darling test

Anderson-Darling (A-D) test emphasizes discrepancies in both tails of the distribution, and that is often of prime importance in hydrologic frequency analysis. The process can be written as follows (Coronel-Brizio, Hernandez-Montoya, 2010; Zhang et al., 2009):

(1) Sorting the samples X (x1, x2, …, xn) by ascending order, and storing it to a new vector X′ (x′1, x′2, …, x′n), calculating the empirical distribution function by equation(15)

(2) Calculating the A-D statistics An^2:

$$An^2 = -n - \frac{1}{n}\sum_{i=1}^{n}\left[(2i-1)logF(x^{'}) + 2a + 1 - 2ilog\left(1 - F\left(x^{i}\right)\right)\right] i == 1,2..n \qquad (20)$$

And specifying a significance level α, if A^2 n < A^2 n(1-α), then accept the hypothesis, otherwise reject it.

However, the critical values of the distributions in this study are unavailable directly at the whole range of series length, and so, they are obtained by simulations, for which the following simulation steps are taken:

(1) Generating a sample of length n from the selected distribution, and estimating the parameters based on the sample.

(2) Calculating the A-D statistics A^2 n.

(3) Based on Monte Carlo simulation, step (1) – step (2) are repeated 10000 times, and the A-D statistics are sorted by ascending order, the critical values at the significance level α = 0.01, 0.05, 0.1 are the values at 9900th, 9500th, 9000th of the statistics series.

2.8 Application of PMP in Spillway Design

The hydrologic problem typically addressed in dam safety analysis is the determination of the capacity of the spillway needed to prevent catastrophic failure of the dam due to overtopping. The PMF is generally accepted as the design inflow for evaluating the spillway when there is a potential loss of life due to dam failure in high hazard situations. As per the first edition of Dam Safety Guidelines by the Canadian Dam Association (CDA, 1999) 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 CDA, 1999 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 the PMF and the 1000-years flood.
- ❖ For low dams: the design flood may be selected between the 1000-year and the 100-year floods.
- ❖ For very low dams the design flood selected is less than100-year floods.

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

2.9 Development of Isohyetal map for PMP

Development of isohyets map is one of the commonly used methods of spatial analysis. 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).

In IDW method, it is assumed substantially that the rate of correlations and similarities between neighbors is proportional to the distance between them that can be defined it as a distance reverse function of every point from neighboring points. One of the advantages of this method is to be suitable for showing Barriers discontinuous lines such as fractures, quasiling, faults levees and rivers which make fracture and discontinuity on the surface. (Yziary,H safari 2007)

2.10 Previous Study in the World

Different studies on the Estimation of Probable Maximum Precipitation (PMP) have been made at the different regions in the world. Fernado and Wickramasuriya (2011), estimate the Probable Maximum Precipitation in Sri Lanka using the Storm maximization method. In this study seven meteorological stations covering several agro-ecological zones of Sri Lanka were selected and hydro-meteorological data such as daily rainfall, dew point temperature and wind runs with directions were used in the computation. According to Fernado (2011), the 24-h point PMP values for seven meteorological stations in Sri Lanka were derived using the hydro-meteorological method come closest to the Statistical method.

M Carmen Casa and his friends try to estimate the PMP in Barcelona (Spain) using storm maximization method and Hershfield's statistical method. According to their study, the PMP values obtained using the two techniques are very similar (Casas, Rudriguez, Prohom, & Gazquez, 2010). The PMP in Barcelona is very reliable because they used both the hydrometeorological and statistical analysis. The 66-year true maximum rainfall annual series was fitted by the Gumbel distribution, using the L-moments method.

The research outputs of countries like China and Romania also showed that their frequency factor (Km) value varies between 6 and 8.5 for their respective countries and rejected the Hershfields chart as it over estimates the PMP. Desa et al. (2001) they employed the Hershfield method to find out the appropriate frequency factor that can give reliable PMP values for stations for practical application. In view of the above mentioned problems and recent research outputs, Hershfield’s chart might not give reliable frequency factor estimates world over. It was, therefore, felt that an appropriate Km value based on historical data of a particular study area might give better estimates of PMP than Hershfield’s chart.

Ssarkar,Rmaity (2020) selected the hershfield’s satatical PMP estimation method as a convinent and effective methods for Estimation of probable Maximum Precipitation in contect of climate change in India from several available PMP estmation methods.

2.11 Previous Studies in Ethiopia

Different Studies show that Ethiopia uses the maximum value of the frequency factor from Hershfield’s chart which is (Km=15), But, research conducted in different basin and region of Ethiopia indicate that the frequency factor obtained by Hershfield’s statical methods and chart is far from each other. In conference held in Addis Ababa from January 12-16 (2010), on water resource in collaboration with Ministry of Water Resource where Dame and Ayalew (2010), presented a case study on the title of ‘Development of regional Probable Maximum Precipitation for Probable Maximum Flood development and application in design flood hydrograph of Blue Nile basin Ethiopia’ and the average ratio of PMP to HOR for one-day rainfall estimated as 1.9.

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

For Tigray Region Gerezihier and Quraishi (2013), had attempted estimation of Probable Maximum Precipitation and to develop PMP Isohyetal map. The maximum frequency factors (Km) of individual rain gauge stations were found to vary from Minimum 1.91 to Maximum 5.91 For 1 day duration at an average value of 3.1 and CV 28.2%. As PMP deals with unusual rainfall values, the corresponding Km used was chosen from the extremely high values i.e. 5.91. 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.

For Bale zone of Oromia region research conducted on Development of one day probable maximum precipitation and Isohyetal map using daily extreme value of 18 stations by statistical method. The frequency factor values varied from 2.24 to 5.09 and PMP value varied from 51.43mm to 234.81mm with an average 118.92mm (Fikre *et al*.,2016).

Abenezer Endale and Dereje Hailu (2015) Estimate the probable maximum precipitation (PMP) using In situ and Re analysis global precipitation product on Upper Blue Nile Basin and according to their paper PMP value using the new Km and the chart values for both in situ and reanalysis products exhibited difference 38% up to 96.4%, this result confirmed the Hershfield's chart overestimated PMP value which leads to uneconomical designs in the Upper Blue Nile Basin (Abenezer & Dereje, 2015).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location and River System of the Study Area

Didessa sub basin is found in western part of Ethiopia. It is mainly located in East and West Wollega zone, in the middle part Illubabor zone, in the most upper and middle part Jimma and some part in Kamashi zone of Benishangul Gumuz. Geographically the sub-basin is located between $07^{0}40'$ to $10^{0}0'$N latitude and $35^{0}32'$ to $37^{0}15'$E longitude respectively in western part of Ethiopia.

Didessa River, which is the largest tributary of the Blue Nile (Abbay) contributes roughly a quarter of the total flow of Blue Nile (Gebrehiwot et al. 2014). The total catchment area drained by the river is estimated to be 28,229 km^2. Didessa River is originating from the mountain ranges of Gomma in South Western Ethiopia. The main upper streams namely; of the river is Dembi river, which located in the South and flows towards East for about 75kms until joined by the Eastern tributaries such as Wama and Indris, then after, turning rather sharply to the North until it reaches the Blue Nile (Abbay) River. In the North East direction, the main tributary of Didessa River with the largest catchment area is the Anger River (Tena, 2015).

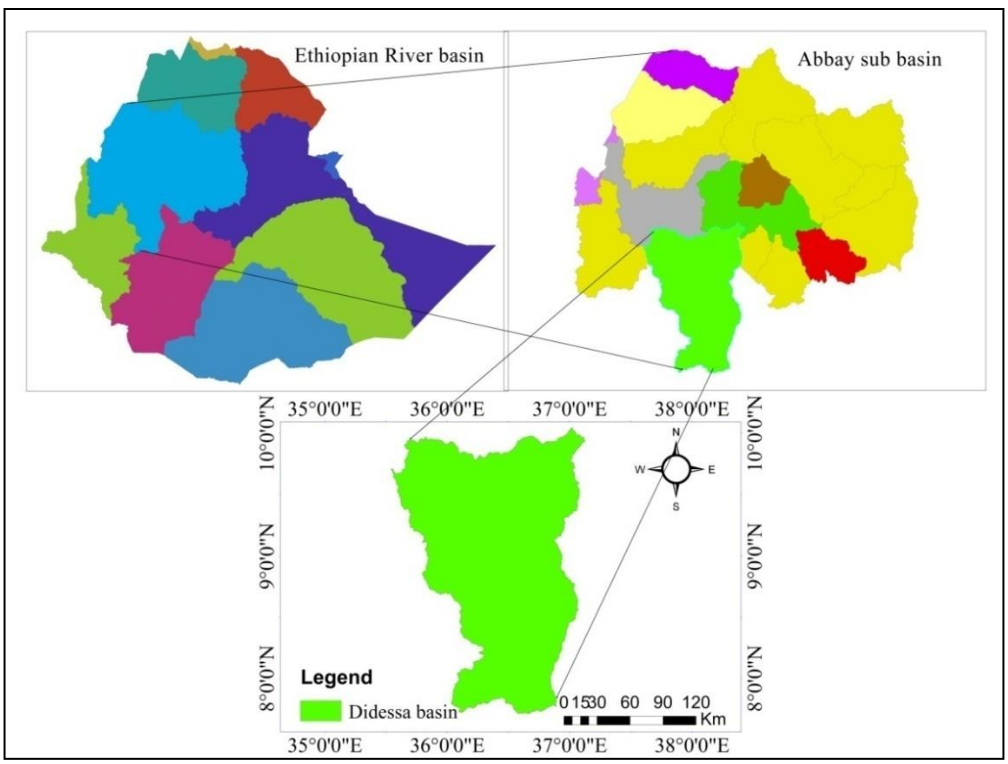

Figure 3.1: Location of the Study area

3.1.2 Topography

The Didessa Sub basin elevation ranges between 626 meter and 3041 metre above sea level (Masl). Physiographically, the Didessa sub basin can be categorized into two broad units which are the high land plateau and the associated low lands. The high land plateaus mainly embrace the Jimma Ilu Abba Bora high lands, the Guduru highlands of Horo Guduru Wellega while the associated low lands include the Didesa low lands (Timketa Adula, 2016). Didessa is made up of three main broad soil and landscape units based on the general physiographic character of the landforms. These are Low land plains and plateau with some undulating to steep landforms including depressions and valley floors, Moderate to high relief hills, severely dissected side slopes and plateau, and high to mountainous relief hills and plains of seasonal wetland and waterlogged. The slope or gradient of the Study area varies from 0 to -36%.

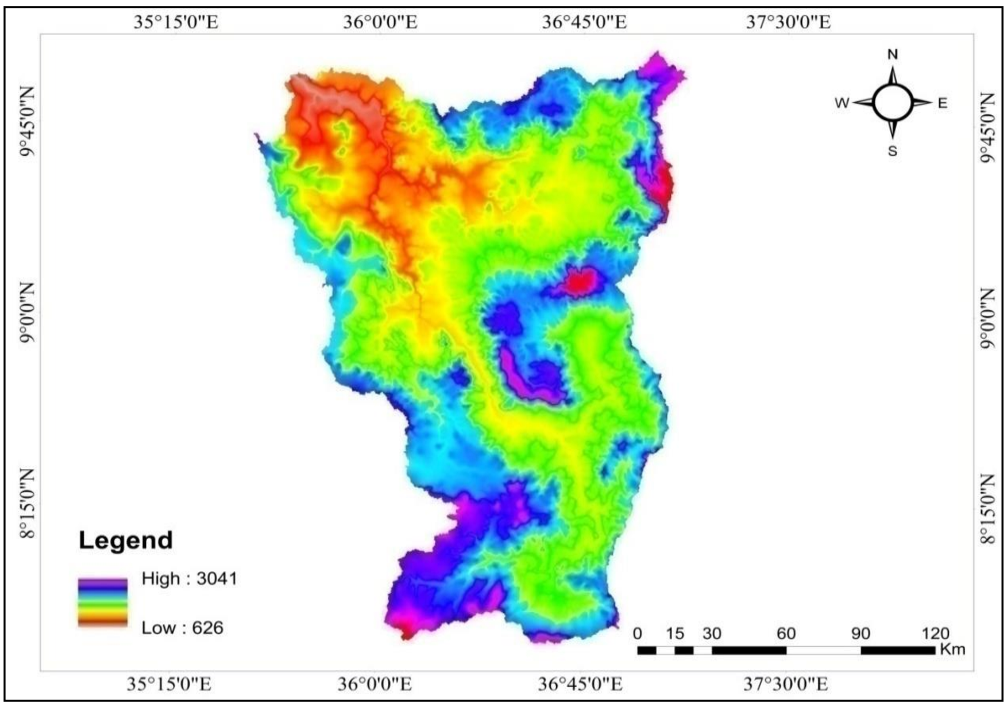

Figure 3.2: DEM map of study area

3.1.3 Climate

According to Hurni (1986) classification, the sub basin has five agro climatic zones. These are wet Dega, moist Dega, wet Weyna Dega, moist Weyna Dega and moist Kolla. Mean annual rainfall is 1745mm having one rainy season. The rainy season occurs from February to October with a peak in rainfall between June and August, and the dry season occurs from November to February. The majority of the area is characterized by a humid tropical climate with heavy rainfall and the maximum and minimum temperature varies between 21.3 – 30.9^{0}C and 10.9 - 15.1^{0}C, respectively (NMA 2015).

