JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

Regional Flood Frequency Analysis for Upper Wabi-Shebelle River Basin, Ethiopia

By: Alemgena Kefele Jima

A Thesis Submitted to the School of Graduate Studies of Jimma University, Jimma Institute of Technology in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering

Feb, 2019

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Main Advisor: Dr.Ing Tamene Adugna (Associate professor)

Co-advisor: Mr. Tadele Shiferaw (MSc)

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Jimma, Ethiopia

DECLARATION

I declare that this research which is entitled as "**Regional Flood Frequency Analysis on Upper Wabi -Shebelle River Basin, Ethiopia**" is my own original work and has not been submitted for a degree award in any other University or institute. All the sources of the materials which were used by the researcher in this study have been appropriately acknowledged.

Alemgena Kefele; Signature___________________ Date ____________________

This research has been submitted for final defense or examination with our approval as University supervisors.

Main Advisor: Dr.-Ing Tamene Adugna (Associate professor); Signature ______________

Date ________________

Co-advisor: Mr. Tadele Shiferaw (MSc.); Signature __________________

Date_________________

APPROVAL

The thesis entitled "**Regional Flood Frequency Analysis of Upper Wabi Shebelle River Basin, Ethiopia**" submitted by Alemgena Kefele Jima is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology, Jimma University.

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As members of the examining board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by Alemgena Kefele Jima. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

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External Examiner _____________________	_________	_________
Internal Examiner _____________________	_________	_________

ABSTRACT

Floods are the most common natural disaster for every country in the world and which is the main cause of fatalities. It is one of the major natural hazards in Ethiopia which causes for displacement of people and animals, property and live damages in different parts of the country. Estimation of maximum flood discharge with a specified return period is crucial for the design of hydraulic structures. The estimation of design floods for a site has been a common problem in some regions, and there is always great interest in this estimation process, particularly for ungagged basins or for sites characterized by a short sample length. Therefore, flood management, and especially flood risk assessment, requires the estimation of the relation between flood magnitude and its probability of exceedance. The main objective of this study was to develop Regional Flood Frequency Analysis on Upper Wabi-Shebelle River Basin of Ethiopia. This was addressed by collecting hydrological data and conducting of analysis using ArcGIS to know the location of stations' distribution and delineation of homogeneous regions, Easy fit software and Matlab2018a for homogeneity testing and selection of flood frequency distribution type and Microsoft excel to rearrange the data, to draw the graphs and tables. Based on gauging stations location and L- moment, the regional homogeneity test was conducted and the study area was regionalized in to three homogeneous regions as region -1, region-2 and region-3. The most suitable flood frequency distributions which were found for the study area were General Extreme Value, General Pareto and Lognormal 3p to region -1, region-2 and region-3 respectively. These flood frequency distributions were selected by using Kolmogorov Smirnov, Anderson-Darling and Chi-Squared goodness-of-tests with easy fit software and linear moment ratio diagram. Based on the identified flood frequency methods the quantile for regions were forecasted for return period of 2-1000 years and flood frequency curve were plotted for each region. The plotted flood frequency curve can help for engineers to design safe, cost wise and serviceable structure in the identified homogenous regions. In addition to this it is helpful for flood management and risk mitigation purposes. Therefore it is advisable for different stakeholders to use the output of this finding in order to increase the life span of the hydraulic structures and to make safe the residents of the basin.

Key words: *Best-fit distribution; Flood frequency; Flood magnitude; Homogeneity; Regionalization*

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ACRONYMS

AM	Annual Maximum
AMFD	Annual Maximum Flood Discharge
CC	Combined coefficient variation
ETB	Ethiopian Birr
ERA	Ethiopia Road Authority
FFA	Flood Frequency Analysis
FFC	Flood frequency Curve
GIS	Geographic Information System
GOF	Goodness of Fit
IHRs	Identification of Homogeneous Regions
MFD	Maximum Flood Discharge
MoWIE	Ministry of Water, Irrigation and Electricity
PD	Partial Duration
POT	Peak over Threshold
RFFC	Regional Flood frequency Curve
RGC	Regional Growth Curve
SNNP	South Nation Nationalities and People
NDRMC	National Disaster Risk Management Commission
UWSRB	Upper Wabi-Shebelle River Basin

1. INTRODUCTION

1.1.Background

Floods are the most common natural disaster worldwide and account for the most deaths (NASA, 2017). It is one of the major natural hazards in Ethiopia which causes significant damages to lives and livelihoods in parts of the country. It is mainly linked with torrential rainfall and the topography of the highland mountains and lowland plains with natural drainage systems formed by the principal river basins (NDRMC, 2018).

Flood frequency analysis is one of the most common methods to estimate the design flood for hydraulic structures and for flood hazard and risk mitigation programs (Frances, 2010). It would enhance the management of water resources applications as well as the effective utilization of water resources. It is concerned with the assessment of flood magnitudes of stated frequency for use as input into the process of flood risk assessment and management. Flood risk assessment is needed in the design of flood relief and protection works and in the assessment of the safety of existing and planned infrastructure. This includes domestic properties, commercial and industrial buildings, bridges, roads and railways, and critical infrastructure such as hospitals, electrical stations, gas stations and water works (Murphy, et al., 2014).

Estimation of maximum flood discharge (MFD) with a specified return period is crucial for the design of hydraulic structures such as bridges, barrages, culverts, dams and drainage systems. Since the hydrologic phenomena governing the MFD is highly stochastic in nature, the MFD can be effectively determined by fitting of probability distributions to the series of recorded annual maximum flood discharge (AMFD) data. An AMFD is the highest instantaneous discharge value at a definite cross-section of a natural stream throughout an entire hydrologic year (water year). The longer the period of observation, the greater would be the length of the recorded series that may offer better results of the flood frequency analysis (FFA) (Vivekanandan., 2015).

Flood frequency estimation is one of the most challenging problems in hydrology, and one that is filled with controversies. The selection of an ‘appropriate’ probability distribution and associated parameter estimation procedure is an important step in flood frequency analysis and has been widely researched as cited by (Haddad, 2011).

Upper Wabi-Shebelle River Basin is found in South Eastern part of Ethiopia. It covers a large part of the country's land mass and the basin is found in the two largest regional state of the country; the Oromiya regional state in the North West and the Somali Regional State in the South East.

The objective of flood frequency analysis was to estimate the return period associated with a given flood magnitude. At-site flood frequency analysis requires a reasonably long period of recorded stream flow data (Imteaz, 2015). Therefore the main objective of this study was to develop Regional Flood Frequency Analysis on Upper Wabi-Shebelle River Basin of Ethiopia. So the researcher tried to gather long period recorded data as much as possible from MoWIE in order to get the best method of flood forecasting.

1.2.Statement of Problems

Recent studies have highlighted how local investments in simple flood preparations often experience 70% less property damage when flooding occurred. But achieving such benefits on a global scale requires full understanding and characterizations of flood exposure (NASA, 2017) .

Flood fatalities in Africa have increased dramatically over the past half-century. Ethiopia is exposed to numerous hazards including, floods, droughts, volcanoes, and earthquakes. Multiple factors influence the country's vulnerability to natural hazards. It includes dependence on rain-fed agriculture, low economic development, deforestation, land degradation, and larger and denser human settlements. Flash floods and seasonal river floods are becoming more frequent and widespread. Climate models indicate that in the next century there will be a 20 percent increase in extreme high rainfall events. The estimation of design floods for a site has been a common problem in some regions, and there is always great interest in this estimation process, particularly for ungagged basins or for sites characterized by a short sample length (Kossi, et al., 2016).

According to (NMA, 2018), overflow of Wabi Shebelle rivers and related tributaries due to recent heavy rains in the Somali region and the highlands of Oromia has affected more than 83 kebeles in 19 woredas (districts) of Afder, Fafan, Liben, Nogob, Siti, Shebele and warder Zones. Several Kebeles are submerged and farmlands are either flooded or washed away at flowering stage. Many people's houses/shelters and livestock have reportedly been washed away, leaving people displaced and homeless

In order to mitigate flood risk, efficient flood management is urgently needed. Flood management, and especially flood risk assessment, requires the estimation of the relation between flood magnitude and its probability of exceedance. Therefore this study would to determine the maximum flood frequency occurrence in Upper Wabi-Shebelle river basin in order to minimize the failures of different structures which will construct on the basin and to give a warning for residents to save their life and properties.

1.3.Objective of the Study

1.3.1. General objective

The general objective of this study was to develop Regional Flood Frequency Analysis on Upper Wabi-Shebelle River Basin of Ethiopia.

1.3.2. Specific objectives

The specific objectives for this study are:

1. To identify hydrologically homogeneous regions of the Upper Wabi-Shebelle River Basin;
2. To select the best fit statistical distributions and quantile estimation for the basin;
3. To establish regional flood frequency curves for the basin.

1.4.Research Questions

In order to meet the above objectives, the key questions addressed in the study are that,

1. Is it Upper Wabi-Shebelle River Basin hydrologically homogeneous?
2. What is the best fitting statistical distribution and quantile estimation for UWSRB?
3. What it seems to flood frequency curves of the UWSRB?

1.5.Significant of the Study

This study is expected to become valuable for different stake holders like designer, policy and decision makers by providing information. It can give information on flood risk estimation, economic evaluation of flood control projects, proper planning, and design of water resources management options on the study area. Also the study can be used as a point of reference for any further investigation that will undertake on the Wabi Shebelle River Basin. In addition to this, the study can be used to save human life from these hazards and to minimize the failure of different hydraulic structures which will be constructed in Upper Wabi-Shebelle river basin by forwarding the best method of maximum flood forecasting.

1.6.Scope of the Study

This study was to address issues related to the probability of flooding frequency occurrence and its magnitude that might take place depending on the hydrological response of the selected basin. The study was limited mainly on regionalization of stream flow data on the Upper Wabi Shebelle River Basin, Ethiopia. The regionalization was performed based on stream flow data statistical value and geographical location of the gauging stations.

2. LITRATURE REVIEW

2.1.Back Ground of the Study

Floods are a sudden increase in the volume, velocity or discharge of a body of water that occur at irregular interval anywhere in drainage system of river and streams. They are unexpected and one cannot say where and when floods will strike, the prediction is difficult for flood. Floods are a natural consequence of stream flow in a continually changing environment. Floods have been occurring throughout Earth history, and are expected so long as the water cycle continues to run. Streams receive most of their water input from precipitation, and the amount of precipitation falling in any given drainage basin varies from day to day, year to year, and century to century (Nelson, 2016).

Flood Frequency Analysis is the estimation of how often specified event will occur. Before the estimation is carried out, analysis of the stream flow data plays a very important role in order to obtain a probability distribution of floods. Whenever an important structure is to be constructed in the vicinity of a river, it must be properly planned and designed keeping in view the damage to which it is susceptible and the catastrophic which it is going to create in the event of its failure. Hence, while designing any important hydraulic structures, provision must be made for the design flood that is likely to occur during the life time of that particular structure (Melese, 2014).

2.2.Flood Frequency Analysis

According to (Ewemoje and Ewemooje, 2011), one method of decreasing flood damages and economic losses is to use flood frequency analysis for determining efficient designs of hydraulic structures. In hydrology, estimation of peak discharges for design purposes on catchments with only limited available data has been a continuing problem. In flood frequency analysis (FFA), a relationship between a flood magnitude (Q) and its return period (T) is developed by statistical modeling of a time series of peak flows (Simonovic, 2012). Moreover, information of spatial and temporal variability of extreme rainfall events is very useful for the design and construction of certain projects, such as dams and urban drainage systems, the management of water resources, and the prevention of flood damage as they require an adequate knowledge of extreme events of high return periods (Laheetharan, 2014).

2.3.Flood Estimation Methods

According to (Mengistu, 2018) there are two commonly used flood frequency analysis methods which are statistical and derived. Statistical flood frequency analysis is the modern method of determining the frequency of peak stream flows. This method of frequency analysis involves fitting extreme value probability distribution functions to the historical record of annual maximum floods while the derived techniques of flood frequency analysis involve the quantification of the processes that govern flood behavior which is less dependent upon historical data.

2.4.Flood Frequency Models

According to (Mayooran & Laheetharan, 2014), modeling of extreme flood events is a fundamental part of flood frequency analysis. Several probability models have been developed to describe the distribution of annual extreme floods at a single site. However, the choice of a suitable model is still one of the major problems in engineering practice since there is no general agreement as to which distribution, or distributions, that should be used for the frequency analysis of extreme floods. The selection of an appropriate model depends mainly on these evaluations that yield very different conclusions than that of previous researches on this subject. In general two types of models are commonly applied for frequency analysis of flood data. These are annual maximum (AM) model and partial duration (PD) model.

2.4.1. Annual Maximum Model

Annual maximum (AM) model is easy to apply and, in general guarantees that the chosen flood peak events are independent because only the peak event in each year of record is considered (Keffale, 2011). Moreover, AM series are directly related to the commonly used concept of return periods for design flood. However, the use of an AM series may involve some loss of information. For example, the second or third peak within a year may be greater than the maximum flood in other years, and yet they are ignored. AM series is widely and commonly used model by different researchers for the purpose of extreme flood analysis. This is mainly due to the need to check for the independence of the PD series, and the question mark in relation to the choice of the threshold or the number of events to be chosen. In addition, the exceedance probability of the PDF, and in turn the corresponding return period, will not conform to the commonly recognized ones derived from the AM series.

2.4.2. Partial Duration Model

In partial duration series all peaks above a certain base value are considered (Demissie, 2008) The annual maximum model limitation is avoided in the partial duration (PD) or peak over a threshold (POT) model where all peaks above a certain base value are considered. The base is usually selected low enough to include at least one event in each year (Roa & Hamed, 2000) as cited by (Keffale, 2011). This usually produces much longer series than the AM, as more than one event per year could be chosen. The PD or POT model, however, is limited by the fact that observations may not be independent which violets the assumption of independence for statistical analysis. An objection to the use of the partial-flood series is that the floods listed may not be fully independent events; closely consecutive flood peaks may actually be one flood. The greater number of floods listed in the partial-duration series might be an advantage, particularly if the record is short. However, most of the additional floods are low discharge and plot where the curve is well denned; the high-discharge floods are generally identical with those in the annual-flood series (Dalrymple, 1960) Therefore, to avoid the problem of dependency data, annual maximum (AM) series model was selected as relevant model for frequency analysis of extreme flood series at different duration in this study.

2.5.Regionalization

Regionalization is a way of grouping of river basins into homogeneous regions. In other words, regionalization means identification of homogeneous regions, which contain stations of similar flood producing characteristics (Ayalew, 2018).

Regionalization, in the context of RFFA, refers to identification of homogeneous regions through homogeneity test and selection of appropriate frequency distribution for the identified region and stations. There is no universally accepted objective method of regionalization. This is due to the complexity of factors that affect the generation of floods. Several attempts have been made by different researchers to identify hydrologically homogeneous regions based on either geographical considerations or flood data characteristics, or a combination of both (Demissie, 2008).

2.5.1. Identifying Hydrological Homogeneous Regions

Homogeneity implies that regions have similar flood generating mechanism. A more Specific definition of a homogeneous region is that region which consists of sites Having the same standardized frequency distribution form and parameter (Demissie, 2008). Hydrologically homogeneous regions consist of regions that subdivide a larger area, grouped based on the similarity of their hydrological characteristics, considering, for example, the flow behavior, the physical and climatic aspects as cited on (Coelho, et al., 2018)

2.5.2. Homogeneity Tests Statistical Method

A homogeneity test based on L-moments is likely to provide more hydrologically and statistical meaningful groups. The L-moments, the one proposed by Hosking and Wallis (1993) seems to be the best viable option.

In general the following are advantage of L-moments: According to (Cunnane, 1989).

I. Compared to conventional moments, L-moments can characterize a wide range of distributions

II. Sample estimates of L-moments are so robust that they are not affected by the presence of outlier in the dataset.

III. They are less subjected to bias in estimation

IV. L-moments yield more accurate estimates of the parameters of a fitted distribution. Even sometime**s** parameter estimated from samples is more accurate than maximum likelihood.

This is used in this study to assess the degree of homogeneity among sites within the region

2.6. Statistical Distributions

Many different distributions and parameter estimation procedures have been tested and recommended around the world as summarized by Cunnane (1989). Some of the commonly used distributions for modeling annual maximum flood series include extreme value type 1 (Ev1), General Extreme Value (Gev), Extreme Value Type 2 (Ev2), Two Component Extreme Value, Normal, Log Normal (Ln), Pearson Type 3 (P3), Log Pearson Type(Lp3), Gamma, Exponential, Weibull, Generalised Pareto And Wakeby (Rahman & Ataur, 2010).

2.6.1. Goodness of Fit Tests

Goodness of Fit test is essential for checking the adequacy of probability distributions to the recorded series of AMD in the estimation of MFD (Vivekanandan, 2015). Studies show that there is no specific method for selecting appropriate probability distributions for hydrological data. Thus, choosing the best statistical distribution is the most important factor in frequency analysis. Therefore, different distributions must be used and then, the most appropriate distribution of data should be selected. Generally, selecting the appropriate probability distribution is based on goodness of fit tests. The procedures of goodness of fit investigate the consistence of observational data with probability distribution (Amirataee, 2014).

2.6.2. L-Moment

Most regional flood frequency analysis procedures attempt to fit to the data a distribution whose form is specified apart from a finite number of undetermined parameters. Sample moment statistics, particularly skewness and kurtosis are often used to judge the closeness of an observed sample to a postulated distribution (Hosking and Wllis, 1997).

L-moments are improvements over ordinary product moments. They are used to characterize the shape of a frequency distribution and estimate the parameters of this distribution, especially for a small size of environmental data (Kossi, et al., 2016).

L-moments have simple interpretations as measures of the location, dispersion (scale) (L-CV), skewness (L-CS) and kurtosis (L-CK) of the data sample similar to the conventional moments (Hosking, 1990). Generally, L-moments are more robust to extreme values in the data and enable more secure inferences to be made from small samples about an underlying probability distribution (Weshah, 2016).

2.7.Method of Parameter and Quintile Estimation

2.7.1. Parameter Estimation

Fitting a distribution to data sets provides a compact and smoothed representation of the frequency distribution revealed by the available data, and leads to a systematic procedure for extrapolation to frequencies beyond the range of the data set. When flood data from a given site is assumed to follow a certain distribution, the next step is to estimate the parameters of that distribution so that the required flood magnitudes can be calculated with the fitted model.

Several general approaches are available for estimating the parameters of a distribution (Bogaard & Winsemius, 2008). These methods are Probability-weighted moments, Method of moment, Method of maximum likelihood, L-Moment method.

a) Probability Weighted Moments

PWMs are useful in deriving expression for the parameters of distributions whose inverse forms X=X (F) can be explicitly defined. In particular they allow parameter estimates to be obtained for distributions. Methods of parameter estimation are obtained in this method by equating moment of the distribution with the corresponding sample moment of observed data. For a distribution with parameter K, the first K sample moments are set equal to the corresponding population moments. The resulting equation is then solved simultaneously for the unknown parameters. Parameter estimation by PWM, which is relatively new, is as easy to apply as ordinary moments is usually unbiased and is almost as efficient as method of maximum likelihood (ML). Indeed in small samples PWM may be as efficient as ML. With a suitable choice of distribution PWM estimation also contributes to robustness and is attractive from that point of view (Cunnane, 1989).

b) Method of Moment

It is one of the most commonly used methods of estimating parameters of a probability distribution. The estimates of the parameters of a probability distribution function are obtained by equating the moments of the sample with the moments of the probability distribution function. It provides simple calculation, but higher order moment estimates are biases (Wallis, et. al. 1974). Parameter estimation by MOM is known to be biased and inefficient especially with three-parameter distribution but it is more preferable for two parameter distribution types as cited in (Ketsela, 2017).

Moment of method is the essence of moment method of parameter estimation lies in the fact that we put the sample moments and the corresponding theoretical moments into equation. We can combine the general and the central moments. This method of estimating parameters is indeed very easy to use, but it is very inaccurate. In particular, the estimate of theoretical variance by its sample counterpart is very inaccurate. However, in the case of income and wage distribution we work with large sample sizes, and therefore the use of moment method of parameter estimation may not be a hindrance in terms of efficiency of estimators (Bílková, 2012)

c) Maximum Likelihood Method

Estimation by the maximum likelihood (ML) method involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations. The parameter estimates that maximize the likelihood function are computed by partial differentiation with respect to each parameters and setting these partial derivatives equal to zero and finally solve the resulting set of equations simultaneously. The equations are usually complex as a result of this difficulty; the solution set may not properly found (Cunnane, 1989)

2.7.2. Quintile Estimation

After selection of best-fit distribution methods and parameters were estimated, the desired quintile estimates are computed from the statistics of the adopted distribution. Flood quintile estimates are required at locations where stream flow series are very short or where no data are available, making a direct estimation impossible (Crochet, 2015).

In the case of major hydraulic structures flood estimates are sometimes requested for very long return period depending on their record data, up to 10000 years or more. It may also be desired to estimate the return period of a deterministically derived probable maximum flood. The reliability of extrapolating of flood frequency curve to such return periods is generally extremely low a minor change in the data series or in the filling distribution can make huge differences to the estimates. Where such estimates are required, it is advisable to consider additional studies using methods other than standard frequency analysis (Rao and Hammed, 2000) as cited by (Mekoya, 2010).

The quantile (X_T) which correspond to different return periods T can be computed by using the selected probability distribution. According to Rao and Srinivas (2008), the return period is related to the probability of non-exceedance (F) by the relation; F= (1−1/T) where; F= F (X_T), is the probability of having a flood of magnitude X_T or smaller. The problem then reduces to evaluating X_T for a given value of F. In practice, two types of distribution functions are encountered. The first type is that which can be expressed in the inverse form X_T= φ (F). In this case, X_T is evaluated by replacing ϕ (F). In the second type, the distribution cannot be expressed directly in the inverse form X_T =φ (F).

2.8. Estimation of Index-Flood for Standardization

The estimation of the index flood plays a major role in design flood prediction and it requires merging statistical and physical hydrology concept to reduce the present uncertainty. The basic idea behind the index-flood method is to increase the reliability of the frequency characteristics within a region. Within a hydrologically homogenous area, a number of hydrometric stations have been operating and recording the effect of the same meteorological factors then a combination of these records will provide, not a longer record, but a more reliable record. The index-flood method is based on the hypothesis that floods from different catchments with in a region normalized by their mean annual flood come from a single distribution. An essential prerequisite for this procedure is the standardization of the flood data from sites with different flood magnitudes. The most common practice is to standardize data by division of quintile data with average (Admasu, 1989).

2.9. Derivation of Flood Frequency Curve

The following steps were adopted in order to develop the flood frequency curve.(1) Standardizing the flow duration curve for all gauged river basins by dividing the empirical flow duration curve by the index stream flow; the index stream flow in this case was the average annual maximum stream flows of the region for all the stations with records; (2) A graphical regional dimensionless flow duration curve is then obtained by averaging the standardized empirical flow duration curve of all gauged river basins in the study region. The flow duration curve for ungauged catchment located within the study area was then estimated as the product of the dimensionless regional flow duration curve and an estimated index stream flow for the catchment (Joel & Jackson, 2011).

