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: A Case Study on Genale-Dawa River Basin, Ethiopia

By: Tarekegn Dejen Mengistu

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

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Jimma, Ethiopia

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Advisor: Prof., Dr.-Ing Esayas Alemayehu

Co-advisor: Tolera Abdisa (MSc.)

November, 2018

Jimma, Ethiopia

DECLARATION

I, the undersigned declare that the thesis entitled as "**Regional Flood Frequency Analysis: A Case Study on Genale-Dawa 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 used in this study have been duly acknowledged.

Tarekegn Dejen Mengistu

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Signature Date

This thesis has been submitted for examination with our approval as University supervisors.

Advisor: Prof., Dr.-Ing Esayas Alemayehu

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APPROVAL

The thesis entitled "**Regional Flood Frequency Analysis: A Case Study on Genale-Dawa River Basin, Ethiopia**" submitted by Tarekegn Dejen Mengistu 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.

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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 Tarekegn Dejen Mengistu. 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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ABSTRACT

Determining the magnitude and frequency of floods for any hydrologically analogous region affords vigorous information in planning, designing, economic evaluation of flood protection and management of various types of water resources projects. The necessity of using this regional information arises from the need to improve estimates. It is due to the fact floods represent the most disastrous natural event causing several damages to enormous economic and life losses in the study area. However, the estimation of flood values with high return periods for a site of interest poses a great challenge due to the paucity of data. To analyze this event, future information on the hydrology of water resources and its impact has to be significantly studied. Thus, the main objective of this study was to perform appropriate regional flood frequency analysis on Genale-Dawa River Basin of Ethiopia. To achieve this, based on data from 16 stream gauged sites, three hydrological homogeneous subregions were defined and delineated based on L-moment homogeneity tests, namely Region-A, Region-B and Region-C. A delineation of homogeneous regions was accomplished using ArcGIS10.4.1. The delineated regions were covered 32.708, 48.328 and 18.963% of Region-A, Region-B and Region-C respectively. Discordancy of regional data of the L-moment statistics was identified using Matlab2017a. All regions have shown satisfactory results for discordance measures and homogeneity tests. For the regions, best-fit distributions were selected. L-moment ratio diagrams and goodness of fit tests with the help of Easy Fit Statistical Software were used to select best-fit probability distributions. The performances of the distributions were evaluated using Kolmogorov Smirnov, Anderson-Darling and Chi-Squared goodness-of-tests. After three goodness of fit tests were carried out and results compared, generalized extreme value and generalized Pareto distributions were identified as suitable distributions for modeling accurate annual maximum flows in the basin. Based on best-fit distributions for the three regions, regional flood frequency curves were constructed and peak flood discharge predicted for the return periods of 2-10,000 years. The derived flood frequency curves at a given confidence limit of 95% and 5%, suggested that how important engineering decisions and actions such as design and operation of the water resources project have to be undertaken. As a result of this, statistical analysis of gauged sites was revealed an acceptable method of regionalization. Henceforth, the study can be further extended into flood hazard, risk and inundation mapping of identified regions of the study area.

Keywords: Best-fit distribution; Flood frequency analysis; Flood magnitude; Homogeneity; L-moment; Parameter estimation; Regionalization

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ABBREVIATIONS AND ACRONYMS

AMF	Annual Maximum Flow
CC	Combined Coefficient of variation
DEM	Digital Elevation Model
FFA	Flood Frequency Analysis
FFC	Flood Frequency Curve
GEV	Generalized Extreme Value distribution
GIS	Geographical Information System
GPA	Generalized Pareto distribution
IHR	Identification of Homogeneous Regions
LCL	Lower Confidence Limit
LCV	Linear Coefficient of Variation
LCs	Linear Coefficient of Skewness
LCk	Linear Coefficient of Kurtosis
Matlab	Mathematics Laboratory
MML	Method of Maximum Likelihood
PWM	Probability Weighted Method
RFFA	Regional Flood Frequency Analysis
T	Return Period
X_T	Estimated flow quantiles value(m^3/s)
UCL	Upper Confidence Limit

1. INTRODUCTION

1.1. Background

Flood is one of the most disasters that can lead to loss of life and property in many parts of the world (Rao and Srinivas, 2008; Zhang and You, 2014; Mallakpour and Villarini, 2015; Steinschneider and Lall, 2015; Wu *et al*., 2015; Komi *et al*.,2016). The estimation of the magnitude of streamflow at various locations in a basin resulting from given precipitation input is a significant feature of flood hydrology (Kannan and Helmenegilde, 2007; Chavoshi and Azmin, 2009). In most of hydrological analysis a reliable estimation of maximum flood discharge at the site of interest is necessary (Vivekanandan, 2015). It is due to that estimation of the flood is used for flood risk assessment, proper planning and design of hydraulic structures such as dams, spillways, bridges, culverts, urban drainage systems and economic evaluation of flood protection of a given project (Romali and Yusop, 2017; Tanaka *et al*., 2017).

The reasonable estimation of the flood has been remained one of the main challenging issues where hydrological data and information are either limited or not available (Kumar and Chatterjee, 2011; Willems *et al*., 2012; Dubey, 2014; Murphy *et al*.,2014). This can be achieved through the recorded annual maximum discharge data using suitable probability distribution and parameter estimation methods. For this purpose, flood frequency analysis played a major role in the estimation of flood quantile at a project location for different return periods on a river system (Vivekanandan, 2015; Tanaka *et al*., 2017).

Flood frequency analysis is the utmost significant statistical method in understanding the nature and magnitude of discharge in a river. Its aim is to relate the magnitude of events to their frequency of occurrence through probability distribution (Bhagat, 2017; Ganamala and Kumar, 2017). If adequate records are available, the common methods give acceptably uniform results within the range of data. However, the location of gauging station occasionally coincides with the sites of interest, or the available records become too short to make important statistical implication (Badreldin and Fengo, 2012). Hence, the estimation of design floods for a site has been a common problem particularly for ungauged basins or for sites of a short record length (Hailegeorgis and Alfredsen, 2017).

Use of regional data, derived from gauged sites and regionalized for use at any location within a homogenous region, would improve the reliability of the design flood estimation. This is due to water resources projects require design flood information are located in areas where flood data are either not available or inadequate (Willems *et al*., 2009; Nobert *et al*., 2014).

Regional flood frequency analysis has demonstrated to be an effective technique for estimating flood quantiles at ungauged sites or with insufficient streamflow data using the flood information at neighboring sites within a homogeneous region (Dubey, 2014; Lu, 2016, Wu *et al*., 2018). It is a data-driven approach, which attempts to transfer flood information from a group of gauged catchments to the catchment location of interest. This technique is expected to be simple so that design flood estimates can be obtained from readily available input data and the region is considered homogeneous (Rahmana *et al*., 2015).

In regional flood frequency analysis, the established curve of flood versus return period used for estimating flood quantiles at any site within the region. These regional relations can alleviate the effects of outliers from time series data (Mishra *et al*., 2010). To derive flood frequency estimates for a site with a limited time series data, it is recommended to use observed time series data since they are the bases for regional information (Wilson *et al*., 2011).

Therefore, use of regional information derived from data at gauged sites and regionalized for use at any location within the basin has practiced major setbacks due to the absence of tools and methods. The availability of such tools would improve the reliability of flood risk estimation, support water management and engineering decisions in the basin (Share Bale Eco-Region, 2017). Therefore, the main aim of this study was to perform regional flood frequency analysis on Genale-Dawa River Basin of Ethiopia using AMF estimation modeling of stream gauging data.

1.2. Statement of the problem

The main challenge of flood from water resources development and management point of view are its recurrent interference and activities made by society (Mengistu and Sivakumar, 2018). These uncontrolled human activities and intervention cause tremendous damages to enormous loss of life and property (Getahun and Gebre,2015; Kamaruddin *et al*., 2016; Anusha and Surendra, 2017; Romali and Yusop, 2017). This happens mainly due to the frequency and magnitude of flooding occurrence. Thus, efficient flood risk management is needed to minimize the vulnerability of the local population. Conversely, efficient estimations of the magnitude of flooding events, either for design or risk management are mostly due to limited availability of data (Ahmad *et al*.,2011; Komi *et al*.,2016).

The frequency of floods with various risks of exceedance is therefore needed in most engineering problems (Vivekanandan, 2015). The estimation must be fairly accurate not only aimed at the preventing of catastrophes, but also at avoiding excessive costs in case of overestimating the flood magnitude, or excessive damage while underestimating flood potential. Thus, engineering works require a reliable estimation of flood quantiles using reliable flood records measured at gauging stations.

However, most of the catchments in developing countries like Ethiopia are poorly gauged or ungauged, which hinders the country's water resources management and flood prediction (Rabba *et al*., 2018). This is owing to the low density of gauging stations, the operation and maintenance of gauging networks are difficult and the lack of infrastructures required for the acquisition of adequate hydrologic data (Gedefa and Seleshi, 2009). This data in both quantity and quality are the primary inputs to the design and successful operation of hydraulic and drainage structures such as dams, spillways, bridges, culverts and flood protection schemes (Saf, 2009; Tanaka *et al*., 2017). Unfortunately, these vigorous inputs are usually inadequate, in most cases incredibly unavailable at points of interest.

Due to the scarcity of the required data at or near the site of interest, professionals responsible for the design of water resources projects have had to depend on unsatisfactory sources of information for their input parameters (Gebeyehu,1989; Dubey,2014; Nobert *et al*.,2014; Salinas *et al*., 2013). This enforces to adopt a more conservative approach in their design techniques with the obvious implication of higher costs on the projects, which is indeed a burden on the financial resources of the country.

In Ethiopian River Basins, different studies were undertaken related with regionalization of basin hydrology. However, most of the studies exclusively tried to concentrate on frequency analysis of their study area under investigation (Gebeyehu,1989; Sine and Ayalew, 2004; Demissie and Michael, 2008; Gedefa and Seleshi, 2009; Mekoya and Seleshi, 2010; Hussein and Wagesho, 2016; Ketsela *et al.*, 2017). But, research conducted by Share Bale Eco-Region (2017) concluded that different drivers of hydrological dynamics in the study area are prone to the risk of flooding. To overcome this problem, the study recommended a regional flood frequency analysis by grouping stations into homogenous regions for the Genale-Dawa River Basin.

Accordingly, this study was conducted bearing in view of the fact that, the development of a regional flood frequency analysis is a practical means of providing flood information at sites with short record flow data for the purposes of flood risk management, safely and economical design of hydraulic structures that might undertake on Genale-Dawa River Basin.

1.3. Objective of the study

1.3.1. General objective

The general objective of this study is to carry out appropriate regional flood frequency analysis on Genale-Dawa River Basin of Ethiopia.

1.3.2. Specific objectives

The specific objectives of the study are:

1. To identify and delineate hydrologically homogeneous regions of the entire basin;
2. To determine the best-fit probability distribution to the data of gauging stations of the basin; and
3. To develop regional flood frequency curves for delineated homogeneous regions corresponding to the required return periods on the basin.

1.4. Research questions

The research questions which address this particular study are:

1. How hydrologically homogeneous regions of the basin for regional flood estimation is identified and delineated?
2. What are the best-fit probability distributions for prediction of hydrological events of gauging stations of the basin? and
3. How regionalization method is crucial to extend the observed hydrologic regimes for future data use in the study area?

1.5. Significance of the study

This study is expected to become valuable up to date information for flood risk estimation, economic evaluation of flood control projects, proper planning, and design of water resources management options on the study area. In addition, the study can be used as a point of reference for policy and decision makers, and any further investigation that will undertake on the Genale-Dawa River Basin.

1.6. Scope of the study

Generally, the study address issues related to the probability of flooding occurrence and its magnitude that might take place depending on the hydrological response of the selected basin. The study is limited mainly on regionalization of streamflow data on the Genale-Dawa River Basin, Ethiopia.

2. LITERATURE REVIEW

In the planning and design of water resources projects, professionals are interested in the determination of the reasonable estimation of extreme events with defined return periods (Rahmana et al., 2015). These extreme events are necessary in the design of various flow control structures such as levees, culverts, bridges, barrages and dams, reservoir management, economic evaluation of flood protection projects, land use planning and management, flood risk assessment (Rao and Srinivas, 2008; Noto and Loggia, 2009; Bhagat, 2017; Kanti et al., 2017).

2.1. Flood frequency analysis

Hydrological analysis plays the most important task to achieve a likelihood distribution of floods before estimation. This probability of events can be predicted by suitable historical data to selected distributions (Ahmad *et al*., 2011). For this, frequency analysis is used to determine the magnitude of extreme events to their probability distribution (Chow *et al*.,1988; Rao and Srinivas, 2008; Ganamala and Kumar, 2017; Ashraful *et al*., 2018).

A common approach, therefore, is the annual maximum, where for each water year the peak streamflow is determined and a distribution is fitted to this series of data (Schendel and Thongwichian,2017). These data are used to make frequency distributions for various discharges as a function of their recurrence interval or exceedance probability (Hosking and Wallis,1997). Data observed over an extended period in a river system are analyzed in frequency analysis. The flood data are considered stochastic and may even be assumed space and time independent (Rao and Hamed, 2000).

2.2. Flood estimation techniques

Flood frequency assessment is indispensable for flood management. It addresses the subject of flood risk assessment required in flood zoning and spatial planning, and in the arrangement of flow values for the design of flood alleviation and control works (Murphy *et al*., 2014; England *et al*., 2015). The accurate estimation of flood magnitude with corresponding frequency of occurrence is the challenge for hydrologists due to planning, management and design of water resource projects depends on the frequency and magnitude of maximum floods (Chavoshi and Azmin, 2009**;** Saf, 2009; Javelle *et al*., 2010; Dubey, 2014; Alam *et al*., 2016) on the sites of interest.

A realistic estimation of flood magnitude for a given return period is also essential in the economic evaluation of flood protection projects; minimizing flood-related costs to government and private enterprises, floodplain management by assessing hazards related to the expansion of floodplains. Over or under-estimation of design floods results in losses like a waste of resources, and infrastructural damage. Investigation in design flood estimation is on the decline and there is a large gap between design flood and practice (Irwin *et al*., 2014; Arnaud *et al*., 2017).

The literature identified two comprehensive methods for flood frequency analysis, 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. This method is reliant upon the availability of observed streamflow to fit suitable probability distributions relevant to gauged sites (Kumar and Chatterjee, 2011; Vivekanandan, 2015). The derived techniques of flood frequency analysis involve the quantification of the processes that govern flood behavior which is less dependent upon historical data (Badreldin and Fengo, 2012).

2.3. Flood frequency models

Different magnitudes of flooding have a different probability of occurrence. According to Cunnane (1989) and Desalegn *et al.* (2016), in flood frequency modeling the problems related to the following points have to point out. Choice of model type, choice of distribution to be used and choice of method of parameter and quantile estimation. It should be noted that two separate features are important. These are the descriptive and predictive properties of the method. The descriptive property relates to the requirements that the chosen distribution shape resembles the observed sample distribution of floods and that random samples drawn from the chosen model distribution must be statistically similar to the properties of real flood series, the predictive properties relates to the requirement that quantile estimates are robust with small bias and standard error (Murphy *et al*., 2014).

In FFA, the objective is to determine a Q-T relationship at any required site along a river. At any river site, it is usually assumed that nature affords an exclusive relationship and that Q is a monotonically increasing function of T. In order to estimate this natural relation from a good quality continuous hydrometric record of N year’s duration, it is necessary to resort to a statistical or stochastic model of the continuous hydrograph, which retains information in the hydrograph relevant to the relation, and discard the rest (Das and Simonovic, 2012; Desalegn *et al*., 2016) and the following two models were available for this purpose.

2.3.1. Annual maximum series model

In the annual maximum flow (AMF) series, only the peak flow in each year of record is considered. Desalegn *et al.* (2016) discussed that a series of AMF flood is implicit to form a random sample from the stationary population in which is accidental variable with distribution. In the AMF flow series, only the peak flow in each year of record is considered, that may occupy some loss of information (Chow *et al*.,1988). An AMF is a universally used model by different investigators for the purpose of flood frequency analysis (Badreldin and Fengo, 2012).

2.3.2. Partial duration series model

In this model, most of the flow hydrograph is disregarded and the hydrograph is viewed as a series of randomly spaced flood peaks of random magnitude. For the case of statistical modeling and identification of the values, which form the series, only the series of peak exceeding an arbitrary threshold are considered. In partial duration series, all peaks above a certain base value are considered. The base is usually selected low enough to include at least one event each year (Rao and Hammed, 2000).

Therefore, to avoid the problem of data dependency, the annual maximum flow series model was selected. In addition to this, AMF series is widely and universally used model by different researchers for the purpose of flood frequency analysis (Desalegn *et al*., 2016). As a result, to keep away from the concern of requirement on data, AMF series model was chosen.

2.4. Regionalization

In flood frequency analysis regionalization reflects about the identification of homogeneous regions. This suggests grouping of sites into homogeneous regions, which contain stations of identical flood producing features through the homogeneity test and selection of appropriate distribution for the identified regions (Sine and Ayalew, 2004). Delineation of hydrologically homogeneous regions is a common major step of any RFFA. Regionalization is performed to transfer the hydrologic characteristics from gauged basins to ungauged basins. But, due to the complexity of factors that affect the generation of floods, there is no universally accepted unbiased method of regionalization (Kachroo *et al*., 2000; Mishra *et al*., 2010).

In regionalization, expectations are about the statistical similarity of the sites in a region. For this analysis the values of coefficient of variation and the site-to-site the coefficient of variation has to be used. For homogeneity test of each site in a region the mean, standard deviation and coefficient of variance have to be calculated (Nobert *et al*., 2014).

Hydrologic information may be used in a number of ways, depending on the availability of gauging stations within the region. Several attempts have been made by different authors to identify hydrologically homogeneous regions based on either geographical considerations or flood data characteristics, or a combination of both (Kachroo *et al*., 2000). The set of defined homogenous catchments can then be pooled together and described via statistical properties. This has resulted in regional flood methods being widely used and provide a viable way to estimate discharge in data-poor regions (Zaman *et al*., 2012).

2.4.1. Identification and delineation of homogeneous regions

The identification of flood-producing natures in data-poor regions has got a considerable attention in recent years (Smith *et al*., 2015). This delineates an area consisting of sites with the same standardized frequency distribution and parameters (Ahmad *et al*., 2016). Such regions are expected to be geographically continuous and basically used for carrying out regional frequency analysis for estimation of flood magnitude of water resources projects (Sine and Ayalew, 2004).

Hosking and Wallis (1997) mentioned all the stages in RFFA involving many sites. The authors discussed that identification of homogeneous regions (IHRs) is usually most difficult and requires the greatest amount of subjective judgment. The grouping into homogeneous regions can be done by the identification of geographically contiguous regions. Geographical proximity does, however, not guarantee hydrological similarity (Patil and Stieglitz, 2012).