3.1.4 Geology

The upper part of Didessa sub basin is dominated by Jimma Volcanic and the central part with Wellega Basalt and the lower parts are dominated by undifferentiated lower complex, Wellega Basalt, and Adigrat Sand Stone (Timketa Adula, 2016).

3.2 Materials

Microsoft Excel Sheet is used to transposing daily rainfall data, Infilling missing data, to calculate the various statistical parameters of hydrological and raw data available, and to determine return periods of Probable Maximum Precipitation.

Easy fit Software Easy fit software is used for; Selection of suitable probability distribution for each selected stations, in selection of parameter estimation method and to estimate Goodness of Fit.

Arc-GIS Arc Map is used to clip the Didessa sub basin from Ethiopia River Basins, particularly from Abbay River Basin and it is used to prepare the Isohyetal map for Probable Maximum Precipitations.

3.3 Data Types and Data Sources

Two major categories of data collection methods are used for collecting necessary data and information which is primary and secondary data collection type. Most of the data for this study were collected by secondary data collection type. These data are: Rainfall data collected from the National Meteorological Service Agency (NMSA) of Ethiopia, and Digital Elevation Model (DEM), SRTM 30m x 30m resolution wich was obtained from the Ministry of Water Irrigation and Electricity (MoWIE).

3.3.1 Data Availability

For this study 34 years daily rainfall data were taken from the National Meteorological Service Agency. The selected meteorological stations were Arjo, Bedele, Didessa, Gimbi, Nekemte and Shambu. The selections of the stations were based on the availability of the data and the representative of the study area. Stations with missed value greater than 10% is rejected for this study. The geographical location and data period of the Selected Stations Were Shown in the Table 3.1.

Table 3.1 Selected Meteorological Stations and Data period

Station name	Zone	Easting	Northing	Elevation	Period
Arjo	East wellega	224945.16	968126.35	2565	1986-2019
Bedele	Ilu abba bor	200851.17	935089.33	2030	1986-2019
Didessa	East wellega	181462.22	1038544.33	1200	1986-2019
Gimbi	West wellega	146425.32	1014864.59	1970	1986-2019
Nekemte	East wellega	219695.3	1005046.79	2080	1986-2019
Shambu	East wellega	291462.06	1058080.74	2430	1986-2019

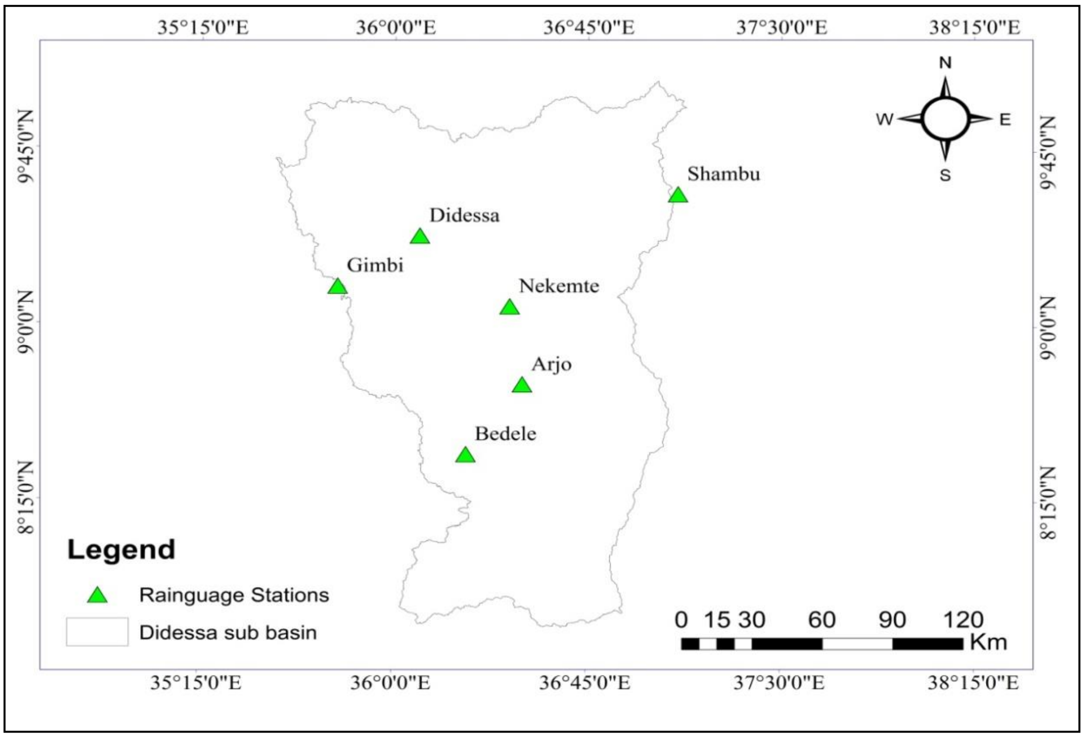

Figure 3.3: Didessa Sub basin rain gauge distribution

3.4 Data Analysis

Hydrological data records may have missing or error due to different reasons, including extreme natural phenomena and human induced phenomena such as mishandling of the observed data by field personnel, wars, etc. so must have checked before using for the further hydrological modeling. In this study, the rainfall data collected from the National Metrological Service Agency (NMSA) have some missing data. The missed daily rainfall data were filled by using XLSTATSoftware by a nearest neighbor Approch

3.4.1 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. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environment characteristics and structures, and location of stations (Kang & Yusof, 2012). In this study homogeneity of the data were checked using RAINBOW software.

Figure (3.4) shows the homogeneity test result for Arjo station by RAINBOW Soft ware and for all remain stations the homogeneity test result is shown in Appendex A

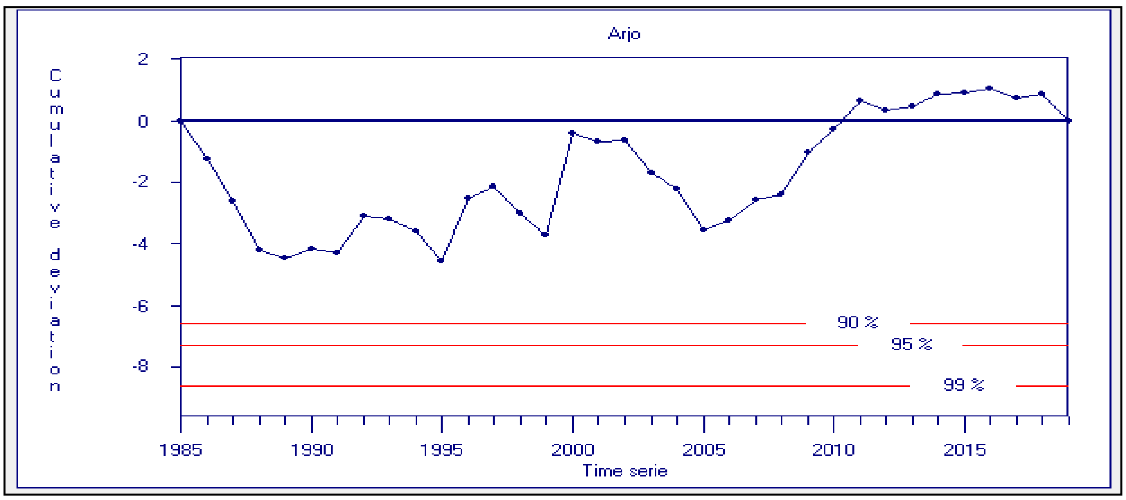

Figure 3.4: RAINBOW homogeneity test result of Arjo station

3.4.2 Consistency Test of Rainfall data

Data obtained from any organization who supply the data is not always consistent because of many problems. Inconsistency of climatic data could be happen during record, changes in instrumentation, changes in gauge location, changes in observation practices etc. Therefore, adjustment of the measured data is necessarily the problem that hydrologists need to address first before data use for any purposes to provide a consistent record. To overcome the problem of inconsistency; a technique most widely applied called double mass curve was used.

The result of a double mass curve for Arjo station is shown in Figure 3.4 putting the cumulative of whole stations on the x-axis and cumulative of each station on the y-axis. The result of other stations is presented in Appendix B.

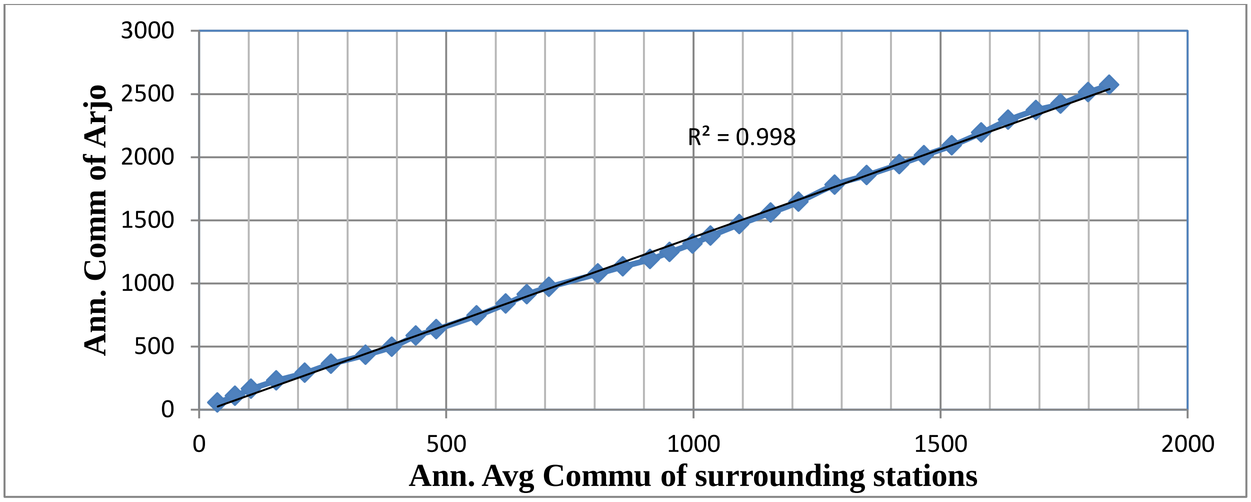

Figure 3.5: Double mass curve for consistency of Arjo station

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

Hershfield prepare a curve for estimation of frequency factor by analysing data from 2700 stations (90% of which were in United States and remaining 10% from different other parts of the world to determine Frequency factor (km) using Equation (3.5) and found that Km varie from slightly less than 3 to a highest value of 14.5. hence, the highest value rounded to 15 was adopted as Km for estimating 1day PMP using equation (3.2) but in 1995 Hershfield's him self found that Km is not independent of rainfall the value of 15 may be too high for areas of generally heavy rainfall and too low for arid areas hence cannot have a universal value. Therefore, he constructed a chart indicating that Km varies between 5 and 20 depending on the rainfall duration and the mean (WMO, 2009).

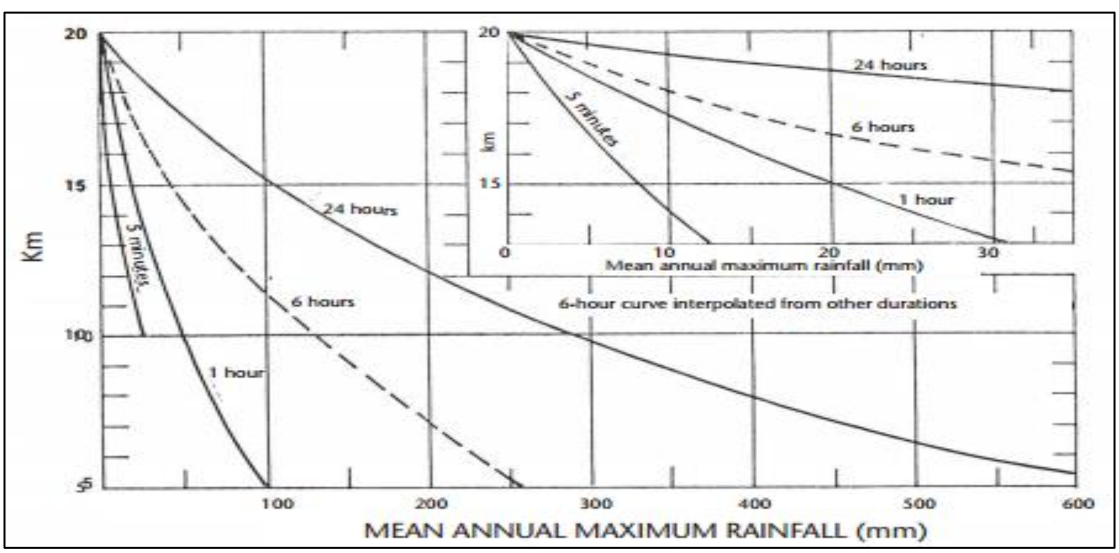

Figure 3.6: The Hershfield's chart for determination of frequency factor Km

3.6 Probable Maximum Precipitation Estimation Methods

The World Meteorological Organisation (WMO) has published a number of guidelines which describe methods for estimating the PMP. The latest WMO guideline published in 2009 provides two approaches for estimating the PMP: (i) hydro-meteorological methods (ii) statistical methods. Storm maximization and transpositation method requires more site specific data and thus provides more reliable estimate than other methods. Where site specific data are not available statistical method (Hershfield method) can be applied that requires data for annual maximum rainfall series in the region for required storm durations. Factors that influency calculations of PMP values are rainfall, dew point, temperature, wind speed, temperature and pressure.