3. MATERIALS AND METHODS

3.1.Description of the Study Area

The study area is found in South Eastern Ethiopia covering a large part of the country‘s land mass. The basin is found in the two largest regional state of the country; the Oromiya regional state in the North West and the Somali Regional State in the South East. There are also two regions that contribute their part for the basin (i.e. North Eastern part of the SNNP and the whole Harari regional state). The higher elevation area is found in Oromiya regional state which is the major contributor of the surface water of the basin. On the other hand the lowest elevation part is found in Somali regional state, which is south and south eastern part of the basin. Geographically, the study area is bounded between latitudes 7° 55' 31" N and 9° 34' 59" N latitudes and 39° 41' 38" E and 42° 28' 11" E longitudes having areal extent of about 10247 sq. km.

The WSRB can be accessed by the Addis Ababa - Dire Dawa main asphalt road and Ethio-Djibouti railway. Additionally, it can also be reached by Addis Ababa-Adama- Assela, all weather roads, Addis Ababa-Shashemene- Kofele-Dodola-Adaba-Robe all weathered roads and a number of dry weather road like (Babile- Fik- Hamere- Imi- Gode) networked starting from the main road Addis Ababa- Harar.

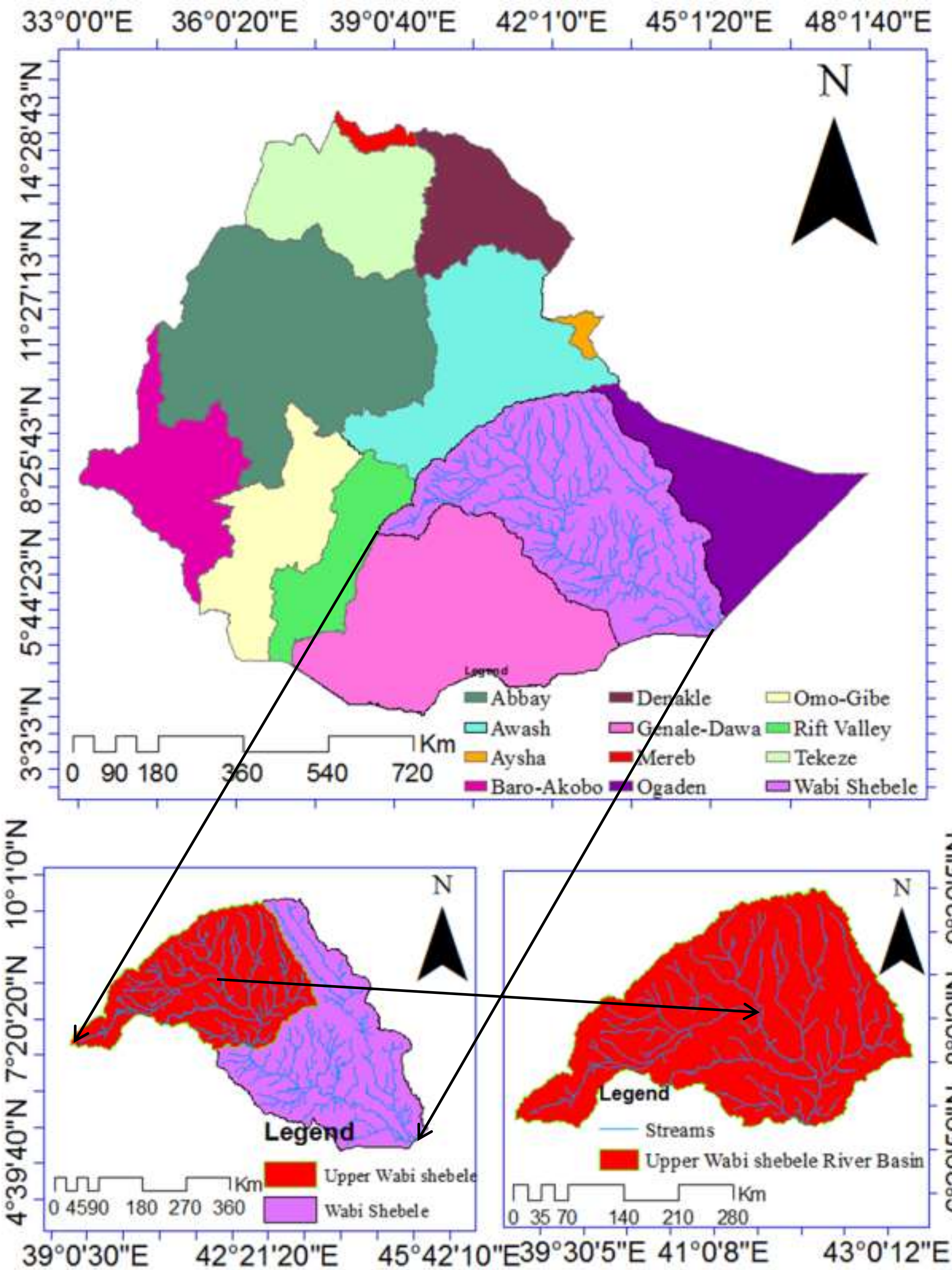

Figure 3.1 Map of Study Area

3.1.1. Climate of the study area

Water is indispensable for life, but its availability at a sustainable quality and quantity is threatened by many factors, of which climate plays a leading role. Climatic elements such as precipitation, temperature, humidity, sunshine and wind are affected by geographic location and altitude. Ethiopia in general, and the basin in particular being near the equator and with an extensive altitude range, has a wide range of climatic features suitable for different agricultural production systems. Climatic heterogeneity is a general characteristic of the country as well the basin. (FAO, 2006) .This basin is known generally for its wide range of variation of climate and primarily because of climatic factors most of the crop production in the basin is in the highland areas as cited by (Tesema, 2015).

3.1.2. Soil Types

The wide ranges of topographic and climatic factors, parent material and land use have resulted in extreme variability of soils (FAO, 1984). In different parts of the country, different soil forming factors have taken precedence. According to the Ministry of Agriculture about 19 soil types are identified throughout the country (FAO, 2006). Soils About 50% of the soils in the UWSRB are soils of calcarious or gypseous di erentiation types. Vertisols comprise 12% of the basin covering significant areas at the middle Study Area belt (Kebede, 2015).

3.1.3. Hydrology

Hydrologic time series almost always exhibit seasonality due to the periodicity of the weather. This arises greatly from seasonal variations in precipitation volume, as well as the rate of evapotranspiration (Githui & Bauwens, 2017).

The volume of water discharge of surface drainage of upper Wabi Shebelle basin is determined by climatic condition, while its relief controls the flow pattern of rivers. High seasonal fluctuation and variation of climatic condition characterize precipitation of the basin. So, the volume of discharge is subjected to high fluctuation, sporadic flash of flood as a result of torrential tropical rains in summer and dry channels for some rivers and streams in dry season (Tesema, 2015).

3.1.4. Land Use Land Cover

The actual meaning of land use is the way in which land is used by people in an area to produce what is needed by the people for use through the involvement of labor, capital, and available technology. However, cultivation has been expanded both in the lowland and highland areas at the expense of natural vegetation cover including forest areas as demands of people changed through time and as land use land cover are dynamics. Different land cover types characterize the land cover of the basin (MoWIE, 2007).

In WSRB, only a small percentage of the north western area is intensively and moderately cultivated land. Large parts of the area are bush, wooded or open grasslands. The northeastern part of the lowlands is covered by shrubs and bush and is used mainly for pasture; crop cultivation is not common in this area (Mulugeta, 2011).

3.2.Materials and Tools

A. Arc-GIS

Arc Map used to clip the Upper Wabi-Shebelle river basin from Ethio-basins. Arc-GIS View is used for representation of sub-stations of the basin and delineation of homogeneous regions. It is also used for regionalization of the homogeneous regions.

B. Easy Fit Software

This software allows the researcher to perform statistical analyses of hydrologic data. In general Easy fit software is used for selection of suitable probability distribution for each selected stations; parameter estimation and Goodness of Fit tests for each station.

C. Microsoft Excel Spread Sheet

MS-Excel used for transposing daily data, to calculate the various statistical parameters of hydrological and raw data available and infilling of missing data using regression method by using nearby station. Frequency curves return period, and quintiles are also plotted.

D. Matlab

It is used to check the homogeneity test of a region by computing discordance value. Using the value of linear coefficient variation, linear coefficient of skewness, and linear coefficient kurtosis in the mat- lab software it is possible to determine the value of discordancy of the identified region data to check whether it is homogeneous or not.

3.3.Data Collection and Analysis

Any research may have its own procedural activities which were followed by different researchers in order to achieve his or her objectives because following certain procedures can lead to better output of the paper. In this study collecting of the hydrological(stream flow) data and Digital Elevation Model (DEM) data which are required for flood frequency analysis of the upper Wabi-Shebelle river basin is the first task. Stream flow data are used to indicate the present hydrologic conditions and the discharge amounts of a watershed and to check methods for estimating present and future conditions (Amend, 2015). Digital Elevation Model (DEM) data were used for identification of homogenous region and to delineate the study area. Therefore in order to achieve the final objective of the research, the researcher was followed the following work procedures starting from data collection up to final analysis and output.

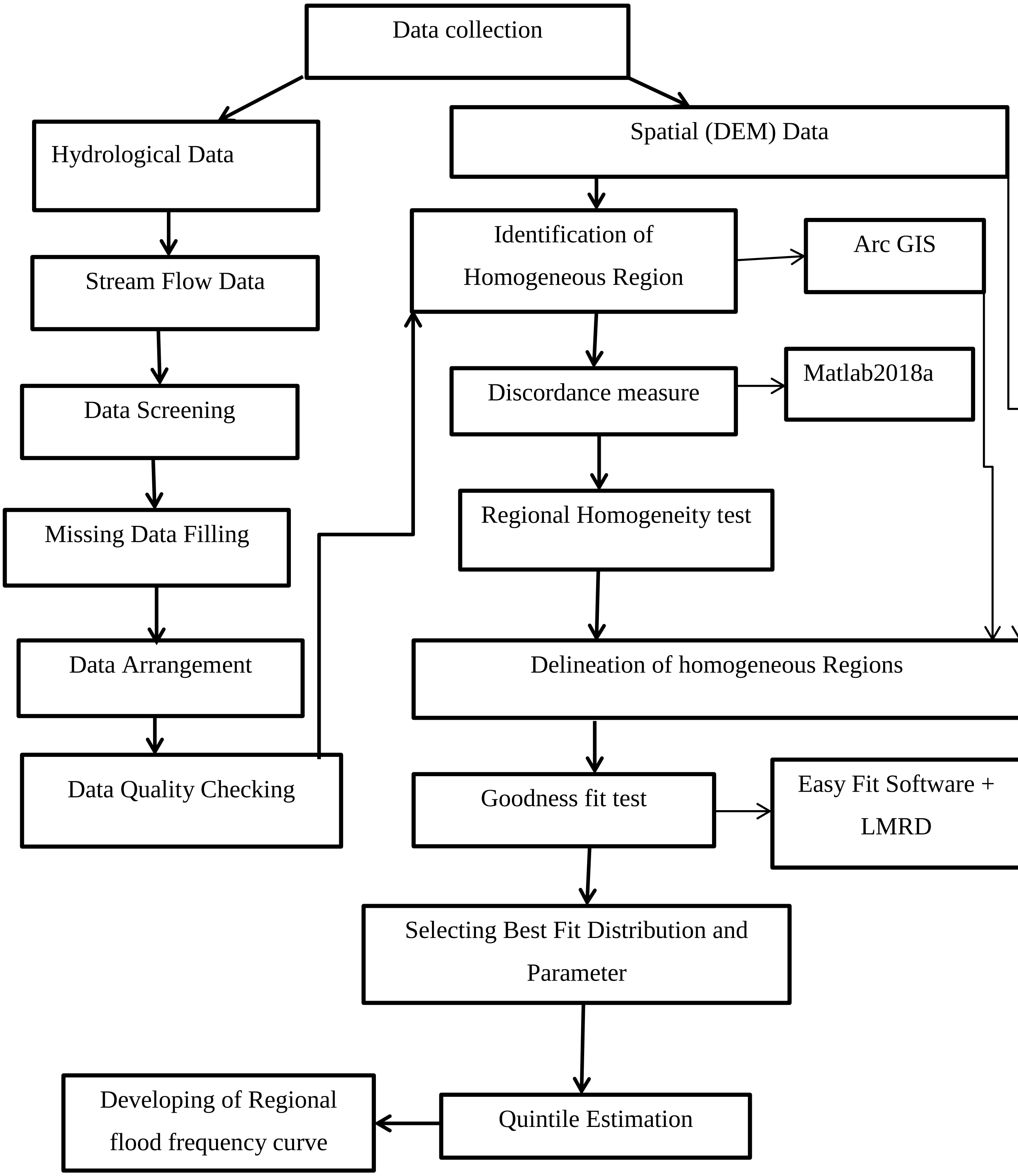

Figure 3.2 Work flow diagrams

3.3.1. Source and Availability of Data

The Hydrological and DEM (digital elevation model) data of Upper Wabi-Shebelle River Basin were collected from MoWIE from hydrology and GIS department. The annual maximum stream flow hydrological data was used for flood analysis and DEM data was used to delineate the identified homogeneous and to specify the location of the gauging stations in the river basin. The 16 stations stream flow data was collected from MoWIE office.

Table 3.1 the site characteristics of stations used in detail analysis

S.No	Name of Gauging station	Gauging station Location	Coordinates		Area coverage (Km^2)	Record Period (Year)	Length (Year)
			Latitude	Longitude			
1	Ukuma	Nr.Dodola	70100	390300	137	1999-2014	16
2	Wabi	at Birdge	70100	390200	1035	1999-2014	16
3	Assassa	Nr.Assassa	70600	391300	68.1	1985-2009	25
4	Robi	At Shewrobit	75100	393800	263	1998-2011	14
5	Dawe	Nr.Gara Muleta	92000	414800	344	1993-2002	10
6	Weiyb	Nr.Agarfa	72200	394800	7719	1998-2011	14
7	Lelisso	Nr.Adab	70000	392300	135	1993-2008	16
8	Maribo	Nr.Adaba	70100	392000	185	1985-2009	25
9	Harero	at Herero	70000	391900	133	1985-2009	25
10	L.Alamaya	at Alemaya	92400	420100	50	1980-2002	23
11	Funura	Nr Adaba	70100	392500	7.5	1993-2002	10
12	Lake Adel	at Adel	92400	4101000	48	1980-2002	23
13	Madahidu		83925	414420	123	1999-2015	17
14	Jaweis	Nr.Bedassa	8 54 00	404700	21.5	1993-2015	23
15	Robi	Nr.Robe	75100	393800	175	1980-2010	21
16	Hamaressa	Nr.Harer	92000	420500	56	1981-2004	24

3.3.2. Data Screening

Data screening is the process of ensuring our data is accurate and ready before we conduct further statistical analyses. Data must be screened in order to ensure the data is useable, reliable, and valid for testing causal theory. Before entering into analysis the collected data was screened for their continuity and gross error.

In this study, stream flow data were used from gauging stations in the Upper Wabi-Shebelle River Basin. After the data screening was done the total stations which were used for further analysis become 13 and three of the stations Hamaressa, Jaweis and Robi at Robe were rejected due to their poor data availability. Because different scholars state that if one station has many years missed data consecutively or if the length of the data is less than 10 years rather than using it, it is advisable to reject station from further analysis. For instance according to the guideline for FFA allows a minimum 10 years flow data (USWRC, 1976) (Hussen, 2016). The above three stations (Hamaressa, Jaweis and Robi at Robe) have more than ten years conclusive missing data due to this they are rejected from further analysis and the following stations are selected screened out for the next step.

Table 3.2 List of stations which are ready for further analysis after screening

S.No	Name of Gauging station	Gauging station Location	Coordinates		Area coverage (Km2)	Record Period (Year)	Length (Year)
			Latitude	Longitude			
1	Ukuma	Nr.Dodola	70100	390300	137	1999-2014	16
2	Wabi	at Birdge	70100	390200	1035	1999-2014	16
3	Assassa	Nr.Assassa	70600	391300	68.1	1985-2009	25
4	Robi	At Shewrobit	75100	393800	263	1998-2011	14
5	Dawe	Nr.Gara Muleta	92000	414800	344	1993-2002	10
6	Weiyb	Nr.Agarfa	72200	394800	7719	1998-2011	14
7	Lelisso	Nr.Adab	70000	392300	135	1993-2008	16
8	Maribo	Nr.Adaba	70100	392000	185	1985-2009	25
9	Harero	at Herero	70000	391900	133	1985-2009	25

S.No	Name of Gauging station	Gauging station Location	Coordinates		Area coverage (Km2)	Record Period (Year)	Length (Year)
10	L.Aalamaya	at Alemaya	92400	420100	50	1980-2002	23
11	Funura	Nr Adaba	70100	392500	7.5	1993-2002	10
12	L.Adel	at Adel	92400	4201000	48	1980-2002	23
13	Madahidu		83925	414420	123	1999-2015	17

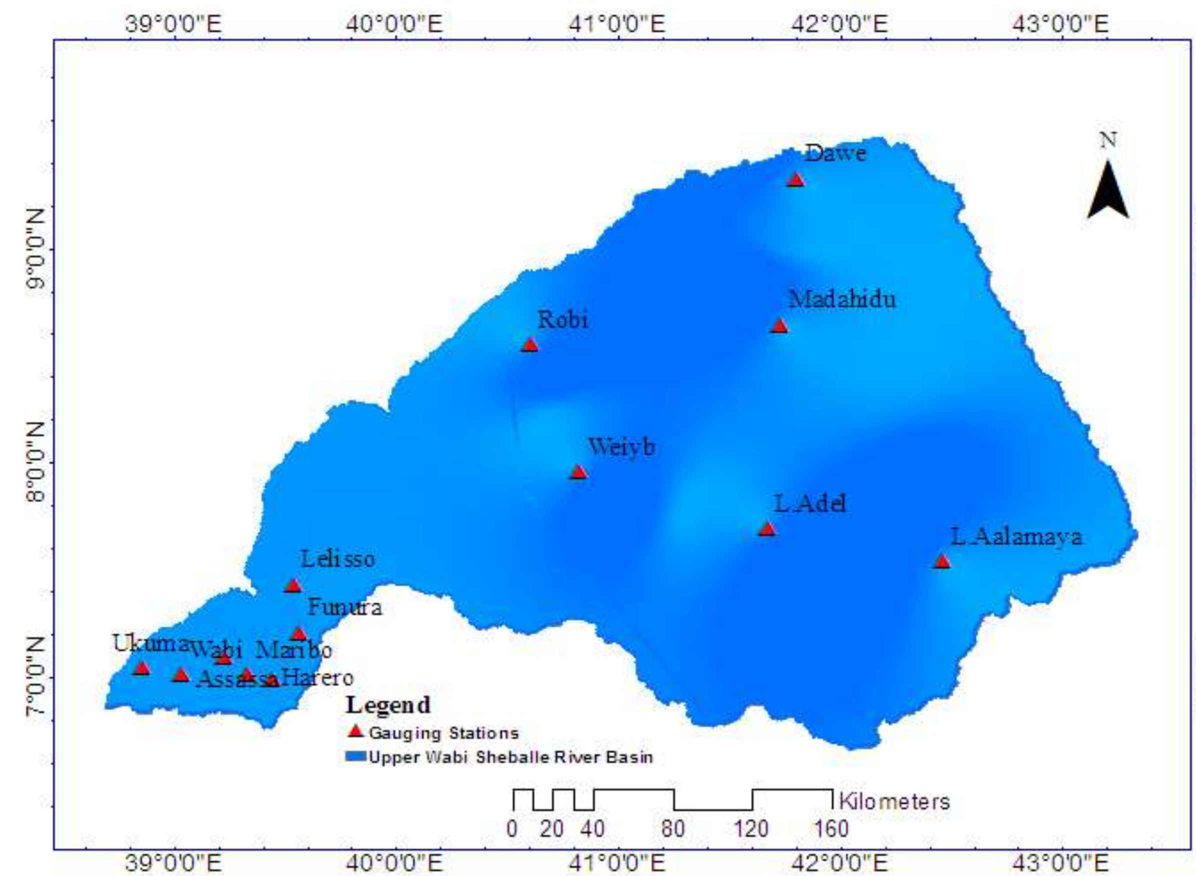

Figure 3.3 Location of Gauging Station

3.3.3. Missed Data Infilling

Hydrological missing data is a common issue for hydrologists as it poses a serious problem for many statistical approaches in hydrology which require complete data sources since missing data is often harmful beyond reducing statistical power. For reasons of convenience, researchers often resort to simple solutions to deal with missing data such as simply discarding observations characterized by missing data or by replacing missing data with a statistical methodology. Despite its convenience, discarding is suboptimal as it reduces the quality of the conclusion to be drawn when analyzing the data (Yongbo, 2017).

Actually, a variety of statistical techniques are available to treat missing data. The continuity of the record may be broken with missing data due to many reasons such as: absence of recorder, carelessness of the observer, break or failure of instruments, reallocation of instrument. Therefore, it is often necessary to estimate these missing records. The missing data can be estimated by using the data of neighboring stations. There are different methods used for filling the missing flow data records of a given gauging station. Some of these are:-

i. Linear Regression Method
ii. Arithmetic Average Method
iii. Graphical Correlation Method
iv. Normal Ratio Method

I. Linear Regression Analysis

This method is a commonly used technique for estimation of significant missing observations as accurate as possible (Elshorbagy et al., 2000). Reference variables for regression analysis may be of the same type (e.g. flow vs. flow) or different (e.g. flow vs. climate variables or flow vs. physical catchment characteristics). Simple linear regression has been applied to fill missing stream flow values using nearby flow gauging station observations. The equation for linear regression is given as:

$$\boldsymbol{y} = \boldsymbol{a}\boldsymbol{x}+\boldsymbol{b} \quad \ldots\ldots \quad 3.1$$

Where X-average monthly run-off depth (mm)

Y-average monthly stream flow (m3/sec) and a & b-Coefficients

In this study, regression with correlated stations by scatter plot is used to obtain missing daily flow, using nearby station by deriving a common equation using scatter graph, $0.6 \leq r \leq 1$, as well as for short length of missing data arithmetic average method also used. The researcher has selected this method due to the following reasons: -

It is the most widely used method when compared to other method for large data. Estimation of significant missing observations as accurate as possible, It is applied by creating a correlation with the nearby station. Due to this reason for this study Linear Regression method was selected for missing data filling by using XLSTAT 2019 software was used.

3.4. Data Quality Control

Conduction of data quality control is an essential activity in regional flood frequency and other statistical analysis because some errors may exist in the stream flow data observation. The error may exist due to misplacing of decimal numbers, very huge unrealistic numbers and negative flow records due to recorder mistake in some cases and reallocation of recording device and luck of calibration of gauging instruments. Performing of data quality control on observed data before using it for our necessary purposes is a crucial step. Engineering studies of water resources development and management depend heavily on hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system (Hall E. D., 1990)

The following approaches were considered to check stream flow data quality.