The catchments of a given homogeneous region may not be geographically contiguous, but may similar in terms of their flood generation processes. So, it is powerfully preferred to cluster regions on site characteristics and at site statistics in the consequent testing of homogeneity of a suggested set of regions (Hosking and Wallis, 1997). This is to group sites that almost satisfy homogeneity condition of sites. Several authors (Capesius and Stephens, 2009; Noto and Loggia, 2009) have proposed methods for forming groups of similar sites for use in RFFA.

2.4.2. Statistical homogeneity tests

The L-moment based homogeneity tests form the basis to check the regions for homogeneity. The regions formed by any regionalization method are heterogeneous in general and need adjustments to make homogeneous (Rao and Srinivas, 2008). To investigate whether those have been meeting or not; many researchers have used the values of the mean of Cv and the site-to-site Cv of both convention and L-moment of the proposed region. Homogeneity tests based on Cv and LCv are applied to verify if the preliminary identified and delineated region is homogeneous. In this case, the hydrological data have to be used and the region is confirmed to be homogeneous if it satisfies both criteria of homogeneity tests (Nobert *et al*., 2014).

The discordance measure estimates how far a given site from the center of the group. It is also helpful to screen out the data from unusual sites to look for the appropriate datasets for regionalization (Hosking and Wallis,1997; Parida *et al*.,1998; Rao and Hamed, 2000; Noto and Loggia, 2009; Kanti *et al*., 2017). These sites were due to the presence of inaccuracies in data or some other local conditions (Guru and Jha, 2016). It is a useful measure in assessing whether any of the regions obtained from the cluster analysis contain potential outliers and should, therefore, be adjusted accordingly (Smith *et al*., 2015).

In RFFA, the homogeneity of a group of stations is an essential assumption. A standard procedure in hydrology to evaluate this condition is the homogeneity measures, which relates to L-moments (Hosking and Wallis, 1997; Lilienthal *et al*., 2018). In this method stations data in a region can be tested for homogeneity and can be taken as a base for many criteria for any other investigation (Malekinezhad *et al*., 2011). It is unreasonable to expect that a region can be chosen in which the flood frequency distribution at all site are identical. The delineation of the homogeneous region is important for site characteristics to be truly representative of the observed discharge data used to estimate hydrologic design values (Irwin *et al*., 2014).

2.5. Statistical distributions for flood frequency analysis

The main aim of regional flood frequency analysis is to find a distribution that will yield as accurate as possible quantile estimates for each site. The optimal of distribution is the one which is capable of giving good quantile estimates when several distributions fit the data adequately (Hosking and Wallis, 1997). The choice of distribution for a given application is generally made arbitrarily as there is no sound physical basis to justify the selection (Rahman *et al*., 2013).

The choices of the distribution models were based on the previous studies where most of these have been used and recommended in various countries. This is also influenced by many factors, such as methods of discrimination between distributions, methods of estimation parameters and the availability of data (Kumar and Chatterjee, 2011).

2.5.1. Best fit probability distributions

Probability distribution fitting is judging a suitable probability distribution to a given dataset. In flood frequency analysis accurate estimation of maximum flood are obtained by fitting probability distribution for a specified return period (Vivekanandan, 2015). The objective is to predict the frequency of occurrence of the magnitude of phenomenon in a certain interval. This can lead to a good prediction of flood. The probability distributions most closely fitted to the observed data depends on the nature of the occurrence and the distribution (Athulya and James, 2017).

Thus, choosing the best statistical distribution is the most important factor in frequency analysis. Therefore, different distributions must use and then, the most appropriate distribution of data should be selected (Amirataee *et al.*, 2014). In flood frequency analysis, an assumed probability distribution is fitted to the available data to estimate the flood magnitude for a specified return period. Details of commonly used distributions in flood data are found in Rao and Hammed (2000).

The first of error, which is associated with the wrong assumption of a particular distribution for the given data checked to a certain extent by using goodness-of-fit tests (Millington *et al.*, 2011). A couple of goodness-of-fit tests have been conducted such as Kolmogorov-Smirnov test, Anderson-Darling test along with the chi-square test at significance level (α=0.05) to assess the reasonability and check the adequacy of best-fitting probability distributions to the recorded data. These are statistical tests, which provide a probabilistic framework to evaluate the adequacy of a distribution. The selection of a distribution for flood frequency analysis goes with the selection of the method of parameter estimation (Das and Simonovic, 2012).

2.5.2. Goodness of fit tests

The choice of distribution to be used in flood frequency analysis has been a subject of interest for a long time (Rao and Hamed, 2000). These test statistics are used for checking the validity of a specified or assumed probability distribution model. The method of moments, maximum likelihood and L-moments are used for parameter estimations. These parameters are used to calculate the quantiles corresponding to return periods (Ashraful *et al*., 2018). The results of the goodness of fit tests are used to select a distribution for observed flow at the site of interest (Ghosh *et al*., 2016).

2.5.3. Method of L-moment ratio diagram

The suitability of probability distribution can be assessed with the help of L-moment ratio diagrams. This method effectively used in regional frequency analysis to select a distribution for a region (Das and Simonovic, 2012). The LMRDs are considered as a reliable diagnostic tool for identifying a probability distribution. This provides a visual comparison of the sample estimates with the population values of L-moments and is always preferable to product moment ratio diagram for a goodness-of-fit test (Hosking and Wallis, 1997; Amalina *et al*., 2016). An advantage of LMRD is that one can compare the fit of several distributions using a single graphical instrument (Chavoshi and Azmin, 2009).

This is a graph between L-kurtosis and L-skewness. Usually, a two-parameter distribution with a location and a scale parameter plots as a single point on such a diagram while a three-parameter distribution with the location, scale and shape plots as a line or curve on the diagram. The clusters of stations are categorized into different regions based on the proximity of stations in the LMRD (Hosking and Wallis, 1997; Badreldin and Fengo, 2012).

2.5.4. Parameter estimation

The data analysis often requires estimation of parameters for a few probability distributions. Before the analysis can be done, the parameter for each selected distribution needs to be estimated first (Ahmad *et al*., 2011). Since the parameters are estimated from the sample data, the estimates are subject to sampling errors. A method of fitting must be chosen to minimize these errors. A method suitable to estimate the parameters of one distribution might not necessarily be as efficient for another distribution. Hosking and Wallis (1997) noted that even if an acceptable distribution is selected, proper estimation of parameters is important. Some of the parameter estimation methods may not yield good estimates. Hence, some guidance is needed for estimation methods.

i. Probability-weighted moments

Probability-weighted moments (PWM) are useful in the deriving expression for the parameters of distributions can be explicitly defined. Methods of parameter estimation obtained in this method are by equating moment of the distribution with the corresponding sample moment of observed data. For a distribution with a parameter, the first sample moments are set equal to the corresponding population moments. The resulting equation 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 MML. Indeed, in small samples, PWM may be as efficient as MML; with a suitable choice of distribution PWM, contributes to assessing robustness point of view (Cunnane, 1989).

ii. Method of moment

Method of moment (MOM) is relatively easy and is more commonly used methods of estimating parameters of a probability distribution. It can also be used to obtain starting values for numerical procedures involved in ML estimation. However, MOM estimates are generally not as efficient as the ML estimates. Especially for distributions with a large number of parameters, as higher order moments are more likely be used to obtain starting values for numerical procedure involved in ML estimation and to be highly biased for relatively small samples. The most popularized method to frequency analysis in recent time is that L-moment approach introduced by Hosking and Wallis (1997).

iii. Method of maximum likelihood

The method of maximum likelihood (MML) is considered the most accurate method, especially for large datasets since it leads to efficient parameter estimators with Gaussian asymptotic distributions. It provides the smallest variance of the estimated parameters, and hence of the estimated quintiles, compared to other methods. However, with small samples, the results may not converge. This method involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations (Cunnane, 1989). In general, the PWM and MOM are better for estimating the parameters for three and two parameter distributions respectively of the underlying distribution from which the data are sampled. They are less sensitive than others are to sampling variability (outliers), and therefore, they yield more accurate and robust estimates of the characteristics or parameters of the underlying probability distribution (Rao and Srinivas, 2008).

iv. L-Moment method

L-Moments(LMM) are analogous to the method of moments and linear functions of the expectations of order statistics and they are viewed as an alternative system of describing shapes of probability distributions. It is a powerful and efficient method to compute statistical parameters, because such methods can give an unbiased estimate of sample parameters, and cannot easily influence with the presence of outliers (Ghosh *et al*., 2016; Rao and Hamed, 2000). The L-moments technique depicts accurate predictions of all kinds of statistical analysis and as such, the method can be suggested for policies and decision-making pertaining to hydrological catchment design (Kanti *et al*., 2017).

Compared to the method of moments and maximum likelihood, L-moments can characterize a wide range of distributions. Sample estimates of L-moments are so forceful, may not be affected by the presence of an outlier in the dataset and less subjected to bias in estimation. L-moments can yield accurate estimates of the parameters of a fitted distribution (Cunnane, 1989).

2.5.5. Quantile estimation

Quantile estimation is the main focus of hydrologic frequency analysis and estimated by applying a distribution function. The selected quantile of under or over design criterion concerning with hydraulic structures is exposed to risk as the return period is determined according to cost and economic-strategic significance of the structure. Selecting a reliable design quantile, are necessary for the delineation of floodplains, the development of floodplain management and flood warning systems, which effects on design, operation, and management of a hydraulic structure, considerably depends on statistical methods used in parameter estimation belonging to the probability distribution (Amalina *et al*., 2016).

The parameter estimates that maximize the likelihood function are computed by partial differentiation with respect to each parameter 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). Although the use of these parameters yield less biased estimates compared to the two-parameter ones, as there is no general agreement in the choice (Parida *et al*.,1998).

When quantiles have to be estimated for sites where no observations have been recorded or observation recorded only for a very small period, and then the estimates using frequency analysis is neither possible nor reliable. RFFA is one of the means to overcome such problems while reasonably quantifying the flood estimates at desired frequencies for series within a more or less hydrological homogeneous region (Dubey, 2014).

After the parameters of a distribution are estimated, quantile estimates (X_T) which correspond to different return periods T may be computed. 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 $X_T = \varphi$ (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 $X_T = \varphi$ (F).

2.6. Derivation of flood frequency curves

Flood frequency curves (FFC) describe the relationship between the magnitude of river peak flows and the recurrence interval or return period. FFC, the estimation of flood for various return periods is needed when analyzing flood risk (Das and Simonovic, 2012). Developing FFC for different return period helps to estimate flood quantiles. The curves can be derived from data at flow monitoring stations. Then it regionalized for use at any location along the basin's river network by relating the spatial differences to geographical regions and to variations in upstream subbasin characteristics inside each region (Willems *et al*., 2009).

Regional flood frequency curves have the ability to considering the spatial pattern of variation of hydrologic phenomena across many gauging sites, can be used for estimating flood quantiles at any ungauged site within the region (Parida *et al*.,1998). In every RFFA, the main goal of the analysis is to develop a regional curve that can represent the averagely weighted distribution of the homogeneous regions. It is the final process of FFA to estimate the normalized regional quantile floods (X_T); FFC for a give return period (Tadesse *et al*., 2011).

For a given region, the model parameters derived from the best-fitted distribution to the observed data are used. This helps to compute standardized quantile estimates and then used to construct a regional flood frequency curve for the homogeneous region. These curves are plots of quantiles representing for all sites of a homogeneous region (Hosking and Wallis,1997; Hailegeorgis and Alfredsen, 2017).

2.6.1. Confidence levels in estimation of flood frequency curve

Regional flood frequency analysis has been used to reduce uncertainties for poorly gauged sites or ungauged sites by using data from various sites. This helps in reducing the uncertainties in estimating frequency at ungauged sites or sites with short records. Thus, regional models differ in the way used to transfer data through the region (Sun *et al*., 2015; Ganora and Laio, 2016; Halbert *et al*., 2016).

Sources of uncertainty in flood assessment can be identified and this can be quantified and minimized. Minimizing in uncertainty can avoid both dangerous under-design and expensive over-design of structures such as dams, embankments, control structures, bridges, culverts, and flood protection works. For dam safety assessments the final uncertainty in the flood frequency estimation is addressed by a subjective evaluating the quality of the data used results based on flood frequency analysis (Wilson *et al*., 2011).

2.7. Previous Studies on RFFA in Ethiopian River Basins

Investigation of regional flood frequency analysis based on monthly rainfall pattern and geographical proximity was conducted by Gebeyehu (1989) for the Blue Nile River Basin. The study had some limitation about the way that it does not delineate homogeneous regions accurately because the responses of the statistical approach in similar rainfall regions are different consequences of changes in basin topography. In his conclusion, Gebeyehu (1989) point out the following information. The regionalization approach provides useful information about the flood frequency of gauged and ungauged catchments, a small amount of site data greatly improves the estimate of the mean annual flood that can be used with a regionally based estimate of X_T relationship and the results of RFFA should always be updated as more relevant information becomes available.

Blue Nile River Basin has also been regionalized into similar flood producing characteristics based on statistics of at site data (Sine and Ayalew, 2004). The author defined a homogeneous region found have to be with geographical proximity and it performs mainly for carrying out regional frequency analysis for estimation of flood magnitude for water resources project planning and design. Identification and delineation of homogeneous regions for all stations of the respective regions satisfy homogeneity criteria. The types of distribution most likely to fit data of each region were identified from the regional average statistical value of L-Moment ratio. The study recommended that selection of best-fit single distribution and dynamic parameter estimation method require further investigation.

Demissie and Michael (2008), Mekoya and Seleshi (2010) established RFFA for Upper Awash sub-basin using the application of index flood method. The former regionalizes the sub basin into two as upper and lower regions and the later delineated the sub basin into five homogeneous regions and log Pearson type-III as best fit distribution for quantile estimations. The former recommended that additional testing of stations for homogeneity should be done considering geographical factors are a good method in RFFA of the basin and the later to extend the method of RFFA for the other Ethiopian river basins.

Gedefa and Seleshi (2009) investigated Upper Omo-Gibe sub-basin using index flood estimation based on the observed AMF. L-moment based statistical homogeneity tests were used to identify homogeneous regions. The study concluded that regionalization provides valuable information even in possibly heterogeneous regions, and regional analysis is more accurate and flexible than single-site analysis.

According to Hussein and Wagesho (2016), regionalization of Abaya-Chamo sub-basin was performed based on site characteristics such as elevation, soil type, soil texture, slope, land use land cover and mean annual rainfall. Site statistics were used for testing of homogeneity of the proposed region. The authors concluded that to get reliable quantile estimate more gauging stations should be installed in the basin to infer something for ungagged sites.

Ketsela *et al*. (2017) performed FFA on Awash River Basin using statistical distribution technique. The Easy Fit Software was employed for selection of best-fit distributions and estimation of parameters for stations. Kolmogorov–Smirnov test was used for the choice of a suitable distribution for estimation of maximum flood discharge. According to this study, Awash basin was delineated into five satisfactory homogeneous regions and recommended software-based techniques like Easy Fit and other alternative statistical software packages to get accurate and reliable flood estimation results.

2.8. Parameter estimation model

Data fitting process involves using certain statistical techniques, which allow estimating fitness parameters in accordance to data sample. One advantage of using software to fit the data and interpreting probability data is that they are able to automatically fit data with a variety of known distribution patterns simultaneously. Easy Fit Software is a data analyzer and simulation Software which is capable to fit and simulate statistical distributions with sample data, choose the best model, and then use the obtained result of analysis to provide better decisions. For many distributions, Easy Fit uses the maximum likelihood method regarding the maximization of the log-likelihood function (Mehrannia and Pakgohar, 2014).

Easy Fit Software is an interactive software system to identify parameters, allows the most flexible input of the underlying model in form of Fortran code, and are executable independently from the interface. It consists of a database containing models, data and results, and of underlying numerical algorithms for solving the parameter estimation problem depending on the mathematical structure (Schittkowski, 2002).

The selections of the distribution models are based on the previous studies where most of these have been used and recommended in various countries. In this study selection of best-fit probability distribution and its method of parameter estimation suitable for each distribution within the interface was conducted using Easy Fit software due to the results of analysis leads to taking a better decision (Romani and Yusop, 2017).

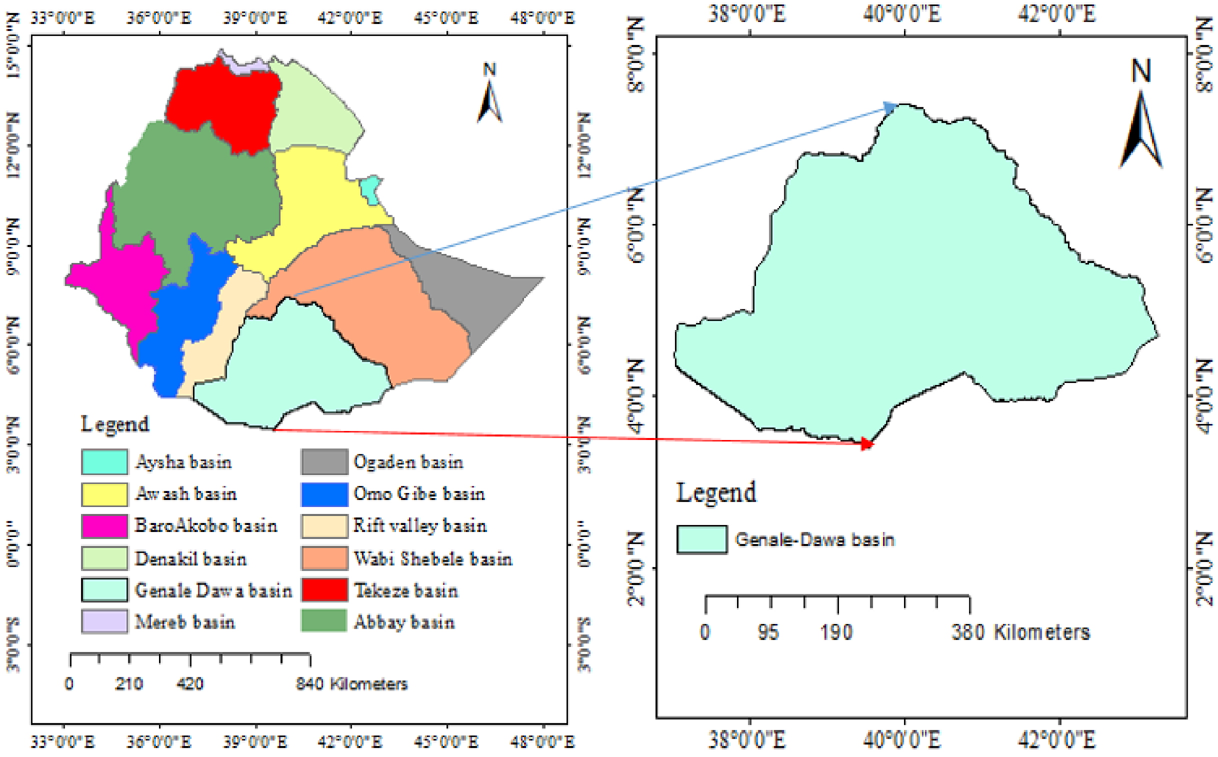
According to Irwin *et al.* (2014), watersheds are delineated using ArcGIS with DEM data and subsequently, several flood generation characteristics are assigned to each watershed. The outcome of this procedure can be directly applied in regionalization to group watersheds into hydrologically homogeneous regions based on the similarity of their attributes, and hydrologic variables are estimated from the regions. Hence, to delineate and characterize watersheds for regionalization ArcGIS10.4.1 environment was used for this study using the procedure of Abdulla (2011) and Irwin *et al*. (2014).