3.7 Estimation of Probable Maximum Precipitation by Statistical Methods.

Statistical method involves statistical analysis of station observations on extreme rainfall. statistical method is useful for estimation of PMP because once a statistical model is constructed; its application is simple and fast. This technique mostly used for small areas of watershed up to 1000 km^2 and also used for much larger areas and one does not have to be a meteorologist to use it (WMO, 2009).

Probable Maximum Precipitation by Hershifield's statical method can be estimated from the following equation:

$$PMP = \bar{X}n + Km\,\sigma n \qquad (3.2)$$

Where:

PMP Probable Maximum Precipitation estimate for a station

$\bar{X}n$ Mean of the annual extreme series and

σn are standard deviation for a series of n annual maximum rainfall values of a given duration.

The sample mean $\bar{X}n$ and standard deviation (S_n) could be computed by:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} xi \qquad (3.3)$$

$$sn = \sqrt{\frac{\sum_{i=1}^{n}(x-\bar{x})^2}{n-1}} \qquad (3.4)$$

The value of Frequency Factor Km is calculated using the following equation.

$$\mathrm{Km} = \left(\frac{\mathrm{X1} - \bar{\mathrm{X}}\mathrm{n} - 1}{\sigma\mathrm{n} - 1}\right) \qquad (3.5)$$

Where:

X1 is highest observed annual maximum rainfall in the series

$\bar{X}n$ -1 is mean of the annual maximum, excluding the highest value and

σn-1 is standard deviation excluding the X1 value from the series.

3.7.1 Adjustment of Mean and Standard deviation for Maximum Observed Events

Hershfield (1961b) has been studied Extreme rainfall amounts of rare magnitude or occurrence with such as return periods of 500 or more years, are often found to have occurred at some time during a much shorter period of record, for example, 30 years. Such a rare event, called an outlier,

The magnitude of the effect is less for long records than for short, and it varies with the rarity of the event, or outlier. and the following Figure (3.7) and Figure (3.8) were made to show the adjustments of mean and standard deviation to compensate for outliers, From the Figures Xn-m and Sn-m refers the mean X̄n and standard deviation Sn of annual maximum series computed for excluded maximum observed values in the series respectivily.

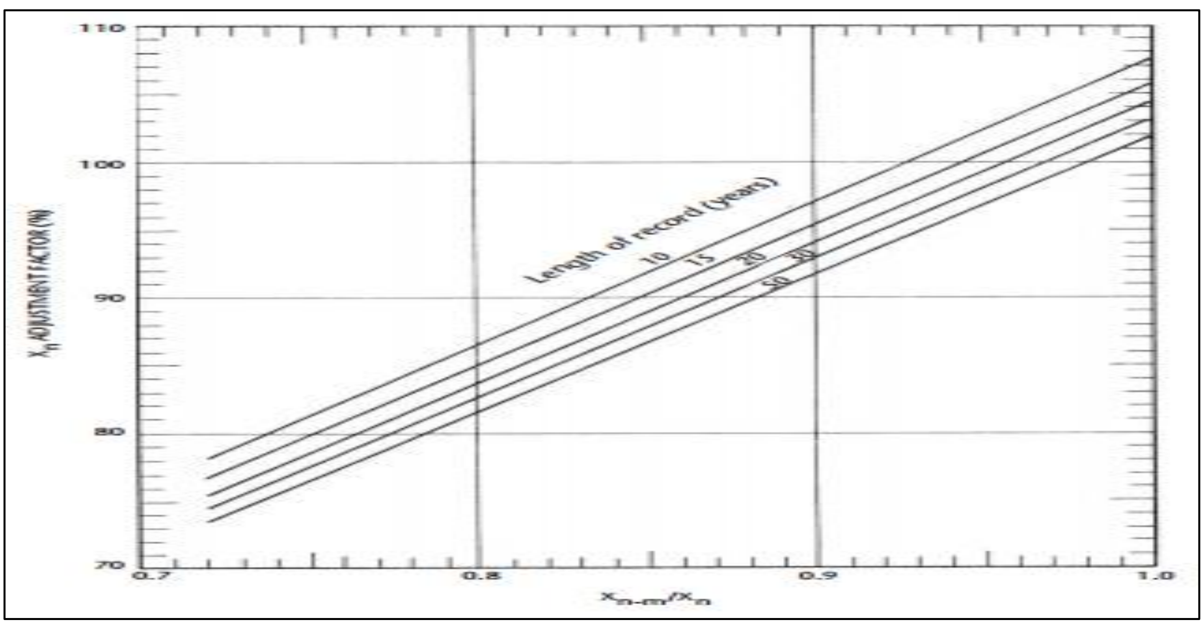

Figure 3.7: Adjustment of mean of annual series for maximum observed rainfall (Hershfield, 1961b)

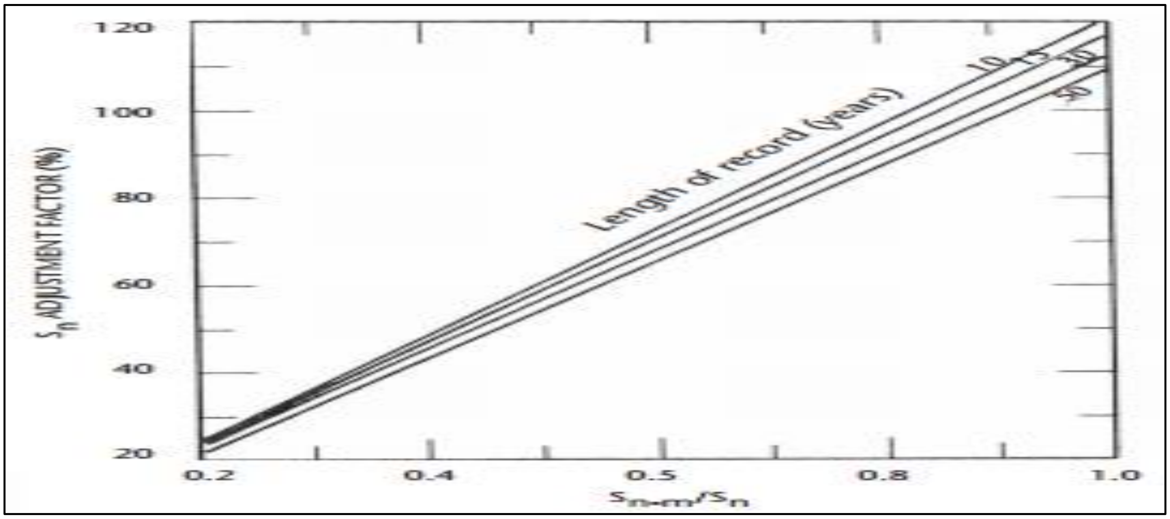

Figure 3.8: Adjustment of standard deviation of annual series for maximum observed rainfall (Hershfield, 1961b)

3.7.2 Adjustment of Mean and Standard Deviation for Sample Size

The mean $\bar{X}n$ and standard deviation Sn of the annual series tend to increase with length of record, because the frequency distribution of rainfall extremes is skewed to the right so that there is a greater chance of getting a large than a small extreme as length of record increases. Figure (3.9) shows the adjustments to be made to Xn and Sn for length of record. There were relatively few precipitation records longer than 50 years available for evaluating the effect of sample size, but the few longer records available indicated adjustment only slightly different from that for the 50-year records.

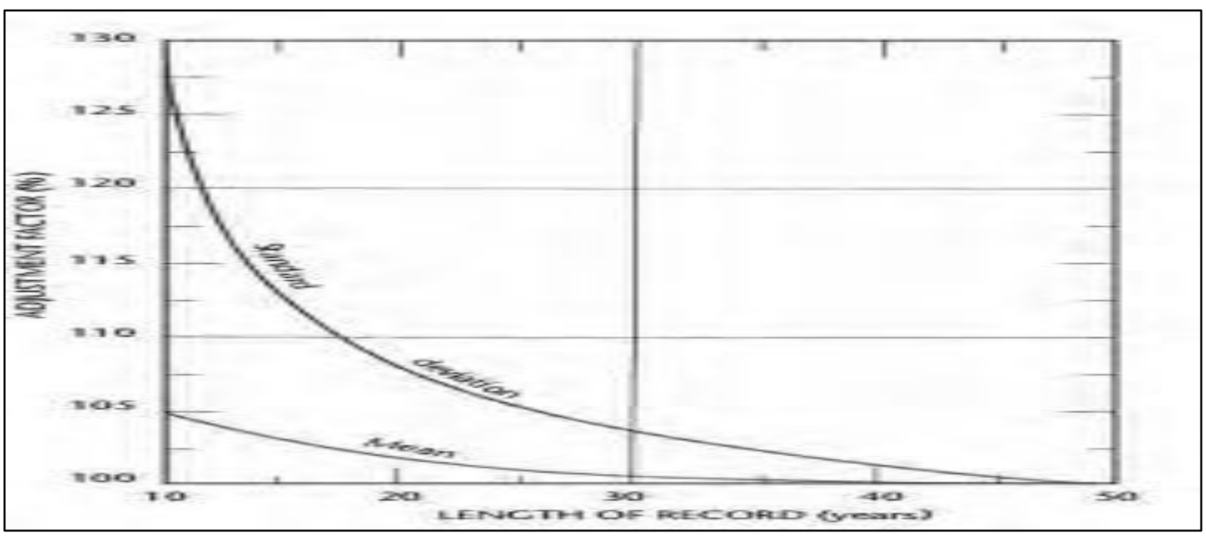

Figure 3.9:Adjustment of mean and standard deviation of annual series for length of record (Hershfield, 1961b)

3.7.3 Adjustment of Data for Fixed Observational Time Intervals

Rainfall data are usually published for fixed time intervals, e.g., 08:00-08:00 (daily), 06:00-12:00 (six-hourly), 03:00-04:00 (hourly). Such data rarely yield the true maximum amounts for the indicated durations. For example, the annual maximum observational day amount is very likely to be appreciably less than the annual maximum amount determined from intervals of 1440 consecutive minutes unrestricted by any particular time. Similarly, maxima from fixed six-hourly and hourly intervals tend to be less than maxima obtained from 360 and 60 consecutive one-minute intervals, respectively, unrestricted by fixed beginning or ending times (WMO 2009).

Studies of thousands of station years of rainfall data indicate that multiplying annual maximum hourly or daily rainfall amounts for a single fixed observational interval of one to 24 hours by 1.13 will yield values closely approximating those to be obtained from an analysis of true maxima (Hershfield (1961a). Hence, the PMP values yielded by the statistical procedure should be multiplied by 1.13 if data for single fixed time intervals are used in compiling the annual series (WMO 2009).

3.8 Parameter Selection for Frequency Analysis

Several methods can be used for parameter estimation. The Method of Moments (MOM), the Method of Maximum Likelihood (MML) and the L-moment method (LMM) are used for parameter estimation. The method of maximum likelihood (MML) is considered to be the most accurate method, especially for large data sets. is relatively easy and is more commonly used. In this study Easy Fit statistical computer software were used for parameter estimation of selected distributions. Rainfall data from Didessa sub basin were evaluated with three probability models to find the best fit model. The probability models used include the normal (N), log-Pearson type III (LP3) and General Extreme Value (GEV) probability models.