3.4.1. Test for Randomness and Independence

The basic assumptions in statistical flood frequency analysis are the independence and stationary of the data series. By principle, it is known that FFA is carried out when the at-site data are independent and identically distributed conditions satisfied (Hosking and Wllis, 1997).

In few hydrologic time series studies, no distinction is made between persistence and randomness. Therefore, the tests to examine the randomness of a hydrologic time series are used for detecting both trend and persistence. Generally, randomness or non-persistence is defined as the independence among data in a hydrological time series. On the contrary, the series is called persistent if the data in the series are dependent on each other (Jha, Deepesh, & Madan, 2006).

It is assumed that all the peak magnitudes in the AM series are mutually independent in the statistical sense. In this study, the correlation coefficient was applied to verify the independence of the data of the selected hydrological stations. According to Dahmen and Hall (1990), the lag-1 serial correction coefficient, R1, defined as follows.

$$R1 = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(x_{i+1}-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad \ldots\ldots 3.2$$

Where: X_i is an observation,

$X_{i+1,}$ is the following observation and n is the number of data.

After computing R1, the test hypothesis is H0: R1= zero (that there is no correlation between two consecutive observations) against the alternative hypothesis, H1: R1< > 0. Anderson (1942) defines the critical region, R1 at the 5% level of significance as: (−1, (LCL) R1 (UCL), 1) and the above equation 3.2 gives:

The upper confidence limit, UCL, for R1 as:

$$UCL(R1) = \frac{(-1+1.96(N-2)^{0.5}}{N-1} \quad \ldots\ldots 3.3$$

The Lower confidence limit, LCL, for R1 as:

$$LCL(R1) = \frac{(-1-1.96(N-2)^{0.5}}{N-1} \quad \ldots\ldots 3.4$$

To accept the hypothesis H0: R1=0, the value of R1 should fall between the UCL and LCL. Applying this condition to the time series: LCL (R1) <R1< UCL (R1) is satisfied for the all stations. Thus, no correlation exists between successive observations. The data are independent and there is no persistence in the time series.

Since, all the statistical values are less than the critical test the statistical values of this data in the stations are independent. It is usually that all the peak magnitudes in the AM series are mutually independent in the statistical sense.

According to the equation numbers 3.2-3.4 the randomness and independence of the collected hydrological data analysis was done and it is tabulated as shown in the following table 3.3. The result indicated that the data is independent with time series since R1 value is between UCL and LCL.

Table 3.3 Results of randomness and independency of AMF data

S.NO	Station Name	LCL (R1)Value	R1 Value	UCL(R1) Value
1	Furuna	-0.573	0.179	0.439
2	Lake Adel	-0.764	-0.182	0.542
3	Madhadu	-0.463	0.464	0.482
4	Ukuma	-0.573	0.269	0.439
5	Wabi below bridge	-0.573	-0.225	0.439
6	Assassa	-0.442	-0.118	0.358
7	Robi	-0.621	-0.144	0.467
8	Dawe	-0.573	0.404	0.439
9	Weiyb	-0.621	-0.282	0.467
10	Lelliso	-0.573	-0.248	0.439
11	Maribo	-0.442	0.088	0.358
12	Herero	-0.452	0.36	0.365
13	Lake Alemaya	-0.463	0.362	0.372

3.4.2. Test for consistency and stationary

Before conducting the analysis, the series should be scrutinized for possible errors or inconsistency and for any indication that contravene basic statistical assumption (Rao & Hamed, 2000). Specific statistical test for independence are incorporated in various computation in frequency analysis. When applied to short series, however, commonly used tests can be misleading: they may indicate no independence when the events are actually independent, or failed to indicate it when serial correlation long lags is in fact present as cited (Ketsela, 2017).

3.4.3. Consistency of Data

Consistency is the most widely used technique for evaluating a time series data record, such as stream flow and rain fall data. The reliable of estimates of population quintile derived from frequency analysis depends in the first instance on the data series used in the analysis. Before conducting the analysis, the series should be scrutinized for possible errors or inconsistency and for any indication that violate basic statistical assumption.

The relative consistency of time series from different stations is often irrelevant, and the data in these series can very well be suitable for independent use if they are absolutely consistent and homogeneous (Dahmen, 1990). For this study test for absence of trend and stability of variance and mean are used to check consistency of data by Spearman's Rank-Correlation Method for absence of trend and F-test for the stability of variance, t-Test for stability of mean are the methods.

3.4.3.1. Test for Absence of Trend

It is Criteria of test against absence of trend in dispersion characteristics. Such tests are designed to test hypotheses for randomness or absence of a trend in dispersion characteristics. Respective studies are carried out for different sample sizes with the tested hypothesis being true.

Spearman's Rank-Correlation Method

After plotting a time series, one must be sure that there is no correlation between the order in which the data have been collected and the increase (or decrease) in magnitude of those data. It is common practice to test the whole time series for absence of trend. Although one can choose to test only specific periods of the time series if these show signs of a possible trend, we advise against testing periods that are too short (ten to fifteen years). To verify absence of trend, we recommend using Spearman's rank-correlation method. It is simple and distribution-free, i.e. it does not require the assumption of an underlying statistical distribution. Yet another advantage is its nearly uniform power for linear and non-linear trends (WMO 1966) as cited on (Hall E. D., 1990). The method is based on the Spearman rank-correlation coefficient, Rsp, which is defined as:

$$R_{sp} = 1 - \frac{6 * \sum_{i=1}^{n} Di * Di}{n * (n * n - 1)} \qquad \ldots 3.5$$

Where n is the total number of data, D is difference, and 'i' is the chronological order number. The difference between rankings is computed with: $Di = Kx - Ky$,

Where Kx, is the rank of the variable x, which is the chronological order number of the observations. The series of observations' y' is transformed to its rank equivalent, Ky, by assigning the chronological order number of an observation in the original series to the corresponding order number in the ranked series y. If there are ties, i.e. two or more ranked observations, y, with the same value, the convention is to take Kx as the average rank. One can test the null hypothesis, H: R = 0 (there is no trend), against the alternate hypothesis, H: R, < > 0 (there is a trend), with the test statistic:

$$t_t = Rsp\left[\frac{n-2}{1-Rsp*Rsp}\right]0\cdot5 \quad \text{……………………………………………………..3.6}$$

Where t, has flow t-distribution with V = n-2 degrees of freedom. Flow t-distribution is symmetrical around t = 0. Appendix D contains a table of the percentile points of the t-distribution for a significance level of 5 per cent (two-tailed). (Incomplete tables, i.e. those listing only positive t-values and upper significance levels, are the rule in most statistical textbooks. One should therefore keep in mind that t {v,p} = -t{v, -p} when using such tables.) At a significance level of 5 per cent (two-tailed), the two-sided critical region, U, of t, is bounded by: {- ∞,t{v,2.5%}}U {t{v,97.5%},+∞) and the null hypothesis is accepted if t, is not contained in the critical region. In other words, the time series has no trend if t{v,2.5%} < t, < t{v,97.5%}. If the time series does have a trend, the data cannot be used for frequency analyses or modeling. Removal of the trend is justified only if the physical processes underlying it are fully understood, which is rarely the case.

The collected data was checked for absence of trend by using equation 3.5, 3.6 and appendix C. As it is shown below in table 3.4 the trend analysis result indicated us that the value of t-distribution is bounded by t {v, 2.5%} < t, < t {v, 97.5%} which implies the data have not a trend for the time series.

Table 3.4 Results of trend analysis

Station Name	V	t_t ,2.5%	t_t value	t_t, 97.5%
Furuna	14	-2.145	-2.06408	2.145
Lake Adel	21	-2.08	-1.4694	2.08
Madhadu	15	-2.131	0.362294	2.131
Ukuma	14	-2.145	1.699953	2.145
Wabi below bridge	14	-2.145	1.145118	2.145
Assassa	23	-2.069	1.919218	2.069
Robi	12	-2.179	2.138365	2.179

Station Name	V	t_t ,2.5%	t_t value	t_t, 97.5%
Dawe	8	-2.306	0.725578	2.306
Weiyb	12	-2.179	-0.35975	2.179
Lelliso	14	-2.145	0.376051	2.145
Maribo	23	-2.069	2.03001	2.069
Herero	24	-2.064	0.308602	2.064
Lake Alemaya	21	-2.08	1.4266	2.08

3.4.3.2. Tests for Stability of Variance and Mean

A. F-test for the stability of variance

In addition to testing the time series for absence of trend, one must test it for stability of variance and mean. The test for stability of variance is done first. There are two reasons for this sequence: firstly, instability of the variance implies that the time series is not stationary and, thus, not suitable for further use; secondly, the test for stability of mean is much simpler if one can use a pooled estimate of the variances of the two sub-sets. (This is permissible, however, only if the variances of the two sub-sets are statistically similar.) The test statistic is the ratio of the variances of two split, non-overlapping, sub-sets of the time series. The distribution of the variance-ratio of samples from a normal distribution is known as the F, or Fisher, distribution. Even if the samples are not from a normal distribution, the F-test will give an acceptable indication of stability of variance.

$$Ft = \frac{\sigma_1{}^2}{\sigma_2{}^2} \qquad 3.7$$

Where σ_1^2: variance of series one and σ_2^2 variance of series two. The null hypothesis for the test, Ho: $\sigma_1^2 = \sigma_2^2$, is the equality of the variances; the Alternate hypothesis is Hl: $\sigma_1^2 <> \sigma_2^2$. The rejection region, Ft computed, is bounded by: $\{-\infty, F\{v_1, v_2, 2.5\%\}\} \cup \{F\{v_l, v_2, 97.5\%, +\infty\}$

Where $v_1 = n_1-1$ is the number of degrees of freedom for the numerator, $v_2 = n_2-l$ is the number of degrees of freedom for the denominator, and n_1, and n_2 are the number of data in each sub-set.

B. The t-Test for Stability of Mean

The t-test for stability of mean involves computing and then comparing the means of two or three non-overlapping sub-sets of the time series (the same subsets from the F-test for stability of variance). A suitable statistic for testing the null hypothesis, Ho: $\dot{x}_1 = \dot{x}_2$ against the alternate hypothesis, HI: $X_1 <> X_2$, is:

$$tt = \frac{\overline{x_1} - \overline{x_2}}{\left[\frac{(n_1-1)*S^2 1+(n_2-1)S^2 2}{n_1+n_2-2} * \frac{1}{n_1 * n2}\right]^{0.5}} \quad \text{.......................................} 3.8$$

Where n_1 and n_2 is the number of data in the sub-sets, $\overline{x_1}$, $\overline{x_2}$ the mean of the sub-sets, and $\mathbf{s_1, s_2}$ its variance. The test statistic t, is valid for small samples with unknown variances. These variances can, however, differ only because of sampling variability if the t-test is applied in this form. This means that the variances of the sub-sets should not differ statistically: hence' the requirement that the time series must be tested for stability of variance before it is tested for stability of mean. In samples from a normal distribution, t, has a flow t-distribution. The requirement for normality is much less stringent for the t-test than for the F-test. One can apply the t-test to data that belong to any frequency distribution, but the length of the sub-sets should be equal if the distribution is skewed. One can avoid problems from a possibly skewed, underlying distribution by making the lengths of the sub-sets equal, or approximately so. For t,, the two-sided critical region, tt, is: { - ∞,t{v,2.5%}U} {t{v,97.5%},+∞). With v = n,-1+ n_2-1 degrees of freedom, i.e. the total number of data minus 2.If t, is not in the critical region, the null hypothesis, H1: x1 = x2, is accepted instead of the alternate hypothesis, H: $x_1 <> x_2$. In other words, the mean of the time series is considered stable if: t (v, 2.5%} < t, < t (v, 97.5}

In order to use the collected data for hydrological analysis in addition to the above tests like absence of trend test the data should be pass the test of stability of variance and mean. The Upper Wabi-Shebelle River annual maximum flow was checked for its variance and mean stability using equations 3.7 and 3.8.The data satisfied the requirement as shown below in table 3.5 and 3.6 which is the value of Ft is bounded {-∞,F{v_1,v_2,2.5%}}U {F {v_l, v_2, 97.5 %, $_{+\infty}$} for variance and the value of tt is bounded by { - ∞,t{v,2.5%}**U**} {t{v,97.5%},+∞) for stability of mean.

Therefore, there was no trend, and the variance and mean were stable. So the time series of the data is stationary in the sense used for this data screening, and there is no immediate objection to use the data.

Table 3.5 Checking for stability of variance

S.NO	Station Name	Subset I	Subset II	V1,V2	Ft 2.5%	Ft	Ft 97.5%
1	Furuna	1993-2000	2001-2008	7,7	0.200	4.033	4.990
2	Lake Adel	1980-1990	1991-2002	10,11	0.283	2.968	3.620
3	Madhadu	1999-2007	2008-2015	8,7	0.204	1.237	4.530
4	Ukuma	1999-2006	2007-2014	7,7	0.200	3.063	4.990
5	Wabi b. bridge	1999-2006	2007-2014	7,7	0.200	1.184	4.990
6	Assassa	1985-1997	1998-2009	12,11	0.300	2.748	3.280
7	Robi	1998-2004	2005-2011	6,6	0.172	4.974	5.820
8	Dawe	1993-1997	1998-2002	4,4	0.104	4.330	9.600
9	Weiyb	1998-2004	2005-2011	6,6	0.172	0.372	5.820
10	Lelliso	1993-2000	2001-2008	7,7	0.200	0.428	4.990
11	Maribo	1985-1997	1998-2009	12,11	0.300	0.302	3.280
12	Herero	1985-1996	1997-2008	12,11	0.314	3.089	3.180
13	Lake Alemaya	1980-1990	1991-2002	10,11	0.283	0.237	3.620

Table 3.6 Checking for stability of mean

Stations Name	V	t_t , 2.5%	t_t	$t_{t,}$ 97.5%
Furuna	14	-2.145	1.591	2.145
Lake Adel	21	-2.08	-0.983	2.08
Madhadu	15	-2.131	0.399	2.131
Ukuma	14	-2.145	-2.188	2.145
Wabi below bridge	14	-2.145	-1.341	2.145
Assassa	23	-2.069	0.614	2.069
Robi	12	-2.179	-1.258	2.179
Dawe	8	-2.306	0.592	2.306
Weiyb	12	-2.179	-1.221	2.179
Lelliso	14	-2.145	0.393	2.145

Stations Name	V	t_t , 2.5%	t_t	$t_{t,}$ 97.5%
Maribo	22	-2.064	-0.128	2.064
Herero	22	-2.064	2.023	2.064
Lake Alemaya	21	-2.08	1.041	2.08

3.4.4. Data Adequacy and Reliability

The accuracy of statistical mean is a function of the sample size. The data taken for analysis were checked for its adequacy and reliability. Accuracy and adequacy of data were checked and defined in (McCuen, 1998) as cited (Mengistu, 2018).

$$De = \frac{C_v}{N^{0.5}} \quad \text{...} 3.9$$

Where,

De- Standard error

Cv-Coefficient of variation and

N-number of yearly data in the series

The adequacy and reliability of the data was checked using the equation of 3.9. As shown in table 3.7 the whole stations have the standard error below 10%. According to Mc Cuen, (1998) a data is said to be adequacy and reliability if the standard error (De) of the data is below 10%. Therefore the collected data is adequate and reliable.

Table 3.7 Data adequacy and reliability

S.NO	Station Name	Standard Deviation	Average	Coefficient of Variation	De. value
1	Furuna	3.489	9.955	0.3505	0.0876
2	Lake Adel	0.588	0.916	0.642	0.033
3	Madhadu	19.5419	47.4626	0.4117	0.0998
4	Ukuma	2.3525	9.4721	0.2484	0.0621
5	Wabi below bridge	16.3123	46.1386	0.3535	0.0884
6	Assassa	0.4729	1.7465	0.2708	0.0542
7	Robi	5.0254	15.8661	0.3167	0.0847

S.NO	Station Name	Standard Deviation	Average	Coefficient of Variation	De. value
8	Dawe	1.3886	4.8716	0.285	0.0901
9	Weiyb	13.4954	38.5133	0.3504	0.0936
10	Lelliso	4.3367	13.487	0.3215	0.0804
11	Maribo	4.8176	18.8649	0.2554	0.0521
12	Herero	8.2401	17.3608	0.4746	0.0969
13	L.Alemaya	0.7141	1.8017	0.3963	0.0826

3.4.5. Check for Outliers of the Data Series

The Water Resources Council method recommends that adjustments be made for outliers. In a set of annual maximum flood series there is a possibility of outliers being Present. An outlier is an observation that deviates significantly from the bulk of the Data, which may be due to errors in data collection or recording, or due to natural Causes (Rahman, Haddad, Kuczera, & Weinmann, 2009). Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. Procedures for treating outliers require judgment involving both mathematical and hydrologic considerations. For this study L-moment parameter estimation technique was employed. Because Sample estimator of L-moments are so robust that they are not affected by the presence of outlier in the dataset (Moges, 2018).

3.5.Regionalization of Upper Wabi-Shebelle River

Many types of regionalization procedures are available (Chnnanie, 1989). One of the simplest procedures which have been used for along is the index flood method. The index flood method basically takes the assumption that, flood data at different site within a region follow the same distribution except for a scale or an index factor which is a function of the physiographic basin characteristics (Eregno, 2014). In this thesis the regionalization by index flood L-moment method is used to determine the magnitude and frequency of flood quintiles for basins of any size, gauged or ungagged, as long as it is located within a hydrologically homogeneous region.

3.6.Identification of Homogeneous Regions

It is one of the essentials steps in regional flood frequency analysis which the assignment of sites to the region is conducted. A region is a set of sites whose frequency distributions are considered to be approximately the same is the fundamental units of regional frequency analysis. We do not suppose that the sites can be divided into regions within which the homogeneity criterion is exactly satisfied. Approximate homogeneity is sufficient to ensure that regional flood frequency analysis is much more accurate than at site analysis (Hosking & Wllis, 1997).

According to (Hosking and Wllis, 1997) regions need not be geographical, but should instead consist of sites having similar values of those site characteristics that determine the frequency distribution. Suitable site characteristics depend on the kinds of data being analyzed. Latitude and longitude are also site characteristics and may be used surrogates for unmeasured characteristics that vary smoothly with location. The homogeneity of a proposed region should be tested by calculating summary statistics of at-site and comparing between –site variability of these statistics with what would be expected of homogeneity regions. L-moments are suitable statistics for this purpose.

Clustering of sites into homogeneous regions was carried out by applying the hierarchical geographic regionalization technique with the method of L-moments as a guideline for regionalization. The stream gauging stations were grouped into geographically continuous sites such that the response of streams to physiographic variables should be similar. DEM size of 30mx30m the Basin was used to identify site characteristics. This enables stream flow records to be transferred from gauged basins to un-gauged basins within a region.

3.6.1. Site Characteristics

In this study, preliminary IHRs of stations into a certain category are achieved by looking at stations site characteristics. The following site characteristics were used as a preliminary IHR; latitude and longitude, AMF, station area and altitude of the flow gauging station. Then those stations having nearly same kind of characteristics are clustered and set forth to see their parent distribution on LMRD. And finally they are checked for the regional homogeneity.

3.6.2. Method of L-Moment Ratio Diagram

This popular and widely accepted method is used for preliminary selection of distribution for the stations and regions of upper wabi shebelle river basin. Here regional average L-moment statistical value of stations (LCS & LCk), are used and plotted on LMRD for initial parent distribution.

3.6.3. Homogeneity Tests

A homogeneous flood frequency region will contain annual maximum flood populations whose flood frequency relationships have similar slopes on a probability plot. Since the slope of a probability plot is related to the coefficient of variation (CV) of the standardized annual maximum flood series it is reasonable to develop a homogeneity test based upon the regional variability in the site CV's. Such a test would have the advantage of being relatively distribution-free and constitutes the first approach described here. A second, alternative, approach is to select a priori the type of parent distribution applicable to the region and to examine the scatter of the site data about the fitted region-average distribution.

- **Flood Statistics of Upper Wabi-Shebelle River Basin**

Flood statistics of Upper Wabi-Shebelle River basin stations were computed using both conventional moment and L-moment methods. However, L-Moment method is a powerful and efficient method to compute any statistical parameters. Such methods can give unbiased estimation of sample parameters and also cannot be easily influenced with the presence of outliers. (Roa & Hamed, 2000) as cited on (Moges, 2018)

Generally, the statistical parameters computed include: Mean (μ), Standard deviation (σ), Coefficient of variation (CV, LCv), Coefficient of skewness (Cs, LCs), Coefficient of kurtosis (Ck, LCk).

3.6.3.1.Conventional Moment based homogeneity test

Moments about the origin or about the mean are used to characterize probability distributions.

The criterion used to check for regional homogeneity was based on the value of CC. According to the researchers, the higher the values of CV and CC the lower the performance of index flood method for the considered region. According to Lettenmailer (1985), this is due to the dominance of the flood quantile estimation variance by the variance of the at – site sample mean. Hence for better performance of the index flood method, CC should be kept low (Melsew, 1996). In this research also both conventional and L – moments have been used to calculate Cv, LCV and their respective CC, value.

For each site in the delineated regions; the mean $\bar{Q}$, standard deviation (σ) and coefficient of variation (Cv) were given and calculated by Sine and Ayalew(2004), Nobert *et al*.(2014) and Guru and Jha (2016) . In this method to calculate CC values, the procedures are described below.

The mean of AMF of the station:

$$\overline{Qi} = \frac{1}{n} * \sum_{i=1}^{n} Qi \ldots\ldots 3.10$$

The standard deviation of AMF of the station;

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^{n}(Qi-\overline{Qi})^2}{n}} \ldots\ldots 3.11$$

$$CVi = \frac{\sigma}{Qi} \ldots\ldots 3.12$$

Where:

Qi= the flow rate of the station in the region (m^3/s), at site i

$\overline{Qi}$ =The mean flow rate for the region (m^3/s), at site i

σi= Standard deviation for the region, at site i

n = number of a record year

Cvi = Coefficient of variation of a region, at site i

For each region, using the statistic calculated Cv above, the regional mean, Cvi and finally the corresponding CC value using the following relation:

Regional mean: $\overline{cvi} = \frac{1}{N} * \sum_{i=1}^{N} cvi \ldots\ldots 3.13$

Regional standard deviation: $\sigma c = \sqrt{\sum_{i=1}^{N} \frac{(Cvi-\overline{cvi})^2}{N}} \ldots\ldots 3.14$

Combined coefficient $cc = \frac{\sigma c}{\overline{cvi}} < 0.3 \ldots\ldots 3.15$

3.6.3.2. L-Moment Based Homogeneity Test

In regionalization, assumptions must be made about the statistical similarity of the sites in a region. To investigate whether those has been met or not many researchers as Letten mailer (1989), Letten mailer et.al (1987) and Cunnane (1989) have used the values of mean coefficient of variation (CV) and the site – to – site coefficient of variation of the coefficient variation (CC) of both conventional and L – moments of the proposed region (Melsew, 1996) as cited (Moges, 2018).