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location and topography

Genale-Dawa River Basin is the southernmost basin in Ethiopia, covering the western half of Bale, southeast, southwestern and northeastern parts of Sidamo, and Somali regional states. It is geographically located between 3^{0}30’, 7^{0}20’ North latitude and 37^{0}05’, 43^{0}20’ East longitude respectively. It covers an area of 171,050km^2 which is about 13.87% of the total area of the country. Neighboring River basins are the Wabi-Shebelle to the north and east, Rift Valley Basin to the west. The basin is characterized by great geographical diversity with high and rugged mountains, flat-topped plateau, deep gorges, and plains. On the northern side of the basin, the highest peak is 4,377m a.m.s.l and the altitude decreases from north to south and west to east to attain an elevation of 176m a.m.s.l (MoWIE, 2007; Awulachew *et al*., 2007).



(a). Ethiopian River Basins

(b). Genale-Dawa River Basin

Figure 3.1: Location map of the study area

3.1.2. Climate and hydrology

The climate of the country is mainly controlled by the seasonal migration of the Inter-Tropical Convergence Zone, which is conditioned by the convergence of trade winds of the northern and southern hemisphere and the associated atmospheric circulation. the tropical rainy climate in the extreme south and high central basin areas. the warm temperate rainy climate in the Sidamo Mountains and intermediate zone south of the Bale Mountains. the cool highland climate at the highest elevations in the Bale Mountains. The entire basin falls under the “bi-modal” rainfall regime with two wet seasons. Type I in which the rainfall continues for a period of months from April to October with less pronounced peaks at the beginning and end, and Type II in which pronounced rainfall peaks occur in April and October with little rainfall between these peaks (MoWIE, 2007).

The regional distribution of temperature is strongly reliant on elevation. Studies show that the predicted drop of temperature with a decreasing elevation was 0.64ºC per 100 m. Latitude is a secondary factor influencing mean monthly temperature. The mean annual temperature at the mountainous station is only 14.9^0C. With an elevation drop of more than 1000 m and to the south the mean annual temperature is around 22^0C. It may be expected that mean annual temperature over the basin varies from less than 15^0C in the river headwater area to more than 25^0C, at the elevation of 500m (Dejene and Hailu, 2014).

3.1.3. 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. The main land cover types in the basin are settlements and infrastructures, cultivated land, afro-alpine and sub-afro-alpine vegetation, forest, woodland, bushland, grassland, bare land, and water body. Grassland is dominant which accounts about 50% of the total basin area while water body and built up areas account the least less than 0.3%. The other is covered by agriculture, forests, settlements, brushes and bare land (MoWIE, 2007).

3.2. Materials used

For the proper execution of this study, materials and Software used was based on the capability to work on achieving the predetermined objectives. ArcGIS10.4.1 Software was used to generate the study area map representing geographical location of gauging stations and delineate hydrologically homogeneous regions. Easy Fit 5.6 Statistical Software (trial version) was used to select the best fit probability distribution with its method of parameter estimations, a goodness of fit tests and to check the estimation accuracy of each of data of stations. XLSTAT2018 and Microsoft Excel were used for data arrangement, filling missed data and calculate the statistical parameters of hydrological data used in the flood frequency analysis. Matlab2017a to execute discordancy of sites from the identified regions and to plot flood regional growth curves.

3.3. Data collection and analysis

Defining a clear and efficient methodology is vital for the quality of the findings of the study. The procedures of data analysis in this study includes from the preliminary screening of data to develop a regional flood frequency curve depending on AMF series data. Screening the data was carried out to check for gross errors and make sure the continuity of data. After relevant data which were useful for the regional analysis identified from the study basin, checking of data for its quality was performed.

Identifying homogeneous region was done to decide on which subbasins can be grouped together which might have similar flood producing nature. This was performed based on the L-moment ratio diagram and site characteristics of stations. The regional frequency distribution by the average L-moment ratios and a goodness-of-fit test with help of Easy Fit Software was then used to confirm how well the selected distribution fit the data in the region. Estimation of the frequency distribution is then designed to compute the flood quantiles for certain return periods at ungauged sites derived from the regional growth curve. In general, to achieve the regional flood frequency analysis of this study, the following procedures were employed.

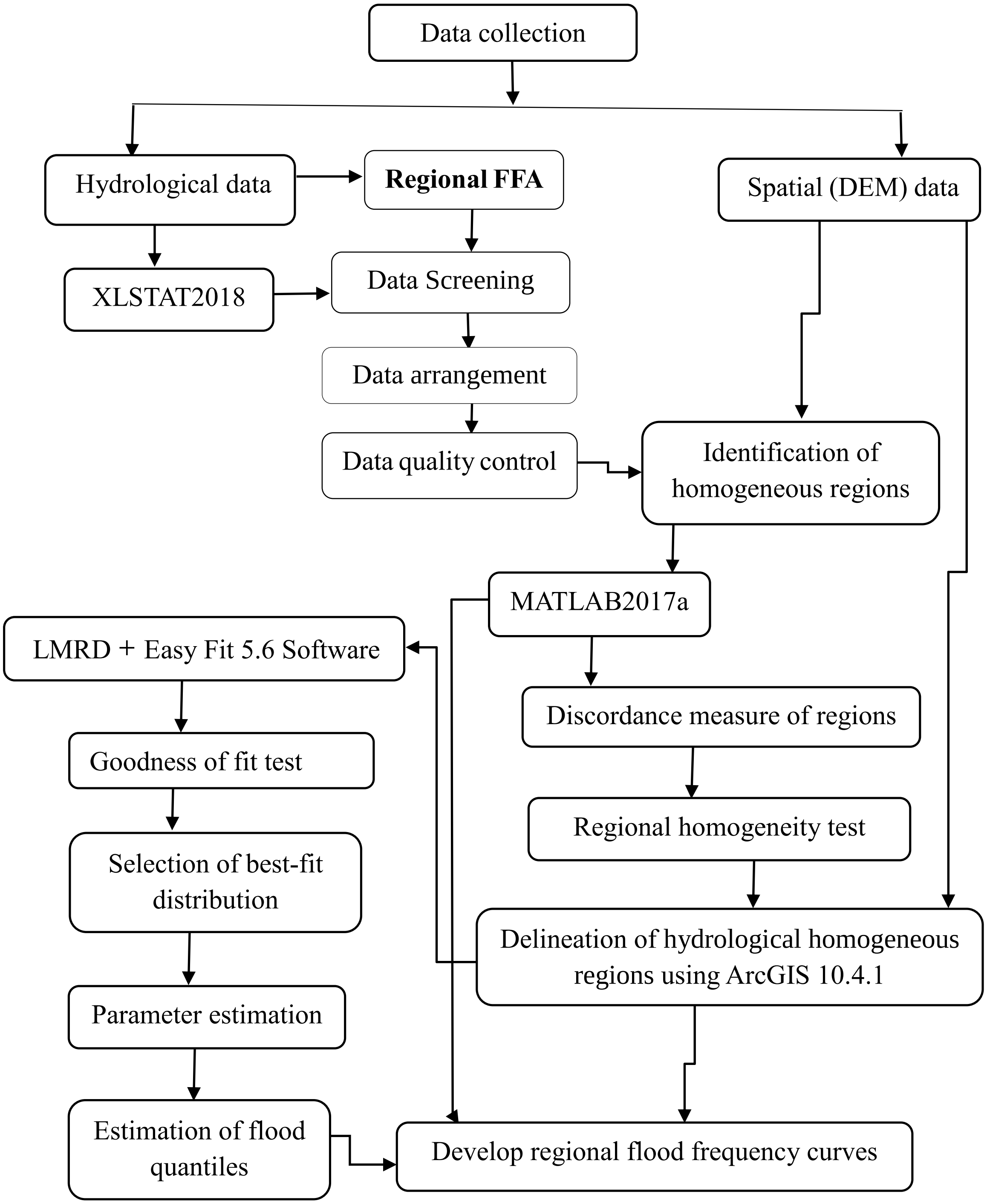


Figure 3.2: Flowchart of the methodology

3.3.1. Sources and availability of data

Flood frequency analysis primarily uses observed annual maximum flood data at gauging stations to estimate flood magnitude. Hydrological and DEM (digital elevation model) data of Genale-Dawa River Basin were collected from Ministry of Water Irrigation and Electricity, department of hydrology and GIS. DEM data was employed as basic input for delineation and specifying the location of the gauging stations in the basin. The site characteristics of stations for this study includes the code of the stations, the name of the river and their gauging sites, the locations (latitude and longitude) and catchment area (km^2).

Table 3.1: The site characteristics of stations used in detail analysis

Station code	River name	Location of gauging station	Coordinate		Area (Km^2)	Record period	Record length
			Latitude	Longitude			
71001	Dawa	at Melka Guba	$4^0$52' N	$39^0$19' E	19611	1986-2015	30
7009	Dawa	nr.Digatty	$4^0$17' N	$39^0$20' E	12710	1997-2015	19
71004	Awatta	nr.Oddo-Shakiso	$5^0$54' N	$38^0$56' E	1611	1997-2014	18
72002	Genale	at Chenemasa	$5^0$31'N	$39^0$41'E	10574	1985-2008	24
72001	Genale	at Halwey	$4^0$26'N	$41^0$50'E	54093	1985-2009	25
72011	Genale	at Kolle Bridge	$4^0$32'N	$41^0$45'E	83219	1998-2008	13
72006	Halgol	nr.Gom-Goma	$6^0$20' N	$39^0$50'E	160	1990-2008	19
71005	Mormora	nr. Megado	5041'N	$38^0$48'E	1375	1985-2015	31
73006	Shaya	nr. Robe	$7^0$10'N	$39^0$58'E	433.8	1985-2014	30
73002	Togona	at Shallo Village	$7^0$0'N	$39^0$58'E	336.2	1985-2008	24
73003	Weyib	nr. Agarfa	$7^0$12'N	$39^0$48'E	7719	1985-2008	24
73005	Weyib	at Alemkerem	$6^0$59'N	$40^0$58'E	3576.9	1990-2009	20
73004	Weyib	nr. Denbel	$7^0$2'N	$40^0$48'E	1215	1986-2008	23
73009	Weyib	at Sofumer	$6^0$54'N	$40^0$50'E	3792.7	1990-2010	21
73008	Welmel	at Melka Amana	$6^0$14'N	$39^0$46'E	1048	1990-2009	20
72005	Yadot	nr. Dello Mena	$6^0$25'N	$39^0$51'E	531	1990-2008	19

3.3.2. Data screening

Data screening is the first task in which employed methods that the unwanted observation from the data series as well as the sites from the analysis can be filtered. It is used to check the data are appropriate for performing the regional flood frequency analysis (Hosking and Wallis, 1997; Kachroo, 2000; Kumar and Chatterjee, 2011). In this study, streamflow data were used from gauging stations in the Genale-Dawa River Basin.

From this, representative stations were decided according to the guideline for FFA (USWRC, 1976 as cited in Hussein and Wagesho, 2016; England *et al.*, 2015; Guru and Jha, 2016) which allows a minimum of 10 years' historical flow data and no consecutive gap. Therefore, once the above method of data screening was carried out, stations contain the following conditions were excluded from the subsequent step of data analysis. Stations which have short record length i.e., less than 10 years, stations which consist a lot of no data in the series i.e. contains more consecutive gaps and if a station contains insignificant magnitude of observed series.

In the study area, there are about 23 gauging stations, out of these only 18 gauging stations were selected for the proper RFFA. The selected stations by themselves have no fully recorded data; they have a number of years of record having missing data that needs to be filled before analysis. Out of those selected 18 gauging stations almost 16 stations have one or more missed data and two stations have less than 10 years of record data which is less than the guideline for FFA. Accordingly, 16 gauging sites which satisfied the minimum record length were selected. The minimum and maximum length of the at-site AMF records respectively are 13 and 31 years. For all the stations listed in Table 3.1 and shown in Figure 3.3, the AMF data were selected and later subjected for investigative data analysis in order to choose representative stations for the study area.

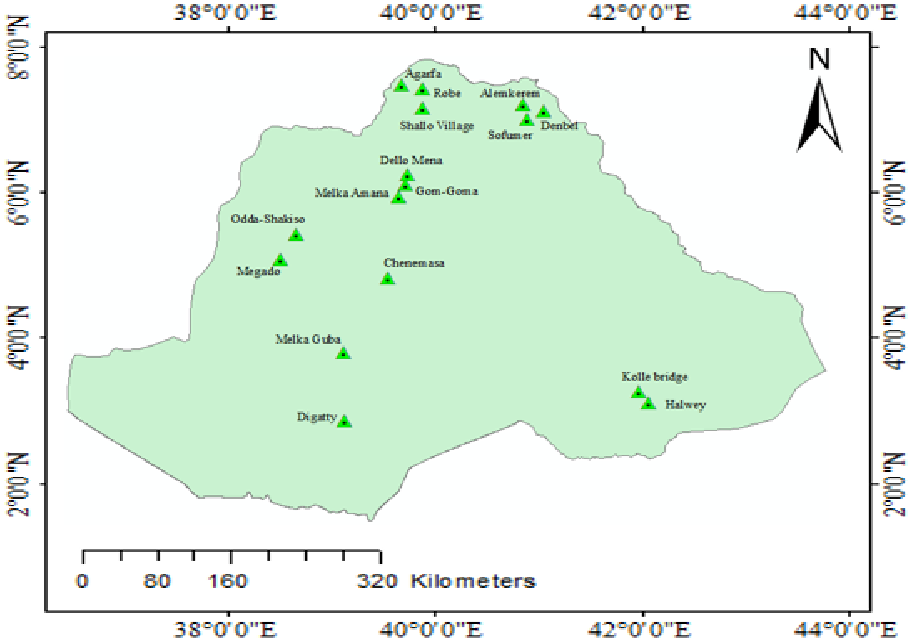


Figure 3.3: The spatial distribution of gauging stations in Genale-Dawa River Basin

3.3.3. Missed data filling

When undertaking an analysis of streamflow data from gauges where observations are made, it is often to find times where no observations are recorded at one or more gauges. The continuity of the record may be broken with missing data due to many reasons such as the absence of recorder, carelessness of the observer, break or failure of instruments.

Therefore, it is often necessary to estimate these missing records (Sine and Ayalew, 2004). The missing data can be estimated by using the data of the neighboring station. There are different methods used for filling the missing flow data records of a given gauging station. For this study, any missing data were filled by the method of linear regression. Reference variables were the same type i.e. flow vs. flow. Simple linear regression has been applied to fill missing streamflow values using nearby flow gauging station observations. The equation for linear regression is given as:

$y = ax + b$……………………..……………...……………………...…………3.1

Where x and y- instantaneous daily stream flows (m^3/sec) and, a and b-constants. In this study, regression with correlated stations by scatter plot was checked and used to obtain missing daily flow data, using nearby station by deriving a common equation using a scatter graph.

The model performance can be good if the correlation coefficient (R) between 0.6 and 1. Ketsela *et al.* (2017) discussed that this method was selected and commonly used due to the following reasons: It is the most widely used method when compared to other methods for large data, estimation of significant missing observations as accurate as possible, it is applied by creating a correlation with the nearby station.

As a result, linear regression analysis is used to fill the missing instantaneous daily flow data with satisfactory correlation coefficients. The correlation coefficients(R), in these stations, was greater than 0.6. The results of correlation between stations were indicated on Appendix-A and indicated that all selected stations are well correlated and performed. It is an indication for the accuracy of the equation that was tested on different gauging stations of the basin.

3.4. Data quality control

Some errors may exist in the stream flow observation that were collected, such as misplaced decimal numbers, very huge unrealistic numbers and negative flow records in some cases. Performing observation quality before using it for our necessary purposes is a crucial step. The following approaches were considered to check streamflow data quality.

3.4.1. Test for randomness and independence

By principle, it is known that FFA is carried out when the at-site data are independent and identically distributed conditions satisfied (Hosking and Wallis, 1997). This provides that the extreme events might appear randomly and all might have the same frequency distribution. The requirement of RFFA is that the AMF at different stations in a homogeneous region should be spatially independent. Hailegeorgis and Alfredsen (2017) noted that independence of data series is one of the main assumptions in frequency analysis and the intersite correlation has a considerable effect on the variance of regional parameters and flood quantiles and reduces the effective length of records.

However, Hosking and Wallis (1997) noted that a small amount of serial dependence in annual data series has little effect on the quality of quantile estimates. According to Guru and Jha (2016), the randomness test is needed to find independent AM series from all the data sets values at each station.

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, R_1, defined as follows:

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

Where Xi is an observation,

X_{i+1} is the following observation and

n is the number of data.

After computing R_1, the test hypothesis is that H_0: R_1= 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: $(-1, (\mathrm{LCL})\ \mathrm{R1}\ (\mathrm{UCL}), 1)$ and equation 3.2 gives:

The upper confidence limit, UCL, for R_1 as:

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

The lower confidence limits, LCL, for R_1 as:

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

To accept the hypothesisH0: R1=0, the value of R_1 should fall between the UCL and LCL. Applying this condition to the time series, we see that the condition: LCL (R_1) <R1< UCL (R_1) is satisfied for the all stations.

Table 3.2: Result of test for independence of stations time series data

Station name	R1	UCL(R1)	LCL(R1)	Station name	R1	UCL(R1)	LCL(R1)
Melka Guba	0.136	0.370	-0.465	Melka Amana	-0.168	0.356	-0.443
Megado	0.164	0.344	-0.424	Dello Mena	-0.071	0.363	-0.454
Digatty	0.004	0.393	-0.505	Robe	0.236	0.338	-0.415
Odda-Shakiso	0.716	0.402	-0.520	Shallo village	0.026	0.363	-0.454
Chenemasa	0.179	0.356	-0.443	Denbel	0.210	0.363	-0.454
Kolle bridge	0.171	0.458	-0.625	Alemkerem	-0.239	0.385	-0.490
Halwey	0.272	0.350	-0.433	Agarfa	0.210	0.356	-0.443
Gom-Goma	0.369	0.385	-0.490	Sofumer	0.143	0.377	-0.477

Thus, no correlation exists between successive observations. The data are independent and there is no persistence in the time series. The summarized result of the test for annual maximum flow series for example for Melka-Guba station -0.465<0.135<0.370 and the other stations are given in Table 3.2 and the results show that the annual maximum flow series for all stations were independent.