Normal Distribution

The Gaussian or N distribution is often applied in annual precipitation and runoff analysis (Markovic, 1965). The two moments, mean μ and variance σ2, are the parameters of the normal distribution. The probability density function (pdf), f(x) and cumulative distribution function (cdf), F(x) for a normal random variable x are expressed as,

$$f(x) = \frac{1}{\delta\sqrt{2\pi}} exp\left[-\frac{1}{2\delta^2}(x-\mu)^2\right] \quad (3.6)$$

$$F(x) = \frac{1}{\delta\sqrt{2\pi}} \int_{-\infty}^{\infty} \exp\left[-\frac{1}{2\delta^2}(x-\mu)^2\right] dx \quad (3.7)$$

In the normal distribution, the maximum value of expected discharge (XT) corresponding to any return period (T) can be calculated by Equation (3.8)

$$XT = \bar{X}(1 + CvKT \qquad (3.8)$$

Where XT is the maximum value of expected rainfall, X is the mean, Cv is the coefficient of variation and KT is the frequency factor, which depends on the return period and probability distribution. KT is calculated using equation (3.9).

$$KT = \frac{XT - \mu}{\sigma} \qquad (3.9)$$

Log Pearson Type III Distribution

The Log-Pearson Type 3 (LP3), another gamma family distribution, describes a random variable whose logarithm follows the P3 distribution. The probability density function (pdf), f(x) and cumulative distribution function (cdf), F(x) of the LP3 are expressed as:

$$f(x) = \frac{1}{|\alpha|x\Gamma(\beta)}\left[\left[\left(\frac{\ln(x) - \xi}{\alpha}\right)^{\beta-1} exp\left[-\left(\frac{\ln(x) - \xi}{\alpha}\right)\right]\right. \qquad (3.10)$$

$$F(x) = \frac{1}{|\alpha|x\Gamma(\beta)}\int_0^x \frac{1}{x}\left[\left[\left(\frac{\ln(x) - \xi}{\alpha}\right)^{\beta-1} exp\left[-\left(\frac{\ln(x) - \xi}{\alpha}\right)\right] dx\right. \qquad (3.11)$$

In the log-Pearson type 3 distributions, the maximum value of expected discharge (XT) corresponding to any return period (T) can be calculated using Equation (3.12)

$$Xt = Antilog(x) \qquad (3.12)$$

Where

$$-\log(x) = \bar{x} + KTSd$$

Where

$$KT = \frac{2}{cs} \quad \left[\left\{\left(z - \frac{cs}{6}\right)\frac{cs}{6} + 1\right\}^3 - 1 \qquad (3.13)$$

where $\bar{x}$, Sd and Cs are the mean, standard deviation and coefficient of skewness of rainfall data, respectively, and KT is the frequency factor.

Generalized Extreme Value (GEV) Distribution

The GEV distribution is a family of continuous probability distributions that combines the

Gumbel (EV1), Fréchet and Weibull distributions. GEV makes use of 3 parameters: ξ is the location parameter, α is the scale parameter and k is the shape parameter.

The maximum value of expected discharge (XT) corresponding to any return period (T) can be calculated using Equation (3.14)

$$XT = \xi + \frac{\alpha}{k}\left[1 - \left(-\ln\left(1 - \frac{1}{T}\right)\right)\right] \quad (3.14)$$

where, T is the return period, is the return level at T years

Gumbel Distribution

The equation for fitting the Gumbel distribution to observed series of flood flows at different return periods T is

$$XT = \bar{X} + k\sigma$$

where, XT denotes the magnitude of the T year flood event, K is the frequency factor $\bar{X}$ and σ are the mean and the standard deviation of the maximum instantaneous flows respectively. The frequency factor expresses as:

$$K = -\sqrt{\frac{6}{\pi}}\left(0.5772 + \ln(ln\frac{T}{T-1})\right) \quad (3.15)$$

Goodness of Fit tests

Goodness of Fit tests, as suggested by their very name, can be used to determine whether a certain distribution is fitted properly to the data or not. Calculating statistics of Goodness of Fit also helps to rank the fitted distributions according to quality of fit over the raw data. Most used Goodness of Fit tests include Kolmogorov Smirinov, Anderson Darling, and Chi squared tests.

In this study the three probability distributions were subjected to three Goodness of fit tests to determine the best fitting probability distribution model at each rainfall gauging station.

3.9 Estimation of Return Period Values for PMP

Return period (T) or recurrence interval is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once.

$$T = \frac{n+1}{m} \quad (3.16)$$

where, N is the total number of years of record and R is the rank of observed rainfall values arranged in descending order. Return levels represents the amount of rainfall equalled or exceeded at the given return period. In this study, the return levels of rainfall are calculated for the assumed return periods of 2 to 10,000 years

3.10 Developing Probable Maximum Precipitation Isohyetal Map

Interpolation is a method or mathematical function that estimates the values at locations where no measured values are available. The interpolation techniques are used to solve such a problem. The methods such as Nearest Neighbour (NN), Thiessen polygons, Spline, and various forms of Kriging and Inverse Distance Weighting (IDW) used for interpolation.

Many studies have been dedicated to the comparison and evaluation of different spatial interpolation methods at various spatial scales. For example, Hsieh et al.2006 used daily rainfall records from 20 rain gauges stations between 1990 and 2000 to predict the spatial rainfall distribution in the Shih-Men Watershed in Taiwan using ordinary Kriging (OK) and IDW. The results indicated that IDW produced more reasonable representations than OK. The study by (Chen & Liu, 2012) shows that rainfall data interpolated using IDW and resulted in more accurate values. The IDW is a suitable method to interpolate average rainfall using latitude, longitude, and gauged station average rainfall. IDW interpolation gives accurate results with a reasonable calculation based on temporal and spatial structure (Yang et al., 2020 and Maleika, 2020; Ryu et al., 2020). In this study, IDW used for spatial analysis of the distribution of the PMP in the study area.

$$R_P = \sum_{i=1}^{N} W_i P_i \quad (3.17)$$

$$W_i = \frac{di^{-\alpha}}{\sum_{i=1}^{N} d_i^{-\alpha}} \quad (3.18)$$

Where, R_P = the required rainfall data in mm, P_i = rainfall data of the gauged station W_i is represents the weighting of each depth the weighting of individual rainfall stations, w_i is a weighting factor that represents the relative importance of the individual rainfall station, i and N is the number of gauging stations, di is the distance from each depth to the calculated grid node; and α is the power and is also a control parameter, the value ranges from 1 to 3, for this study it is assumed as 2.

3.11 Flow Chart of The Study

The overall method implemented can be summaries as shown in Figure 3.10

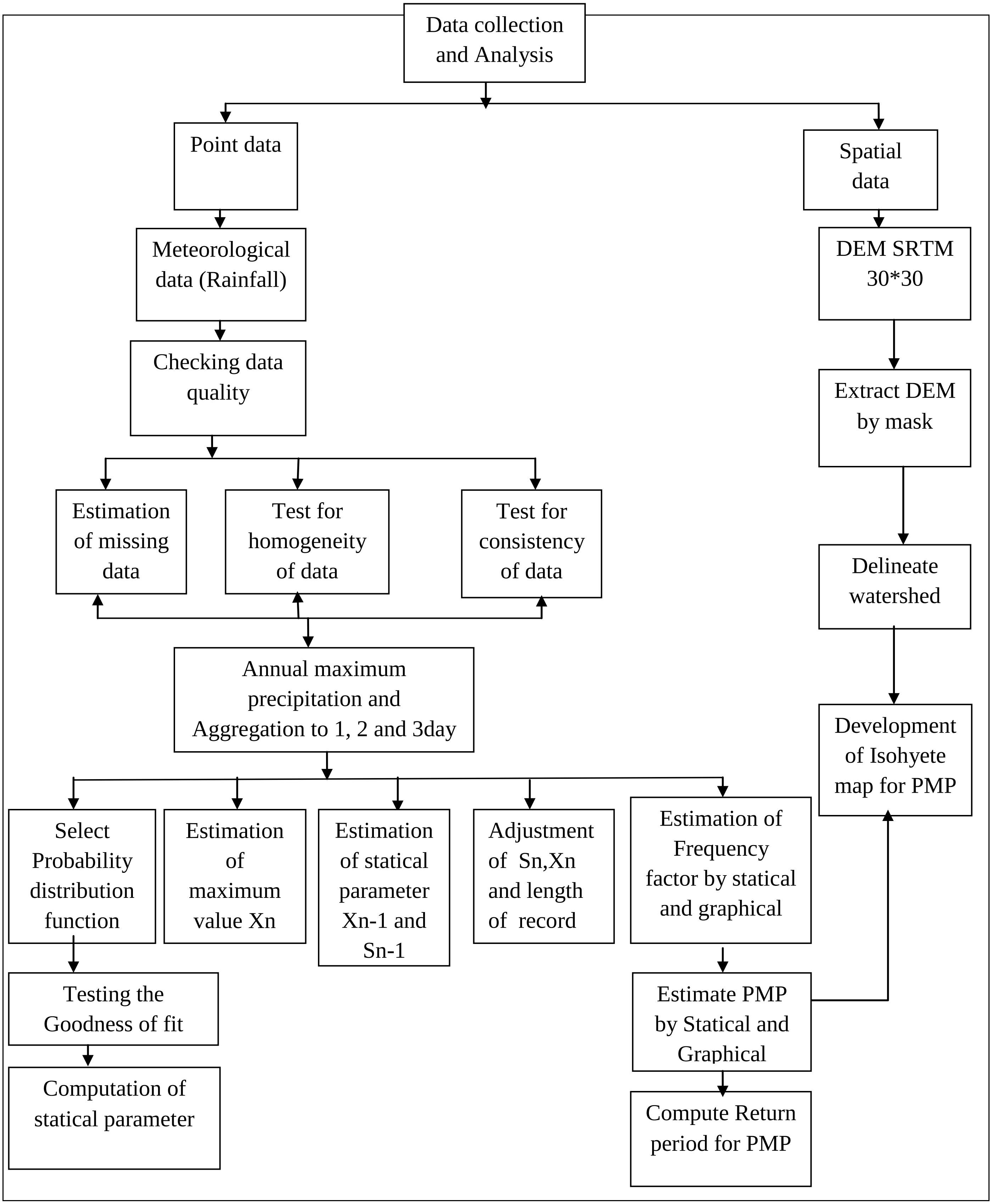

Figure 3.10: Conceptual framework for the study.

4 RESULT AND DISCUSSION

4.1 Estimation of Frequency Factor (Km) Using Hershfield's Chart

For estimation of Km using a Hershfield's Graphical chart the mean of annual maximum rainfall of station was used. The only difference from that of Hershfield statistical method was the frequency factor value is read from the chart or Figure (3.6). Since the mean of the annual maximum rainfall at Arjo station for 1day duration is 99mm, the Km corresponding to the mean from Figure (3.6) is 15.5. The result of this study shows that the maximum frequency factor of stations in Didessa sub basin for 1day duration is 16. Table (4.1) gives the km value obtained from Hershfield's graphical methods of stations in DSB for 1day duration. 2 and 3day durations presented in Appendix C

Table 4.1: Frequency factor (Km) from Hershfield's chart for 1day duration

Stations name	Km from Hershfield graph	Remark
Arjo	15.5	Fig 3:6
Bedele	14.3	
Didessa	13.8	
Gimbi	14.8	
Nekemte	13.6	
Shambu	16	

4.2 Estimation of Frequency factor(Km) by Hershfield's statical method

The Hershfield statistical method was used to estimate Maximum Frequency factor (Km) values for stations using equation (3.5) that can give PMP values for stations in the Didessa sub basin. The annual maximum rainfall series of observed rainfall data were used for analysis of Frequency factor Km. Table (4.2) shows 1day Annual Maximum Rainfall depth and procedure of estimation of Km value of Arjo station, and the detail of all stations Annual Maximum Rainfall depth for different duration is shown in Appendix D.

Table 4.2: km value for 1day duration at Arjo station.

year	Rainfall depth(Xn) in mm for one day duration	Rainfall depth(Xn-1) in mm excluding the 99mm Rainfall depth
1986	37.15	37.15
1987	35.8	35.8
1988	32	32
1989	51	51
1990	57.9	57.9
1991	52.8	52.8
1992	70.3	70.3
1993	53	53
1994	48.4	48.4
1995	41.3	41.3
1996	81.6	81.6
1997	59.4	59.4
1998	42.6	42.6
1999	44.4	44.4
2000	99	
2001	50.5	50.5
2002	55	55
2003	40	40
2004	46.6	46.6
2005	36.2	36.2
2006	58.4	58.4
2007	63.2	63.2
2008	56.3	56.3
2009	73.2	73.2
2010	64.6	64.6
2011	66.4	66.4
2012	49.9	49.9
2013	56.4	56.4
2014	59.6	59.6
2015	54.2	54.2
2016	56.4	56.4
2017	49.9	49.9
2018	55.7	55.7
2019	42.6	42.6
	Max Xn	99
	Mean Xn-1	52.81
	Standard Devn. Xn-1	11.13
	Frequency factor Km	4.15

The statistical Hershfield Frequency factor(Km) was varied from a Minimum of 3.08 (Didessa station) to a Maximum of 4.34 (Nekemte station) with an average value of 3.71 for a 1day duration. The research conducted on Upper Blue Nile Bain by Abenezer & Dereje, 2015, Alemayehu & Semu , 2010 indicates that value of Km from the chart was overestimated in the UBNRB. However Ethiopia use Hershfield's Frequency factor (Km)=15 for estimating the PMP for all river basins. This Study indicates that using frequency factor which is 15 without detailed study of estimating the PMP leads the country to construct uneconomical hydraulic structures. Table (4.3) shows the value of Frequency factor (Km) calculated for 1day duration.