L – Moments procedures homogeneity test are described below.

$$mo = \frac{1}{n}\sum_{i=1}^{n} Qi \quad \text{.......3.16}$$

$$m_1 = \sum_{i=1}^{n-1} \frac{(J-1)*Qi}{n(n-1)} \quad \text{.......3.17}$$

$$m_2 = \sum_{i=1}^{n-2} \frac{(J-1)\,(J-2)Qi}{n(n-1)(n-2)} \quad \text{.......3.18}$$

$$m_3 = \sum_{i=1}^{n-3} \frac{(j-1)(j-2)(j-3)Qi}{n(n-1)(n-2)(n-3)} \quad \text{.......3.19}$$

Where

- Qi - annual maximum flow (m^3/s) from stations dataset
- n - the number of years, j-rank of data
- mo, m_1 , m_2, and m_3- are L-moments estimator.

The first few moments are:

$$\lambda_1 = m_o \quad \text{.......3.20}$$

$$\lambda_2 = 2m_1 - m_o \quad \text{.......3.21}$$

$$\lambda_3 = 6m_2 - 6m_1 + m_o \quad \text{.......3.22}$$

$$\lambda_4 = 20m_3 - 30m_2 + 12m_1 - m_0 \quad \text{.......3.23}$$

In specific, λ_1 is the mean of the distribution or measure of location; λ_2 is a measure of scale; τ_3 is a measure of skewness, and τ_4 is a measure of kurtosis. L-skewness and L-kurtosis are both defined relative to the L-scale, λ_2; and sample estimates of L-moment ratios can be written as L-Cv, L-Cs, and L-Ck. L-moment ratios are independent of units of measurement and are given by Hosking and Wallis (1997) as follows:

$$\tau_2 = \frac{\lambda 2}{\lambda 1}; = \text{L-cv} \quad \text{.......3.24}$$

$$\tau_3 = \frac{\lambda 3}{\lambda 2} = \text{L-skewness} \quad \text{.......3.25}$$

$$\tau_4 = \frac{\lambda 4}{\lambda 2} = \text{L-kurtosis} \quad \text{.......3.26}$$

Using the above formula step by step the following statistics also computed as follows:

$$\overline{Lcvi} = \frac{1}{n}\sum_{i=1}^{N} Lcvi \quad \ldots 3.27$$

$$\sigma Lcv = \sqrt{\frac{\sum_{i=1}^{N}(Lcvi-\overline{Lcvi})2}{N-1}} \quad \ldots 3.28$$

And then the combined coefficient of the data is computed as follows

$$cc = \frac{\sigma Lcv}{\overline{Lcvi}} < 0.3 \quad \ldots 3.29$$

Therefore the region should be satisfy all the above criterion in order to be homogeneous.

3.6.3.3.Discordancy Measure of Regions

Discordant is used to identify those sites which are grossly discordant with the group as whole. Discordancy is measured in terms of the L-moments of the sites' data. Regarding the sample L-moment ratios of (L-CV, L-Skewness, L-Kurtosis), the site is considered as a point three-dimensional space. If a vector, Ui = ($\tau_2{}^i$, $\tau_3{}^i$, $\tau_4{}^i$)T, which controlled the L-moment ratios for site i, T is the transpose of the vector Ui (Hosking and Wllis, 1997), then the discordancy measure for a site can be defined as follow:

$$Di = \frac{N}{3}(Ui - \overline{U})^T A^{-1}(Ui-\overline{U}) \quad \ldots 3.30$$

$$\overline{U}=\frac{1}{N}\sum_{i=1}^{N} Ui \quad \ldots 3.31$$

$$A=\sum_{i=1}^{N}(Ui - \overline{U})(Ui-\overline{U})^T \quad \ldots 3.32$$

Where:

N-is the total number of sites

Di-discordancy measure

Ui-is defined as a vector containing the L-moment ratios for site i,

$\overline{U}$ı-is the group averages of Ui,

A-sample covariance matrix of Ui

It is declared that for site i to be discordant the value of Di should be exceed from the critical value for a given sites in the group. According to (Hosking and Wllis, 1997) the critical value of the discordancy is given as shown in the following table:

Table 3.8 Critical value of discordancy

Number of sites in region	Critical value	Number of sites in region	Critical value
5	1.333	10	2.491
6	1.648	11	2.632
7	1.917	12	2.757
8	2.14	13	2.869
9	2.329	14	2.971
		>=15	3

(source: (Hosking and Wllis, 1997)

The Discordancy measure for this study was estimated by using matlab2018a software and the discordant value for each region was calculated and comparing with the Critical values for the grouped statons as it is stated in the table 3.8.

3.7. Delineation of Homogeneous Regions

The tool used in delineation of homogenous regions where GIS version 10.6 software. All stations under analysis were identified according to their geographical location (latitude and longitude) on the digitized map of the basins. For each stations the statistical values (LCs, LCk) were computed.

Depending on the statistical values, the geographical and altitude of the basin, the stations can be grouped to form region. In the case of upper Wabi-Shabelle basin, since the basin is found in a great variation of elevation from higher mountainous to the plain area the influence of altitude plays a great role in variation of flood for upper and lower part of the sub-basin. This differ the flood producing characteristics of the stations. Combining the results from the statistical values, and altitude of the area, the flood producing characteristics of the stations and the area can be grouped to form regions. On the digitized map of the basin, all stations under analysis were identified according to their geographical location (latitude and longitude) and statistical value was checked.

The procedure adopted in delineation of homogeneous region comprises the following three steps:

1. Geographic information was used' to identify likely homogenous regions that are geographically continuous and having similar flood producing characteristics.
2. Each region that was identified in step '1' was checked for similarity in the statistics of observed flood data. Based on this step, regions obtained in step "1" were modified.
3. The proposed test of homogeneity was applied to confirm that the delineated regions are statistically homogenous.

3.8.Selection of Regional flood Frequency Distribution

After the regional homogeneity of the study area is identified the second activity which was done in this paper is selecting of the regional flood frequency distribution. The choice of frequency distributions is determined based on goodness-of-fit test measures, which indicates how much the considered distributions system is fit to the available data (Hailegeorgis and Alfredsen, 2017). In flood event analysis, the annual maximum flow corresponding to a given return period (T) can be estimated from the annual flood series using varies theoretical distributions.

The best fit distribution was selected by using easy fit software and LMRD while the best parameter was selected based on the standard error. The best distribution is the one which has better rank order or minimum horizontal summation of Kolmogorov-Smirnov Anderson-Darling, Chi-square rank value. The method of parameter estimation goes parallel with the distribution selection and can be tested for accuracy using standard error estimation, the less in standard error the more the selection of the method of the parameter estimation. Therefore for this study the easy fit software was used to determine the parameters which are indicators for best regional flood frequency distribution methods.

3.8.1. Easy Fit Software for Distribution Fitting

Easy fit software is a freely online available tool which can be used for flood frequency analysis. This is the software which is used to find the best flood distribution fitting type. In order to determine the best distribution model could fit the data properly, goodness-of-fit tests were used. In the present study Easy Fit Statistical Software Package, trial version 5.6 was used to find the best-fit distribution and its estimation parameters.

Easy Fit software is a data analysis and simulation software which enables us to fit and simulate statistical distributions with sample data, choose the best model, and use the obtained result of analysis to take better decisions. This software can function as a stand-alone windows application or as an add-on for Excel spread sheet (Pakgohar, Using Easy Fit Software for Goodness-Of-Fit Test and Data Generation, 2014).

3.8.2. Goodness-of-Fit tests

In addition to visual inspection and subjective judgment of distribution selection, statistical tests are required to confirm the appropriateness of the chosen distribution and to give a certain degree of confidence in it. The goodness-of-fit test for each of various distributions is defined in terms of L-moments (Hosking and Wallis, 1997).

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. This particular characteristic feature of the software is very useful for comparing fitted models to each other. Most used Goodness-of-Fit tests include Kolmogorov-Smirinov, Anderson-Darling, and Chi squared tests. Usage logic is all similar for these tests. However, they differ in practical method (and type of usage). Kolmogorov-Smirinov test can be named as the most used Goodness-of-Fit test.

GoF tests are essential for checking the adequacy of probability distributions to the recorded series of AMD in the estimation of MFD. Out of a number GoF tests available, the widely accepted GoF tests are K-S, AD and X^2, which are used in this study. The theoretical descriptions of GoF tests statistic are as follows (kanandan, 2015):

A. Kolmogorov-Smirnov Goodness of Fit

The Kolmogorov-Smirnov Goodness of Fit Test (K-S test) compares your data with a known distribution and lets you know if they have the same distribution. Although the test is nonparametric, it doesn’t assume any particular underlying distribution, it is commonly used as a test for normality to see if your data is normally distributed. It’s also used to check the assumption of normality in Analysis of Variance. More specifically, the test compares a known hypothetical probability distribution (e.g. the normal distribution) to the distribution generated by your data the empirical distribution function.

The K-S test statistic measures the largest distance between the CDF $F_{data}(x)$ and the theoretical function F0(x), measured in a vertical direction (Kolmogorov as cited in Stephens, 1992). The test statistic is given by:

$DN = sup_x|Fo(x) - F_{data}(x)|$……………………………………………………..………3.33

Where (for a two-tailed test):

- $F_0(x)$ = the cdf of the hypothesized distribution,
- $F_{data}(x)$ = the empirical distribution function of your observed data.

For one-tailed test, omit the absolute values from the formula.

If DN is greater than the critical value, the null hypothesis is rejected. Critical values for DN are found in the K-S Test P-Value Table.

B. Anderson-Darling test

The Anderson-Darling test (Stephens, 1974) is used to test if a sample of data comes from a population with a specific distribution. It is a modification of the Kolmogorov-Smirnov (K-S) test and gives more weight to the tails than does the K-S test. The K-S test is distribution free in the sense that the critical values do not depend on the specific distribution being tested. The Anderson-Darling test makes use of the specific distribution in calculating critical values. This has the advantage of allowing a more sensitive test and the disadvantage that critical values must be calculated for each distribution. Currently, tables of critical values are available for the normal, lognormal, exponential, Weibull, extreme value type I, and logistic distributions.

The Anderson-Darling test statistic is defined as:

$A^2 = -N - \frac{1}{N}\sum_{i=1}^{N}(2i-1)[lnF(Xi) + \ln\left(1 - F(X_N - i + 1)\right)]$……………………………3.34

F is the cumulative distribution function of the specified distribution. Note that the X_i is the ordered data.

The critical values for the Anderson-Darling test are dependent on the specific distribution that is being tested. Tabulated values and formulas have been published (Stephens, 1974) for a few specific distributions (normal, lognormal, exponential, Weibull, logistic, extreme value type 1). The test is a one-sided test and the hypothesis that the distribution is of a specific form is rejected if the test statistic, A, is greater than the critical value as cited (Ghosh, 2016).

C. Chi-square Test

The Chi-square test assumes that the number of observations is large enough so that the chi-square distribution provides a good approximation as the distribution of test statistic. The Chi-squared statistic is defined as:

$x^2 = \sum_{i=1}^{k}\frac{(Oi-Ei)}{Ei}$……………………………………………………………………….3.35

Where

O_i = observed frequency

E_i = expected frequency

'i'= number observations (1, 2, ……k)

Calculated by $E_i = F(X_2) – F(X_1)$

F = the CDF of the probability distribution being tested

This equation is for continuous sample data only and is used to determine if a sample comes from a population with a specific distribution (Sharma and Sing, 2010).

3.9.Performance Evaluation of Probability Distributions

The results obtained from statistical analysis can be uncertain, and to be trustful methods of uncertainty assessments should be applied (Hosking and Wllis, 1997). Assessment of the accuracy of the probability distribution should be taking into account the possibility of heterogeneity in the region, misspecification of the frequency distribution and statistical dependence between observations at different sites, to an existent that is consistent with the data. Analytical goodness-to-fit criteria are helpful as an approval for whether a particular elimination of the data from the model is statistically significant or not as cited (Mengistu, 2018).

The distribution that has the most number of points nearby to the line signifies the best-fitted distribution model. This implies that the frequency distributions that were chosen as the best distribution could be fitting regional flood models for the basin. Hence, for this analysis, two methods of uncertainty assessments were achieved. These are probability-probability (P-P) and quantile-quantile (Q-Q) plots. The performance of the best distribution model identified for the respective regions was evaluated by comparing observed with simulated values by employing the P-P and Q-Q plot techniques with Easy Fit Software.

I. Probability-probability plots

Probability plots are generally used to decide whether the distribution of a variable matches a given distribution. P-P plots show that the observed values together with the simulated from the regional values may reveal a systematic regional bias in the estimation of the quantile events. This is for visually informative the character of a data set and to determine if fitted distribution seems reliable with the data.

If the selected variable matches the test distribution, the points come together approximately a straight line. The following basic issues should arise when selecting a distribution: (i). It is true and reliable with the distribution for which the observations are drawn, (ii). It should be used to obtain reasonably perfect and strong estimations of design quantiles and hydrologic risk (Desalegn *et al.*, 2016) as cited in (Tarekegn, 2018).

II. Quantile-Quantile Plots

A Q–Q plot is a plot of the quantiles of two distributions against each other, or a plot based on estimates of the quantiles. The pattern of points in the plot is used to compare the two distributions. The main step in constructing a Q–Q plot is calculating or estimating the quantiles to be plotted. If one or both of the axes in a Q–Q plot is based on a theoretical distribution with a continuous cumulative distribution function (CDF), all quantiles are uniquely defined and can be obtained by inverting the CDF.

A simple case is where one has two data sets of the same size. In that case, to make the Q–Q plot, one orders each set in increasing order, then pairs off and plots the corresponding values. A more complicated construction is the case where two data sets of different sizes are being compared. To construct the Q–Q plot in this case, it is necessary to use an interpolated quantile estimate so that quantiles corresponding to the same underlying probability can be constructed.

The points plotted in a Q–Q plot are always non-decreasing when viewed from left to right. If the two distributions being compared are identical, the Q–Q plot follows the 45° line $y = x$. If the two distributions agree after linearly transforming the values in one of the distributions, then the Q–Q plot follows some line, but not necessarily the line $y = x$. If the general trend of the Q–Q plot is flatter than the line $y = x$, the distribution plotted on the horizontal axis is more dispersed than the distribution plotted on the vertical axis. Conversely, if the general trend of the Q–Q plot is steeper than the line $y = x$, the distribution plotted on the vertical axis is more dispersed than the distribution plotted on the horizontal axis. Q–Q plots are often arced, or "S" shaped, indicating that one of the distributions is more skewed than the other, or that one of the distributions has heavier tails than the other.

3.10. Parameter selection and Quantile estimation

3.10.1. Parameter estimation

In the present study, the parameter estimation was done by using maximum likelihood with the help of Easy fit, method of moment and probability weighted method. From these three ways of parameter estimation methods maximum likelihood method was selected based on the standard error. According to (Rao, 2000) the most efficient parameter estimation method is maximum likelihood method. Based on the selected distributions for each station, the quantile can be calculated according to the formula of the selected distributions. For stations with a computed value of scale, location and shape parameter, then it is possible to determine the quantile with different return periods using different equations for different distributions.

3.10.2.Standard Error of Parameter Estimation

The standard error of the estimate is a measure of the accuracy of predictions. The development of the relationship between the mean annual flood or index flood and the catchment characteristics was a necessary step in predicting flood magnitudes at any point in a region where the frequency curve has been derived and error in quantitative terms. Different researchers use different measures of error. The most common measures are standard errors. From the various source of error only sampling error can be evaluated theoretically a consensus seems to be emerging that at least sampling error should normally be reported in quantitative terms.

3.10.3.Quantile Estimation

In order to determine the quantile (X_T) of a region which correspond to different return periods first the return period and the parameters of the identified probability distribution type should be computed. By inserting probability of non-exceedence,F =1-1/T where T is the return period, the T-year flow quantile estimate. Based on the selected distributions for each station, the quantile was calculated according to the formula of the selected distributions as shown below in equation 3.36-3.40. To calculate the quantile for each selected distribution the parameters and return period has to be determined first.

$X_T = \mu + \frac{\sigma}{K}(1 - (-ln\left(1 - \frac{1}{T}\right))^k$; For, k≠0 ……………………………Equation 3.36(GEV)

$X_T = \mu + \sigma(\ln(-\ln\left(1 - \frac{1}{T}\right))$; For k=0……………………………………..Equation 3.37(GEV)

$X_T = \mu + \sigma(\ln\left(\frac{1}{T}\right))$ For k=0 ……………………………………………..Equation 3.38(GPA)

$X_T = \mu + \frac{\sigma}{K}\left(1 - \left(\frac{1}{T}\right)^{K}\right)$ For k≠0 ……………………………………………Equation 3.39GPA)

$X_T = \gamma + e^{\wedge}(\mu + u * \sigma$…………………………………………..........Equation 3.40(LN3P)

Where

σ= Scale parameter,	T = Return period
μ = Location parameter	k = Shape Parameter
e = exponential value	u= standard variante

3.10.4.Estimation of Return Period

The return period is the time elapsed between successive peak flows exceeding a certain flow Q. Given a verified or accepted discharge Q for the maximum known flood the plotting position formula used in the frequency analysis provides a rough estimate of its own return period T as a function solely of the record length N. For the formula previously quoted, the plotting-position return periods in years are: T=1.67N+0.3 (Cunnane); or T =N+ 1 (Weibull). The Cunnane formula gives a return period substantially longer than the period of record, and generally seems to the result in a more compatible plot. A more refined estimate of return period T is given by the position of Q on the adopted probability distribution. For the usual use of single probability distribution, both T and its associated standard error can be calculated from the statistics of the distribution (Roa and Hammed, 2000) as cited in (Mekoya, 2010).

After the return period was determined the quintile of the region can be computed by using the selected flood frequency distribution method and the corresponding parameters. Then it is possible to draw the regional flood frequency curve for the homogeneous region.

3.10.5.Derivation of the Regional Flood Frequency Curves

The flood frequency curve has important implication for hydrological processes. The slope of a frequency curve graphically represent the standard deviation of the flood frequency distribution and the higher the slope, the greater the standard deviation in flood discharge (Pitiick, 1994). Depending up on the above quantile estimation developed or determined the Flood Frequency

Curve (FFC) on the bases of different return period versus the estimated quantile stream flow values (XT).

Accordingly the quantile versus return period graph of each region was drawn as the growth curve for each region delineated. Depending on the growth curve of each region in the sub-basin and the representative growth curve of the sub-basin, the importance of regionalization of the sub basin can be determined. If the growth curve of the sub-basin can represent the station growth curve with less diversion from curve of each station, the sub basin can be taken as a single region otherwise the sub-basin has to be divided in to the proper homogeneous regions.

3.10.5.1. Estimation of Index-Flood

The index-flood (IF) method, developed by the U.S. Geological Survey (Dalrymple, 1960; Benson, 1962), is widely used to perform regional flood-frequency analysis. The basic premise of this method is that a combination of stream flow records maintained at a number of gaging stations will produce a more reliable, not a longer, record, and thus will increase the reliability of frequency analysis within a region. Index-flood is a dimensionless frequency curves representing the ratio of the flood of any frequency to the mean annual flood (Q_T/Qm) (Micovic, 2017).

The index- flood method (Hosking, 1993) is based on the hypothesis that floods from different catchments within a region normalized by their mean annual flood come from a single distribution. An essential prerequisite for this procedure is the standardization of the flood data from sites with different flood magnitudes as cited by (Moges, 2018).

Indexed flood frequency curve is drawn by (Q_T/Q_m) versus Gumbel reduced variante (Yt). The value of Gumbel reduced variante (Yt) can be calculated by:

$$Yt = (-Ln(\ln\left(\frac{T}{T-1}\right)) \qquad \text{3.41}$$

Where

Yt- Gumbel reduced variante

T-Retun period

4. RESULTS AND DISCUSSIONS

In order to achieve the research objectives the researcher makes the data appropriate for future analysis by conducting of screening, missing data filling and by performing quality control of the data like independency and adequacy, trend checking, consistency.

4.1. Identification of Homogeneous Region

The collected data were checked for their quality, the homogeneity of the stations was performed. In order to identify the homogeneity of the region different activities were performed. At the first the stations at the study area were grouped or clustered in to different groups based on their geographical location. Then different statistical parameters were computed for each station under a group and then these statistical values are checked with different standards. Those statistical values which were computed in this study were combined coefficient of variation (cc) value and discordancy (Di) of each station.

Identification of homogeneous region is an iterative process of checking for homogeneity because the researcher was categorized the flow gauging stations in the study area in to different groups and then it was checked for homogeneity, if the grouped data is failed the required criteria for homogeneity test it should be regrouped and again should be tested for homogeneity. Based on the above procedure the researcher first grouped in to one group and then the data checked for homogeneity.