3.4.2. Test for consistency and stationarity

A time series of hydrological data is relatively consistent if the periodic data are proportional to an appropriate simultaneous time series (Dahmen and Hall, 1990). According to Dahmen and Hall (1990), F-test for the stability of variance and t-test for the stability of mean verify not the stationary of time series, but also its absolute consistency and homogeneity. According to this, if F-test shows stable variance and t-test shows stable mean, then we can say that the time series is stationary, consistent and homogenous. Thus, the two tests were adopted to check streamflow observations stationarity and consistency.

i. F-test for the stability of variance

The test statistic is the ratio of the variances of two split, non-overlapping, sub-sets of the series (Dahmen and Hall, 1990). The annual maximum streamflow observations during are divided into equal or nearly equal time series. Then, the variance of both time series is calculated for all gauging stations.

The test statistic (Ft) is calculated as:

$$\mathrm{Ft} = \frac{\text{Variance of time series1}}{\text{Variance of time series2}} \quad \ldots\ldots 3.5$$

According to this method, the variance of the time series is stable if and only if: F (V_1, V_2, 2.5%) <Ft < F (V_1, V_2, 97.5%), where $V_1 = n_{1-1}$, $V_2 = n_{2-1,}$ and $n_1 = n_2$-the number of observation point in each subset.

ii. Test for the stability of mean

The test for stability of the mean involves computing and then comparing the mean of non-overlapping subsets of the time series (Dahmen and Hall, 1990). The same subsets from the F-test are used for calculations of the t-test values.

The statistic t-test (T_t) is given as:

$$Tt = \frac{(\text{Xm series1} - \text{Xm series2})}{\left((n1-1)S1^2 + (n2-1)S2^2 * \frac{1}{n1+n2-2} * \left(\frac{1}{n1} + \frac{1}{n2}\right)\right)^{0.5}} \ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where $\bar{x}$: is the mean of the series

n: is the number of monthly streamflow records

S: is the standard deviation of the two series

According to this test, the mean of the time series is stable if and only if: t (V,2.5%) < T_t< t (V,97.5%), Where the value of V is different for each station and values are read from Appendix-D using percentile columns (2.5% and 97.5%).

Noting that both F {V_1, V_2, 2.5%} and F {V_1, V_2, 97.5%} values for 5% significance level as Appendix-B. For the station having year are listed using V_1, V_2 and percentile row 2.5 % or 97.5 % Appendix-C. The results of observations of data of gauging stations T-test and F-test, are presented in Appendix-E and shows that mean and variance of the time series was stable.

3.4.3. Check for data adequacy and reliability

The accuracy of statistical the 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) using the equation 3.7.

$$De = \frac{C_V}{N^{0.5}} \ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

Where, De- Standard error

Cv-Coefficient of variation and

N-number of yearly data in the series

The data series could be regarded as reliable and adequate if De is less than 10% significance level. Hence, the data of stations are found accurate, adequate and reliable as De value for most of the stations are less than 10% significant level.

Table 3.3: Results of test for adequacy and reliability of AMF data

Site location	Cv	N	De	Site location	Cv	N	De
Melka Guba	0.3900	30	0.0712	Denbel	0.2303	23	0.0480
Megado	0.3537	31	0.0635	Sofumer	0.2521	21	0.0578
Digatty	0.2891	19	0.0663	Chenemasa	0.3767	24	0.0769
Oddo Shakiso	0.3117	18	0.0735	Kolle bridge	0.2409	13	0.0668
Robe	0.2864	30	0.0523	Halwey	0.3457	25	0.0706
Agarfa	0.4151	24	0.0830	Melka Amana	0.3559	20	0.0796
Shallo Village	0.2424	24	0.0495	Gom-Goma	0.4281	19	0.1009
Alemkerem	0.2109	20	0.0484	Dello Mena	0.4025	19	0.0900

3.4.4. Check for outliers of the data series

An outlier is an observation that deviates a lot from the bulk of the data. This may be due to errors in data collection, misplaced decimal points, very high flow records during dry months and or low flow record during rainy months or due to natural causes. For statistical tests of outlying observation, it is generally recommended that a low significant level such as 1% is used and that significance level greater than 5% should not be common practice (Grubbs, 1969 as cited in Dahmen and Hall, 1990 and Ketsela *et al*., 2017). However, to minimize or avoid the effect of outliers in this study L-Moment an efficient parameter estimation technique was employed.

3.5. Regionalization of Genale-Dawa River Basin

In this study, the index flood L-moment approach of regionalization was applied depending on the data homogeneity of the stations. The statistical values have been checked for the stations whether they can be classified under one or more regions. Flood statistics of Genale-Dawa River Basin stations were computed using L-moment methods. Due to the fact that such methods can give a balanced estimation of sample parameters and cannot be easily influenced by the presence of outliers (Rao and Hamed, 2000).

3.5.1. Identification of homogeneous regions

Identification of homogeneous regions (IHR) is the significant step in regional frequency analysis (Amalina *et al*., 2016). To IHRs the specification of variables characterizing this similarity has been made. The IHR is usually the most difficult stage and requires the greatest amount of personal judgment.

Consequently, the 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 streamflow records to be transferred from gauged basins to ungauged basins within a region.

3.5.1.1. Site characteristics

In this study, preliminary IHRs of stations into a certain category is 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 stations having nearly same kind of site characteristics are clustered on the same region.

3.5.1.2. Method of L-moment ratio diagram

Method of L-moment ratio diagram is used as a tool to give priority for IHRs and distributions based on the statistical principles. The main hypothesis of the study is that if the annual maximum flows of different stations come from a single distribution model, then these stations belong to the same group and form a homogeneous region.

This is a useful way of representing the moments of different distributions depending on the statistical nature of data. L-moment statistics are used to group stations comparing with geographical proximity and continuity of gauging stations. To use the statistical parameters LCs and LCk are first computed and those stations that has nearly closely fitted are supposed to come from the same parent distribution and are considered to be in the same region. The derived regions and stations included in the group are then tested by different homogeneity tests.

3.5.2. Test for homogeneity of stations and regions

Once a homogeneous region has been preliminary identified, the degree of homogeneity of the candidate region with respect to flow statistics has to be tested. The necessity is that the region is satisfactorily homogenous that no further division of the region into individual sites would improve the accuracy of flood estimates. The main advantage of L-moments is that being a linear combination of data, they are less influenced by outliers, and the bias of their small sample estimates remains fairly small. Unbiased sample estimators of the first four PWMs are given as (Hosking and Wallis, 1997) and suggested a homogeneity test based on L-moments which proved to be efficient.

Stations in a region can be tested for homogeneity that is fall in a region. Different tests are available to inspect regional homogeneity in terms of the hydrologic response of the stations. In this study, to verify the acceptability of clustering techniques; discordance measure, Cv and LCv-based statistical homogeneity tests were applied.

3.5.2.1. Discordancy measure of regions

To estimate discordancy values for sites in a region, the sites are considered as points in three-dimensional space of sample L-moment ratios (LC$_V$, LCs, and LCk). If a vector, $\mathrm{Ui} = \left(\tau_2^i, \tau_3^i, \tau_4^i\right)^T$, which controlled the L-moment ratios for site i, T is the transpose of the vector Ui (Hosking and Wallis, 1997), then the discordancy measure may be defined as:

$$\mathrm{Di} = \frac{1}{3}(\mathrm{Ui} - \overline{\mathrm{Ui}})\,S^{-1}(\mathrm{Ui} - \overline{\mathrm{Ui}})^T \quad \text{…….……………………………………..…….….……….}3.8$$

$$\overline{\mathrm{Ui}} = \frac{1}{N} * \sum_{i=1}^{N} \mathrm{Ui} \quad \text{…………………...…………………………….…………………..….}3.9$$

$$S = \frac{1}{(N\text{-}1)} * \sum_{i=1}^{N} (\mathrm{Ui} - \overline{\mathrm{Ui}})(\mathrm{Ui} - \overline{\mathrm{Ui}})^T \quad \text{…………………….………………………...............}3.10$$

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,

$\overline{\mathrm{Ui}}$ -is the group averages U$_{i,}$

S-sample covariance matrix of U$_i$.

Hosking and Wallis (1997) tabulated critical values of the discordancy statistic Di for various numbers of sites in a region at a significance level of 10%. These were used to assess each of the study sites and identify whether they should be analyzed further to ensure homogeneity. The identified regions have tested for discordancy using equation 3.9. However, to determine the value of Di using simple matrix multiplication was difficult and quite cumbersome.

Due to this, Hosking and Wallis (1997) recommended using Fortran, Matlab and other computer programs to simplify the work and get acceptable accuracy results. For this study, following this recommendation Matlab2017a programming code was employed to simplify the numerical calculations of discordancy index (Di). The programming code used to calculate the covariance matrix and Di were given on Appendix-F.

Figure 3.4: Critical values of discordancy measure with N sites

Number of sites in a region	Critical value	Number of sites in a region	Critical value
5	1.333	6	1.648
7	1.917	8	2.140
9	2.329	10	2.491
11	2.632	12	2.757
13	2.869	14	2.971
>15	3		

(Source: Hosking and Wallis, 1997)

3.5.2.2. Adjustment of regions

If the regions formed are not statistically homogeneous, they are adjusted to improve their homogeneity. This step is justified because regions are not generally likely to be homogeneous based on the homogeneity assessment and discordant sites may also exist.

Rao and Srinivas (2008) point out the following options for revising regions that are grossly discordant with respect to other sites within the region. i). eliminating one or more sites from the data set; ii) transferring (or moving) one or more sites from a region to other regions; iii). dividing a region to form two or more new regions; iv) allowing a site to be shared by two or more regions; v) dissolving regions by transferring their sites to other regions; vi) merging a region with another or others; vii) merging two or more regions and redefining groups; and viii) obtaining more data and redefining regions. Among these, the first three options are useful in reducing the values of heterogeneity measures of a region, whereas the options (iv) to (vii) help in ensuring that each region is sufficiently large.

3.5.2.3. Conventional homogeneity test

The criterion used to check for regional homogeneity was based on the value of CC. According to some researchers, the higher the value of Cv and CC, the lower will be the performance of the index-flood method for the region under consideration. 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. In this method to calculate CC values, the procedures are described below.

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) equation (3.11-3.16).

The mean of AMF of the station:

$$\overline{Q}_i = \frac{1}{n} . \sum_{i=1}^{n} Qi \quad \text{……………………………………………………………………..3.11}$$

The standard deviation of AMF of the station;

$$\delta i = \sqrt{\frac{\sum_{i=1}^{n} (Qi - \overline{Qi})^2}{n}} \quad \text{……………………………………………………………....3.12}$$

$$Cvi = \frac{\delta i}{\overline{Qi}} \quad \text{………………………………………………………………………......3.13}$$

Where: Q_i= 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

δi = 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; $\overline{Cvi} = \frac{1}{N} . \sum_{i=1}^{N} Cvi$ ……………………………………………………3.14

Regional standard deviation, $\delta c = \sqrt{\frac{\sum_{i=1}^{N} (Cvi - \overline{Cvi})^2}{N}}$ …………………………………………3.15

The weighted regional Cvi of all the sites, CC is defined as follows:

$$CC = \frac{\delta_{cv}}{\overline{Cvi}} < 0.3 \text{………………………………………………………………………..3.16}$$

Where: N=Number of the site in a region

$\overline{\mathrm{Cvi}}$ = The mean coefficient of at site Cvi values

δCv = Standard deviation of at site Cvi values

3.5.2.4. L-moment based homogeneity test

LC_V-based homogeneity test is more accurate and effective way of testing the homogeneity of the site when compared with that of the C_v-based homogeneity test. The procedural calculation is the same as that of the C_v. The following are advantage of LC_v (Cunnane, 1989): Compared to C_v, LC_v can characterize a wide range of distribution, sample estimates are so strong that they are not affected by the presence of outliers in the data set, they are less matter to bias in estimation, yields more accurate estimate of the parameter of a fitted distribution.

According to the Central Water Commission (2010), L-moments has the following advantages: i). characterize most of probability distributions than conventional moments, ii). less sensitive to outliers in the data, iii). approximate their asymptotic normal distribution more closely, iv). nearly unbiased for all combinations of sample sizes and populations.

Hosking and Wallis (1993) gave the unbiased estimators of $\beta_{0,}\beta_1, \beta_2$and $\beta_3$as: defined as;

$$\beta o = \frac{1}{n}\sum_{i=1}^{n} Q_i \tag*{……3.17}$$

$$\beta_1 = \sum_{i=1}^{n-1} \frac{(j-1)(Q_i)}{n(n-1)} \tag*{……3.18}$$

$$\beta_2 = \sum_{i=1}^{n-2} \frac{(j-1)(j-2)(Q_i)}{n(n-1)(n-2)} \tag*{……3.19}$$

$$\beta_3 = \sum_{i=1}^{n-3} \frac{(j-1)(j-2)(j-3)(Q_i)}{n(n-1)(n-2)(n-3)} \tag*{……3.20}$$

Where Q_i - annual maximum flow(m^3/s) from stations dataset

n - the number of years, j-rank

β_o , β_1 , β_2, and β_3- are L-moments estimator.

The first few moments are:

$\lambda_1 = \beta_O$; $\lambda_2 = 2\beta_1 - \beta_O$; $\lambda_3 = 6\beta_2 - 6\beta_1 + \beta_O$; $\lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_O$……………………3.21

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:

$$\tau_2 = \frac{\lambda_2}{\lambda_1}\,; \tau_3 = \frac{\lambda_3}{\lambda_2}\,;\ \tau_4 = \frac{\lambda_4}{\lambda_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.22$$

Using the above procedural formula,

$$\overline{Lcvi} = \frac{1}{n}.\sum_{i=1}^{N} Lcvi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.23$$

$$\delta cv = \sqrt{\frac{\sum\limits_{i=1}^{n}(Lcvi - \overline{Lcvi})^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.24$$

The weighted regional LCvi, of all the sites, CC is defined as follows:

$$CC = \frac{\delta_{Lcv}}{Cvi} < 0.3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.25$$

A region that confidently satisfies all criteria for being hydrologically homogeneous can be derived.

3.5.3. Delineation of homogeneous regions

The performance of any regional estimation method highly depends on the grouping of sites into homogeneous regions. In this study, the geographical proximity and LMRD were used in order to cluster preliminary regions which then tested for hydrologic similarity. The delineation of homogeneous regions is closely related to the identification of the common regional distributions that apply within each region. A region can only be considered homogeneous if sufficient evidence can be established that at different sites in the region are drawn from the same parent distribution.

In this study, the DEM of Genale-Dawa River Basin (GDRB) was used and the delineation of homogeneous regions was performed by taking in to account the drainage boundaries of the subbasin with ArcGIS 10.4.1 environment. The preliminarily identified regions have to be checked by various homogeneity tests. All sample stations are located on a digitized map by latitude and longitude. For each station, the statistical values (LCs, LCk) were computed. It was assumed that the LCs and LCk values of one station vary linearly with the neighboring stations.

The procedures followed in the delineation of the boundary of the region are as follows:1).

Compute the (LCs, LCk) value of each station, 2). Identify the location of stations along the distributions of LMRD for the defined regions statistical comparison of observed flood data, 3). Identify the group based on step (2), 4). Each region that was identified in step-1 was checked for statistical homogeneity using the proposed test.

In this particular study, Abdulla (2011) and Irwin *et al.* (2014) procedures were used in delineating the defined homogeneous regions. According to these authors, the methodology used gives efficient and consistent watershed delineation on DEMs of any size. Finally taking into consideration the drainage boundaries of each sub-region the delineation was carried out accordingly with the ArcGIS10.4.1 environment.

3.6. Selection of regional frequency distribution

The choice of frequency distributions is determined based on goodness-of-fit measures, which indicates how much the considered distributions fit the available data (Hailegeorgis and Alfredsen, 2017). In flood event analysis, the annual maximum flow corresponding to a given T can be estimated from the annual flood series using varies theoretical distributions.

3.6.1. L-moment ratio diagram

Regional frequency distribution fitting using LMRD highly depends on a regional average weighted L-moment statistical value of LCs and LCk of all sites for the defined homogeneous regions. This shows that clustering of the sample datasets around the theoretical relationships between LC_s and LC_k of different probability distributions.

Thus, some acceptable design procedures are essentially required to choose a model that minimize uncertainties. Generalized extreme value (GEV), generalized logistic (GLO), Logistic, Generalized Pareto (GPA), Normal, Log Pearson type 3 (LPIII) and Lognormal (LN) distributions are among the employed distributions in this study. Many flood frequency distributions have been practiced for flood modeling, but none has been accepted as universal. Hence, these distributions were considered for the evaluation of the possible distributions that can represent the average frequency distribution of the regional data of the basin.

3.6.2. Easy Fit Software for distribution fitting

These methods are preferred especially in cases where there is little or no information about the base distribution pattern in data and the need to find the best distribution type. In order to determine whether the distribution model could fit the data properly, goodness-of-fit tests were used. In the present study Easy Fit 5.6 Statistical Software Package, trial version 5.6 was used to find the best-fit distribution and its estimation parameters.

3.6.3. Goodness of fit tests

The first of error, which is associated with the wrong assumption of a particular distribution for the given data, was checked to a certain extent by using goodness-of-fit tests. These are statistical tests which provide a probabilistic outline to evaluate the adequacy of distributions. In most cases, a number of distributions provide statistically acceptable fits to the available data so that goodness-of-fit tests are incapable of identifying the accurate distribution to use. The results of the goodness of fit tests are used to select a distribution for frequency analysis of stations.

In this study, to test the statistical hypothesis whether a particular distribution provides an adequate fit to the observed AMF series data three goodness of fit tests were applied. The reason for selecting three different tests is that there is no single test that can give conclusive results and a particular test emphasizes a particular aspect of the goodness-of-fit. All test statistics were defined and carried out at 5% significance level as in (Ashraful *et al.*, 2018).

i. Kolmogorov-Smirnov Test(KS)

The test statistic in the KS test is extremely simple. A statistic based on the deviations of the sample distribution function FN (X) is used in this test.
The test statistic D_N is defined as:

$$DN = \underset{1\le i\le n}{\max}|F_n(x_i) - F_O(x_i)| \ldots\ldots\ldots 3.26$$

The values of FN (x) are predictable as Nj/N, where Nj is the cumulative number of sample events in class i. The value of D_N must be less than a tabulated value of D_N at the specified confidence level for the distribution to be received (Desalegn *et al*, 2016). In this method, the hypotheses take dependability of a specified distributions data of stations.
The hypothesis regarding the distributional form is rejected at the chosen significance level (α) if the test statistic, D, is greater than the critical value obtained from a table. The fixed values of α (0.01, 0.05) are generally used to evaluate the at various significance levels. A value of 0.05 is typically used for most applications.

ii. Chi-Squared Test(X^2)

The x^2 goodness of fit test is a non-parametric test that is used to get exposed how the observed value of a particular phenomenon is considerably unlike from the estimated value. In this test, the method is used to contrast the observed sample distribution with the estimated probability distribution. This test determines how fine theoretical distribution fits the experimental distribution.