Table 4.3:Frequency factor Km values for 1day duration in the Didessa Sub Basin

Station Name	HOR	Xn-1	Sn-1	Km
Arjo	99	52.81	11.13	4.15
Bedele	121.4	61.57	14.50	4.13
Didessa	128.5	72.17	18.29	3.08
Gimbi	116.8	63.83	15.45	3.43
Nekemte	137.5	75.79	14.22	4.34
Shambu	91.3	54.89	10.49	3.47

The maximum frequency factor (Km) for 2Day and 3Day durations are presented in Appendix E

4.3 Comparison of the Frequency factor from Hershfield's Frequency equation and Hershfield's Chart.

Table 4.4: Comparison of Km by statistical and Hershfield graphical method for 1day

Name of stations	Km by Statistical	Km from chart	percent of deviation
Arjo	4.15	15.5	273.49
Bedele	4.13	14.3	246.25
Didessa	3.08	13.8	348.05
Gimbi	3.43	14.8	331.49
Nekemte	4.34	13.6	213.36
Shambu	3.47	16	361.10

Table 4:4 shows the frequency factor from the chart ranges from minimum 13.6 to maximum16 which is more than three times from the maximum Km value obtained by hershfield's statical methods wich is 4.34. So the result of this study shows that the Maximum Frequency factor obtained from Hershfield's chart is over estimated the actual Frequency factor obtained from the statical method for the study area. This large difference of Km value has significant consequence in the total cost of dam spillway projects when dam design is considered based on PMF. Therefore, high attention should be taken for the estimation of Km values. The value of 2 and 3day is presented in Appendix F.

4.4 Estimation of PMP Using Hershfield's Graphical methods

For estimation of PMP by Hershfield Graphical method the value of adjusted parameters mean (Xn) and standard deviation (Sn) wich is computed from series of annual maximum observed rainfall are used. Table (4.5) shows the estimated value of PMP using Hershfield's graphical methods for 1day duration and the maximum value of PMP is 399.96mm wich is observed at Didessa station. and the result of 2 day and 3day duration is presented in Appendix G.

Table 4.5: 1day duration (PMP) value founded from Hershfield's chart

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km From the chart	PMP
Arjo	54.82	13.05	15.5	290.52
Bedele	63.59	16.44	14.3	337.51
Didessa	74.22	20.27	13.8	399.96
Gimbi	65.87	17.42	14.8	365.77
Nekemte	77.83	16.18	13.6	336.60
Shambu	56.95	12.27	16	286.20

4.5 Estimation of PMP using Hershfield statistical method

For Hershfield statistical methods the PMP were computed based on the Hershfield's Frequency equation using the frequency factor (Km) values from series of annual maximum observed rainfall using equation (3.2). Mean and standard deviation were adjusted for sample size and maximum observed event. Adjustments were made based on Figure 3.7,3.8 and 3.9.

The PMP value at Arjo station for 1day duration is shown below. Table (4.6): shows the Procedure of PMP estimation for Arjo Station and Table (4.7) shows PMP values with the adjusted values of mean (Xn) and standard deviations (Sn) of the stations in Didessa sub basin to estimate point PMP for 1day durations and values of all the stations for 2 and 3day durations are presented in Appendix H.

Table 4.6: Procedure of PMP estimation for Arjo Station

No	Descriptions	Symbol	Values
1	Station Name	Arjo	
2	Sample Size	N	34
3	Mean(mm)	$\bar{x}$n	54.17
4	Standard Deviation(mm)	σ_n	13.46
5	Mean after Excluding the maximum rainfall depth from the series(mm)	Xn-1	52.81
6	Standard deviation after Excluding the maximum rainfall depth from the series(mm)	σ_{-1}	11.13
7	The ratio of 5 and 3	Xn-1/Xn	0.975
8	The ratio of 6 and 4	σn-1/σn	0.827
9	Adjustment of mean for the maximum observed series	From Fig(3.7)	1.02
10	Adjustment of mean for length of record	From Fig(3.9)	1.01
11	Adjustment of standard deviation for the maximum observed series	From Fig(3.8)	0.9
12	Adjustment of standard deviation for length of record	From Fig(3.9)	1.03
13	Adjusted mean(mm)	Adj. mean	54.82
14	Adjusted standard dev(mm)	Adj. Sn devn	13.05
15	Frequency factor	Km	4.15
16	1day Probable Maximum Precipitation(mm)	1day PMP	108.98
17	24 hrs Probable Maximum Precipitation(mm)	1.13*daily PMP	123.14

Table 4.7: PMP value for stations in the Didessa sub basin for 1day duration

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km	PMP
Arjo	54.82	13.05	4.15	123.14
Bedele	63.59	16.44	4.13	148.58
Didessa	74.22	20.27	3.08	154.41
Gimbi	65.87	17.42	3.43	141.95
Nekemte	77.83	16.18	4.34	167.29
Shambu	56.95	12.27	3.47	112.47

Table (4:7) shows the value of 1day Probable Maximum Precipitation for Didessa sub basin stations wich is estimated by Hershfield's statical method. Different adjustments like adjustment of mean, standard deviation and adjustment for record length were made for all stations in the sub basin. The estimated value of Probable Maximum Precipitation (PMP) was found to varie from a Minimum of 112.47 mm at (Shambu station) to a Maximum of 167.29mm at (Nekemte station) for 1day duration.

4.6 Comparison of the PMP Values using Hershfield's statical method and Hershfield's graphical method.

From the result of Table (4:5), the 1day duration Maximum value of Probable Maximum Precipitation (PMP) estimated by the graphical method wich is 399.96mm have 139.08 percent deviation from the maximum value of PMP obtained by Hershfield's statical method wich is 167.29mm. This big difference of Probable Maximum Precipitation value as a result of difference in Frequency factor(Km) founded from Hershfield's chart and by Hershfield's statistical method indicate that using Km value from chart for the design of hydraulic structure has significant consequence in the total cost of construction. So far Designer in Ethiopia have been using the Hershfield's chart for estimation of PMP. The result of this study confirm that the value of Probable Maximum Precipitation from Hershfield's chart over estimate the actual one. Therefore, high attention should be given for the estimation of Probable Maximum Precipitation values for the construction of different hydraulic structure in Didessa sub basin. The detail of comparition of PMP by statical and Hershfield's chart for 2 and 3day duration is shown in Appendix I

Table 4.8: Comparison of PMP value from Hershfield chart and Hershfield's statistical method for 1day duration

Name of stations	Xn adjusted	Sn adjusted	Km by Statistical	Km from chart	PMP by Statistical	PMP by Graphical	Percent of deviation
Arjo	54.82	13.05	4.15	15.5	123.14	290.72	135.94
Bedele	63.59	16.44	4.13	14.3	148.58	337.51	127.15
Didessa	74.22	20.27	3.08	13.8	154.41	399.96	159.02
Gimbi	65.87	17.42	3.43	14.8	141.95	365.77	157.67
Nekemte	77.83	16.18	4.34	13.6	167.29	336.60	101.21
Shambu	56.95	12.27	3.47	16	112.47	286.19	154.47

4.6.1 Estimation of PMP to Highest Observed 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 (HOR) from a long period of rainfall data. PMP to HOR was discussed in Table (4.9). The ratio was found to vary from minimum 1.202 to maximum 1.244 at Didessa and Arjo stations respectively with an average value of 1.223 for 1day duration So, the result of this study confirmed Hershfield (1962).

Table 4.9:Derivation of the ratio of PMP to HOR for 1day Duration

Station Name	PMP	HOR	PMP:HOR
Arjo	123.14	99	1.244
Bedele	148.58	121.4	1.224
Didessa	154.41	128.5	1.202
Gimbi	141.95	116.8	1.215
Nekemte	167.29	137.5	1.217
Shambu	112.47	91.3	1.232
Mean			**1.223**

4.7 Frequency Analysis

In this Study comparing the result of different duration point Probable Maximum Precipitation (PMP) with the rainfall events of 10,000 years return period is very important because the dimensions of the emergency spillways and the dam crest level designs depended on the criterion of 10,000 years return period flood.

Table 4.10 shows the statical and Goodness of fit test results of stations in DSB for 1day duration maximum rainfall from Easyfit statistical computer software. The Anderson-Darling (AD), Kolmogorov-Smirnov (KS) and Chi-Squared (X^2) tests were used for the Goodness of fit tests in this Study. The result indicates that the majority of the stations (50%) in the basin is fitted with GEV. This shows that General Extreme Value is the best and validate function for determining the extreme rainfall value related with a large return period in DSB.

Table 4.10: Statistical and Best fit results for the DSB stations for 1day duration

Station name	mean	Standard deviation	Skewness Coeffitient	Max	Min	Best fit test Result		
						K-S test	A-D test	X2
Arjo	54.169	13.658	1.116	99	32	GEV	GEV	GEV
Bedele	63.329	17.764	1.5623	121.4	39	GEV	LN	GEV
Didessa	72.029	20.802	0.74625	128.5	40	LP3	GEV	LP
Gimbi	65.197	18.013	1.2474	116.8	37.8	GEV	GEV	GEV
Nekemte	77.609	20.458	1.2226	137.5	50.5	LN	LP3	LN
Shambu	55.962	13.383	1.3886	91.3	38.5	LP3	LN	LN

4.7.1 Parameter Estimation

Different methods can be used for parameter estimation; the most common methods are the Method of Moments (MOM), the Method of Maximum Likelihood (MML), and the L-Moment Method (LMM). In this study Easy fit statistical computer software are used for parameter estimation. Estimated parameters of GEV distributions for 1day 2day and 3day duration for Arjo station is presented in Table (4.11) and the results of other station for the 1,2 and 3 day duration is presented on Appendix J.

Table 4.11: Estimated parameters of GEV distributions for Arjo station.

1 day maximum rainfall GEV Value			
Station name	Selected distribution	parametre	Value
Arjo	General Extreme Value (GEV)	K	0.04674
		σ	11.134
		μ	48.236
2 day maximum rainfall GEV Value			
Arjo	General Extreme Value (GEV)	K	0.03585
		σ	15.671
		μ	66.012
3 day maximum rainfall GEV Value			
Arjo	General Extreme Value (GEV)	K	0.29799
		σ	24.766
		μ	84.888

4.8 Estimation of Return Period Rainfall Depth for Estimated PMP

For the annual maximum rainfall data of the Didessa sub basin stations, the maximum 1day rainfall frequencies of 2 to 10,000 amounts have been estimated, for the comparison with the estimated period developed by GEV types of distribution.

Table (4.12) was found to vary from minimum of 52.69mm to maximum of 210.74mm for 1day duration at Didessa sub basin stations. The depth of 10,000 years was limited between 142.59mm to 210.74mm for a 1day and 52.69mm is the minimum rainfall found at a return period of 2 years for Arjo station. Detail return period for the different duration is presented in Appendix K.

Table 4.12: Estimated Rainfall Depths for Different Return Periods for 1 day duration

Station name	Recurrence interval (return period) for 1day duration											
	2	5	10	25	50	100	200	500	1000	2000	5000	10,000
Arjo	52.69	64.24	71.91	81.59	88.74	95.89	102.99	112.4	119.4	126.51	135.86	142.93
Bedele	60.89	75.41	85.04	97.21	106.20	115.2	124.11	135.9	144.8	153.66	165.42	174.31
Didessa	70.90	88.79	100.7	115.67	126.76	137.8	148.83	163.4	174.3	185.28	199.77	210.74
Gimbi	63.01	78.39	88.60	101.49	111.02	120.5	129.99	142.5	151.9	161.31	173.77	183.19
Nekemte	75.18	89.46	98.94	110.92	119.77	128.6	137.39	148.9	157.7	166.48	178.05	186.80
Shambu	57.94	68.77	75.96	85.04	91.75	98.45	105.12	113.9	120.5	127.18	135.95	142.59

4.8.1 Comparing the PMP Values with the 10,000 years Return Period Rainfall Depths

For any hydraulic structure the critical flood peaks to be designed mostly based on the extreme rainfall events with the return period 10,000 years (Haktanier, Cobaner, & Kisi, 2010). The estimated PMP values to 10,000 years return period rainfall depth ratios were computed for DSB and presented for 1day duration on Table (4.13). From the result of this study the ratio of PMP to the 10,000 years return period founded by Hershfield's statical methods was 1.12,1.17 and 1.26 times that of 10,000 years return period rainfall depth for 1day 2day and 3day duration respectively in the DSB. The value of 2day and 3day duration ratio of PMP to 10,000 return period is presented in Appendix L.

Table 4.13:Ratio of PMP to 10,000 return period for 1day duration

Stations name	PMP value	Rainfall depth for 10,000 year return period	Ratio
Arjo	123.14	142.93	1.160711
Bedele	148.58	174.31	1.173173
Didessa	154.41	210.74	1.364808
Gimbi	141.95	183.19	1.290525
Nekemte	167.29	186.80	1.116624
Shambu	112.47	142.59	1.267805

4.9 Development of Isohyetal map

The Isohyetal maps for PMP value were generated for the Didessa sub basin for 1day, 2day and 3day duration. Isohyete lines of contour maps were prepared for estimation of design rainfall for ungauged stations at the given catchment or far apart stations to minimize the gap of rain gauge by interpolation techniques at Arc map 10.3 GIS software by IDW method. Based on this PMP grid values for 1day duration were varying between 124mm to 167mm. The highest PMP isohyetal point values for 1day duration were observed at centeral Didessa Nekemte station and Didessa station and decreases towards upper Didessa at Shambu station. The Daily maximum historical rainfall records illustrate a good correspondence with the PMP isohyetal lines of the Didessa sub basin. The PMP Isohyetal map and its contour map are shown on Figure 4.1 for 1, 2 and 3 day duration.