Table 4.1 preliminarily identified homogeneous regions by geographical location and LMRD

Name of the Regions	Station Name	Possible Frequency Distribution Type from figure 4.1
Region-1	Lake Alemaya	GEV,GPA
	Dawi	GEV.GL
	Madahadu	GPA,Pearson,GEV
Region-2	Lake Adel	GPA,Pearson
	Robi	GPA,Pearson
	Weiyb	GPA,LP
	Furana	Pearson, GPA
	Ukuma	GEV, Pearson

Name of the Regions	Station Name	Possible Frequency Distribution Type from figure 4.1
Region-3	Wabi	GPA,Pearson
	Assasa	General logistic, Log normal
	Leliso	General pareto, pearson
	Maribo	Genral Logistic, Log normal
	Herero	Generalized logistic,General logstic

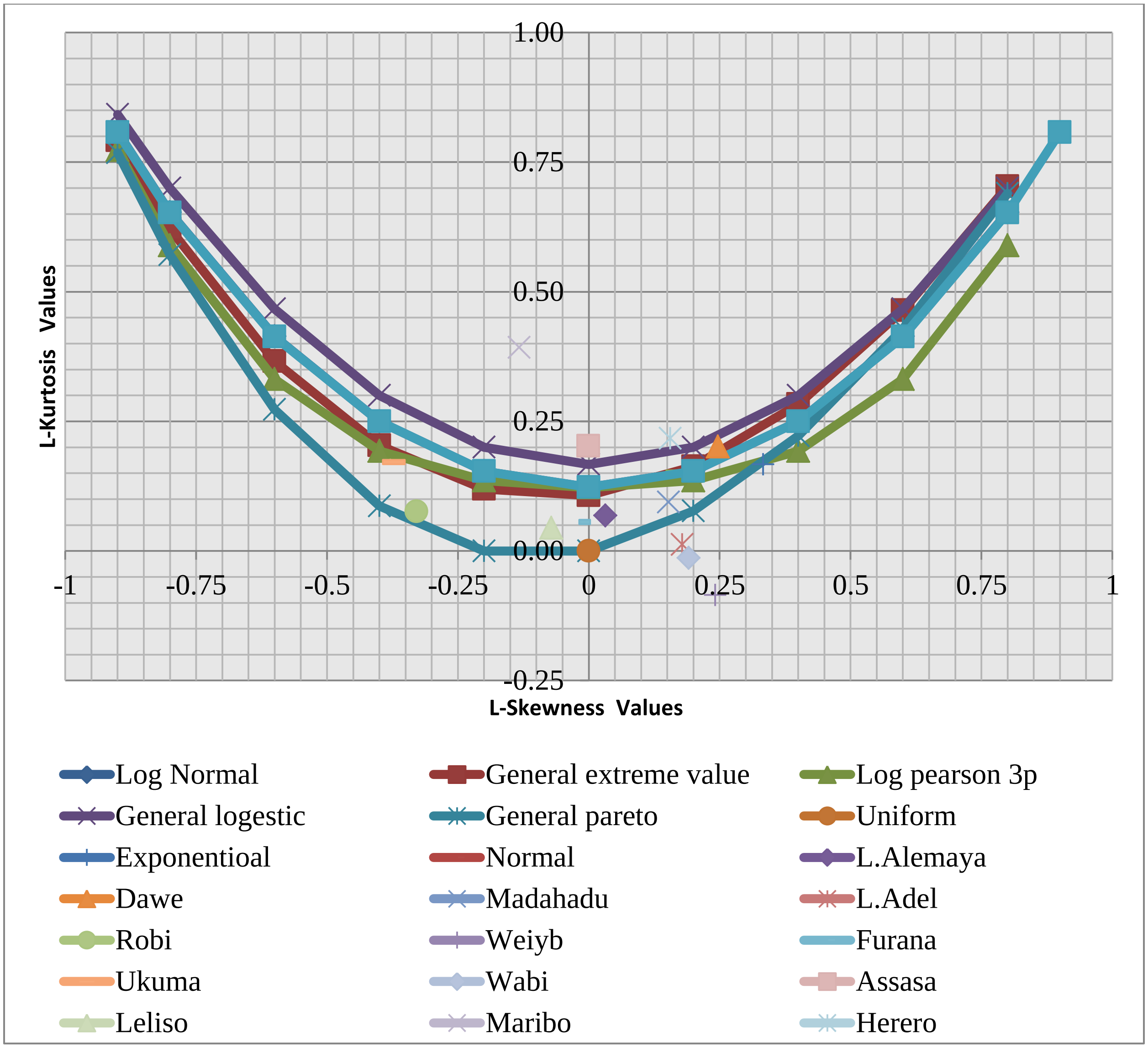

Figure 4.1 L-moment ratio diagram for identified homogeneous regions

4.2. Tests for Regional Homogeneity

In order to check the Homogeneity of the regions the combined coefficient and discordancy value were computed and checked as follows by using conventional moment and L-moment statistical values.

4.2.1. Discordancy Measure of Regions

Discordancy measure was used to check the homogeneity of the regions from its categorization by using the statistical value of L-moment. Values of discordancy of L-moment statistics have been calculated for all the 13 gauging sites of the basin using Equation (3.30) with Matlab program. The values of discordance index (Di) measure for different sites within the regions were presented in Table 4.2 for region-1, 2 and 3 respectively. The critical values of the discordancy index Di for various numbers of sites in a region at a significance level of 10% were obtained from Table 3.8. It was observed that the Di values for all 13 sites vary from 0.191-1.909 and all regions' Di value is with the limit of critical value.

Table 4.2 Statistical value of the data and Discordancy measure

LCV	LCS	LCK	Di	Remark	
-0.298	2.445	-3.891	0.573	Homogeneous	Region-1
-0.287	3.769	-3.45	0.514	Homogeneous	
-0.265	0.325	2.19	0.159	Homogeneous	
-0.295	0.247	1.97	0.776	Homogeneous	Region-2
-0.174	7.137	-3.52	0.762	Homogeneous	
-0.188	6.472	-3.451	0.801	Homogeneous	
-0.248	3.726	-3.699	0.206	Homogeneous	Region-3
-0.173	6.303	-3.56	1.246	Homogeneous	
-0.266	3.299	-2.373	0.362	Homogeneous	
-0.15	-2.529	-6.833	1.909	Homogeneous	
-0.232	4.163	-3.649	0.191	Homogeneous	
-0.155	-0.288	-7.311	1.145	Homogeneous	
-0.281	-0.394	-8.808	1.069	Homogeneous	

Regionalization is an iteration process in which the stations are classified into different groups and checking their cc and Di by using conventional and L-moment statistical value of CV, CS. CK, LCV, LCS and LCK. The iteration process for this study was tabulated in appendix -E, F and G (table 4.3). In the appendix -E the combined coefficient variation (cc)of the data is 0.275 which is fulfilled that cc < 0.3 but the discordance value for Weiyb and Lelisso stations are 2.935 and 3.364 respectively which is greater than the critical value of 2.869 for 13 stations as it is seen from table 3.8. Then the stations in this study area were recategorized into two groups and checked for homogeneity as shown in appendix- F.

When the stations in the study site were grouped in to two groups in appendix -F, both regions are failed its homogeneity test. Region one is failed in combined coefficient of variation (cc) of 0.397 which is not less than the critical value of 0.3 while region two is failed in the discordancy test for homogeneity of the region with discordance value of stations Weiyb (2.635) and Assassa (2.582) which should be less than 2.329 for 9 stations as shown from table 3.8. Therefore the study area should be regrouped in to three and also checked for three regions homogeneity.

4.2.2. CC-Base Homogeneity Test

In this test the value of conventional moment and L-moment of CV, CS, CK, LCV, LCS and LCK for each station were computed in the excel sheet and used for homogeneity test. In order to use these statistical values for homogeneity testing first, the combined coefficient of the regions were calculated by using equations from equation number 3.15 and 3.29. The computation was an iterative process as it is tabulated in appendix – E, F and G. The final result of combined coefficient result of conventional moment and L-moment for homogeneous regions of region -1, 2 and 3 are as shown in table 4.3 below.

Table 4.3 Results of CV and LCV values for Homogeneity test of 3 regions

Conventional moment based homogeneity test				L-moment based homogeneity test			
Station name	CV	CS	CK	LCV	LCS	LCK	Remark
Madhadu	0.4117	0.593	-0.697	-0.298	2.445	-3.891	Region-1
Dawe	0.285	0.902	0.058	-0.287	3.769	-3.45	
Lake Alemaya	0.3963	0.166	-0.724	-0.265	0.325	2.19	
cc	0.168<0.3			0.156<0.3			

Conventional moment based homogeneity test				L-moment based homogeneity test			
Station name	CV	CS	CK	LCV	LCS	LCK	Remark
Lake Adel	0.3708	0.557	-1.074	-0.295	0.247	1.97	Region-2
Robi	0.1367	-1.015	0.242	-0.174	7.137	-3.52	
Weiyb	0.3504	0.618	-1.347	-0.188	6.472	-3.451	
cc	0.106<0.3			0.266<0.3			
Furuna	0.35	-0.083	-0.636	-0.248	3.726	-3.699	Region-3
Ukuma	0.248	-1.561	2.446	-0.173	6.303	-3.56	
Wabi b.bridge	0.354	0.616	-1.33	-0.266	3.299	-2.373	
Assasa	0.271	-0.279	1.565	-0.15	-2.529	-6.833	
Lelliso	0.322	-0.322	-0.632	-0.232	4.163	-3.649	
Maribo	0.255	-0.841	2.362	-0.155	-0.288	-7.311	
Herero	0.475	0.967	1.663	-0.281	-0.394	-8.808	
cc	0.073<0.3			0.225<0.3	2.04		

When the stations in the study area were grouped in to three the test for homogeneity was satisfied both for cc and Di value. Therefore the study area can be classified in to three homogeneous regions as region -1 region-2 and region-3 based on their geographical location or latitude –longitude distribution and stastical values for homogeneity tests by using both conventional moment and L-moment. As shown in table 4.3 the number of stations in each region was 3, 3, and 7 for Region-1, Region-2 and Region-3 respectively.

4.3. Delineation of Homogeneous Regions

Delineation of homogeneous region was performed after conducting of regionalization and homogeneity test was done and satisfied the required criterion. Delineation of homogeneous regions was performed by Arc GIS software using L-moment's combined coefficient of the regions as an input for GIS software. The values of combined coefficient were 0-0.156 for region-1, 0.156-0.225 for region-3 and 0.225-0.266 for region-2.

In identification of homogenous region the study area was grouped in to three regions as region-1, region-2 and region-3 are shown in table 4.3 and figure 4.2. The area coverage of each region is 517km^2, 8030km^2, 1700.6km^2 of region-1, region-2 and region-3 respectively from table 3.2. Stations under region-1 includes Madhadu, Dawe , Lake Alemaya and region-2 consists of

Lake Adel, Robi and weiyb while stations under region-3 are Furuna, Ukuma, Wabi below bridge, Assasa, Lelisso, Maribo and Herero. From the above list seven stations are under region -3 while the rest two regions have equal number of stations. Regarding to area coverage the larger region is in region-2 which has 8030km^2 coverage and the smallest area coverage is under region -1 which has 517km^2.

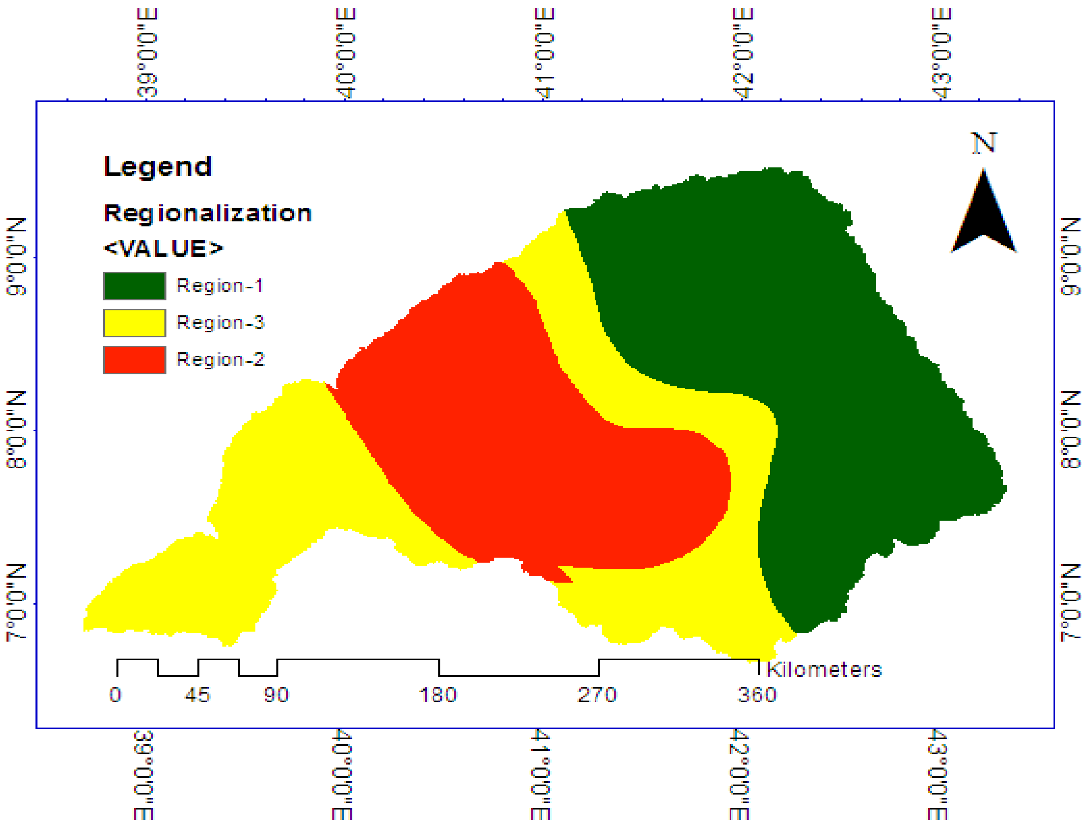

Figure 4.2 Regionalization of homogeneous regions

4.4. Selection of Regional Frequency Distribution

From the two types of partial duration model and annual maximum model, the annual maximum flow model was adopted for this study due to the independency of the data. Therefore in this study only the yearly maximum streams flow data were considered for analysis.

4.4.1. Goodness of Fit Tests

To do this part the researcher took an average value of maximum stream flow of the stations which were grouped under each region. In this study, the goodness of fit tests was performed by using the average maximum stream flow data with easy fit software. For selecting of best fit distributions, Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared methods were used for the data of gauging stations. They were applied to determine whether the distribution to be fitted to the data or not. The best-fit result of each station was taken as the distribution with the lowest sum of the rank orders from each of the three test statistics. These GOFs at 5% level of significance was used to define the best-fit ranking using Easy Fit Statistical Software. There are around 62 flood frequency distribution methods in easy fit software. Among these, ten frequently used frequency distributions methods were selected and tested by using the three testing methods of Kolmogorov Smirnov, Anderson Darling and Chi-Squared goodness fit test are used for flood forcing in the study area.

From table 4.4 for region -1 the best flood frequency distribution method is General Extreme value which has the first rank by horizontal summation of Kolmogorov Smirnov Anderson Darling Chi-Squared goodness fit test ranked value; normal and lognormal 3p distributions take the second and third rank of best distribution methods from selected distribution types with easy fit software.

Table 4.4 Goodness of fit test for region-1 with selected distribution methods by using Easy-fit software

S .No	Distribution type	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.24261	10	1.377	7	3.9147	7
2	Exponential (2P)	0.23126	8	2.6621	9	5.1669	8
3	Gen. Extreme Value	0.14839	2	0.47191	1	1.0549	2
4	Gen. Pareto	0.12259	1	4.1534	10	N/A	
5	Log-Pearson 3	0.17095	5	0.93121	4	2.5171	5
6	Lognormal	0.23726	9	1.6688	8	6.1922	9
7	Lognormal (3P)	0.16466	4	0.57877	3	1.4901	4
8	Normal	0.15508	3	0.50051	2	1.4795	3
9	Weibull	0.20134	7	1.0706	5	0.34243	1
10	Weibull (3P)	0.18072	6	1.1258	6	2.5861	6

From table 4.5 for region -2 the best flood frequency distribution method is Gen. Pareto. This frequency distribution has the lowest horizontal summation value of the three testing methods from ten selected distributions methods; Normal and General Extreme value distributions take the second and third rank from selected distribution types with easy fit software goodness fit test.

Table 4.5 Goodness of fit test for region 2 with selected distribution methods by using Easy fit software

S.No	Distribution type	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.33055	7	4.2832	8	4.681	8
2	Exponential (2P)	0.36323	10	8.8938	10	6.8243	9
3	Gen. Extreme Value	0.26135	3	1.5842	3	1.929	5
4	Gen. Pareto	0.23036	1	1.2084	1	0.84771	2
5	Log-Pearson 3	0.31936	6	2.612	6	2.845	6
6	Lognormal	0.33956	8	2.9507	7	3.3045	7
7	Lognormal (3P)	0.34086	9	2.2778	5	0.49902	1
8	Normal	0.25866	2	1.4413	2	1.2896	3
9	Weibull	0.27784	4	2.0264	4	1.4312	4
10	Weibull (3P)	0.31788	5	5.9519	9	N/A	

From table 4.6 region -3 has the best flood frequency distribution method of Log Normal 3p as it take the first rank; normal and Weibull (3P) distributions take the second and third rank of best distribution methods.

Table 4.6 Goodness of fit test for region 3 with selected distribution methods by using Easy fit software

S.No	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.40516	10	5.2793	8	32.751	8
2	Exponential (2P)	0.35531	9	5.1796	7	13.15	7
3	Gen. Extreme Value	0.11869	4	0.22841	4	0.45263	4
4	Gen. Pareto	0.1575	7	7.8152	10	N/A	

S.No	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
5	Log-Pearson 3	0.17669	8	7.7682	9	N/A	
6	Lognormal	0.14488	5	0.91545	6	1.7859	6
7	Lognormal (3P)	0.10058	1	0.19821	2	0.07863	1
8	Normal	0.10787	2	0.19393	1	0.48173	5
9	Weibull	0.15707	6	0.76699	5	0.27502	2
10	Weibull (3P)	0.11853	3	0.22126	3	0.45097	3

Generally for the above tables 4.4, 4.5 and 4.6 for the identified three homogeneous regions by conducting goodness fit test their best flood frequency distribution method was selected. These are: Gen. Extreme Value for region-1, Gen. Pareto for region-2 and Lognormal (3P) for region-3. From the above tables some distribution types had the symbol N/A which indicates to us that not assigned with that statistical test method.

4.4.1.1. Evaluating the Accuracy of Selected Distribution

The P-P plot and Q-Q plot have to be more or less linear if the particular theoretical distribution is the correct model. The researcher has tried to show the best flood frequency distribution method point distribution pattern as shown from the figure4.3-4.8 below in P-P and Q-Q plot. From selected ten flood frequency distribution General Extreme Value, General Pareto and Log-Normal 3p distribution have a best line fitting relative to the other methods for region-1, region-2 and region-3 respectively as shown below in figures of 4.3-4.8. The figures were plotted by theoretical versus to empirical value. The points were almost lying on the straight line and this implies that the selected flood frequency distribution methods had well relation with observed data. Therefore the flood frequency of the regions was well determined and the model for each region will have a benefit for designers and decision makers.