In x^2 goodness of fit test, sample data is separated into intervals. Then the numbers of points that drop into the interval are compared, with the predictable numbers of points in every interval. The null hypothesis assumes that there is no notable variation between the observed and the expected value. The degree of freedom depends on the distribution of the data sample (Ghosh *et al.*, 2016).

In this goodness of fit test, the alternative hypothesis assumes that there is an essential variation between the observed and the expected value.

$$X^2 = \frac{(O-E)^2}{E} \quad \ldots\ldots 3.27$$

Where $X^2 =$ Chi-Square goodness of fit test

O = observed value

E = expected value

If the considered value of x^2 goodness of fit test is less than the table value, will admit the null hypothesis and conclude that there is no important differentiation between the observed and expected value.

iii. Anderson-Darling test(AD)

The AD test is used to test if a sample of data came from a population with a definite distribution. It is a revision of the KS test and gives further influence to the tails than does the KS test. The KS test is distribution free in the logic that the critical values do not depend on the definite distribution being tested. This test makes utilize of the definite distribution in manipulative critical values. This has the benefit of allowing an additional perceptive test and the drawback that critical values should be intended for each distribution. The critical values for the AD test are dependent on the specific distribution that is being tested (Ghosh *et al.*, 2016).

3.6.4. 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 Wallis, 1997). Assessment of the accuracy of the estimates should, therefore, take 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.

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. Thus 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).

ii. Quantile-quantile plots

Quantile-quantile(Q-Q) plots are plots of two quantiles against each other. A quantile is a small part where certain values fall below that quantile. The purpose of Q-Q plots is to get out if two sets of data come from the same distribution. It is the graph of the input observed and analysis data values plotted against their theoretical or fitted distribution. These are produced by plotting the data values against the x-axis, and the following values against the y-axis. Q-Q plots were used to compare the estimated quantiles and the observed flood values and to check the validity of the estimates provided by a fitted theoretical distribution. The best frequency distribution was subjected to randomly simulate the same size as observed series.

3.6.5. Parameter and quantile estimation

The maximum likelihood is used for parameter estimation with the help of Easy Fit. These parameters are used to calculate the quantiles related to return periods. The method used for regionalization is the index flood method which comprises the standardized AMF series of each station divided by site averaged AMF values. The frequency distribution procedure of AMF data in a homogeneous region consists of similar quantile distribution (Dalrymple, 1960). After the parameters of a distribution are estimated, flood quantile estimates (X_T) which correspond to different return periods can be computed.

In the present study, the parameter estimation was done by using the Easy Fit Statistical Software. 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.

For GEV distribution the flow quantile can be estimated as;

$$X_T = \mu + \frac{\delta}{k}(1 - (-\ln(1 - \frac{1}{T})^{k}), \text{ for } k \neq 0 \quad \ldots\ldots 3.28$$

$$X_T = \mu + \delta(\ln(-\ln(1 - \frac{1}{T})), \text{ for } k = 0 \quad \ldots\ldots 3.29$$

For GPA distribution the flow quantile can be estimated as;

$$X_T = \mu + \delta(\ln(\frac{1}{T})), \quad \text{for } k = 0 \quad \ldots\ldots 3.30$$

$$X_T = \mu + \frac{\delta}{k}(1 - (\frac{1}{T})^{k}), \quad \text{for } k \neq 0 \quad \ldots\ldots 3.31$$

Where σ= Scale parameter,

T= return period

μ= Location parameter; and

k = Shape Parameter

In this study, estimation of parameters and calculation of the magnitude of flood for 10,000 years return period were executed. Comparing the result of the flood events of 10,000 years return period is significant. This is due to the reason that dam safety risk analyses, sizing of emergency spillways, the design of dam crest level and any other hydraulic structures, the critical flood peaks are mostly based on the criterion of 10,000 years return period flood. This may help to make balanced engineering decisions on the choice of design floods used to ensure a satisfactory and reliable standard in the planning and design of flood control structures (Donnelly *et al*., 2008; Haktanier *et al*., 2010 as cited in Tekuame and Seleshi, 2017).

3.7. Derivation of the regional flood frequency curves

The average of the regional growth curves was determined to represent the frequency curves of regions. Index flood method employs data of the gauged catchments to evaluate a regional correlation from the flood magnitudes of various return periods for ungauged catchments to be evaluated (Modi and Mitra, 2017). In this study, the index flood method was used to determine the magnitude and frequency of flood quantiles for sites located within a homogeneous region.

3.7.1. Estimation of index-flood

Derivation of the mean annual flood ($\overline{Q}$) for each station was obtained by relating the annual flood data from each station (Q_i) and dividing it by the number of record years. The main assumption of this is that data at different sites in a region follow the same distribution consisting of IHRs, determination of best-fit distribution and derivation of the RFFC. In this study, the index flood L-moment approach of regionalization is applied depending on the homogeneity of the stations by testing for the homogeneity using different techniques.

Flood quantiles estimation in flood frequency analysis were corresponding to the required return periods. The model parameters for the distributions estimated for each station were used to compute standardized flow estimates conforming to the return periods 2, 5, 10, 20, 25, 50, 100, 200, 500, 1000, 2000, 5000 and 10000 years. Plots of Q/Q_m against the Gumble reduced variate(-ln(-ln(1-1/T)) known as growth curves, were generated for each station and used in the derivation of the regional growth curves.

To do this, the following stages were employed. Select best fitted distributions the parameter values such as shape (k), location (σ) and scale (μ) which were estimated using Easy Fit Software, the model parameters estimated for a given region were then used to compute the standardized quintiles estimates for the return periods, the growth curves for each station was then developed.

In this method, the dimensionless regional growth curves used to estimate X_T. After the regional frequency distribution is determined, the flood quantiles having a return period of T year within a homogeneous region can be estimated based on the equation (3.32) proposed by Hosking and Wallis (1997). The common practice is to get the dimensionless data by dividing the values by an estimate of the at-site mean.

$$X_T = \frac{Q_T}{\overline{Q}} \qquad \text{3.32}$$

Where; $\overline{Q}$ - is the mean annual flood(m^3/s) is the index flood

Q_T - is the quantile (m^3/s) function of fitted distribution at site i

X_T - regional quantile of which can be obtained from regional growth curve; this defines the frequency distribution common to all the sites in a homogenous region.

3.7.2. Confidence level of flood frequency curves

For those of candidate distributions, the goodness of fit measure takes place with a significance level of $\alpha=0.05$ which is a confidence level of 95%. In the present study, the confidence limit of the study area at 95% (UCL) and 5% (LCL) of quantile values for different parameters of distributions are determined. The slope of a flood frequency curve(FFC) graphically represents the standard deviation of the flood frequency distribution and the higher the slope, the greater the standard deviation in flood discharge. The results discussed were depending on the nature of how LCL and UCL fit with FFC. This includes; when the UCL closely overlaps with FFC when LCL overlaps with FFC, when Both UCL and LCL overlaps with FFC when Both UCL and LCL were far from FFC at their significance level.

4. RESULTS AND DISCUSSIONS

4.1. Identification and delineation of homogeneous region

4.1.1. Identification of homogeneous region

The degree of homogeneity of a proposed region was preliminarily judged based on site characteristics and L-moment ratio diagram (LMRD) of flood statistics. The clustering of sites was carried out by hierarchical geographic regionalization procedure. This method considers the stations that were geographically continuous (i.e. the spatial proximity of network of gauging stations as indicated in Figure 3.3) and in clustering, the annual maximum flow of sites in the region should satisfy the Hosking and Wallis (1997) homogeneity test criteria.

LMRD were then used to group stations to confirm the hierarchical clustering. The LMRD shown on Figure 4.1 was used to identify homogeneous regions with site characteristics of gauging stations described in Table 3.1. As indicated in Table 4.1, the accentuated distributions were designated to the same group since stations lie close to the identical distribution. Hence, based on L-moment statistics and suitability of gauging site networks, three homogeneous subregions were identified. Namely Region-A, Region-B and Region-C as shown in Table 4.1.

Table 4.1: Preliminary identified homogeneous regions

Group name	Station name	Possible distributions from Figure 4.1	
Region-A	Chenemasa	GEV	LN/LPIII
	Kolle bridge	GEV	LPIII
	Halwey	GPA	GEV
	Melka Amana	GPA	GEV
	Gom-Goma	GEV	GPA
	Dello Mena	GEV	GPA
Region-B	Melka Guba	GPA	LPIII
	Megado	GEV/GEV	LPIII
	Digatty	GLO/GEV	LPIII
	Oddo Shakiso	LPIII	GLO
Region-C	Robe	LPIII	GPA
	Agarfa	GEV	GPA
	Shallo Village	GEV	GPA
	Alemkerem	GPA	GEV
	Denbel	GPA	GEV
	Sofumer	GPA	GEV

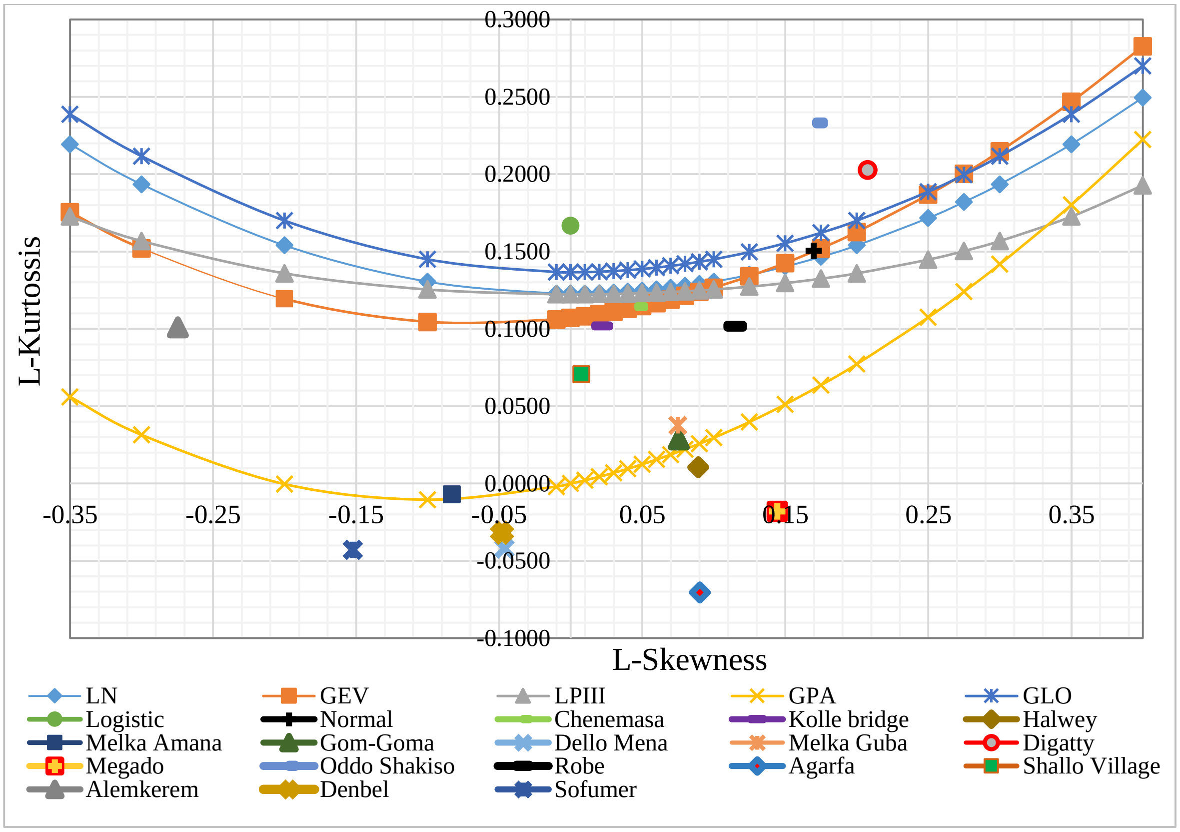


Figure 4.1: L-moment ratio diagram for identification of homogeneous regions

4.1.2. Test for regional homogeneity

The identified homogeneous regions from statistical values have to be statistically homogenous to verify the acceptability of regions.

4.1.2.1. Discordancy measure of regions

This approach was used to validate the defined regions and screen out the data from unusual sites. Values of discordancy of L-moment statistics have been calculated for all the 16 gauging sites of the basin. Using Equation (3.8) with Matlab program code presented in Appendix-F, the values of discordance index (Di) measure for different sites within the regions were presented in Table 4.2, 4.3 and 4.4 for Region-A, B and C 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 3.4. It was observed that the Di values for all 16 sites vary from 0.5846 to 1.5528.

According to Sine and Ayalew (2004), Lim (2007), Nobert *et al.* (2014), Hussen and Wagesho (2016), and Kanti *et al.* (2017), the region on their study under investigation, has been declared homogeneous if Di is less than 3. In this condition, a site is declared to be unusual if Di is large.

This would be considered as grossly discordant and would justify elimination from the defined regions and can be redefined as a single site or merged into other regions.

Hence, all of the stations grouped as a homogeneous in Region-A, Region-B, and Region-C were satisfied the discordance test criteria. As shown in Table 4.2, 4.3 and 4.4, the result of all the Di was below the critical value which implies that all the regions are homogeneous. So, none of the identified regions was found to reveal Di greater than the critical value. This indicated that all sites do not reflect any outlier and discordancy. Thus, data of all gauging sites could be considered for further regional flood frequency analysis.

Table 4.2: Results of major statistics and discordant measure test of sites in Region-A

Station name	LCv	LCs	LCk	Di
Chenemasa	0.1999	0.0467	0.1142	1.0313
Kolle bridge	0.1386	0.0221	0.1017	1.1287
Halwey	0.2008	0.0893	0.0106	1.3149
Melka Amana	0.2079	-0.0830	-0.0070	0.8560
Gom-Goma	0.2575	0.0757	0.0285	0.9737
Dello Mena	0.2399	-0.0462	-0.0420	0.6953

Table 4.3: Results of major statistics and discordant measure test of sites in Region-B

Station name	LCv	LCs	LCk	Di
Melka Guba	0.2205	0.0750	0.0376	0.9999
Megado	0.2014	0.1444	-0.0188	0.9999
Digatty	0.1571	0.2078	0.2027	0.9999
Odda-Shakiso	0.1420	0.1718	0.2330	0.9999

Table 4.4: Results of major statistics and discordant measure test of sites in Region-C

Station name	LCv	LCs	LCk	Di
Robe	0.1674	0.1152	0.1015	1.3966
Agarfa	0.2463	1.0000	-0.0704	1.5528
Shallo-Village	0.1440	0.0074	0.0706	0.6659
Alemkerem	0.1202	-0.2746	0.1009	0.5846
Denbel	0.1458	-0.0479	-0.0317	0.5881
Sofumer	0.1458	-0.1523	-0.0428	1.2120

4.1.2.2. CC-based regional homogeneity test

Sites which have approximately L-moment statistics were grouped together. Here, the internal homogeneity of regions was determined in based on flow statistics. The combined coefficient of variation for the region (CC) values were calculated and the results in sites of each region were summarized as shown in Table 4.5, 4.6 and 4.7.

The value of CC varies from region to region depending on L-moment statistics of flow data. From Cv-based homogeneity test, the CC values were 0.1814, 0.1332 and 0.2714 for Region-A, B and C respectively. On the other hand, from LCv-based homogeneity test, the CC values were 0.1977, 0.2043 and 0.2806 for Region-A, B and C respectively.

According to Melsew (1996) as cited in Ketsela *et al*. (2017); Mkhandi *et al*. (2000) and Saf (2009), a region is declared to be homogeneous if it is geographically continuous and hence for better act of the index flood method, CC should be kept low and small. And other authors like Sine and Ayalew (2004), Nobert *et al.* (2014) and Guru and Jha (2016) noted that for the study regions under their consideration, a region is declared to be homogeneous if CC values were less than 0.3.

Thus, from the results in Table 4.5, 4.6 and 4.7, it can be concluded that all regions were hydrologically homogeneous for both Cv and LCv based homogeneity tests since the CC values were less than 0.3. With regard to the results obtained above, all stations grouped as homogeneous were satisfied the stated homogeneity test criteria. As a result, it can be concluded that all regions were reasonably homogeneous.

Table 4.5: Results of Cv and LCv-based homogeneity test for Region-A

Station	LCv	LCs	LCk	Cv	Cs	Ck
Chenemasa	0.1999	0.0467	0.1142	0.3767	0.7377	1.3105
Kolle bridge	0.1386	0.0221	0.1017	0.2409	0.2473	-0.1652
Halwey	0.2008	0.0893	0.0106	0.3457	0.3285	-1.2458
Melka Amana	0.2079	-0.0830	-0.0070	0.3559	-0.2569	-1.1165
Gom-Goma	0.2575	0.0757	0.0285	0.4281	0.2689	-0.8923
Dello Mena	0.2399	-0.0462	-0.0420	0.4025	-0.1339	-1.3512
Mean	0.2074	0.0174	0.0343	0.3583	0.1986	-0.5768
Std.dev	0.0410	0.0687	0.0618	0.0650	0.3558	1.0168
CC	0.1977			0.1814		

Table 4.6: Results of Cv and LCv-based homogeneity test for Region-B

Station	LCv	LCs	LCk	Cv	Cs	Ck
Melka Guba	0.2205	0.0750	0.0376	0.3900	0.3613	-0.5180
Megado	0.2014	0.1444	-0.0181	0.3537	0.4413	-1.2430
Digatty	0.1571	0.2078	0.2027	0.2891	0.9800	0.5214
Oddo Shakiso	0.1420	0.1718	0.2330	0.3117	0.2892	-1.1837
mean	0.1803	0.1497	0.1138	0.3361	0.5180	-0.6058
Std.dev	0.0368	0.0562	0.1229	0.0448	0.3142	0.8202
CC	0.2043			0.1332		

Table 4.7: Results of Cv and LCv-based homogeneity test for Region-C

Station	LCv	LCs	LCk	Cv	Cs	Ck
Robe	0.1467	0.1152	0.1015	0.2864	0.3858	-0.5594
Agarfa	0.2463	0.0904	-0.0704	0.4151	0.1876	-1.4661
Shallo Village	0.1440	0.0074	0.0706	0.2424	-0.0296	-0.9363
Alemkerem	0.1202	-0.2746	0.1009	0.2109	-0.9492	0.1508
Denbel	0.1458	-0.0479	-0.0317	0.2303	-0.2159	-1.0681
Sofumer	0.1458	-0.1523	-0.0428	0.2521	-0.4272	-1.2117
Mean	0.1581	-0.0436	0.0214	0.2729	-0.1747	-0.8485
Std.dev	0.0444	0.1490	0.0782	0.0741	0.4758	0.5747
CC	0.2806			0.2714		

4.1.3. Delineation of homogeneous regions

After organizing and assembling the data set, important statistical parameters have been computed and interpolation of these statistical values (LCs, LCk) in collaboration with site characteristics are then used to come up with the following results of delineation. Delineation of regions was done depending on the fact that the statistical homogeneity tests were satisfied and proved grossly discordant each other. The regions have covered an area of 56,343, 83,250 and 32,666km^2 for Region-A, B and C respectively.