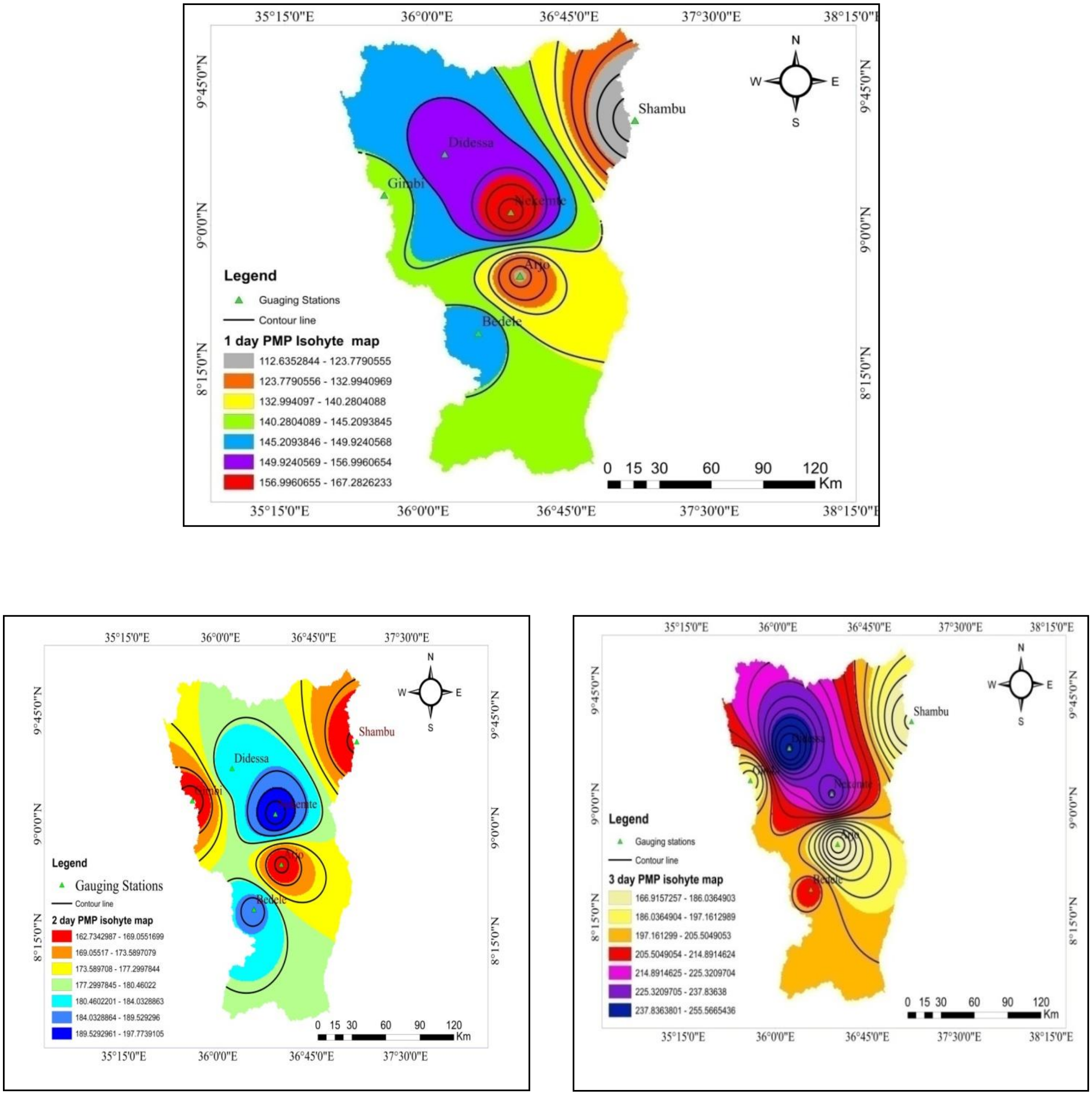

Figure 4.1: PMP Isohyetal and its contour maps

5.CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The Probable Maximum Precipitation helps design a civil structure properly in the study area the PMP approach has been widely used to estimate extreme precipitation, providing disaster risk management procedures including emergency preparedness. Particularly, over the last few decades. There are different methods to estimate PMP Statistical method and moisture Maximization is the most common one.

In order to estimate the Probable Maximum Precipitation, Annual maximum rainfall data was collected from Ethiopian National Meteorological Service Agency. After checking the missing data and its consistence, an adjustment of mean Xn Standard deviation Sn and adjustment for length of record is executed then Hershfield (1961, 1965) techniques is applied for estimating PMP, an adapted version of Chow (1952) for frequency analysis of rainfall and Hershfield chart is used to compare the value of Frequency factor and PMP. Based on this the maximum Frequency factor value from the chart and Hershfield's statical method deviate about 268.66% and value of Probable Maximum Precipitation from the chart and Statical method has deviation about 139.08%. This indicate that the value of Frequency factor and PMP found from the Hershfield's chart is over estimated, the result of this study confirms with the findings of researches on Blue Nile River basin by (Alemayehu & Semu , 2010 and Abenezer & Dereje, 2015).

From the results of applied three frequency distributions which is Normal(N), Log Pearson III and General Extreme Value (GEV) and Goodness of fit tests Kolmogrov Simornov, Chi square and Anderson Darling in this Study, it is found that the best frequency distribution obtained for the maximum daily rainfall in sub basin was the General Extreme Value (GEV) distribution. The PMP return period values were derived using GEV.

The ratios of daily PMP to the design rainfall varying from 2 year to 10.000 year return period were worked out for 1day, 2day and 3day durations. For the flood frequencies of 1day the 2,5,10,25,50,100, 200,500,1000,2000,5000 and 10,000 year floods are found to vary between minimum of 52.69 mm maximum of 210.74 mm. The predicted PMP value to depths of 10,000 years return period ratios were estimated, and it can be concluded that the ratio of PMP to the 10,000 years return period founded by Hershfield's statical methods was 1.12 times that of 10,000 years return period rainfall depth for 1day duration in the DSB.

Isohyetal maps, to understand PMP distribution were generated by means of ArcMap10 GIS software based on the IDW interpolation approach. PMP grid values for 1day were varying between 124mm to 167mm. Generally, the spatial distribution of the PMP presented in this paper will be useful as a background material that gives information for the designers, planners and decision makers' in estimating the area with the most extreme rainfall that is possible to occur in a basin. It can also be used for the planning, designing and management of different type of hydraulic structures and future flood risk management in the study area.

5.2 Recommendations

This study confirmed that the frequency factor Km is highly dependent on the climatic condition of study area, so that further researches should be conducted on the rest of the basins of Ethiopia for fixing the country's reliable Frequency factor.

Researches should be conducted on estimation of PMP by storm transposition method for ungagged stations and by Storm Maximization method for frist class stations.

The value of Probable Maximum flood PMF is a powerful tool for the design of different spillways to avoid the overtopping of dams. So it is advisable to develop the PMF for the Sub basin as well for the country.

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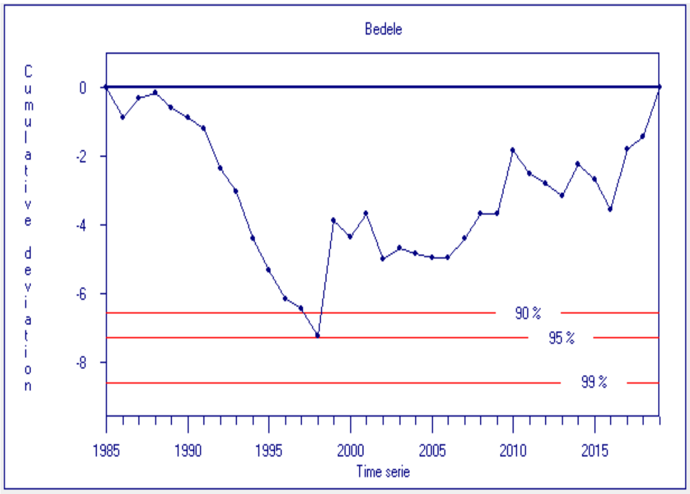
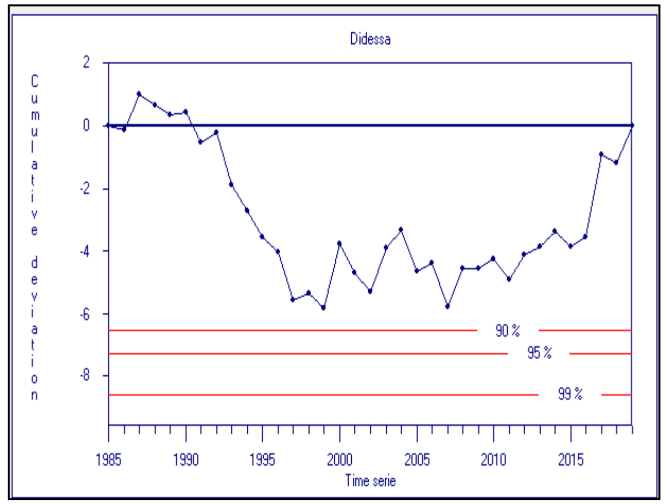
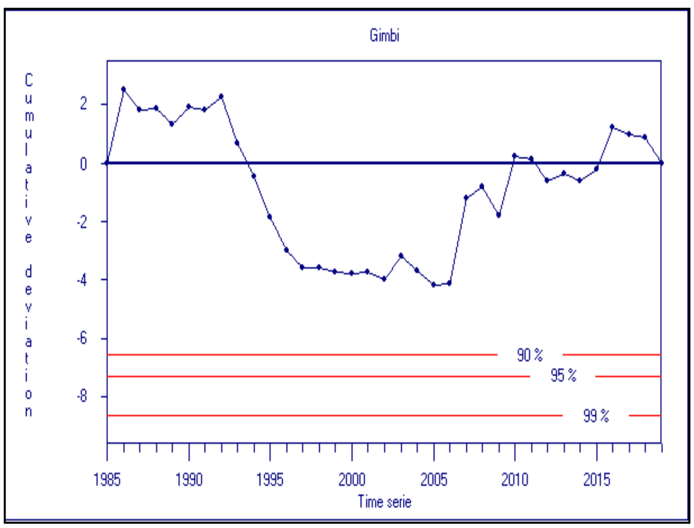
APPENDIXS

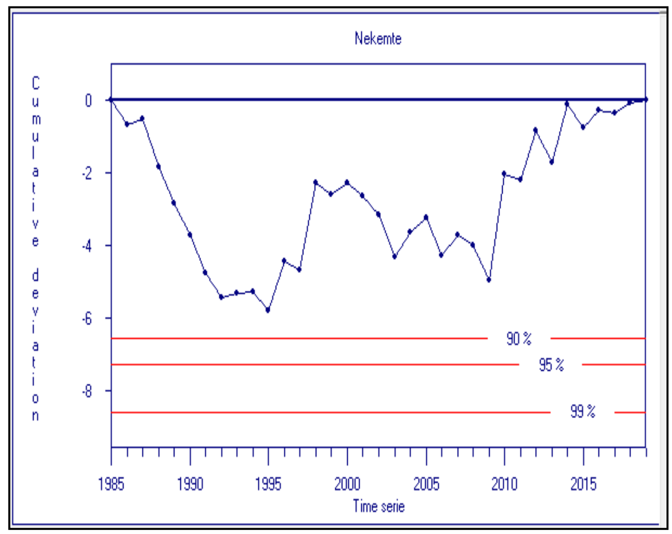
APPENDIX A

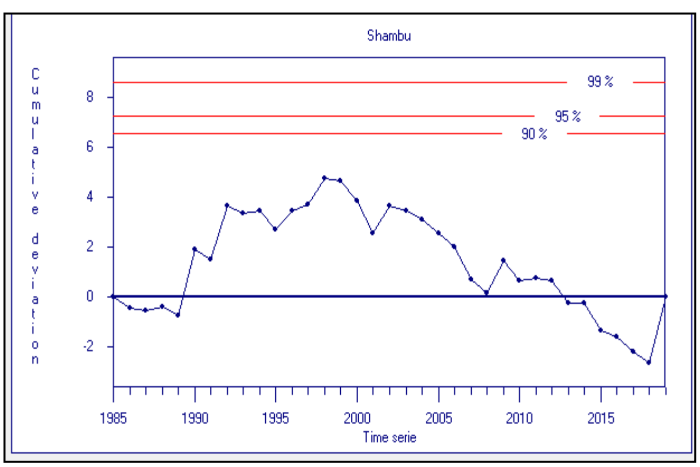
Rainbow software Homogenity test results for Didessa sub basin