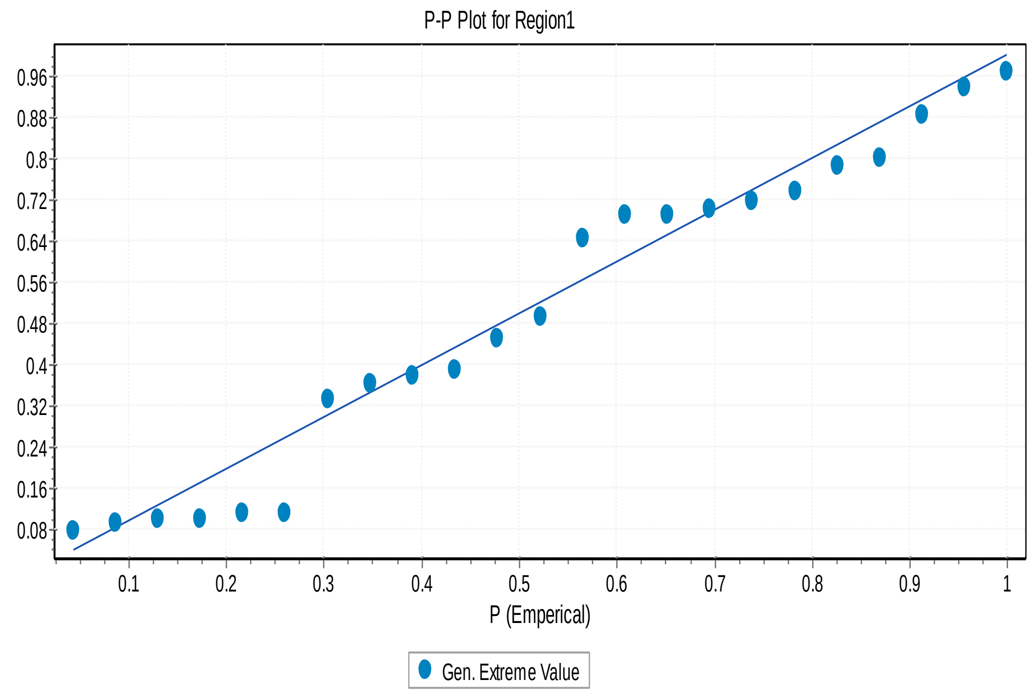

Figure 4.3 P-P Plot of region one for performance evaluation

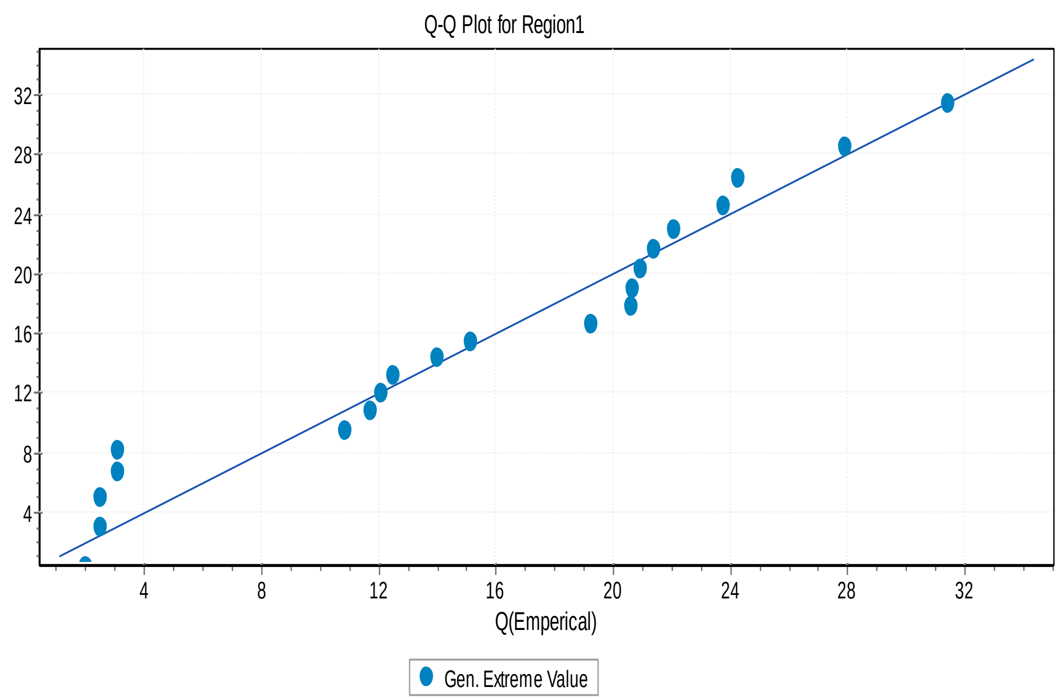

Figure 4.4 Q-Q plot of region one for performance evaluation

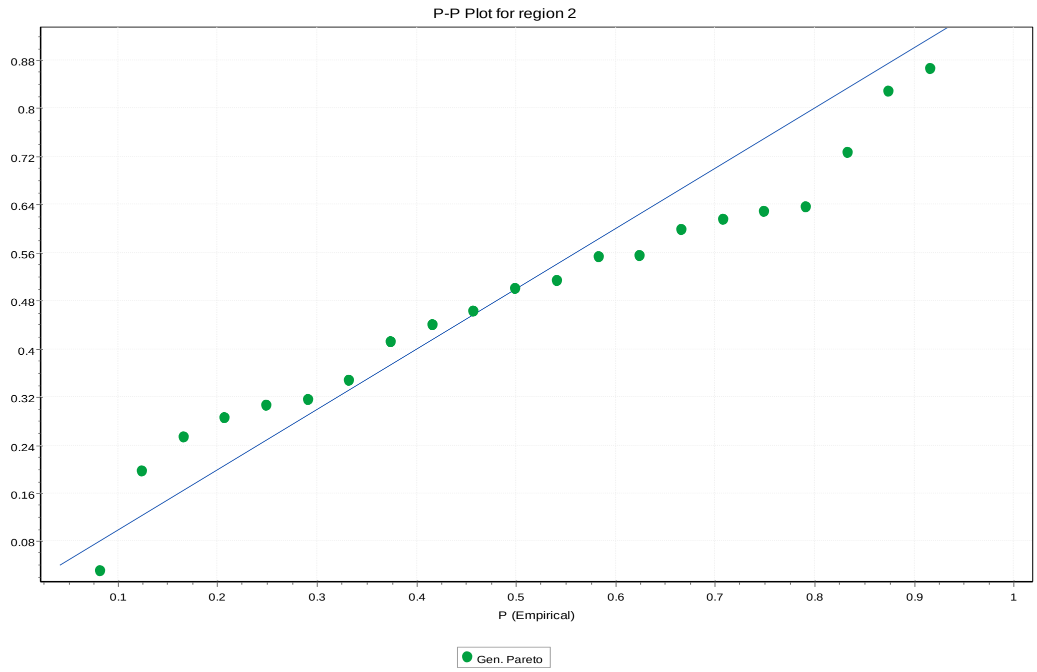

Figure 4.5 P-P plot of region two for performance evaluation

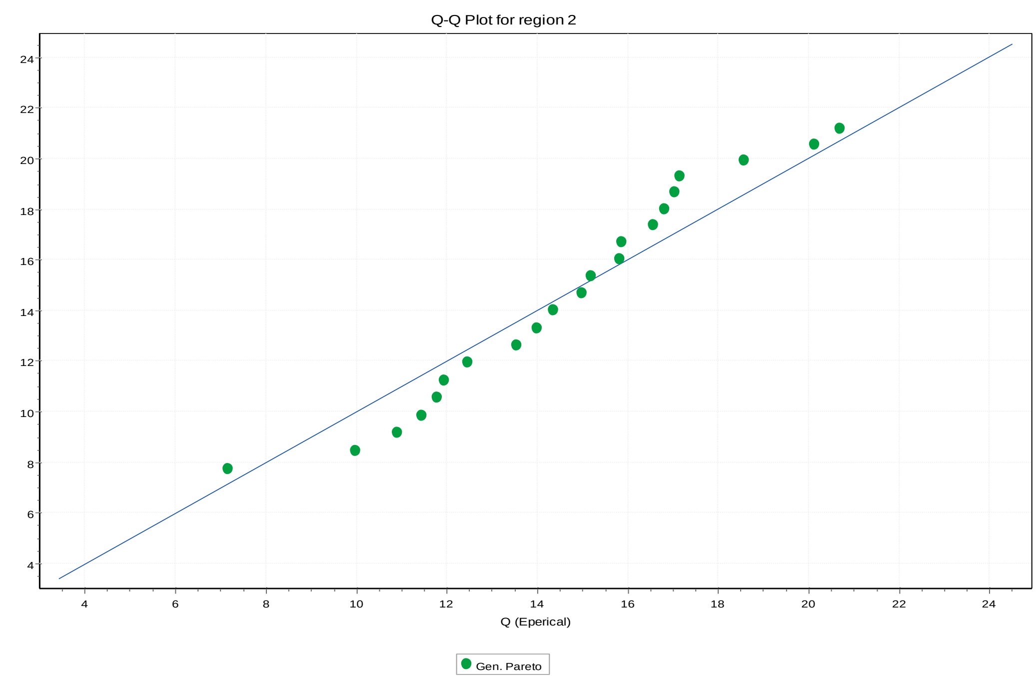

Figure 4.6 Q-Q plot of region two for performance evaluation

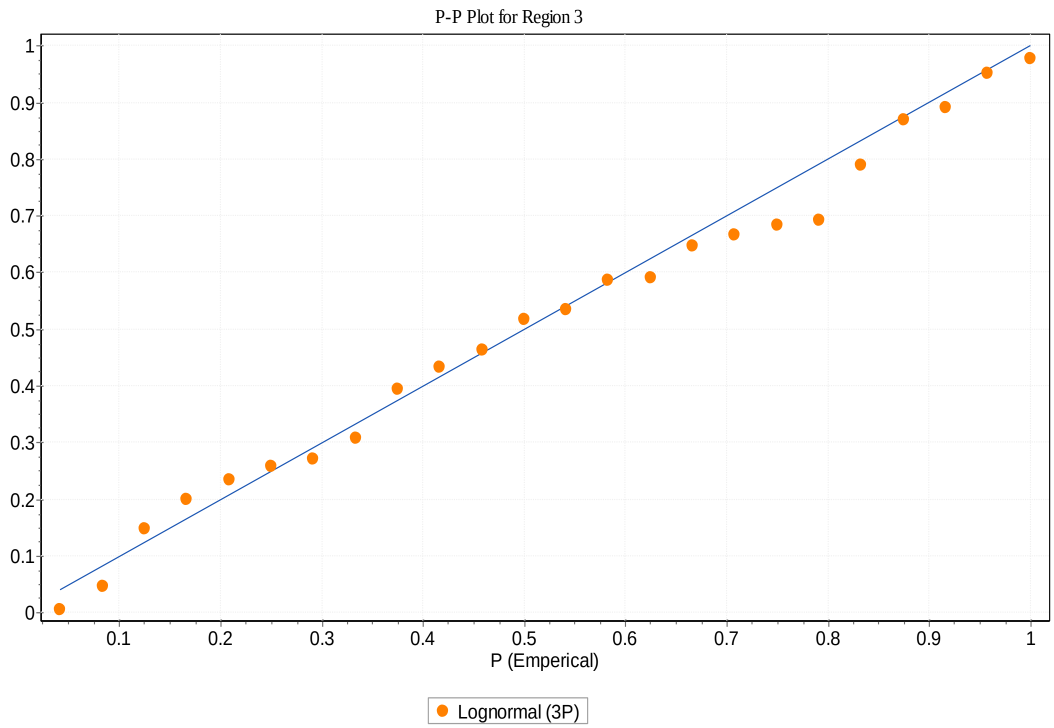

Figure 4.7 P-P plot of region three for performance evaluation

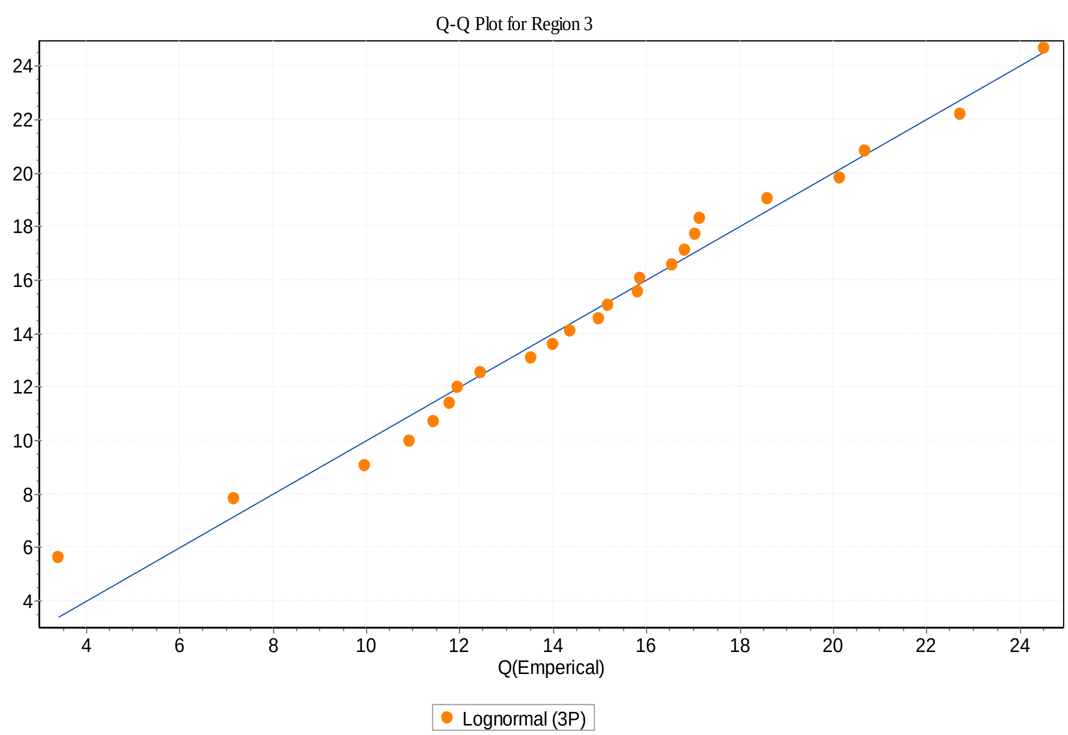

Figure 4.8 Q-Q plots for region three for performance evaluation

4.4.1.2. Method of L-Moment Ratio Diagram

This method is used for assessing the performance of the average values of the point (LCs, LCk) of all stations within the region close to LMRD of the selected parent distributions. The corresponding average weighted value of L-moment statistics results were obtained from regional data as presented in Table 4.3 plotted along with the theoretical lines for some distributions on LMRD to determine a regional probability distribution. From LMRD of figure 4.9 region -1 is lie on the curve of General Extreme value, region -2 on the curve of General Pareto and region-3 is nearest to lognormal distribution curve. The result indicates to us that LMRD also prove the above selected frequency distributions are the best distribution for those three regions.

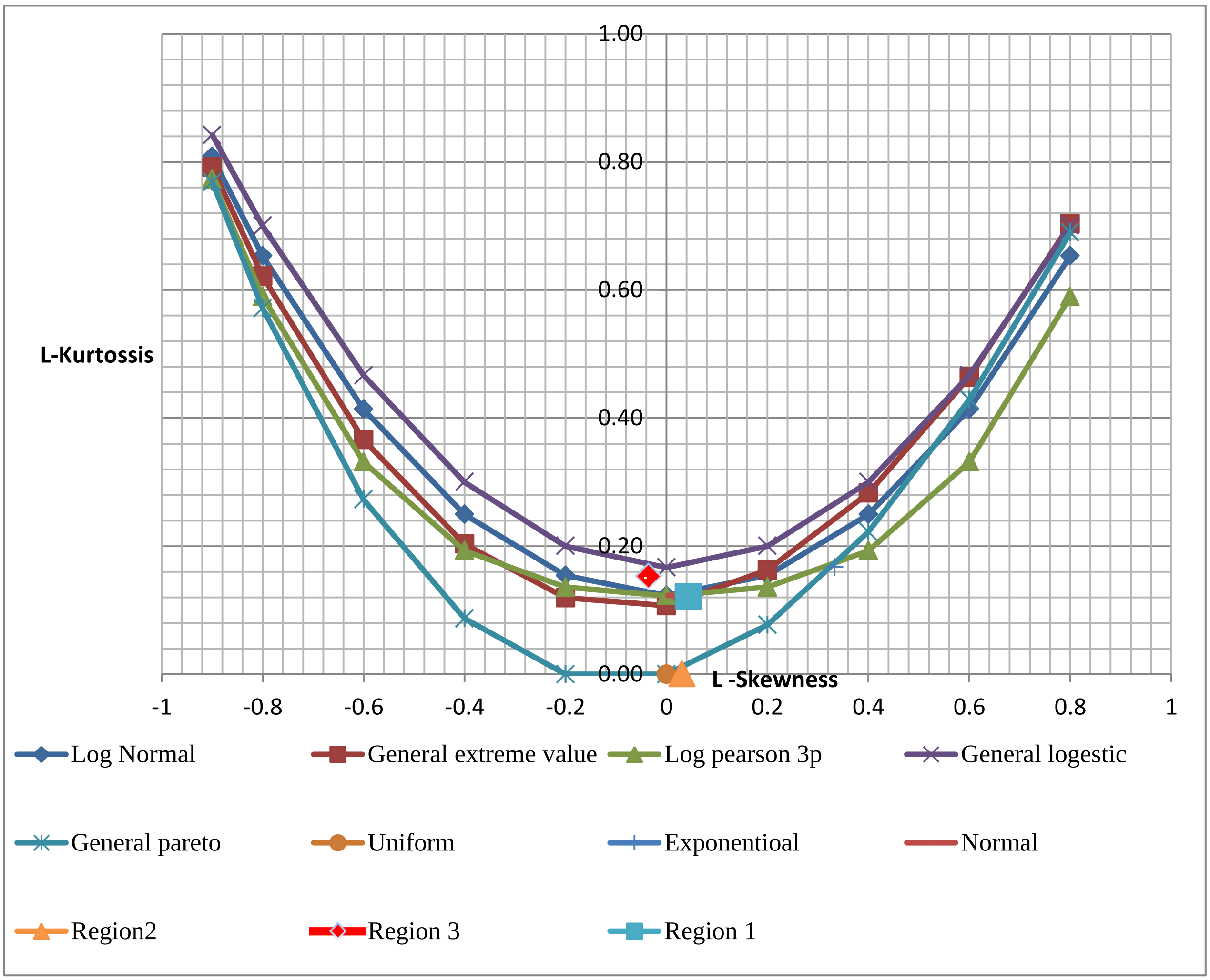

Figure 4.9 L-Moment Ratio Diagram for performance evaluation

4.5. Parameter Selection and Quantile Estimations

4.5.1. Parameter Selection

To estimate amount of quintile to the identified region by using the selected flood frequency distribution method for different return period, first it is essential to find out the parameters of the selected flood frequency methods. From different alternative methods of parameter estimation such us, method of moment, probability weighted moment and maximum like hood method, maximum like hood method is used in this study. The parameters of different distribution systems are tabulated in appendix k which was obtained from Easy-fit software of version 5.6. The best fitted flood frequency distribution and parameters for each identified homogeneous regions are as listed below in table 4.7.

Table 4.7 Best flood frequency distribution methods and parameters selection for three regions

S.No	Best Distribution type	parameters	Remark
1	Gen. Extreme Value	$\kappa = -0.266$, $\sigma = 10.089$, $\mu = 11.886$	Region-1
2	Gen. Pareto	$\kappa = -0.78987$, $\sigma = 27.649$, $\mu = 3.801$	Region-2
3	Lognormal (3P)	$\sigma = 0.03609$, $\mu = 4.8642$, $\gamma = -114.77$	Region-3

4.5.2. Quantile Estimations

The best methods of quintile estimations are selected based on the evalution and ranking of Kolmogorov Smirnov, Anderson Darling and Chi-Squared. The quintile of the identifed homogeneous region can be computed by using corresponding flood frequency system of General Exterme Value, Gen. Pareto and Lognormal3p as follows.

From table 4.7 the best flood frequency distribution method for regions 1, 2 and 3 are general extreme value General Pareto and Log Normal 3p respectively. The Quintile values of each region were computed by using the equations from 3.36 – 3.40 for their corosponding parameter values in the table 4.8 below.

Table 4.8 Quantile estimation for homogeneous regions by selected flood frequency distribution methods

Return Period (T)	Quintile (XT) to Region -1	Quintile (XT) to Region-2	Quintile (XT) to Region-3)
2	15.77	29.32	0.76
5	30.49	93.6	2.66
10	42.98	184.57	6.20
15	51.21	266.02	9.64
20	57.55	341.85	12.91
30	67.29	482.67	19.01
40	74.84	613.77	24.62
50	81.08	738.08	29.85
60	86.46	857.24	34.77
70	91.21	972.28	39.43
100	102.96	1298.83	52.22
200	129.2	2268.32	87.04
300	146.93	3136.38	115.19
400	160.72	3944.49	139.52
500	172.17	4710.77	161.26
600	182.03	5445.28	181.10
700	190.76	6154.39	199.45
800	198.61	6842.45	216.61
900	205.77	7512.62	232.78
1000	212.36	8167.28	248.11

The above table 4.8 indicates to us that the amount of quantile for three identified homogeneous region with the selected flood frequency distribution methods by using their corresponding equations and parameters. As we have seen that region 2 has high amount of floods relative to the other two regions at the return period of 1000 year.

4.5.3. Estimation of Index-Flood for Standardization

The index flood method standardizing flow plays a great role in derivation of flood frequency curves both for the dimensional and standard flow. The table 4.9 shows below the estimated quantile (Q_T) and standardized (Q_T/Q-mean) for regions using the above selected distributions and parameters in quantile estimation with their corresponding return period. As shown in table 4.9 the standard flood quantile of the three regions are different in magnitude and this is due to the variation of flood producing characteristics of the regions in the study area of Upper Wabi Shebelle River Basin. This can significantly help in risk assessment works, water resources management, and engineering decisions and actions in the study area. The regional growth curves of the three regions were developed as shown below from figure 4.10-4.12 by QT/Qm versus Gumble reduced variante using table 4.9.

Table 4.9 Estimated standardize flood quintile of regions

Gumble reduced variante	Q_T/Q_m to Region-1	QT/Q_m to Region-2	QT/Q_m to Region -3
0.37	1.06	2.52	0.05
0.91	1.99	8.04	0.18
1.36	3.22	15.85	0.42
1.64	4.29	22.84	0.65
1.85	5.27	29.35	0.87
2.14	7.04	41.44	1.28
2.36	8.67	52.70	1.65
2.53	10.20	63.37	2.01
2.67	11.65	73.60	2.34
2.79	13.03	83.48	2.65
3.07	16.93	111.52	3.51
3.63	28.21	194.76	5.85
3.96	38.08	269.29	7.74
4.20	47.13	338.67	9.37
4.39	55.62	404.47	10.83
4.54	63.69	467.53	12.17

Gumble reduced variante	Q_T/Q_m to Region-1	QT/Q_m to Region-2	QT/Q_m to Region -3
4.67	71.42	528.42	13.40
4.78	78.87	587.49	14.55
4.88	86.09	645.03	15.64
4.97	93.11	701.24	16.67