Accordingly, the first region which includes most of gauging stations in the upper and lower reaches of Genale sub-river basin i.e. Chenemasa, Kolle bridge, Halwey, Gom-Goma, Dello Mena and Melka Amana stations were delineated under Region-A. The second region, which includes gauging stations in Awata, Mormora and Dawa sub-river basins i.e. Melka Guba, Megado, Odda-Shakiso and Digatty stations were delineated under Region-B.

The third region, which is most of gauging stations in Shaya and Weyib sub-river basins including Robe, Agarfa, Shallo-Village, Denbel, Alemkerem, and Sofumer stations were delineated under Region-C. This implied that 32.708, 48.328 and 18.963% of the river basin were delineated under Region-A, B and C respectively. Having proven to be statistically homogeneous, the delineated homogenous regions shown in Figure 4.2 could be used to generate a regional growth curve at any site located in the study area.

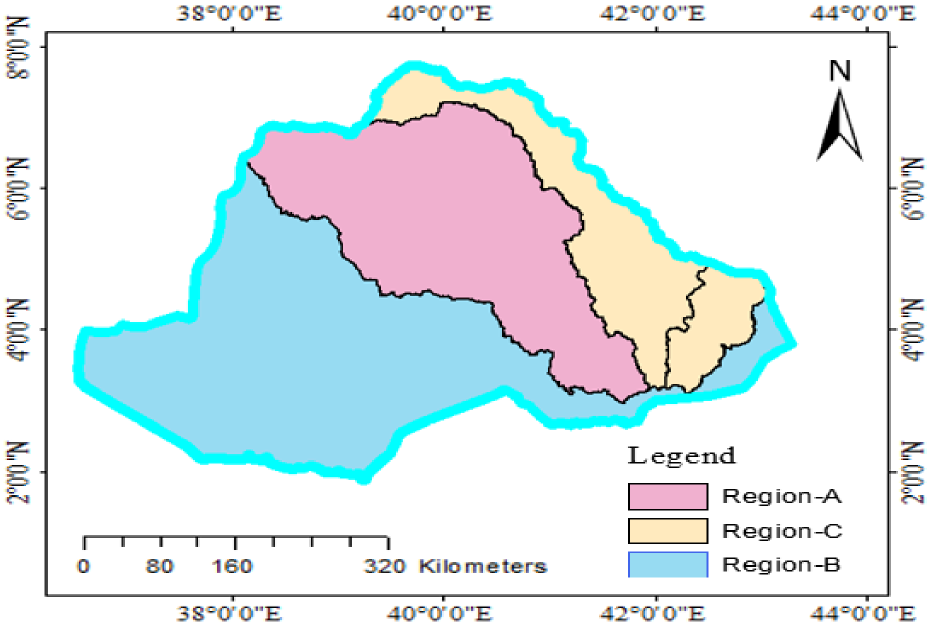


Figure 4.2: Spatial distribution of delineated homogeneous regions

4.2. Determination of suitable regional probability distribution

In this study, the annual maximum series model was adopted where only the maximum flow in each water year is considered.

4.2.1. Goodness of fit tests

In this study, the goodness of fit tests was performed for all distributions using Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared methods 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. This GOFs at 5% level of significance was used to define the best-fit ranking using Easy Fit Statistical Software.

The probability distribution having the first rank along with their test statistic was presented in Table 4.8, 4.9 and Appendix-H. The justification of results was summarized in Table 4.8 for Gom-Goma and Table 4.9 for Sofumer stations and Appendix-H for other stations were presented depending on the ranking of the goodness of fit tests. Using the three tests from Table 4.8 and Table 4.9, it was detected that generalized extreme value distribution for Sofumer and general Pareto distribution for Gom-Goma station provides the best fit to the AMF data. Comparing the results of goodness-of-fit tests, the generalized extreme value and generalized Pareto distributions afford a good fit for the recorded data of stations.

Table 4.8: Goodness of fit test values for selected distributions of Gom-Goma station

Distribution	Kolmogorov-Smirnov		Anderson-Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
General Pareto	0.0776	1	0.1601	1	0.1445	1
General Extreme Value	0.0888	2	0.1976	2	0.3105	3
Log-Pearson type 3	0.0912	3	0.2465	3	1.0717	5
Log-Logistic	0.0949	4	0.2899	5	1.0201	6
Log-Normal	0.0997	5	0.2595	4	0.1605	2
Logistic	0.1174	6	0.3788	6	0.3610	4

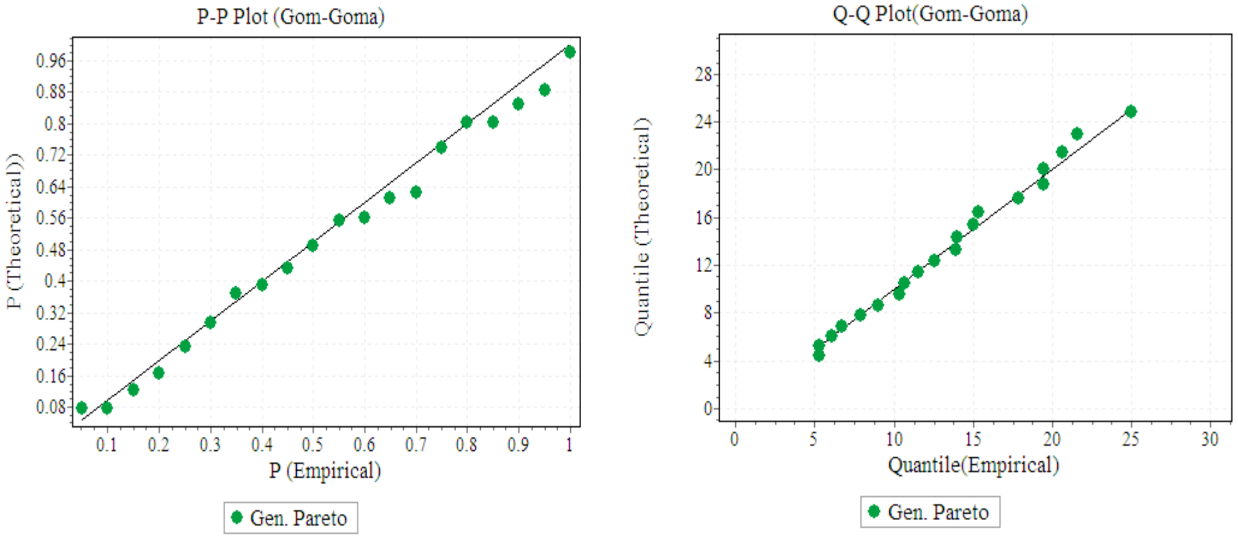
Table 4.9: Goodness of fit test values for selected distributions of Sofumer station

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
General Extreme Value	0.0883	1	0.1601	1	0.1445	1
General Pareto	0.1035	2	0.1976	2	0.3105	3
Log-Pearson type 3	0.1346	3	0.2465	3	1.0717	2
Log-Normal	0.1416	4	0.2899	4	1.0201	5
Log-Logistic	0.0687	5	0.2595	6	0.1605	6
Logistic	0.1143	6	0.3788	5	0.3610	4

It was also observed that most of the probability distributions have the first rank in both Kolmogorov Smirnov and Anderson Darling tests. This indicates that the two goodness-of-fit tests lead to a reasonable estimation of flood in the Genale-Dawa River Basin.

4.2.2. Evaluating estimation accuracy of selected distribution

The P-P and Q-Q plot have to be more or less linear if the particular theoretical distribution is the correct model. It was observed that from the results shown in Figure 4.3 for Gom-Goma station and Appendix-I and J for the rest of the stations, indicated that almost all plots were well fitted to the line. Through all the patterns, the study reveals that GPA and GEV distributions performed well for most of the stations in the basin. Therefore, results from both methods validated that the flood frequencies of the regions were well addressed. Hence, using these distributions and annual maximum flow modeling could have a wide range of applications in agriculture, hydrology, engineering design and future climate evaluation in the study area.



(a) (b)

Figure 4.3: Performance evaluation of frequency distributions

4.2.3. 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 distribution. The corresponding average weighted value of L-moment statistics results were obtained from regional data as presented in Table 4.5, 4.6 and 4.7 plotted along with the theoretical lines for some distributions on LMRD to determine a regional probability distribution.

As shown in Figure 4.4, the points representing the regional average values of L-Kurtosis versus L-Skewness were fitted with GPA and GEV distributions. Therefore, it appears that the GEV and GPA distributions would be suitable distributions for the regions. The choice of a suitable standard frequency distribution is often uncertain and LMRD might not guarantee that the distribution is the actual representative of flood statistics in the given region.

For this reason, a confirmation of candidate distributions is needed. Hence, the results between the goodness-of-fit test with Easy Fit and LMRD indicated that due to the common acceptance of GEV and GPA distributions, could be used as a best-fit distribution for the study area. Therefore, GEV and GPA distributions could be adopted as the regional distribution, while

Logistic, LPIII, Normal, GLO and LN distributions should not be considered. As a result, this justified that the two distributions would be acceptable and the dominate probability distributions in the Genale-Dawa River Basin for estimation of regional flood frequency.

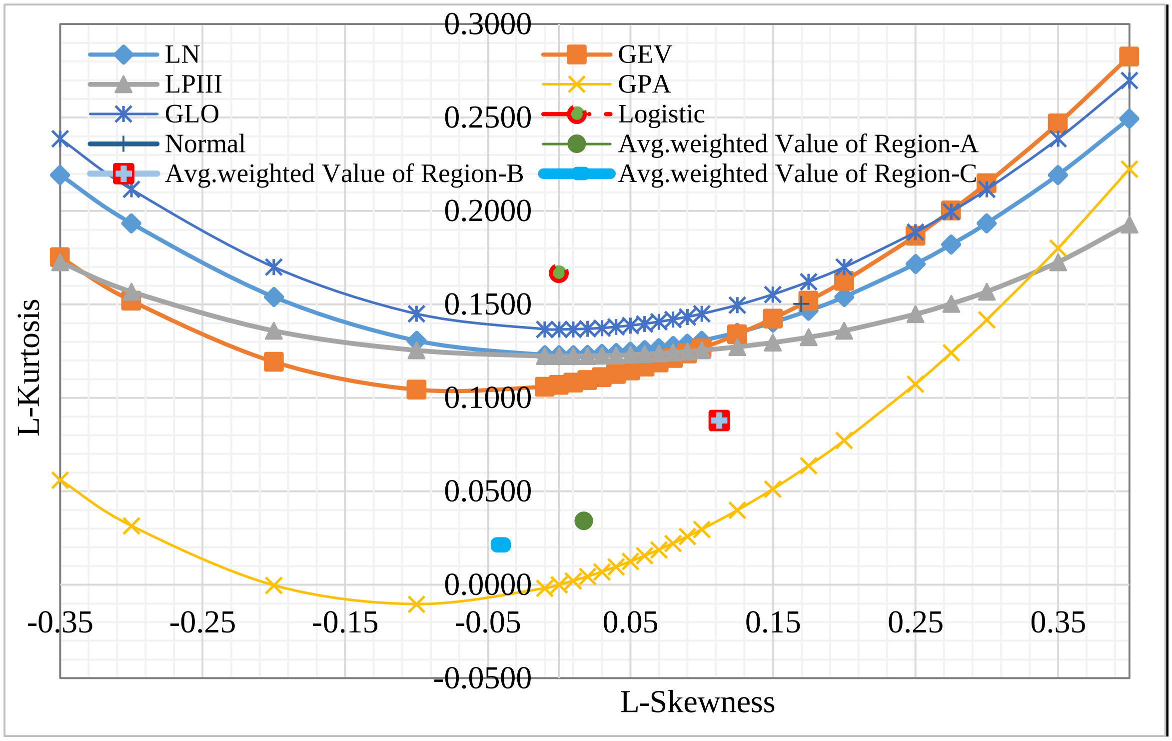


Figure 4.4: Regional weighted L-moment ratio diagram for the established regions

4.3. Estimation of regional flood frequency curves

After regions have been accepted as homogeneous, suitable distributions were identified for the regions. The flood frequency curves were established for each station based on suitable distribution to calculate the deviations in the standardized flow of various return periods.

4.3.1. Parameter and quantile estimations

Estimation by the MML involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations. The best parameter estimates from Easy Fit for selected distribution models were displayed as shown in Table 4.10. These results were generated according to the ranks and descriptive statistics of the goodness fit tests shown in Table 4.8, 4.9 and Appendix-H. As a result, these distributions could be adopted as the appropriate and found to be the dominating distribution in the Genale-Dawa River Basin for accurate evaluation and estimation of floods.

Estimation of flood quantiles was applied for 2, 5, 10, 20, 25, 50, 100, 200, 500, 1000, 2000, 5000 and 10000 years return period and flood frequency curves for stations were developed. Flood frequency curves (FFC) were estimated using equation 3.28 and 3.31. This estimation of the flood can be utilized in the designing of vital hydraulic structures in the river reach.

Table 4.10: Results of estimation parameters for fitted distributions in the basin

Name of stations	Best-fitted distribution	Values of parameters		
		k	σ	μ
Robe	Generalized extreme value	-0.087	22.402	74.957
Shallo village	Generalized extreme value	-0.387	5.209	18.750
Agarfa	Generalized pareto	-1.204	83.537	26.117
Denbel	Generalized pareto	-0.408	18.277	65.798
Alemkerem	Generalized extreme value	-0.853	18.101	73.449
Sofumer	Generalized pareto	-0.519	166.020	51.540
Chenemasa	Generalized extreme value	-0.064	146.330	370.880
Odda-Shakiso	Generalized pareto	-0.640	67.760	44.732
Digatty	Generalized pareto	-0.312	13.365	17.861
Kolle Bridge	Generalized extreme value	-0.244	58.465	222.020
Megado	Generalized pareto	-0.495	73.153	48.395
Halwey	Generalized extreme value	-0.130	197.150	520.820
Dello Mena	Generalized extreme value	-0.369	19.246	37.865
Gom Goma	Generalized pareto	-0.719	5.621	10.887
Melka Amana	Generalized pareto	-0.476	106.480	85.000
Melka Guba	Generalized pareto	-0.521	114.630	44.392

4.3.2. Estimation of index-flood for standardization

In this case, the average of the growth curves was determined to represent the flood frequency curves of regions. The results of Table 4.11 and Appendix-K show that the standardized quantiles for stations using the selected distribution and parameters with their corresponding return periods. It was observed that the magnitude of flood increases as the return period increases for selected distribution parameter for all stations. This may be due to the variability of the flood regimes of hydrological phenomena generating the flood events. This can significantly help in risk assessment works, water resources management, and engineering decisions and actions in the study area.

Table 4.11: Estimated standardize flood quantiles of stations

Gumbel reduced variate	Chenemasa	Kolle Bridge	Halwey	Dello Mena	Gom-Goma	Megado	RGC-A
0.37	1.24	1.24	1.32	1.04	1.19	1.32	1.23
1.50	1.66	1.66	1.89	2.50	2.09	2.13	1.99
2.25	1.95	2.01	2.33	3.40	3.29	3.00	2.66
3.20	2.34	2.56	3.00	4.96	6.13	4.64	3.94
3.90	2.64	3.05	3.57	6.53	9.94	6.41	5.36
4.60	2.96	3.63	4.23	8.54	16.22	8.80	7.39
5.30	3.29	4.31	4.97	11.13	26.54	12.03	10.38
6.21	3.75	5.42	6.13	15.75	51.04	18.15	16.70
6.91	4.11	6.43	7.14	20.43	83.84	24.71	24.44
7.60	4.49	7.63	8.30	26.48	137.82	33.61	36.39
8.52	5.02	9.56	10.09	37.25	266.00	50.40	63.05
9.21	5.44	11.34	11.67	48.19	437.55	68.43	97.10

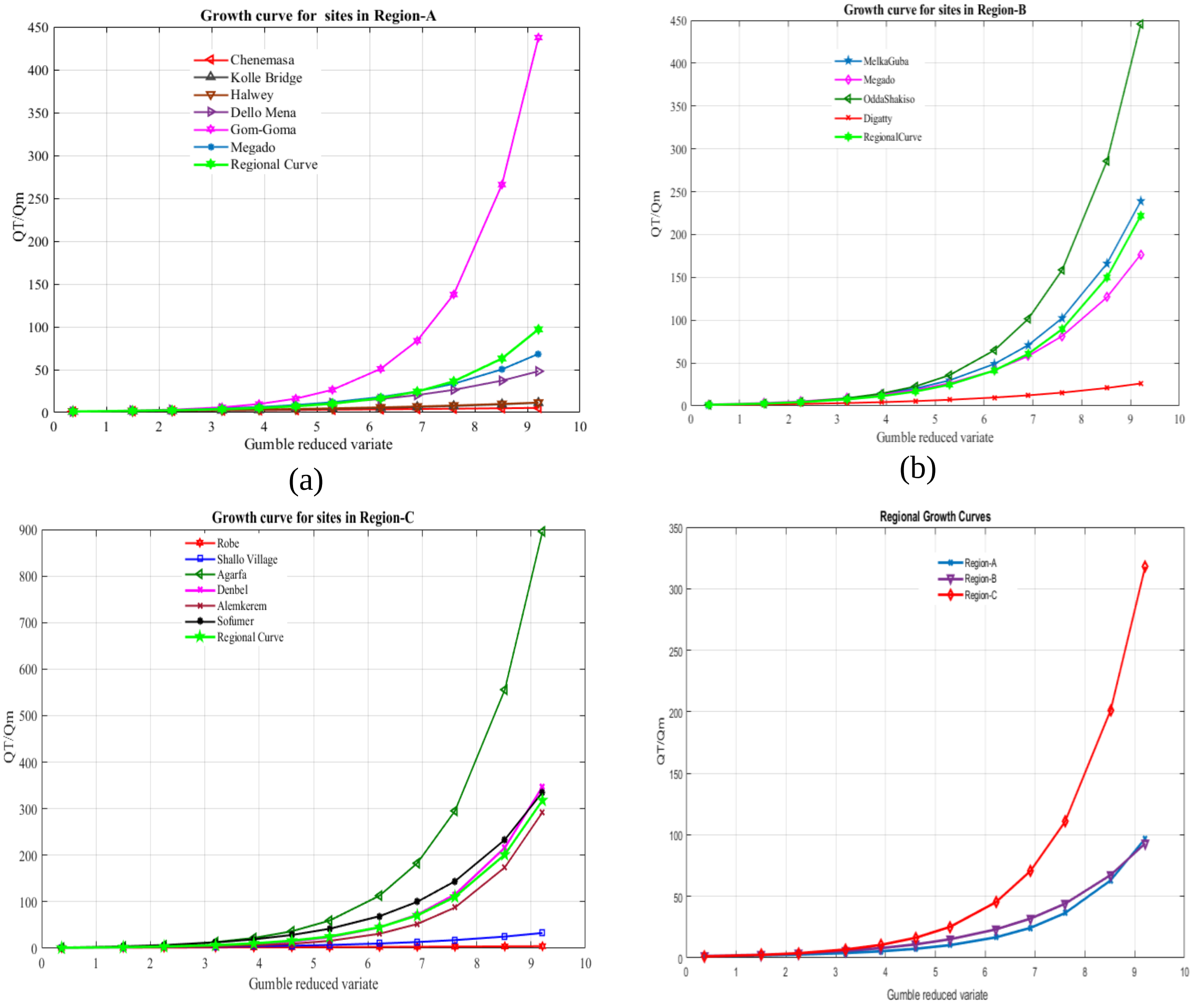
(RGC: Regional Growth Curve)

Depending on selected distributions, regional growth curves were derived as indicated in Figure 4.5. Figure 4.5 (a) indicated that the growth curves of Region-A which represents the main reaches of most of the rivers Halgol, Yadot, Welmel, and Genale at Chenemasa cause extensive floods in their lower reaches experiencing high flood generation from the highlands. The Genale river at Kolle bridge and Halwey might inundate low-lying areas in their outfall reaches. Therefore, the lower reaches of homogeneous Region-A might be affected by the occurrence of flooding.