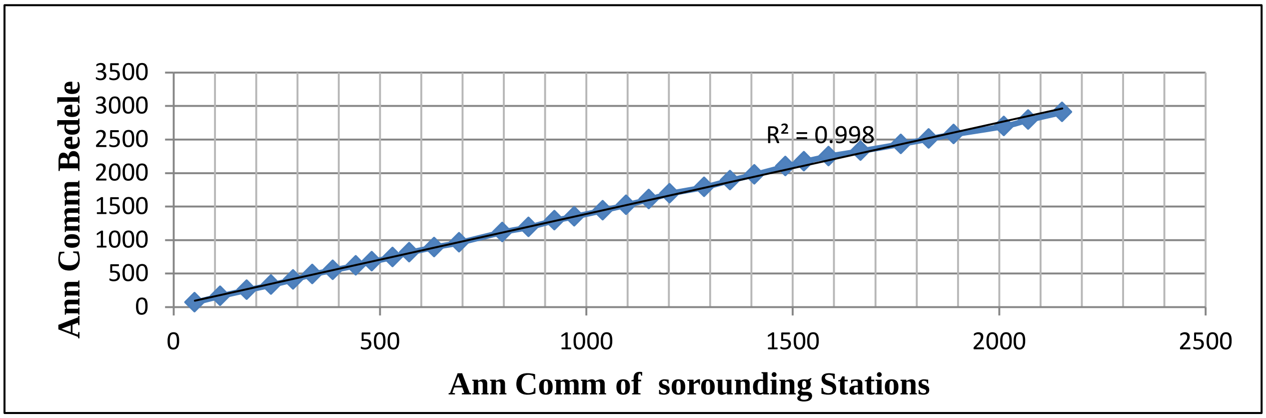


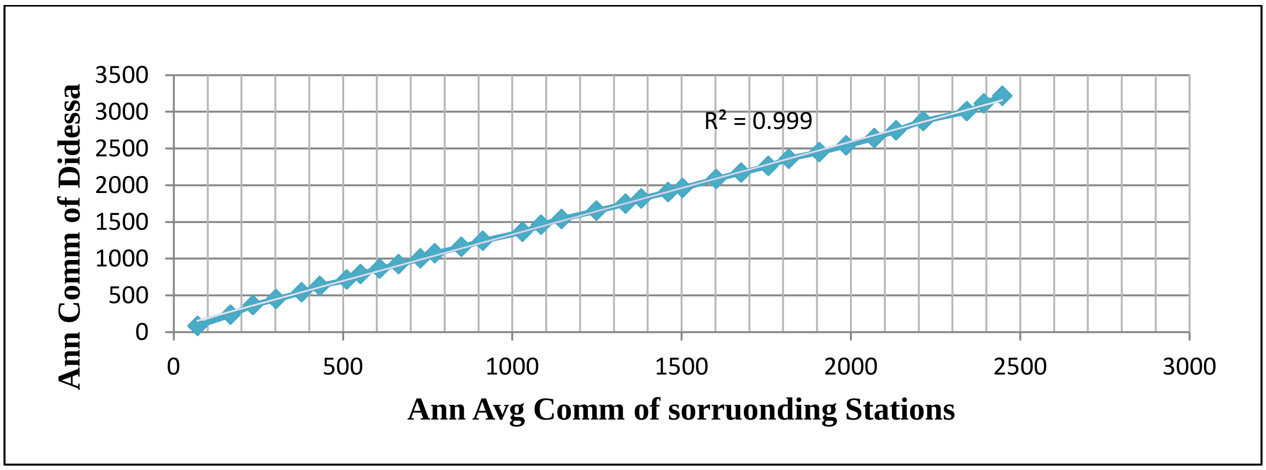


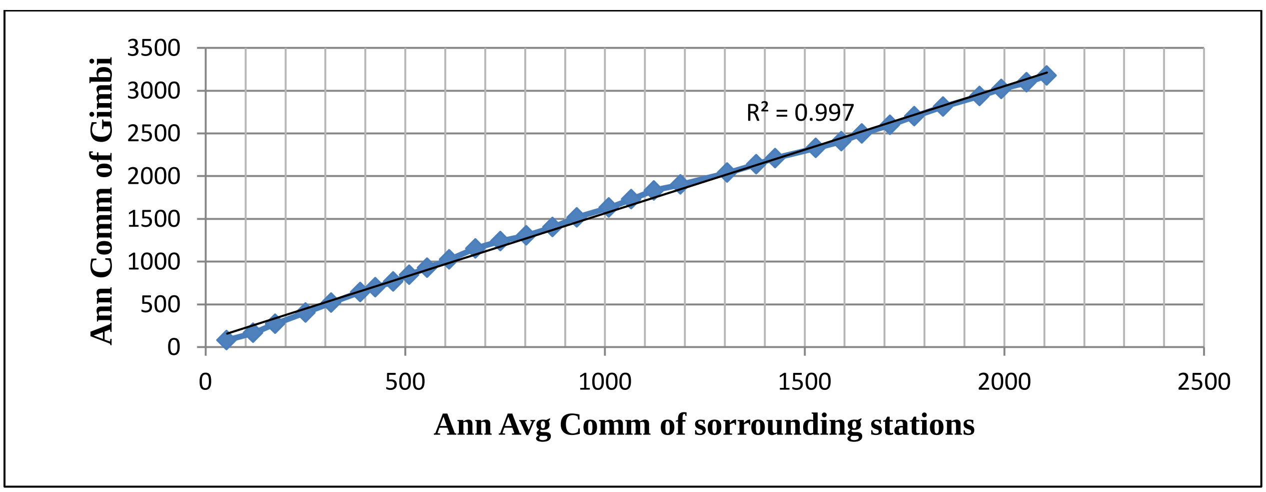


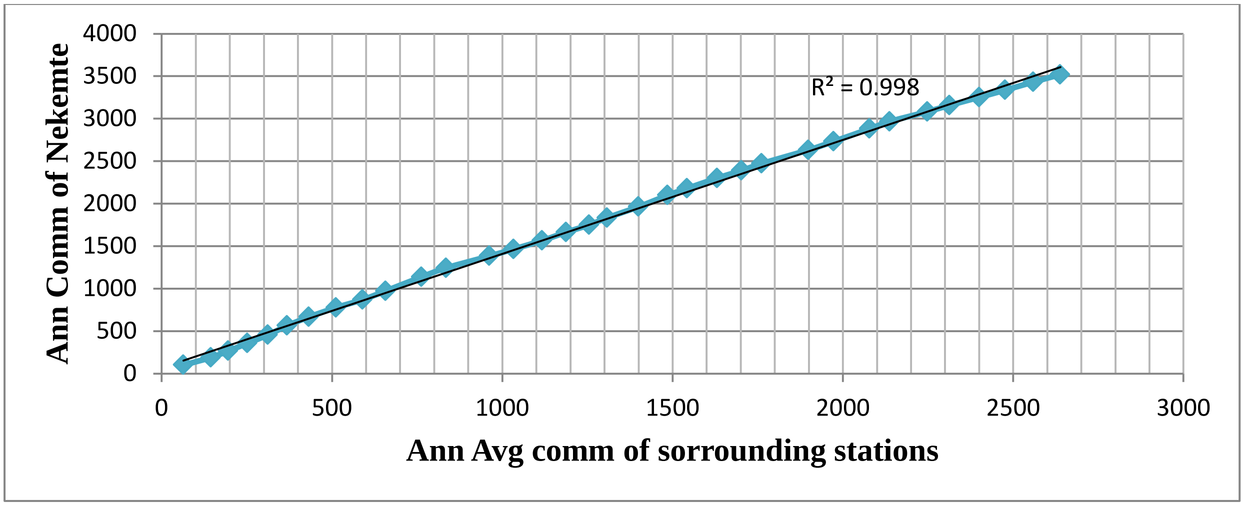
APPENDIX B

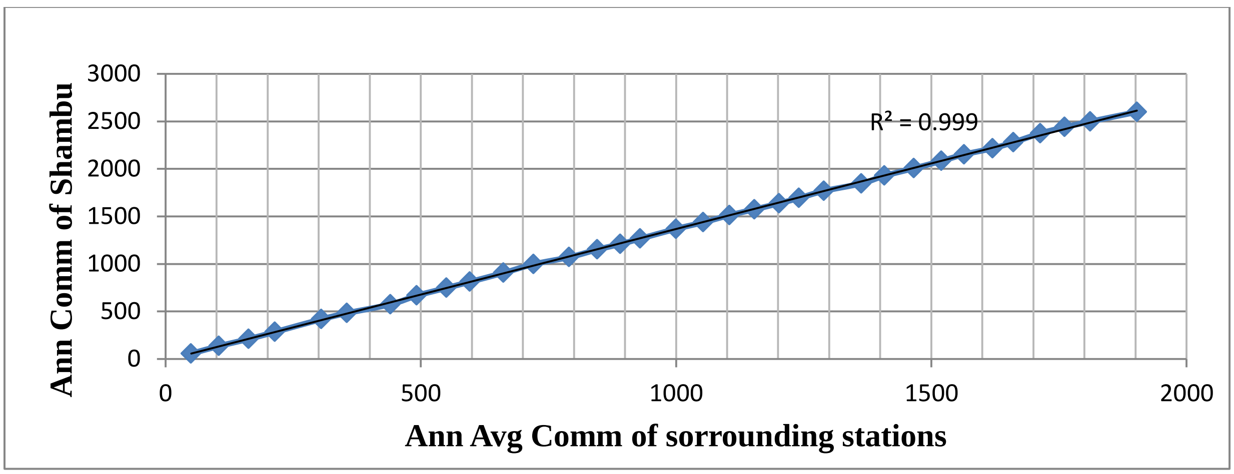
Double mass curve for Consistency of stations











APPENDIX C

Frequency factor (Km) from Hershfield's chart for 2day and 3day duration

Station name	Km from Hershfield graph for 2day	Km from Hershfield graph for 3day	Remark
Arjo	14	13.3	From Fig 3:6
Bedele	12.8	12.5	
Didessa	13	12.6	
Gimbi	13.9	12.7	
Nekemte	12.4	12.1	
Shambu	14.15	13.1	

APPENDIX D

Annual maximum rainfall of Didessa sub basin Stations

Arjo				Bedele			
year	Rainfall depth having a duration of			year	Rainfall depth having a duration of		
	1Day	2Day	3Day		1Day	2Day	3Day
1986	37.15	54.5	59.65	1986	51.7	67.7	73.1
1987	35.8	54.1	60.4	1987	62.2	96.7	111.7
1988	32	54.4	58.5	1988	64.6	88.9	106.2
1989	51	66	89	1989	58.4	76.5	98.2
1990	57.9	62.1	83.8	1990	53.2	79.9	86.5
1991	52.8	69.6	89.6	1991	46.8	78.4	91
1992	70.3	73.1	109.7	1992	49.5	62	78.5
1993	53	63	78.5	1993	56	71	102
1994	48.4	87	123.4	1994	39	57.9	76.4
1995	41.3	51	69.1	1995	50.1	66	92.5
1996	81.6	109.5	129.3	1996	40	68.1	94.1
1997	59.4	93	95.2	1997	61	80.3	101.6
1998	42.6	74.7	77.5	1998	60.1	68.9	70.7
1999	44.4	58.6	72.3	1999	104.5	154.7	172.7
2000	99	105.6	43.3	2000	63.5	75.2	84.3
2001	50.5	56.1	70.8	2001	63	99.5	119
2002	55	58.2	89.8	2002	47.9	58.9	74.3
2003	40	56.6	64.6	2003	69	91.8	111.8
2004	46.6	66.8	87.1	2004	57	82	106
2005	36.2	61.4	71	2005	55	82.8	110
2006	58.4	92.6	110.1	2006	50	85.5	93.8
2007	63.2	91.5	112.1	2007	83.5	97.5	111.5
2008	56.3	85.3	110.1	2008	63	100	100.5
2009	73.2	135.7	141.2	2009	58.5	86	97.5
2010	64.6	76.2	103.9	2010	75.3	123.3	127.3
2011	66.4	86.7	109.5	2011	45	71	97
2012	49.9	70.7	97.2	2012	60	79.8	98
2013	56.4	78	114.9	2013	77.5	78.8	107
2014	59.6	100.8	136.6	2014	97.5	104	121
2015	54.2	100.8	103.2	2015	67.3	76.8	89
2016	56.4	78	116.4	2016	60.5	67.1	83.9
2017	49.9	49.9	103.5	2017	121.4	121.4	124.1
2018	55.7	90.6	112.6	2018	59.2	93.5	99.8
2019	42.6	59.4	81.2	2019	82	115	122.4