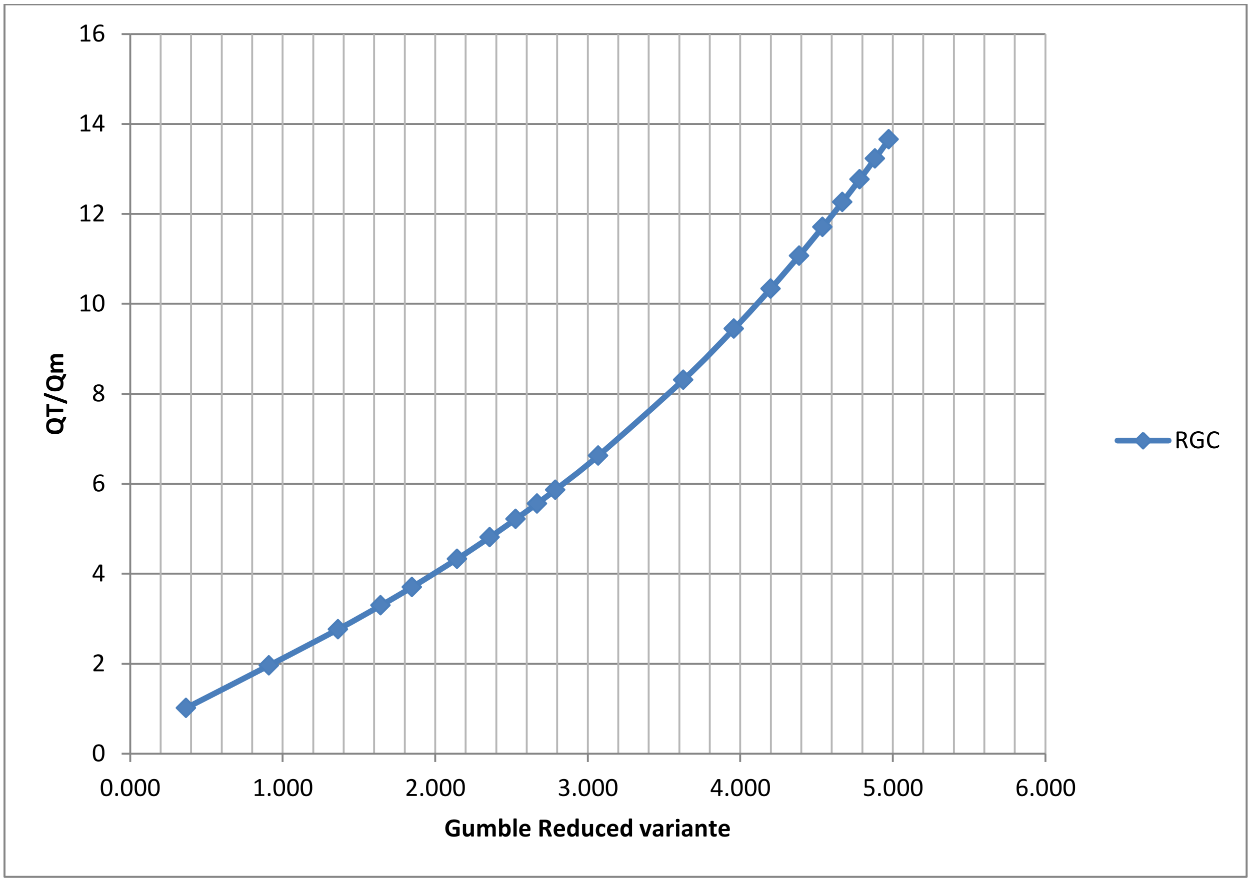

Figure 4.10 Regional Growth curve for Region -1

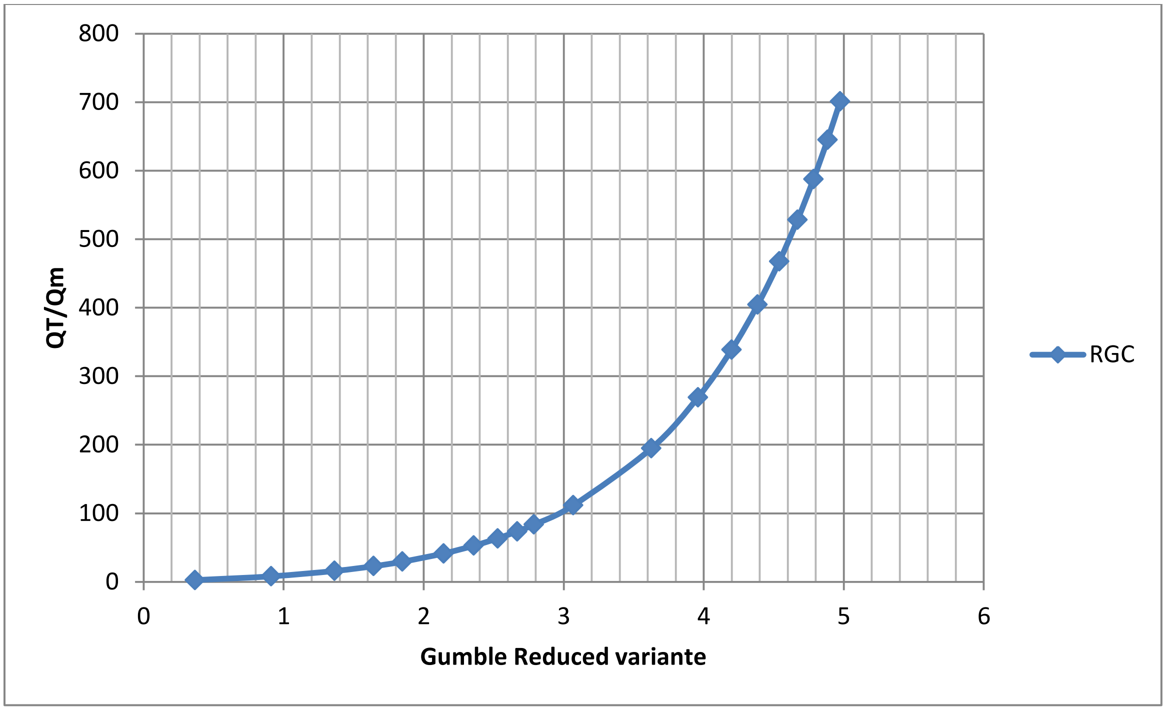

Figure 4.11 Regional Growth curve for Region-2

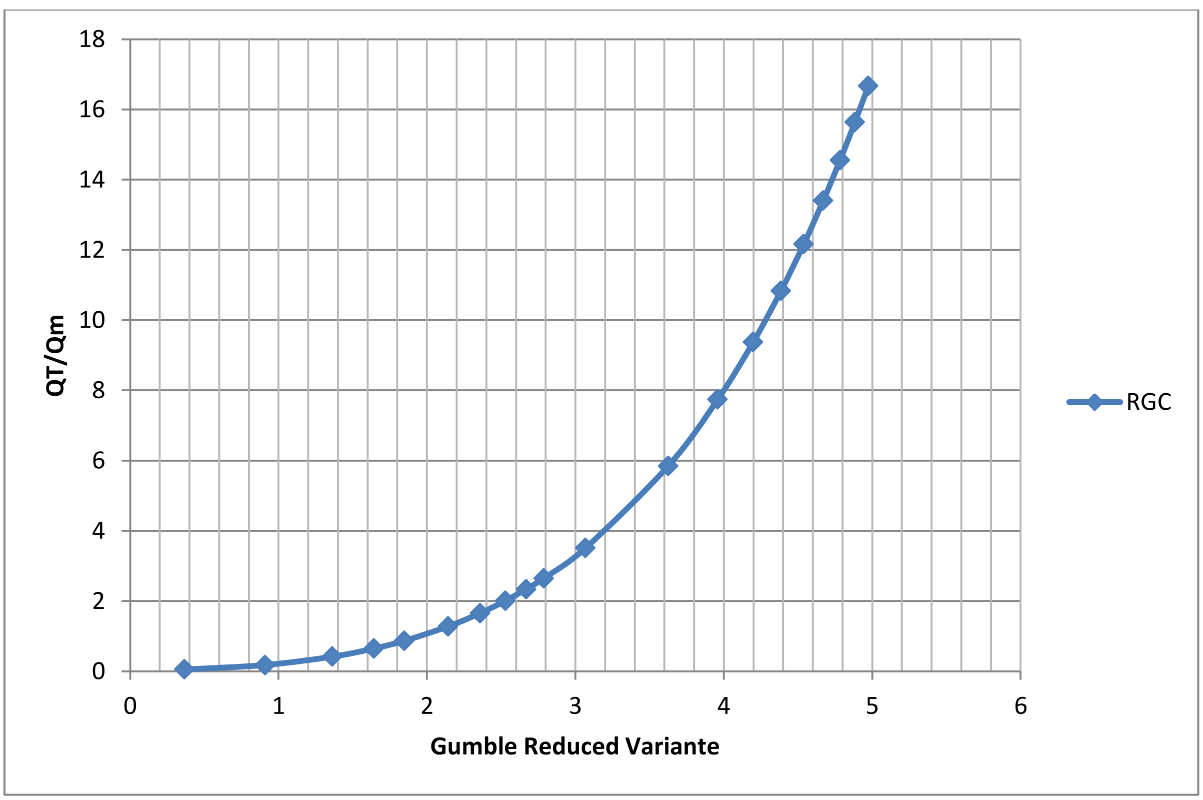

Figure 4.12 Regional Growth Curve for Region -3

4.6. Establishing of Regional Flood Frequency Curves

In order to estimate the regional flood frequency curve first of all the parameters have estimated which are essential for regional flood frequency curve preparation. After regions have been accepted as homogeneous and suitable distributions were identified for the regions, the quintiles of the region was computed by using the corresponding formula of each type of distribution for different return periods and then the flood frequency curves were established for each region as shown below in figures 4.13, 4.14 and 4.15 to Region-1, Region-2 and Region -3 respectively.

The curve was drawn for 2- 1000 years of return period of the three identified regions. As shown below from the figures 4.13, 4.14 and 4.15 the curves have different trends which imply the three regions were heterogeneous in their data.

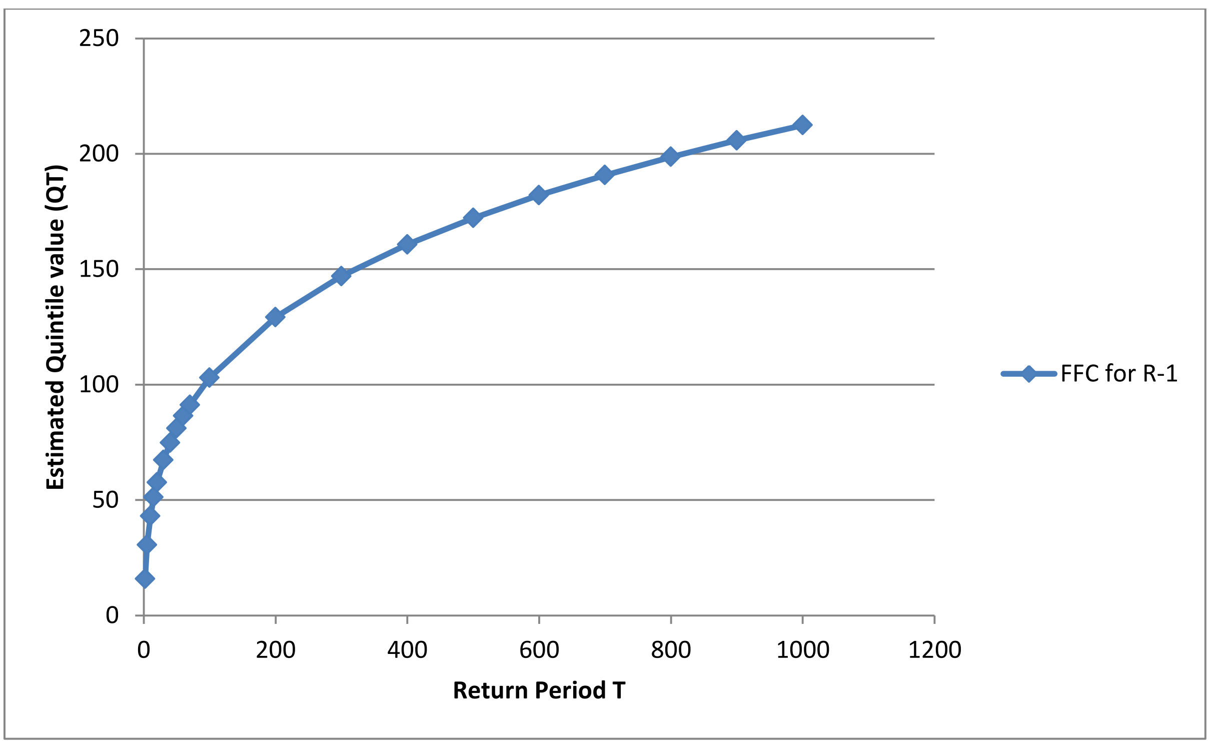

Figure 4.13 Flood Frequency curve for homogeneous region-1

The above figure 4.13 was plotted by considering quintile as y-axis and return period in the x-axis for region one. The curve is increasing with high slope for small return period and increase with decreasing increasing rate. The amount of quintile for 1000 return period is 212.36m^3/s.

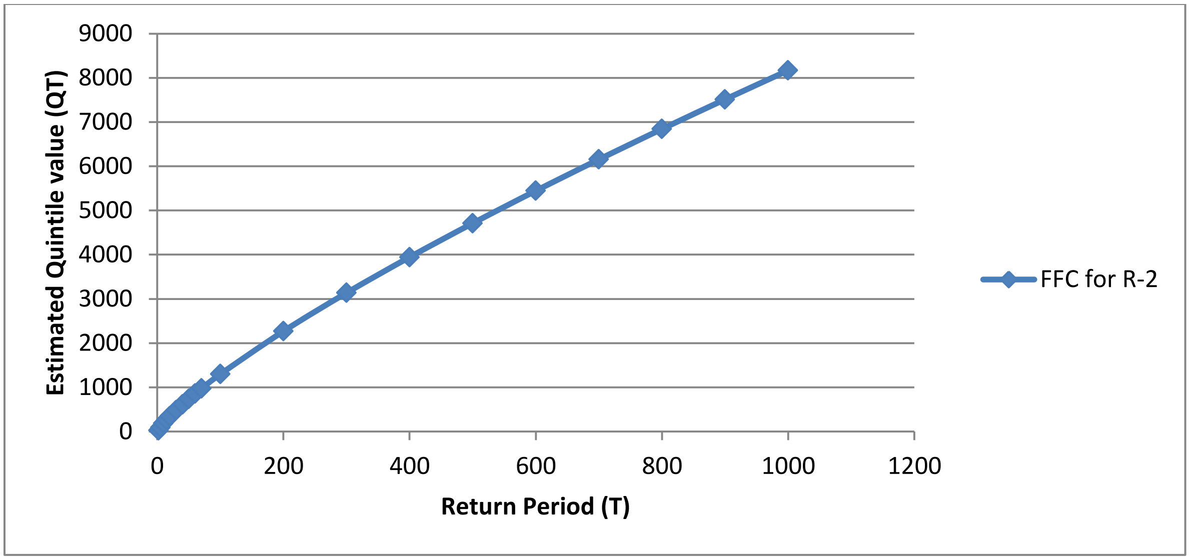

Figure 4.14 Flood frequency curve for homogeneous region 2

The above Figure 4.14 plotted by considering quintile as y-axis and return period in the x-axis for region two. As it is seen in the above graph, the graph is increasing gradually from return period 2 to 1000 with somehow constant slope. The amount of quintile at 1000 return period is 8167.28m^3/s which is larger than region one.

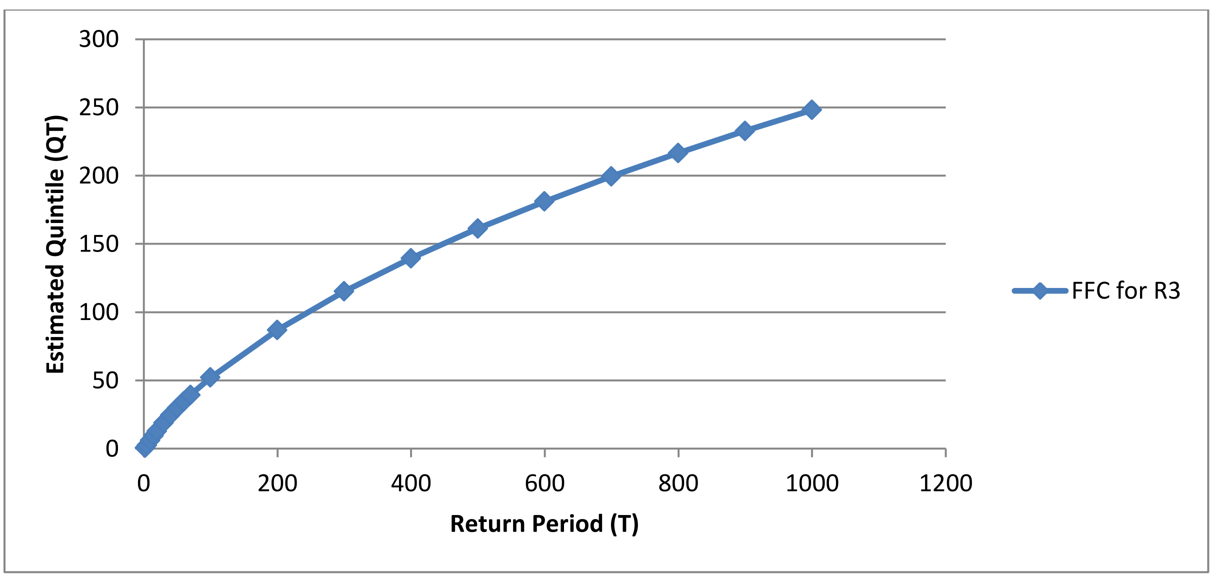

Figure 4.15 Flood Frequency curve for homogeneous region 3

The curve of this region was plotted in the same method of region-1 and region-2.The flood frequency curve for region three is somewhat similar with region one but it is slope a little bit flat relative to region one flood frequency curve.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the above findings of flood frequency analysis in the Upper Wabi-Shebelle River Basin the following conclusions were withdrawn. Around sixteen stations' available data were collected from Ministry of Water Irrigation and Energy and only thirteen of them were used for further flood frequency analysis and three of them were invalid by screening. The thirteen stations' data were checked for their quality relative to their randomness, consistency and adequacy of the data by their corresponding methods and they are fulfilled the requirements. The upper Wabi-Shebelle river basin was regionalized in to three homogeneous regions by using latitude-longitude of the gauging stations and L-moment of the annual maximum model method. The identified regions were designated as Region -1, Region-2 and Region -3 which number of gauging stations they consist of are three, three and seven gauging stations respectively. The three different homogeneous regions were delineated by using average of LCs and LCk with arc GIS version 10.6.

The best probability flood frequency distribution methods were selected by using easy fit software and testing for Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared of goodness-of-fit tests. General Extreme Value, General Pareto and Log Normal three parameters were the selected best fitted distribution methods for Region -1, Region-2 and Region3 respectively. The performance of the selected flood frequency distributions were checked by using P-P,Q-Q plots and LMRD in addition to the Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared of goodness-of-fit tests and they have the best performances.

The quantiles of each homogeneous region were estimated by the identified probability flood frequency distribution methods with their corresponding parameters which were estimated using easy fit software and equations. The quantiles were estimated for the three regions to the same return period of 2-1000 but with their own formulae and parameters. Lastly but not least the flood frequency curve were developed using Microsoft excel sheet. The plotted flood frequency curve can help for engineers to design safe, cost wise and serviceable structure in the identified homogenous regions. In addition to this it is helpful for flood management and risk mitigation purposes.

5.2. Recommendations

Based on the findings which were found in this study on Upper Wabi-Shebelle River Basins the following points were recommended to different stake holders.

Delineation of homogenous regions based on L-moment statistical parameters of gauged site can be one of an alternative method for regionalization to any river basins. Due to the adequacy of best-fit distributions and acceptability of results, Easy Fit statistical software can be used for other related studies. R-studio, Matlab and other programming should be used to simplify and get the good and reasonable results of any statistical analysis.

Naturally nature is dynamic with time. Therefore the parameters that we get today will change after days and due to this the values which were determined to day may leads an error for the future if it is not corrected so those researchers should conduct a research periodically to get the updated information on the river basin.

In this study the regionalization was conducted based on geographical location of stations and statistical value of the flow data but there are different parameters which can be used for regionalization like soil type, land use land cover, topology therefore the other researchers recommended to check the regionalization by using these factors.

The output of flood frequency analysis using statistical parameters is highly dependent on gauging stations recorded data which were collected from ministry of irrigation and electricity, therefore it is strongly recommended for this office to provide sufficient of data for further researchers.

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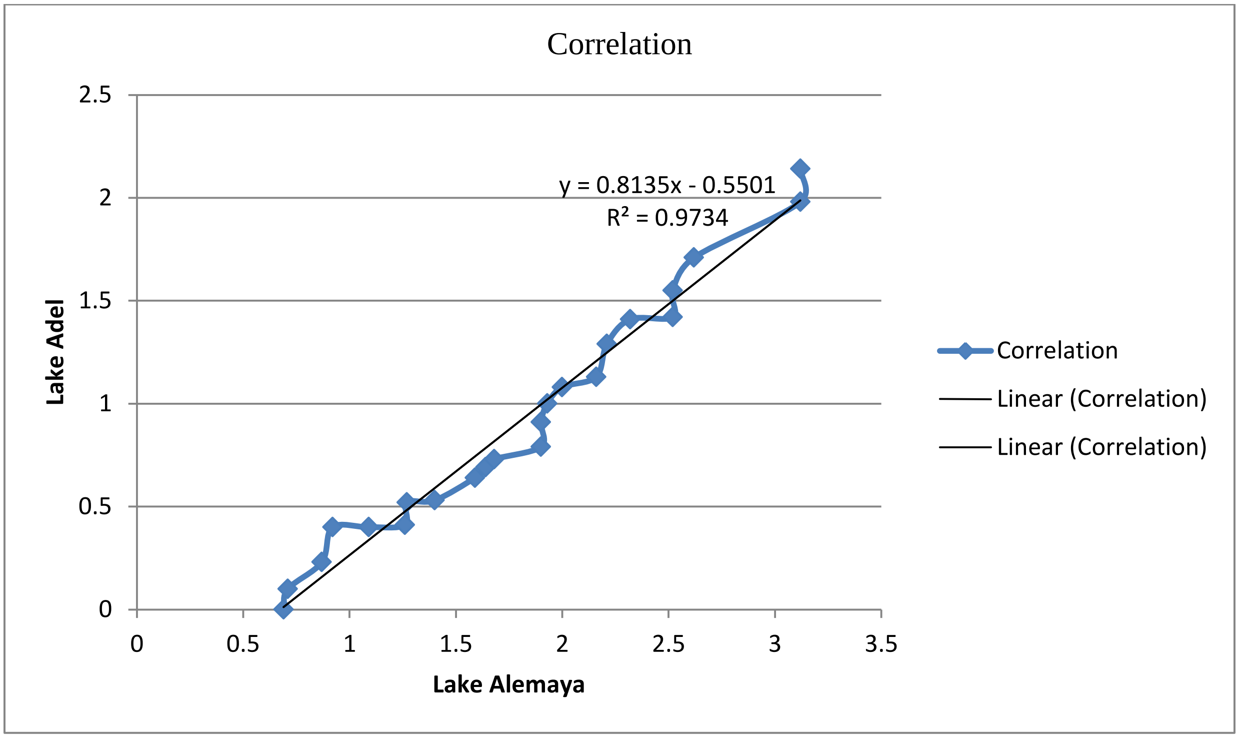
APPENDIXES

Appendix A: Correlation graph for missing data filling



Appendix B: Correlation Equation and R^2 value for missing data filling

S.NO	Y	X	Linear equation	R-square Value	Remark
1	Lake Adel	Lake Alemaya	y=0.813x-0.55`01	R2=0.9734	All R values are >0.6, therefore it is possible to use nearby station linear regression method for missing data filling
2	Wabi	Ukuma	Y=3.8485X+11.569	R2=0.8786	
3	Maribo	Herero	Y=0.5995X+11.371	R2=0.7743	
4	Furuna	Leliso	Y=.9066X+2.8118	R2=0.9017	
5	Maribo	Assassa	Y=0.7124X+8.7757	R2=0.7589	
6	Weiyb	Robi	Y=12.658X-30.134	R2=0.6391	
7	Dawi	Lake Adel	Y=0.856X-2.2093	R2=0.829	
8	Madahidu	Wabi below bridge	Y=3.7683X+13.548	R2==0.9482	

Appendix C: Percentile Points of the F-Distribution F {**v_1, v_2, p)** for the 5% Level of Significance (Two-Tailed)

P=P(F<= Fp)		**v_1:4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**16**
0.025 0.975	v_2: 5	0.107 7.39	0.140 7.15	0.169 6.98								
0.025 0.975	6		0.143 5.99	0.172 5.82	0.195 5.70							
0.025 0.975	7			0.176 5.12	0.200 4.99	0.221 4.90						
0.025 0.975	8				0.204 4.53	0.226 4.43	0.244 4.36					
0.025 0.975	9					0.230 4.10	0.248 4.03	0.265 3.96				
0.025 0.975	10						0.252 3.78	0.269 3.72	0.284 3.66			
0.025 0.975	11							0.273 3.53	0.288 3.47	0.301 3.43		
0.025 0.975	12								0.292 3.32	0.305 3.28	0.328 3.21	
0.025 0.975	14									0.312 3.05	0.336 2.98	0.355 2.92
		v1:14	16	18	20	24	30	40	60	100	160	∞
0.025 0.975	v2: 16	0.342 2.82	0.362 2.76	0.379 2.71								
0.025 0.975	18		0.368 2.64	0.385 2.60	0.400 2.56							
0.025 0.975	20			0.391 2.50	0.406 2.46	0.430 2.41						
0.025 0.975	24				0.415 2.33	0.441 2.27	0.468 2.21					
0.025 0.975	30					0.453 2.14	0.482 2.07	0.515 2.01				
0.025 0.975	40						0.498 1.94	0.533 1.88	0.573 1.80			
0.025 0.975	60							0.555 1.74	0.600 1.67	0.642 1.60		
0.025 0.975	100								0.625 1.56	0.674 1.48	0.706 1.44	
0.025 0.975	160									0.696 1.42	0.733 1.36	
0.025 0.975	∝											1.00 1.00

Appendix D: Percentile Points of the t-Distribution t (v, p for the 5% Level of significance (Two-Tai led)

P=P(t< =tp):	**0.025**	**0.975**
v: 4	-2.78	2.78
5	-2.57	2.57
6	-2.54	2.54
7	-2.36	2.36
8	-2.31	2.31
9	-2.26	2.26
10	-2.23	2.23
11	-2.20	2.2
12	-2.18	2.18
14	-2.14	2.14
16	-2.12	2.12
18	-2.10	2.1
20	-2.09	2.09
24	-2.06	2.06
30	-2.04	2.04
40	-2.02	2.02
60	-2.00	2
100	-1.98	1.98
160	-1.97	1.97
∞	-1.96	1.96

Appendix E. Trial one for homogeneity test as one region

Station Name	**Conventional moment based homogeneity test**			**L-moment based homogeneity test**			
	CV	**CS**	**CK**	**LCV**	**LCS**	**LCK**	**Discordance**
Madhadu	0.412	0.593	-0.697	-0.248	3.726	-3.699	0.091

Dawe	0.285	0.902	0.058	-0.295	0.247	1.97	0.864
Lake Alemaya	0.396	0.166	-0.724	-0.298	2.445	-3.891	0.632
L.adel	0.371	0.557	-1.074	-0.173	6.303	-3.56	0.87
Robi	0.137	-1.015	0.242	-0.266	3.299	-2.373	0.165
Weiyb	0.350	0.618	-1.347	-0.15	-2.529	-6.833	2.935
Furuna	0.350	-0.083	-0.636	-0.174	7.137	-3.52	1.072
Ukuma	0.248	-1.561	2.446	-0.287	3.769	-3.45	0.562
Wabi below bridge	0.354	0.616	-1.330	-0.188	6.472	-3.451	0.728
Assasa	0.271	-0.279	1.565	-0.232	4.163	-3.649	0.091
Lelliso	0.322	-0.322	-0.632	-0.155	-0.288	-27.311	3.364
Maribo	0.255	-0.841	2.362	-0.281	-0.394	-8.808	0.78
Herero	0.475	0.967	1.663	-0.265	0.325	2.19	0.845
CC	0.083<0.3			0.275<0.3			