Figure 4.5 (b) indicated that, the growth curves of Region-B, which represents the main reaches of most of the rivers Awata, Mormora and Dawa, which causes extensive floods in their lower reaches experiencing high flood generation from the highlands of Awata sub-watershed. The flood that comes from the highlands might inundate low-lying areas in their outfall reaches. Hence, the middle and lower reaches of this region are very might be susceptible to the risk of flooding. Generally, Figure 4.5 (a), (b) and (c) revealed that lower elevation catchments have lower flood values but higher extreme flood variability than higher elevation catchments.

The constructed regional frequency curves from three regions reflect that all curves have different flood characteristics. This could be due to the fact that the flood in different regions has different flood statistics. As indicated in Figure 4.5 (d), the derived regional growth curve of Region-C was revealed higher quantile estimates than Region-A and B, for the same return periods. This high flood within the region might cause tremendous damages and disruptions to local communities. This could be attributed to the variability in their flood regimes and the corresponding contributing areas.

The higher variations of regional curves may be due to the considerable spatial fluctuations of elevations with their spatially undulating mountainous topography of regional boundaries, which causes uncertainties in flood prediction.



(a) (b)

(c) (d).weighted

Figure 4.5: Regional growth curves for delineated homogeneous regions

4.3.3. Confidence limits of flood frequency curves

In this study, confidence limits indicated that the uncertainty of a given estimation of frequency curves. The results of the confidence limit of the study areas at 95% and 5% of quantile values for the distribution models were determined as shown in Table 4.12 and Appendix-L. Flood frequency curves were plotted on the bases of different return periods versus the estimated flood quantiles values (X_T) as shown in Figure 4.6.

Table 4.12: Estimated quantiles and Confidence limits of stations (m^3/s)

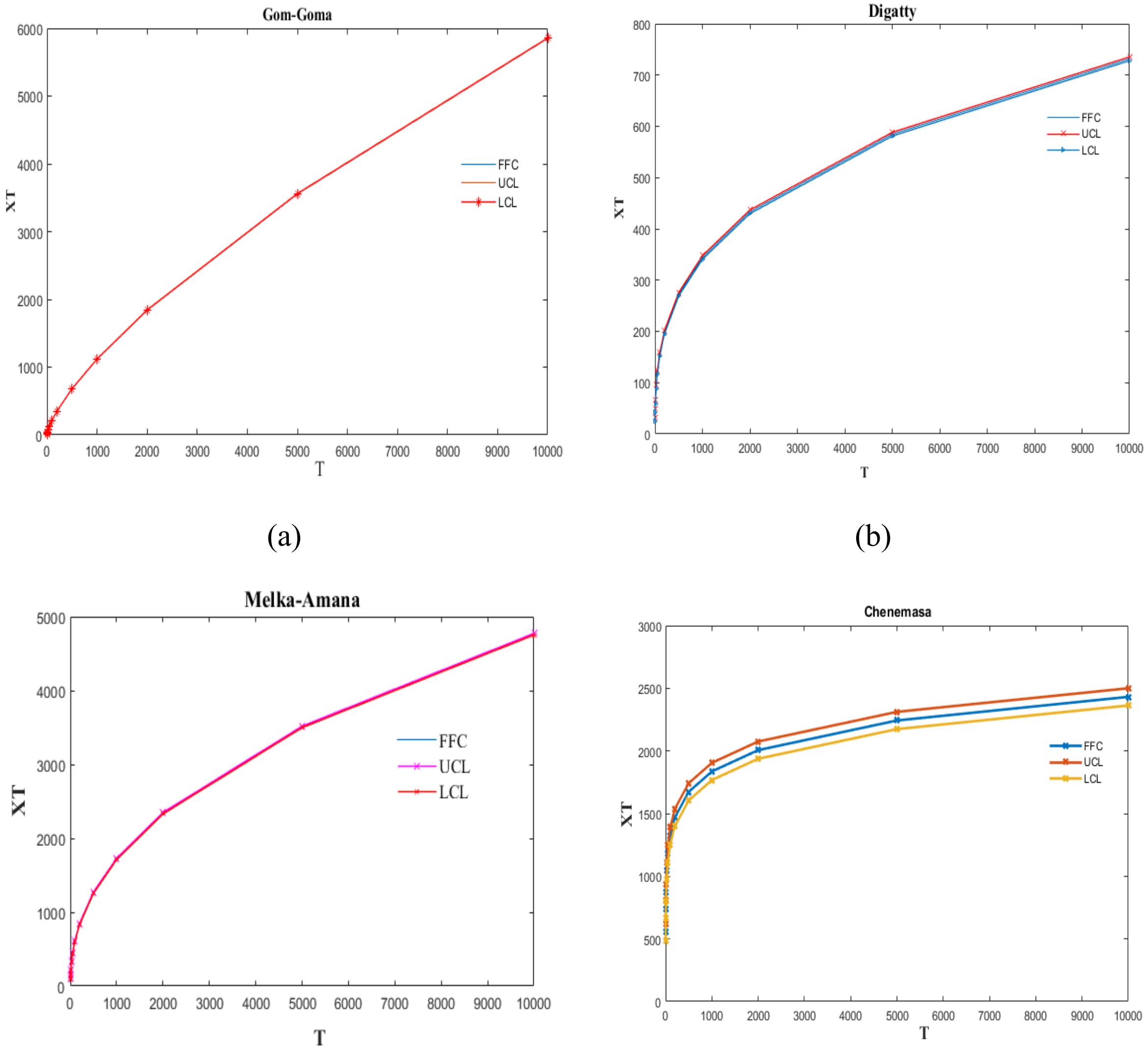
Station	Chenemasa			Kolle Bridge			Halwey		
T	FFC	UCL	LCL	FFC	UCL	LCL	FFC	UCL	LCL
2	553.47	622.22	484.71	303.60	329.27	277.93	809.57	894.20	724.94
5	739.18	807.93	670.43	405.99	431.66	380.32	1153.96	1238.59	1069.33
10	869.75	938.50	800.99	491.19	516.86	465.52	1426.95	1511.58	1342.32
25	1043.92	1112.68	975.17	623.79	649.46	598.12	1833.28	1917.91	1748.65
50	1180.13	1248.88	1111.37	744.04	769.71	718.37	2186.38	2271.01	2101.75
100	1321.51	1390.27	1252.76	885.70	911.37	860.03	2587.44	2672.07	2502.80
200	1468.80	1537.55	1400.04	1053.06	1078.73	1027.39	3044.34	3128.97	2959.71
500	1673.39	1742.15	1604.64	1322.24	1347.91	1296.57	3748.69	3833.32	3664.06
1000	1836.18	1904.93	1767.43	1569.74	1595.41	1544.07	4369.89	4454.52	4285.26
2000	2006.28	2075.03	1937.53	1862.86	1888.53	1837.19	5079.46	5164.10	4994.83
5000	2242.97	2311.72	2174.21	2334.93	2360.60	2309.26	6174.90	6259.53	6090.27
10000	2431.43	2500.18	2362.68	2769.26	2794.93	2743.59	7141.65	7226.29	7057.02

At Melka Amana, Dello Mena, Shallo Village, Megado, Gom-Goma and Alemkerem stations of flood frequency curves overlap with 95% confidence limit, which indicates the magnitudes of flood discharge at 95% confidence limit have high reliability, so that constructions of hydraulic structure and any other water resources development project is possible on the area around the stations.

For Sofumer, Agarfa, Denbel, Odda-Shakiso, and Digatty stations flood frequency curve overlaps with 5% confidence limit, which indicates the magnitude of flood discharge is higher. So that in order to reduce the flood risk around the area of these watersheds, flood protection structures should be constructed.

At Melka Guba, Robe, Chenemasa, Kolle Bridge and Halwey stations flood frequency curve positions separately from 5% and 95% confidence limit, which indicates the magnitude of flood discharge placed between 5% and 95% confidence limit. When the return period increases the flood frequency curve of the station resemble 5% and 95% confidence limits. Because of this, these stations are the highly reliable stations in accordance with flood risk within the region.

Generally, this might help to develop policies, which will reduce risk and damage from extreme flood events in both short and long-term planning which might happen in the study area. The estimated flood frequency curves at a given confidence limit advances the accuracy and reliability of flood risk estimations for this stations.



(a) (b)

(c) (d)

Figure 4.6: Flood frequency curves of stations with confidence limits

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study, regional flood frequency analysis was performed using the data of 16 stream gauging stations so as to ensure reliable estimation of flood in Genale-Dawa River Basin. The basin has defined and delineated into three hydrologically homogeneous regions using AMF frequency model. The regions were named as Region-A, Region-B and Region-C comprising 6, 4 and 6 gauging sites respectively. The delineation of the regions was done with ArcGIS10.4.1. The discordancy of sites from the region was estimated using Matlab2017a. Further, regional homogeneity tests were conducted to verify the homogeneity of regions. All regions were shown acceptable results for discordancy index and statistical homogeneity tests. Thus, a method of L-moment has found suitable for regional frequency analysis of the study area.

Kolmogorov-Smirnov and Anderson-Darling of goodness-of-fit tests were applied and found suitable for checking the adequacy of fitting a suitable distribution for the recorded data of the basin. As a result, GEV and GPA were identified as the best fit distributions in the study area with the help of Easy Fit and LMRD. Using the model parameters of the distributions of each station, flood quantiles were estimated corresponding to different return periods. The study concluded that LMRD and Easy Fit Statistical Software were acceptable methods for selecting best-fit distribution in Genale-Dawa River Basin.

Regional flood frequency curves were derived using Matlab2017a. The regional flood frequency curves were significantly different for the three regions, which confirmed that the heterogeneity of regions. This variation of curves may be due to the variability of hydrological phenomena of flood-generating events. Due to this UCL and LCL of sites were derived to improve the accuracy of flood estimation for 2, 5, 10, 20, 25, 50, 100, 200, 500, 1000, 2000, 5000 and 10000 years of return period.

This information can be used to safely and feasibly design hydrologic projects under prediction uncertainty in both gauged and ungauged catchments. To end with, the derived results can be useful as a reference in any hydrological considerations like flood risk management, proper planning, and designing of pivotal hydraulic structures such as dams, spillways, bridges, culverts, and urban drainage systems in the study area.

5.2. Recommendations

On the basis of the study, the directions in which additional effort should be undertaken are presented. The following recommendations are made for further work in the area.

The study directed that delineation of hydrological homogenous regions on the basis of statistical parameters of gauged sites could be considered an acceptable method of regional analysis. Due to the adequacy of best-fit distributions and acceptability of results, Easy Fit Statistical Software can use for other related studies. Matlab and other programming should be used to simplify and get the accurate and reasonable results of any statistical analysis.

Due to the evidence of future climate changes, further analyses should include the effects of climatic variables like precipitation on the variability of L-moments of AMFs in the study area. For proper land and watershed management, the estimated floods should use as an input to develop hydraulic models like flood hazard, risk and inundation mapping of delineated homogeneous regions separately.

Flood frequency curves should be developed using varies types of catchment characteristics such as elevation, slope, area, precipitation, soil type, land use land cover and shape factor to compare the results and get a more reasonable flood estimation for ungauged catchments.

In order to get a reliable estimate of regional flood quantile more hydrometric stations should be installed in the basin. The methodological framework of this study can be suitable for developing similar studies on other river basins.

REFERENCES

Abdulla, M.N. (2011). Catchment Area Delineation Using GIS Technique for Bekhma Dam. Spatial Information Processing II, Paper No. 5335.

Ahmad, I., Fawad, M., Akbar, M., Abbas, A. and Zafar, H. (2016). Regional Frequency Analysis of Annual Peak Flows in Pakistan Using Linear Combination of Order Statistics. *Journal of Environmental Studies. Vol. 25 (6), 2255-2264. DOI: 10.15244/pjoes/63782*

Ahmad, U.N., Shabri, A. and Zakaria, Z.A. (2011). Flood Frequency Analysis of Annual Maximum Streamflow Using L-Moments and TL-Moments. *Applied Mathematical Sciences, Vol. 5, 243-253.*

Alam, J., Muzzammil, M. and Khan, M.K. (2016). Regional Flood Frequency Analysis: Comparison of L-moment and Conventional Approaches. *Journal of Hydraulic Engineering. Vol. 22 (3).*

Amalina, N.M, Shabri, A. and Badyalina, B. (2016). Selecting Probability Distribution for Regions of Peninsular Malaysia Streamflow. *AIP Conference Proceedings 1750, 060014. the American Institute of Physics. doi.org.: 10.1063/1.4954619*

Amirataee, B., Montaseri, M. and Rezaei, H. (2014). Assessment of Goodness of Fit Methods in Determining the Best Regional Probability Distribution of Rainfall Data. *International Journal of Engineering. Vol. 27(10), 1537-1546. doi: 10.5829/idosi.ije. 2014.27.10a.07*

Anusha, M. and Surendra, H.J. (2017). Regional Flood Frequency Analysis Using Computer Simulations. *International Journal of Advanced Engineering Research and Science: Vol. 4 (1). ISSN: 2349-6495(P) | 2456-1908(O). dx.doi.org/10.22161/ijaers.4.1.37*

Arnaud, P., Cantet, P. and Odry, J. (2017). Uncertainties of Flood Frequency Estimation Approaches Based on Continuous Simulation Using Data Resampling. *Journal of Hydrology. 554,360–369.http://dx.doi.org/10.1016/j.jhydrol.2017.09.011 0022-1694*

Ashraful A. M., Emura, K., Farnham, C. and Yuan. (2018). Best-Fit Probability Distributions and Return Periods for Maximum Monthly Rainfall in Bangladesh. *The Journal of climate. Vol.6(9).*

Athulya, P. S. and James, K.C. (2017). Best Fit Probability Distributions for Monthly Weather Data. *International Journal of Advances in Management, Technology and Engineering Sciences. Vol.7 (12).*

Awulachew, S. B., Yilma, A.D., Leuleseged, M., Loiskandl, W., Ayana, M. and Alamirew, T. (2007). Water Resources and Irrigation Development in Ethiopia. *International Water Management Institute. Working Paper 123. Colombo, Sri Lanka.*

Badreldin, G. and Fengo, P. (2012). Regional Rainfall Frequency Analysis for the Luanhe Basin using L-moment and Cluster Techniques.