Didessa				Gimbi			
year	Rainfall depth having a duration of			Year	Rainfall depth having a duration of		
	1Day	2Day	3Day		1Day	2Day	3Day
1986	71.3	85.5	92.7	1986	109.9	113.7	114.7
1987	97.5	152	160.2	1987	53.5	81.4	108.7
1988	66.5	128	130.6	1988	66.1	86.6	122.1
1989	68	82.5	94.7	1989	55.8	105.5	110.2
1990	75.5	93.5	132.1	1990	75.4	131.4	141.9
1991	53.7	87.5	123.5	1991	64.4	114.6	134.8
1992	80	84.5	85.6	1992	72.6	124.4	152.8
1993	40	77	77.2	1993	37.8	55	70.8
1994	57	72	96.5	1994	44.7	67.9	83.8
1995	56	60.5	64.2	1995	40.2	79	101.1
1996	64.5	79	118.7	1996	45	82.3	85.7
1997	42.4	70.2	84.7	1997	55.2	97.2	98.3
1998	78	87	107.2	1998	65.5	127.5	158.7
1999	64.1	83.1	96.9	1999	62.4	85.2	118.8
2000	116.6	124.5	130.7	2000	64.9	70	92.1
2001	55.1	93.1	123.9	2001	65.9	96	96
2002	60.6	81	99.4	2002	61.3	113.9	114.8
2003	103	111	124.4	2003	79.7	114.2	120.5
2004	85.9	97.7	109.4	2004	56.3	98.2	117.6
2005	46.5	69.3	86.7	2005	56.8	101	113.6
2006	79.3	88.5	102.5	2006	66.3	71.1	100.7
2007	43	54.5	75.2	2007	116.8	137.6	141.5
2008	99	124.5	142.9	2008	72.9	99.6	120.5
2009	74	86.3	90.4	2009	47.7	71.7	95.2
2010	80	91.2	104.2	2010	101.3	117	124.2
2011	60.2	96.7	118.2	2011	64.3	80.4	95.9
2012	90	90	112	2012	51.6	89.3	105.4
2013	80	92	115.7	2013	69.9	101.4	114.6
2014	83	101.5	119.1	2014	61.3	101.1	115.4
2015	64	102.4	110.5	2015	72	112	131.6
2016	80.5	126.8	152	2016	91.3	125.9	136.8
2017	128.5	134.1	138.8	2017	54	80.9	89.1
2018	50.5	107.01	126.39	2018	63.7	77.3	84
2019	54.8	102.81	113.56	2019	50.2	80.9	89.1

Nekemte				Shambu			
year	Rainfall depth having a duration of			year	Rainfall depth having a duration of		
	1Day	2Day	3Day		1Day	2Day	3Day
1986	63.9	100.9	108.5	1986	50.2	56.9	77.2
1987	81	89.7	106	1987	54.5	79.3	84.7
1988	50.3	76	93	1988	58.1	74.4	87.6
1989	57	92.4	96.8	1989	51.3	73.6	107.7
1990	60	97	101.2	1990	91.3	134.7	145.3
1991	55.9	108.1	115.8	1991	50.2	64.2	86.6
1992	63.9	102.7	130.6	1992	85.1	92.2	96.1
1993	80	110.8	141.3	1993	51.6	91.8	101.1
1994	78.4	93.4	119.1	1994	57.8	80.6	84.4
1995	67.3	102.6	144	1995	45.7	63.7	70.9
1996	105.4	165.4	178.9	1996	66.2	94.8	133.6
1997	72.3	105.2	138.8	1997	58.7	90.9	101.4
1998	126.5	139.5	155.4	1998	70	74	87.4
1999	71.2	81.7	103.2	1999	55.1	80.7	95.5
2000	84.2	101.5	125.3	2000	45	57.5	64.7
2001	70	96.7	117.9	2001	38.7	56.5	78.8
2002	67.7	87	108.5	2002	70.3	103.2	140.2
2003	53.3	84	115.8	2003	53.2	68.4	87.6
2004	91.8	129.5	132.4	2004	51.4	75.3	79.8
2005	85.4	134.7	153.9	2005	49	61.5	73.1
2006	56.9	80.6	121.1	2006	48.7	64	70.8
2007	89	122	132.5	2007	38.5	54.5	69.2
2008	71.6	89.7	106.3	2008	48.8	75.2	95.1
2009	58.3	80.3	98.7	2009	73.6	78.8	94.8
2010	137.5	160.7	182.9	2010	45	81	90.8
2011	74	100.1	114.3	2011	57.6	78.3	79.7
2012	105.5	149.4	158	2012	54.2	77.8	90.7
2013	59.2	85.1	96.5	2013	44.3	68.8	79.4
2014	110.6	116.2	199	2014	56	64	68.7
2015	64.7	74.6	120.9	2015	40.7	63.8	82.9
2016	87.6	94.8	159.9	2016	53	94	94
2017	76.1	84.1	140.3	2017	47.4	64.9	84.3
2018	83.2	96.4	150.1	2018	50.2	59.3	77.4
2019	79	86.8	145.2	2019	91.3	100.6	102.6

APPENDIX E

Km values for 2day and 3day duration in the Didesa Sub Basin By statical method

Station Name	HOR	Xn-1	Sn-1	Km
Arjo	135.7	73.81	17.09	3.62
Bedele	154.7	83.4	16.61	4.29
Didessa	152	70.59	18.09	4.5
Gimbi	137.6	95.56	19.45	2.16
Nekemte	165.4	101.64	16.98	3.76
Shambu	134.7	74.68	11.76	5.10

Station Name	HOR	Xn-1	Sn-1	Km
Arjo	141.2	91.93	22.52	2.19
Bedele	172.7	98.81	15.10	4.89
Didessa	160.2	169.11	20.42	2.50
Gimbi	158.7	110.37	19.13	2.53
Nekemte	199	127.67	19.15	3.72
Shambu	145.3	88.45	14.38	3.95

APPENDIX F

Comparison of Km by statistical and Hershfield graphical method for 2day and 3day

Name of stations	Km by Statistical	Km from chart	Percent of deviation
Arjo	3.62	14	286.74
Bedele	4.29	12.8	198.37
Didessa	4.5	13	188.89
Gimbi	2.16	13.9	543.52
Nekemte	3.76	12.4	229.79
Shambu	5.10	14.15	177.45

Name of stations	Km by Statistical	Km from chart	Percent of deviation
Arjo	2.19	13.3	507.31
Bedele	4.89	12.5	155.62
Didessa	2.50	12.6	404.00
Gimbi	2.53	12.7	401.97
Nekemte	3.72	12.1	225.27
Shambu	3.95	13.1	231.65

APPENDIX G

2 day and 3day duration Probable Maximum Precipitation founded from Hershfield's chart

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km From the chart	PMP
Arjo	75.85	19.05	14	387.08
Bedele	85.43	18.53	12.8	364.55
Didessa	72.37	20.02	13	375.87
Gimbi	97.63	21.46	13.9	447.39
Nekemte	103.7	18.97	12.4	382.99
Shambu	76.72	13.5	14.15	302.55

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km From the chart	PMP
Arjo	93.99	24.53	13.3	474.87
Bedele	100.86	16.84	12.5	351.84
Didessa	170.12	22.42	12.6	511.45
Gimbi	112.44	21.14	12.7	430.44
Nekemte	129.73	21.14	12.1	435.64
Shambu	90.51	16.15	13.1	341.35

APPENDIX H

PMP estimation for stations in Didessa sub basin for 2 day and 3day durations by statical method.

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km	PMP
Arjo	75.85	19.05	3.62	163.64
Bedele	85.43	18.53	4.29	186.36
Didessa	72.37	20.02	4.5	183.58
Gimbi	97.63	21.46	2.16	162.70
Nekemte	103.7	18.97	3.76	197.78
Shambu	76.72	13.5	5.10	164.49

Station Name	Adjusted (Xn)	Adjusted (Sn)	Km	PMP
Arjo	93.99	24.53	2.19	166.91
Bedele	100.86	16.84	4.89	207.03
Didessa	170.12	22.42	2.50	255.57
Gimbi	112.44	21.14	2.53	187.49
Nekemte	129.73	21.14	3.72	235.46
Shambu	90.51	16.15	3.95	174.36

APPENDIX I

2 day and 3day comparition of PMP value from chart and by statical method

Name of stations	Xn adjusted	Sn adjusted	Km Statistical	Km from chart	PMP Statistical	PMP by graphical	percent of deviation
Arjo	75.85	19.05	3.62	14	163.64	387.08	136.55
Bedele	85.43	18.53	4.29	12.8	186.36	364.55	95.61
Didessa	72.37	20.02	4.5	13	183.58	375.87	104.75
Gimbi	97.63	21.46	2.16	13.9	162.70	447.39	174.98
Nekemte	103.7	18.97	3.76	12.4	197.78	382.99	93.64
Shambu	76.72	13.5	5.10	14.14	164.49	302.55	83.93

Name of stations	Xn adjusted	Sn adjusted	Km Statistical	Km from chart	PMP Statistical	PMP by graphical	percent of deviation
Arjo	93.99	24.53	2.19	13.3	166.91	474.87	184.50
Bedele	100.86	16.84	4.89	12.5	207.03	351.84	69.95
Didessa	170.12	22.42	2.5	12.6	255.57	511.45	100.12
Gimbi	112.44	21.14	2.53	12.7	187.49	430.44	129.58
Nekemte	129.73	21.14	3.72	12.1	235.46	435.64	85.02
Shambu	90.51	16.15	3.95	13.1	174.36	341.35	95.77

APPENDIX J

Estimated Parameter for GEV Distribution for 1,2 and 3day duration

Estimated Parameter for GEV Distribution for Maximum rainfall					
			1day	2day	3day
Station name	Selected distribution	Parameter	Value	Value	Value
Bedele	General Extreme Value (GEV)	K	0.16034	0.10856	0.07053
		σ	11.198	14.262	16.16
		μ	54.774	75.561	92.714
Didesa	General Extreme Value (GEV)	K	0.05867	0.03318	0.26225
		σ	17.759	17.842	22.327
		μ	62.757	84.894	102.43
Gimbi	General Extreme Value (GEV)	K	0.06283	0.21411	0.17016
		σ	13.005	20.402	19.732
		μ	56.832	88.657	103.29
Nekemte	General Extreme Value (GEV)	K	0.10309	0.18109	0.0039
		σ	14.432	15.02	21.75
		μ	67.651	91.603	117.3
Shambu	General Extreme Value (GEV)	K	0.18206	0.13528	0.17493
		σ	8.2947	12.338	25.176
		μ	49.371	81.108	68.693

APPENDIX K

Estimated Rainfall Depths for Different Return Periods for 2 day and 3 day duration

Station name	Estimated rainfall depth for 2 day duration for different Station in (mm)											
	2	5	10	25	50	100	200	500	1000	2000	5000	10000
Arjo	72.7	89.6	100.7	114.8	125.2	135.6	145.9	159.6	169.9	180.2	193.9	204.1
Bedele	82.3	98.8	109.6	123.3	133.5	143.6	153.6	166.9	176.9	186.9	200.2	210.2
Didesa	69.0	86.8	98.5	113.3	124.3	135.2	146.1	160.4	171.3	182.1	196.3	207.2
Gimbi	94.1	113.1	125.6	141.5	153.3	164.9	176.6	191.9	203.6	215.2	230.6	242.1
Nekemte	100.6	117.3	128.4	142.5	152.9	163.2	173.5	187.1	197.4	207.6	221.2	231.5
Shambu	74.5	86.4	94.34	104.3	111.7	119.1	126.4	136.1	143.4	150.7	160.3	167.6

Station name	Estimated rainfall depth for 3 day duration for different Station in (mm)											
	2	5	10	25	50	100	200	500	1000	2000	5000	10000
Arjo	89.9	111.6	126.0	144.1	157.6	170.9	184.3	201.9	215.1	228.4	245.9	259.2
Bedele	98.1	112.9	122.8	135.3	144.5	153.7	162.9	174.9	184.0	193.1	205.2	214.3
Didesa	166.4	186.2	199.4	215.9	228.2	240.5	252.7	268.7	280.9	292.9	308.9	321.1
Gimbi	108.9	127.6	140.0	155.7	167.2	178.8	190.3	205.4	216.9	228.3	243.4	254.8
Nekemte	126.3	144.9	157.3	172.9	184.5	196.1	207.6	222.7	234.1	245.6	260.7	272.1
Shambu	87.9	102.1	111.6	123.5	132.4	141.2	149.9	161.5	170.3	179.0	190.5	199.3

APPENDIX L

Ratio of PMP to10,000 year return period rainfall depth for 2day and 3day

Station name	PMP value	Rainfall depth for 10,000 year return period	Ratio
Arjo	163.64	204.15	1.247556
Bedele	186.36	210.23	1.128085
Didessa	183.58	207.2	1.128663
Gimbi	162.7	242.16	1.488384
Nekemte	197.78	231.46	1.17029
Shambu	164.49	167.64	1.01915

Station name	PMP value	Rainfall depth for 10,000 year return period	Ratio
Arjo	166.91	259.2	1.552933
Bedele	207.03	214.28	1.035019
Didessa	255.57	321.12	1.256486
Gimbi	187.49	254.82	1.359112
Nekemte	235.46	272.11	1.155653
Shambu	174.36	199.28	1.142923