Appendix F;Trial 2 for homogeneity test as two regions

Station Name	**Conventional moment based homogeneity test**			**L-moment based homogeneity test**				
	CV	**CS**	**CK**	**LCV**	**LCS**	**LCK**	**Discordance value**	**Remark**
Madhadu	0.4117	0.593	-0.697	-0.298	2.445	-3.891	0.467	region-1
Dawe	0.2850	0.902	0.058	-0.287	3.769	-3.450	0.441	
Lake Alemaya	0.3963	0.166	-0.724	-0.265	0.325	2.190	0.469	
L.adel	0.3708	0.557	-1.074	-0.2950	0.2472	1.9701	0.64	
cc	**0.397>0.3**			**0.147<0.3**				
Robi	0.1367	-1.015	0.242	-0.1740	7.1367	-3.520	0.533	region-2
Weiyb	0.3504	0.618	-1.347	-0.1880	6.4717	-3.451	2.635	
Furuna	0.3505	-0.083	-0.636	-0.248	3.726	-3.699	0.685	

Station Name	**Conventional moment based homogeneity test**			**L-moment based homogeneity test**				
	CV	**CS**	**CK**	**LCV**	**LCS**	**LCK**	**Discordance value**	**Remark**
Ukuma	0.2484	-1.561	2.446	-0.173	6.303	-3.560	0.419	
Wabi below bridge	0.3535	0.616	-1.330	-0.266	3.299	-2.373	0.132	
Assasa	0.2708	-0.279	1.565	-0.150	-2.529	-6.833	2.582	
Lelliso	0.3215	-0.322	-0.632	-0.232	4.163	-3.649	1.227	
Maribo	0.2554	-0.841	2.362	-0.155	-0.288	-27.31	0.262	
Herero	0.4746	0.967	1.663	-0.281	-0.394	-8.808	0.524	
cc	**0.288<0.3**			**0.289<0.3**				

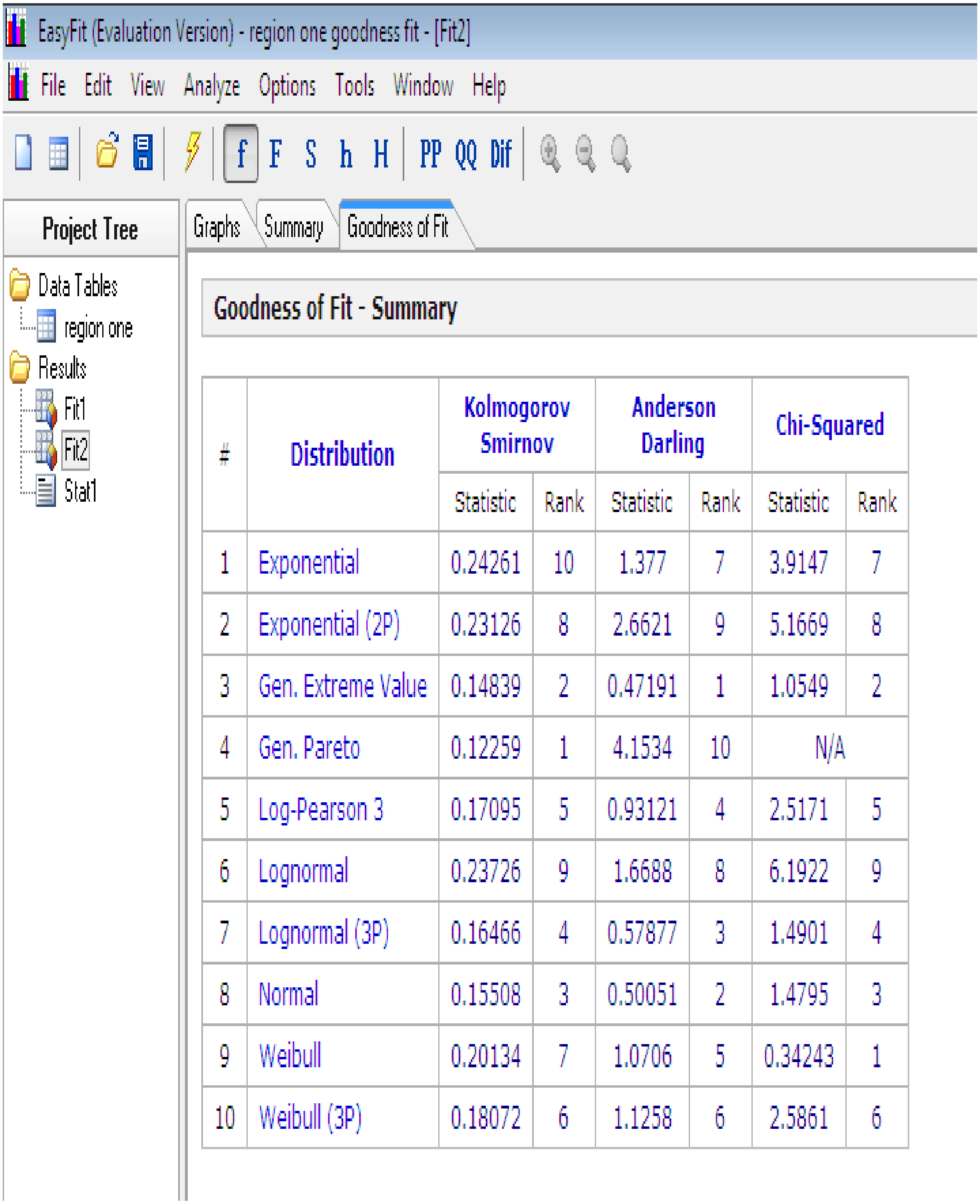
Appendix G; Trial 3 for homogeneity test as two regions

Conventional moment based homogeneity test				L-moment based homogeneity test			
Station Name	**CV**	**CS**	**CK**	**LCV**	**LCS**	**LCK**	**Remark**
Madhadu	0.4117	0.593	-0.697	-0.298	2.445	-3.891	Region-1
Dawe	0.285	0.902	0.058	-0.287	3.769	-3.45	
Lake Alemaya	0.3963	0.166	-0.724	-0.265	0.325	2.19	
cc	0.168<0.3			0.156<0.3			
Lake Adel	0.3708	0.557	-1.074	-0.295	0.247	1.97	Region-2
Robi	0.1367	-1.015	0.242	-0.174	7.137	-3.52	
Weiyb	0.3504	0.618	-1.347	-0.188	6.472	-3.451	
cc	0.106<0.3			0.266<0.3			
Furuna	0.35	-0.083	-0.636	-0.248	3.726	-3.699	Region-3
Ukuma	0.248	-1.561	2.446	-0.173	6.303	-3.56	
Wabi below bridge	0.354	0.616	-1.33	-0.266	3.299	-2.373	
Assasa	0.271	-0.279	1.565	-0.15	-2.529	-6.833	
Lelliso	0.322	-0.322	-0.632	-0.232	4.163	-3.649	
Maribo	0.255	-0.841	2.362	-0.155	-0.288	-7.311	
Herero	0.475	0.967	1.663	-0.281	-0.394	-8.808	
cc	0.073<0.3			0.225<0.3	2.04		

Appendix H: Average maximum stream flow data used for detail analysis

Region -1	Region-2	Region-3
19.277	14.010	11.789
21.422	23.361	17.054
10.890	17.961	17.152
12.121	13.398	16.572
15.146	15.514	14.366
11.735	19.135	24.517
22.114	16.211	15.870
23.789	27.097	18.588
31.460	20.680	14.988
27.939	25.020	16.821
20.629	25.759	20.698
34.386	16.016	15.188
12.503	14.129	22.722
20.678	14.438	13.998
24.302	0.520	20.144
14.040	0.470	15.826
20.950	0.620	12.467
2.520	0.690	7.170
2.520	0.530	9.978
2.000	0.730	11.453
1.090	0.410	11.959
3.120	0.540	10.923
3.120	0.640	13.549
		3.419
		1.132

Appendix - I: Goodness of fit test results and descriptive statistics for selected distribution of region-1

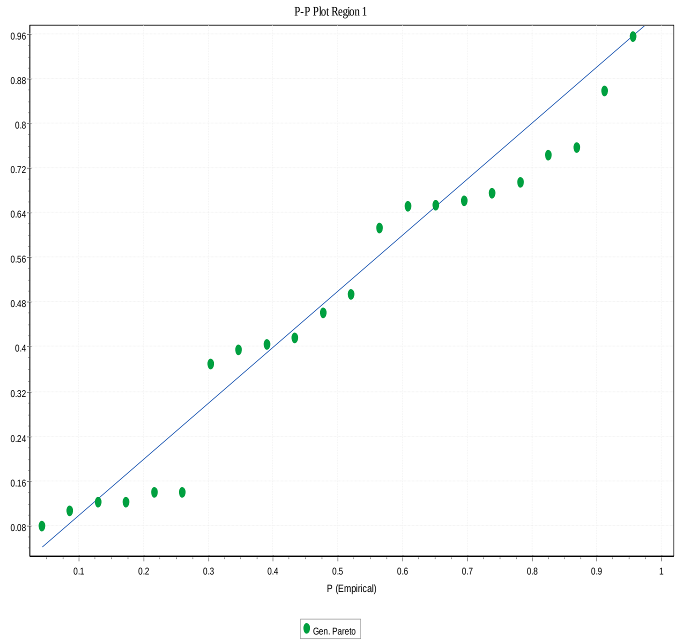


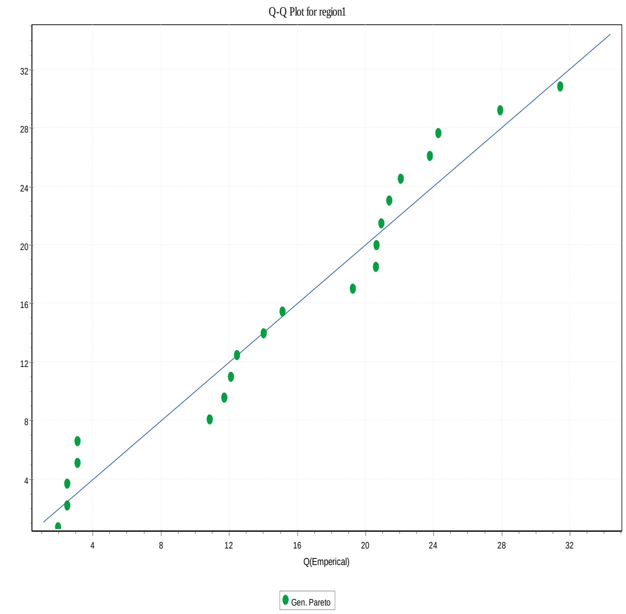
#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.24261	10	1.377	7	3.9147	7
2	Exponential (2P)	0.23126	8	2.6621	9	5.1669	8
3	Gen. Extreme Value	0.14839	2	0.47191	1	1.0549	2
4	Gen. Pareto	0.12259	1	4.1534	10	N/A	
5	Log-Pearson 3	0.17095	5	0.93121	4	2.5171	5
6	Lognormal	0.23726	9	1.6688	8	6.1922	9
7	Lognormal (3P)	0.16466	4	0.57877	3	1.4901	4
8	Normal	0.15508	3	0.50051	2	1.4795	3
9	Weibull	0.20134	7	1.0706	5	0.34243	1
10	Weibull (3P)	0.18072	6	1.1258	6	2.5861	6

Fit2
Stat1

Gen. Extreme Value [#3]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	23 0.14839 0.63851 2				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.21645	0.24746	0.2749	0.30728	0.32954
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	23 0.47191 1				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	2 1.0549 0.59012 2				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	3.2189	4.6052	5.9915	7.824	9.2103
Reject?	No	No	No	No	No

Appendix J: Probability –probability and Quantile - Quantile plot





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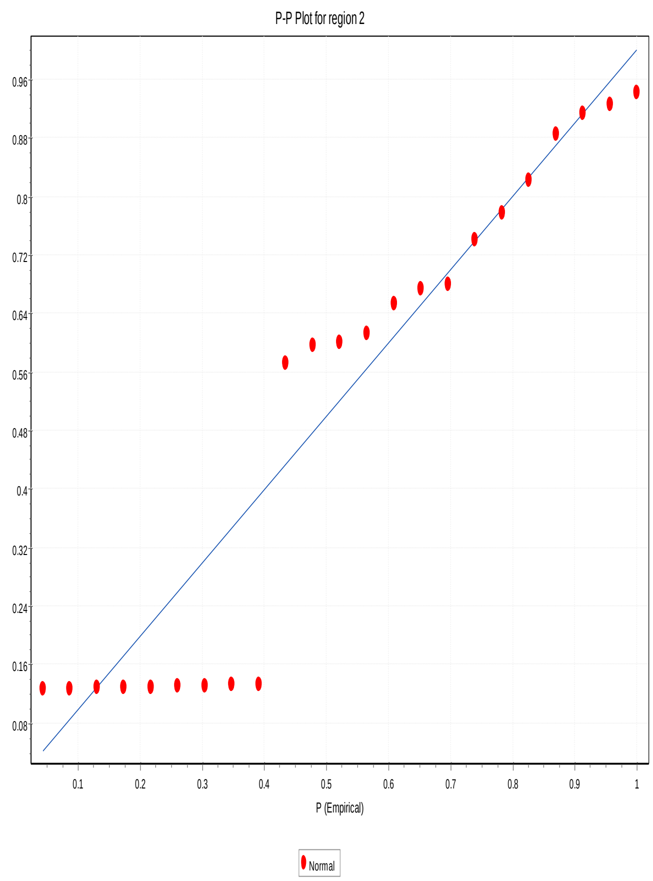

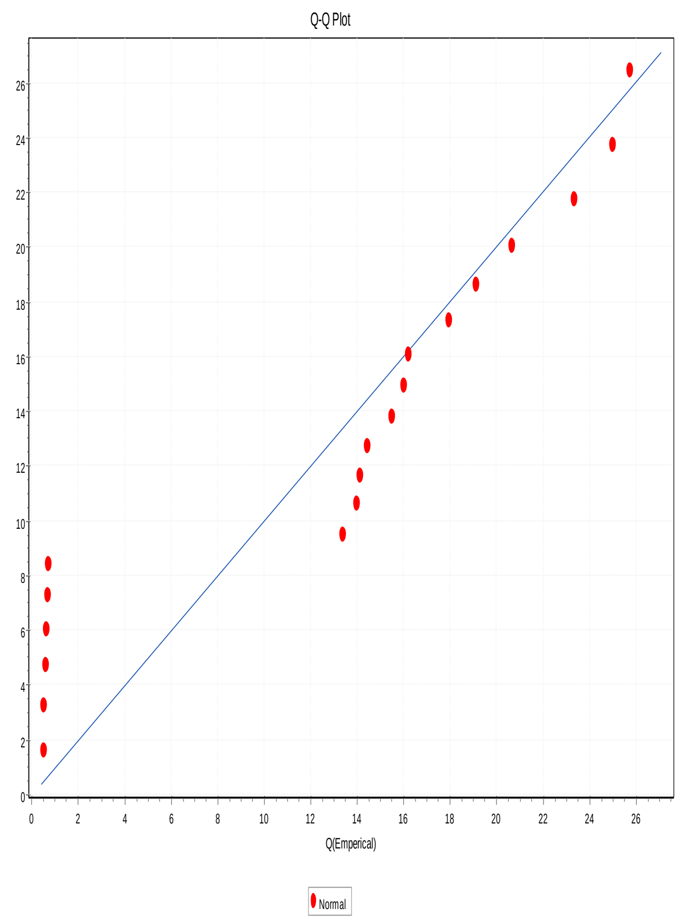

Appendix-K: Parameter estimation for selected types of flood frequency methods by easy fit software

S.No	Distribution	Parameters	Remark
1	Exponential	λ=0.064	Region -1
2	Exponential (2P)	λ=0.069, γ=1.09	
3	Gen. Extreme Value	κ=–0.266, σ=10.089, μ=11.886	
4	Gen. Pareto	κ=–0.961, σ=33.495, μ=–1.525	
5	Log-Pearson 3	α=4.017, β=–0.509, γ=4.438	
6	Lognormal	σ=0.998, μ=2.393	
7	Lognormal (3P)	σ=0.065, μ=5.005, γ=–133.87	
8	Normal	σ=9.954, μ=15.554	
9	Weibull	α=1.0387, β=17.247	
10	Weibull (3P)	α=1.448, β=16.917, γ=0.073	
1	Exponential	λ=0.086	Region-2
2	Exponential (2P)	λ=0.089, γ=0.41	
3	Gen. Extreme Value	κ=–0.186, σ=9.238, μ=7.778	
4	Gen. Pareto	κ=–0.78987, σ=27.649, μ=3.801	
5	Log-Pearson 3	α=19.627, β=–0.39475, γ=9.2906	
6	Lognormal	σ=1.7104, μ=1.5426	
7	Lognormal (3P)	σ=2.8674, μ=0.78816, γ=0.4095	
8	Normal	σ=9.8, μ=11.647	
9	Weibull	α=0.55418, β=11.171	
10	Weibull (3P)	α=0.49673, β=8.4922, γ=0.41	
1	Exponential	λ=0.06719	Region-3
2	Exponential (2P)	λ=0.08722, γ=3.419	
3	Gen. Extreme Value	κ=–0.31674,σ=4.8112, μ=13.29	
4	Gen. Pareto	κ=–1.0741, σ=17.088, μ=6.6451	
5	Log-Pearson 3	α=1.1328, β=–0.38288, γ=3.0692	
6	Lognormal	σ=0.39892, μ=2.6355	

S.No	Distribution	Parameters	Remark
7	Lognormal (3P)	σ=0.03609, μ=4.8642, γ=−114.77	
8	Normal	σ=4.7417, μ=14.884	
9	Weibull	α=2.6183, β=16.655	
10	Weibull (3P)	α=4.4791, β=20.283, γ=−3.6437	

Appendix-L: Standard error for parameter estimation

	REGION-1			REGION-2			REGION-3		
T	GEV/MOM	GEV/PWM	GEV/MLM	GPA/MOM	GPA/PWM	GPA/MLM	LN/MOM	LN/PWM	LN/MLM
2	0.002	0.002	0.0005	0.0065	0.4357	0.1958	0.552	0.063	0.156
5	0.130	0.031	0.1046	0.0303	0.7719	0.5277	0.315	0.344	0.135
10	0.238	0.069	0.1984	0.0639	0.8993	0.6911	0.263	0.722	0.096
15	0.310	0.102	0.2621	0.0940	0.9457	0.7623	0.912	1.029	0.058
20	0.365	0.132	0.3121	0.1220	0.9702	0.8044	1.583	1.294	0.022
30	0.450	0.187	0.3905	0.1739	0.9960	0.8537	2.938	1.741	0.046
40	0.515	0.238	0.4523	0.2223	1.0097	0.8829	4.277	2.118	0.107
50	0.570	0.285	0.5042	0.2681	1.0182	0.9026	5.590	2.449	0.165
60	0.616	0.330	0.5493	0.3119	1.0240	0.9171	6.875	2.746	0.219
70	0.658	0.373	0.5896	0.3542	1.0283	0.9283	8.131	3.017	0.271
100	0.760	0.493	0.6906	0.4744	1.0363	0.9510	11.747	3.719	0.412
200	0.988	0.843	0.9228	0.8315	1.0464	0.9846	22.543	5.429	0.796
300	1.142	1.149	1.0843	1.1509	1.0501	0.9992	32.051	6.676	1.106

400	1.262	1.429	1.2122	1.4480	1.0521	1.0078	40.706	7.688	1.375
500	1.362	1.692	1.3199	1.7295	1.0533	1.0137	48.737	8.552	1.615
600	1.447	1.942	1.4137	1.9991	1.0541	1.0180	56.281	9.314	1.833
700	1.523	2.181	1.4974	2.2592	1.0547	1.0213	63.429	9.998	2.036
800	1.591	2.412	1.5733	2.5113	1.0552	1.0239	70.247	10.623	2.225
900	1.654	2.636	1.6430	2.7567	1.0556	1.0261	76.782	11.199	2.404
1000	1.711	2.854	1.7077	2.9962	1.0559	1.0280	83.072	11.736	2.573
Avg.	0.865	0.969	**0.8214**	0.9902	0.9902	**0.8770**	26.852	5.023	**0.8824**

Appendix-M: Probability Density functions for selected distributions (Chow, 1964

Distribution	CDF or PDF	Domain
Generalized Extreme Value	$F(x)=\begin{cases}\exp\left(-\left(1+kz\right)^{-1/k}\right) & k\neq 0\\ \exp\left(-\exp(-z)\right) & k=0\end{cases}$	$\begin{rcases}1+k\frac{(x-\mu)}{\sigma}>0 & for\quad k\neq 0\\ -\infty<x<+\infty & for\quad k=0\end{rcases}$
Generalized Logistics	$F(x)=\begin{cases}\dfrac{1}{1+(1+kz)^{-1/k}} & k\neq 0\\ \dfrac{1}{1+\exp(-z)} & k=0\end{cases}$	$\begin{rcases}1+k\frac{(x-\mu)}{\sigma}>0 & for\quad k\neq 0\\ -\infty<x<+\infty & for\quad k=0\end{rcases}$
Log-Pearson 3	$F(x)=\left.\dfrac{\Gamma(\ln(x)-\gamma)/\beta^{(\alpha)}}{\Gamma(\alpha)}\right\}$	$\begin{rcases}0<x\leq e^{\gamma} & \beta<0\\ e^{\gamma}\leq x<+\infty & \beta>0\end{rcases}$

Logistic	$f(x) = \frac{\exp(-\left(\frac{x-\mu}{\sigma}\right))}{\sigma\left(1+\exp(-\left(\frac{x-\mu}{\sigma}\right))\right)^2}$	$-\propto < x < +\propto$	σ continuous scale parameter($\sigma > 0$) μ continuous location parameter
Log-Logistic (3P)	$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-2}$	$\gamma \le x < +\propto$	α continuous shape parameter ($\alpha > 0$) β continuous scale parameter ($\beta > 0$) γ continuous location parameter ($\gamma = 0$ yields the two-parameter Log-Logistic distribution)
Log-Logistic (2P)	$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x}{\beta}\right)^{\alpha}\right)^{-2}$		
Lognormal (3P)	$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$	$\gamma \le x < +\propto$	σ continuous parameter($\sigma > 0$) μ continuous parameter γ continuous location parameter ($\gamma = 0$ yields the two-parameter Lognormal distribution)
Lognormal (2P)	$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x)-\mu}{\sigma}\right)^2\right)}{(x)\sigma\sqrt{2\pi}}$		
Log-Pearson 3 (3P)	$f(x) = \frac{1}{x\lvert\beta\rvert\Gamma(\alpha)}\left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1} * \exp(-\frac{\ln(x)-\gamma}{\beta})$	$0 < x \le e^{\gamma}$ for $\beta < 0$ and $e^{\gamma} \le x < +\propto$ for $\beta > 0$	α continuous parameter ($\alpha > 0$) β continuous parameter ($\beta \neq 0$) γ continuous parameter