Bhagat, N. (2017). Flood Frequency Analysis Using Gumbel's Distribution Method: A Case Study of Lower Mahi Basin. *Journal of Water Resources and Ocean Science. Vol. 6(4), 51-54. ISSN:2328-7969; ISSN: 2328-7993. doi: 10.11648/j.wros.20170604.11.*

Capesius, J.P. and Stephens, V.C. (2009). Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: *U.S. Geological Survey Scientific Investigations, Report. 5136, 46.*

Chavoshi, S.B. and Azmin, W.S. (2009). Development of L-Moment Based Models for Extreme Flood Events. *Malaysian Journal of Mathematical Sciences. Vol. 3(2), 281- 296.*

Chow, V.T., Maidment, D.R. and Mays, L.W. (1988). Applied Hydrology.McGraw, Singapore

Cunnane, C. (1989). Statistical Distributions for Flood Frequency Analysis. *WMO operational Hydrology Report No. 33. World Meteorological Organization, Giuseppe Motta. No. 5, Geneva, Switzerland.*

Dahmen, E.R. and Hall, M.J. (1990). Screening of Hydrological Data: Tests for Stationarity and Relative Consistency.Wageningen, The Netherlands. *International Institute for Land Reclamation and Improvement.*

Das, S. and Simonovic, S.P. (2012). Assessment of Uncertainty in Flood Flows Under Climate Change-the Upper Thames River basin (Ontario, Canada). *Water Resources Research Report.*

Demissie, M. and Michael, Y. (2008). Regional Flood Frequency Analysis for Upper Awash Sub-basin (Upstream of Koka). *MSc. Thesis Submitted to Addis Ababa University.*

Dessalegn, B., Ayalew, S. and Hailu, D. (2016). Evaluation of Extreme Flow Quantiles Estimated from Global Reanalysis Runoff data. A Case Study on Blue Nile River Basin. *MSc. Thesis Submitted to Addis Ababa University.*

Donnelly, C.R., Zhou, R.D. and Judge, D.G. (2008). On the Relationship Between the 10,000 Year Flood and Probable Maximum Flood. *Conference Paper No. 131*

Dubey, A. (2014). Regional Flood Frequency Analysis Utilizing L-Moments: A Case Study of Narmada Basin: *International Journal of Engineering Research and Applications. Vol. 4(2): pp:155-161. ISSN: 2248-9622*

England, J.F., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, Jr., W.O., Veilleux, A.G., Kiang, J.E., and Mason, R.R. (2015). Guidelines for Determining Flood Flow Frequency-Bulletin 17C: *U.S. Geological Survey Techniques and Methods 4–B5.*

Ganamala, K. and Kumar, P.S. (2017). A Case Study on Flood Frequency Analysis. *International Journal of Civil Engineering and Technology.Vol.8(4), 1762-1767.*

Ganora, D. and Laio, F. (2016). A Comparison of Regional Flood Frequency Analysis Approaches in a Simulation Framework. *Water Resources Research Report. 52, 5644-5661.*

Gebeyehu, A. (1989). Regional Flood Frequency Analysis, *PhD. Dissertation Submitted to Stockholm University. Hydraulics Laboratory, the Royal Institute of Technology. Florida: CRC Press LLC.*

Gedefa, T.W. and Seleshi, Y. (2009). Regional Flood Frequency Analysis for Upper Omo-Gibe Sub-basin; *MSc. Thesis Submitted to Addis Ababa University.*

Getahun, Y.S. and Gebre, S.L. (2015). Flood Hazard Assessment and Mapping of Flood Inundation Area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS Model. *Journal of Civil and Environmental Engineering. Vol. 5(4), 179.*

Ghosh, S., Roy, M.K., and Biswas, S.C. (2016). Determination of the Best Fit Probability Distribution for Monthly Rainfall Data in Bangladesh. *American Journal of Mathematics and Statistics. Vol. 6(4), 170-174. DOI: 10.5923/j.ajms.20160604.05*

Grubbs, F.E. (1969). Procedures for Detecting Outlying Observations in Samples. *Techno metrics 11(1): pp. 4.*

Guru, N. and Jha, R. (2016). Flood Frequency Analysis of Partial Duration Series Using Soft Computing Techniques for Mahanadi River Basin. *Aquatic Proceedings. Vol. 4, 427-434.*

Haktanier, T., Cobaner, M., and Kisi, O. (2010). Frequency Analysis of Annual Extreme Rainfall. *Journal of Hydrological Process.*

Hailegeorgis, T.T and Alfredsen, K. (2017). Regional Flood Frequency Analysis and Prediction in Ungauged Basins including Estimation of Major Uncertainties for Mid-Norway. *Journal of Hydrology: Regional Studies. Vol. 9,104–126.doi.org/10.1016 /j.ejrh.2016. 11.004*

Halbert, K., Halbert, K., and Nguyen. (2016). Reducing Uncertainty in Flood Frequency Analyses: A Comparison of Local and Regional Approaches Involving Information on Extreme Historical Floods. *Journal of Hydrology. 541, 90-98.*

Hosking, J. R. M., and Wallis, J. R. (1997). Regional Frequency Analysis: An Approach Based on L-moments. *Cambridge University Press, New York, USA.*

Hussein, B. and Wagesho, N. (2016). Regional Flood Frequency Analysis for Abaya-Chamo Sub-Basin, Rift-Valley River Basin, Ethiopia: *Journal of Resources Development and Management. An International Peer-Reviewed Journal: Vol.24: ISSN 2422-8397*

Irwin, S.K, Srivastav, R. and Simonovic, S. P. (2014). Instruction for Watershed Delineation in an ArcGIS Environment for Regionalization Studies: *Water Resources Research Report No: 87*

Javelle, P., Fouchier, C., Arnaud, P. and Lavabre, J. (2010). Flash Flood Warning at Ungauged Locations Using Radar Rainfall and Antecedent Soil Moisture Estimations. *Journal of Hydrological. 394 (1–2), 267–274.*

Kachroo, R.K., Mkhandi, S.H. and Parida, B.P. (2000). Flood Frequency Analysis of Southern Africa: I. Delineation of Homogenous Regions. *Journal of Hydrological Science. 45 (3), 437–448.*

Kamaruddin, R., Islam, R., Ahmad, S.A., Jan, S.J. and Anuar, A.R. (2016). A Review on Mechanism of Flood Disaster Management in Asia. *International Review of Management and Marketing: Vol. 6(1).*

Kannan, N. and Helménégilde, H. (2007). Relationship Between Discharge, Sediment and Flood Control in Kinoni Stream at Byangabo, Rwanda. Conference Paper. *Australian Journal of Water Resources. Vol.14 (1), 17-32.*

Kanti, K. K., Sung-Kee Y., Jun-Ho L. and Khan, K. (2017). Regional Flood Frequency Analysis for Using L-moments Approach in Jeju Island, Korea. *Geo-environmental Disasters. Vol.4(18). DOI 10.1186/s40677-017-0082-0*

Ketsela, H., Tadele, K. and Temam, D. (2017). An Assessment of Predictive Accuracy for Regional Flood Frequency Distributions and Analysis Estimation Methods on Awash River basin. *MSc. Thesis Submitted to Jimma University*.

Komi, K., Amisigo, B.A. and Diekkruger, B. (2016). Regional Flood Frequency Analysis in the Volta River Basin, West Africa. *Journal of Hydrology. Vol.3(5). doi:10.3390/hydrology3010005.*

Kumar, R. and Chatterjee, C. (2011). Development of Regional Flood Frequency Relationships for Gauged and Ungauged Catchments Using L-Moments. *Journal of Hydrology, In Extremis. Descriptive Events and Trends in Climate and Hydrology. DOI 10.1007/978-3-642-14863-7-5*

Lilienthal, J., Fried, R., and Schumann, B. (2018). Homogeneity Testing for Skewed and Cross-correlated Data in Regional Flood Frequency Analysis. *Journal of Hydrology. 557–571. https://doi.org/10.1016/j.jhydrol.2017.10.056/0022-1694*

Lim, Y.H. (2007). Regional Flood Frequency Analysis of the Red River Basin Using L-Moments Approach. *World Environmental and Water Resources Congress: Restoring Our Natural Habitat.*

Lu, Y. (2016). Regional Flood Frequency Analysis for Newfoundland and Labrador Using the L-Moments Index-Flood Method. *MSc. Thesis Submitted to the Memorial University of Newfoundland.*

Mallakpour, I. and Villarini, G. (2015). The Changing Nature of Flooding Across the Central United States. *Journal of Natural Climatic Change. Vol.5, 250-254.*

Malekinezhad, H., Nachtnebel, H.P. and Klik, A. (2011). Regionalization Approach for Extreme Flood Analysis Using L-moments. *Journal of Agricultural Science and Technology. Vol.13, 1183–1196.*

Mkhandi, S. H., Kachroo, R. K. and Gunasekara, T. A. (2000). Flood Frequency Analysis of Southern Africa: II Identification of Regional Distributions. *Journal of Hydrological Science. Vol. 45(3), 449-466.*

McCuen, R.H. (1998). Hydrologic Analysis and Design. Second Edition. *Library of Congress Cataloging-in-Publication Data.*

Mehrannia, H. and Pakgohar, A. (2014). Using Easy Fit Software for Goodness-of-Fit Test and Data Generation. *International Journal of Mathematical Archive: Vol. 5(1), 118-124.*

Mekoya, S.Y. and Seleshi, Y. (2010). Regional Flood Frequency Analysis Upstream of Awash at the Confluence of Kesem River. *MSc. Thesis submitted to Addis Ababa University.*

Melsew. (1996). Regional Flood Frequency of Namibia and Zimbabwe. *MSc. Thesis report. The University of Dares Elam.*

Mengistu, K.H and Sivakumar, K. (2018). An Assessment of Predictive Accuracy for Regional Flood Frequency Distribution Estimation Methods on Awash River Basin. *International Journal of Latest Trends in Engineering and Technology. Vol. 11(1),30-039. ISSN:2278-621X: DOI: http://dx.doi.org/10.21172/1.111.06*

Millington, N., Das, S. and Simonovic, S. P. (2011). The Comparison of GEV, Log-Pearson Type 3 and Gumbel Distributions in the Upper Thames River Watershed under Global Climate Models. *Water Resources Research Report: The University of Western Ontario London. ISSN: (online) 1913-3219. ISBN:10.40.40.10/30.10.40.40.10.*

Mishra, B.K., Takara, K., Yamashiki, Y. and Tachikawa, Y. (2009). Selection of Regional Distribution Using Simulated Flood Data. *Annual Disaster Prevention Research Institute, Kyoto University, No.52B.*

Mishra, B.K., Takara, K., Yamashiki, Y. and Tachikawa, Y. (2010). An Assessment of Predictive Accuracy for Two Regional Flood-Frequency Estimation Methods. *Annual Journal of Hydraulic Engineering. Vol.54.*

Modi, M. and Mitra, A. (2017). Regional Flood Frequency Analysis: A Case Study of Sabarmati River Basin. *International Journal of Engineering Science Invention. Vol.6 (7), 55-65. ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726*

MoWIE. (2007). Genale-Dawa River Basin Integrated Resources Development Master Plan Study Report.

Murphy, C., Cunnane, C., Das, S. and Mandal, U. (2014). Flood Frequency Estimation. Flood Studies Update: *Technical Research Report. Volume II.*

Nobert, J., Mugob, M. and Gadain, H. (2014). Estimation of Design Floods in Ungauged Catchments Using a Regional Index Flood Method. A Case Study of Lake Victoria Basin in Kenya: *Journal of Physics and Chemistry of the Earth. 30(30),1474-7065. http://dx.doi.org/10.1016/j.pce.2014.02.001*

Noto, L.V. and Loggia, G.L., (2009). Use of L-Moments Approach for Regional Flood Frequency Analysis in Sicily, Italy. *Journal of Water Resources Management.Vol.3, 2207–2229. DOI 10.1007/s11269-008-9378-x*

Parida, B. P., Kachroo, R. K. and Shrestha, D. B. (1998). Regional Flood Frequency Analysis of Mahi Sabarmati Basin (Subzone-3a) Using Index Flood Procedure with L-Moments. *Water Resources Management. Vol. (12), 1–12.*

Patil, S. and Stieglitz, M. (2012). Controls on Hydrologic Similarity: Role of Nearby Gauged Catchments for Prediction at Ungauged Catchment. *Hydrological Earth System Science. Vol. (16), 551–562.*

Rabba, Z.A., Fatoyinbo, B.S. and Stretch, D. D. (2018). Applications of the PyTOPKAPI model to ungauged catchments. *Centre for Research in Environmental, Coastal and Hydrological Engineering, University of KwaZulu-Natal, South Africa. Water SA Vol. 44(2).*

Rahman, A.S., Rahman, A., Zaman, M.A., Haddad, K and Ahsan, A. (2013). A Study on Selection of Probability Distributions for at-site Flood Frequency Analysis in Australia. *Journal of Natural Hazards. DOI 10.1007/s11069-013-0775-y*

Rahmana, B, K. Haddad and Kuczerac, G. (2015). Features of Regional Flood Frequency Estimation Model in Australian Rainfall-Runoff. *21st International Congress on Modeling and Simulation, Gold Coast, Australia.*

Rao, A.R. and Hamed, K.H. (2000). Flood Frequency Analysis. CRC Press, Washington.

Rao, A.R. and Srinivas, V.V. (2008). Regionalization of Watersheds by Hybrid Cluster Analysis. *Journal of Hydrology. ISBN: 978-1-4020-6851-5/ISBN: 978-1-4020-6852-2*

Romali, N.S and Yusop, Z. (2017). Frequency Analysis of Annual Maximum Flood for Segamat River. *MATEC Web of Conferences 103, 04003. DOI: 10.1051/matecconf/ 20171030*

Saf, B. (2009). Regional Flood Frequency Analysis Using L-moment for the West Mediterranean Region of Turkey. *Journal of Water Resources Management.Vol.23(3), 531-551. DOI 10.1007/s11269-008-9287-z*

Schendel, T and Thongwichian, R. (2017). Considering Historical Flood Events in Flood Frequency Analysis. *Journal of Advances in Water Resources.105, 144-153. http://dx.doi.org/10.1016/j.advwatres.2017.05.0020309-1708*

Schittkowski, K. (2002). Easy-Fit: A Software System for Data Fitting in Dynamic Systems. Vol. 23(2), 153-169.

Share Bale Eco-Region. (2017). Drivers of Hydrological Dynamics in the Bale Eco-Region. *Research Report Series No. 7.*

Sine, A. and Ayalew, S. (2004). Identification and Delineation of Hydrological Homogeneous Regions. The Case of Blue Nile River Basin. *Lake Abaya Research Symposium Proceedings. Vol.4*

Smith, A., Sampson, C. and Bates, P. (2015). Regional Flood Frequency Analysis at the Global Scale. *Water Resources Research. Vol. 51, 539–553. doi:10.1002/ 2014WR015814.*

Steinschneider, S. and Lall, U. (2015). A Hierarchical Bayesian Regional Model for Nonstationary Precipitation Extremes in Northern California Conditioned on Tropical Moisture Exports. *Water Resources Research.51, 1472-1492.*

Sun, X., Lall, U., Merz, B., and Nguyen, V. D. (2015). Hierarchical Bayesian Clustering for Non-Stationary Flood Frequency Analysis: *Application to Trends of Annual Maximum Flow in Germany. Water Resource Research Report. 51, 6586-6601.*

Tadesse, A.H., Gottschalk, L. and Tallaksen, L.M. (2011). Regional Flood Frequency Analysis in Southern Africa, *MSc. Thesis Submitted to the University of Oslo.*

Tanaka, T., Tachikawa, Y., Ichikawa, Y. and Yorozu, K. (2017). Impact Assessment of Upstream Flooding on Extreme Flood Frequency Analysis by Incorporating a Flood-Inundation Model for Flood Risk Assessment. *Journal of Hydrology. 554,370–382. https://doi.org/10.1016/j.jhydrol.2017.09.012.*

Tekuame, B. and Seleshi, Y. (2017). Estimation Probable Maximum Precipitation (PMP) (A Case Study on Upper Awash Sub River Basin). *MSc. Thesis submitted to Addis Ababa University.*

USWRC, United State Water Resource Council (1976). Guidelines for Determining Flood Flow Frequency*, Bulletin-17 of the Hydrology Committee, Washington, D.C.*

Vivekanandan, N. (2015). Flood Frequency Analysis using Method of Moment and L-moment of Probability Distribution. American Institute of Science. *International Journal of Mathematics and Computational Science. Vol. 2 (3). 141-146.*

Willems, P., Sonbol M., Mkhandi, S., Tadesse, L., Zaki, A. and Al-Weshah, R. (2009). Regional Flood Frequency Analysis in the Nile Basin. *International Conference of UNESCO Flanders Fit Friend/Nile Project "Towards a better cooperation". 55(4), 555-570.*

Willems, P., Ogiramoi, N.P., Mutua, F. M. and Moges, S. A. (2012). An elusive search for regional Flood Frequency Estimates in the River Nile basin. *Hydrology and Earth System Sciences, by Copernicus Publications on behalf of the European Geosciences Union.*

Wilson, D., Fleig, A.K., Lawrence, D., Hisdal, H., Pettersson, L-E. Holmqvist, E. (2011). A review of NVE's flood frequency estimation procedures. *Norwegian Water Resources and Energy Directorate. ISSN:1502-3540, ISBN: 978-82-410-0774-3.*

Wu, Y., Zhong, P., Lall, U. and Lima, H.R. (2018). Local and Regional Flood Frequency Analysis Based on Hierarchical Bayesian Model: Application to Annual Maximum Streamflow for the Huaihe River Basin. *Journal of Hydrology and Earth System Science Discussions. https://doi.org/10.5194/hess-2018-22*

Wu, Y., Zhong, P., Zhang, Y., Xu, B., Ma, B. and Yan, K. (2015). Integrated Flood Risk Assessment and Zonation Method: A Case Study in Huaihe River basin. *Journal of Natural Hazards. 78, 635-65.*

Zaman, M. A., Rahman, A. and Haddad, K. (2012). Regional Flood Frequency Analysis in Arid Regions: A Case Study for Australia. *Journal of Hydrology. 475,74–83.*

Zhang, Y. L. and You, W. J. (2015). Social Vulnerability to Floods: *A Case Study of Huaihe River Basin. Journal of Natural Hazards. 71, 2113-2125.*

APPENDIX

Appendix-A: Results for correlation of gauging stations used for analysis

Code	Gauging station (Y)	Nearby station (X)	Regression equation	R²	Remark
71004	Oddo-Shakiso	Megado	y = 0.6855x + 17.74	0.9549	WC
07009	Digatty	Melka Guba	y = 0.1606x + 12.186	0.7287	WC
71001	Melka Guba	Megado	y = 1.1297x - 0.1924	0.8049	WC
71005	Megado	Melka Guba	y = 0.7125x + 19.128	0.8049	WC
72001	Dello Mena	Gom-Goma	y = 0.1855x + 4.4372	0.7913	WC
72002	Melka Amana	Chenemasa	y = 0.198x-17.451	0.9607	WC
72005	Chenemasa	Kolle Bridge	y = 0.5917x-98.987	0.9385	WC
72006	Kolle Bridge	Halwey	y = 0.4144x + 46.937	0.9061	WC
72011	Halwey	Kolle Bridge	y = 2.1865x - 56.121	0.9061	WC
73002	Shallo Village	Robe	y = 0.2573x-3.5831	0.8999	WC
73003	Denbel	Agarfa	y = 0.4743x + 29.544	0.9495	WC
73004	Denbel	Alemkerem	y = 1.2409x - 22.132	0.7325	WC
73005	Alemkerem	Sofumer	y = 0.2975x + 44.721	0.926	WC
73006	Robe	Agarfa	y = 0.5377x + 42.288	0.9573	WC
73008	Melka Amana	Gom-Goma	y = 4.3779x + 10.208	0.9146	WC
73009	Sofumer	Denbel	y = 2.1092x - 45.193	0.8939	WC

(WC: Well Correlated)

Appendix–B: Critical values of the Grubbs T Test Statistic as a function of the number of Observations and Significance level

n	5%	2.50%	1%	n	5%	2.50%	1%
3	1.15	1.15	1.15	20	2.56	2.71	2.88
4	1.46	1.48	1.49	21	2.58	2.73	2.91
5	1.67	1.71	1.75	22	2.6	2.76	2.94
6	1.82	1.89	1.94	23	2.62	2.78	2.96
7	1.94	2.02	2.1	24	2.64	2.8	2.99
8	2.03	2.13	2.22	25	2.66	2.82	3.01
9	2.11	2.21	2.32	30	2.75	2.91	
10	2.18	2.29	2.41	35	2.82	2.98	
11	2.23	2.36	2.48	40	2.87	3.04	
12	2.29	2.41	2.55	45	2.92	3.09	
13	2.33	2.46	2.61	50	2.96	3.13	
14	2.37	2.51	2.66	60	3.03	3.2	
15	2.41	2.55	2.71	70	3.09	3.26	
16	2.44	2.59	2.75	80	3.14	3.31	
17	2.47	2.62	2.79	90	3.18	3.35	
18	2.5	2.65	2.82	100	3.21	3.38	
19	2.53	2.68	2.85				

(source: Grubbs,1969)

Appendix–C: Percentile Points of the F-Distribution F {V1, V2, P} for the 5 % level of Significance (Two-Tailed)

$P=P(F<F_P)$		V_1:4	5	6	7	8	9	10	11	12	14	16
0.025 0.975	V_2:5	.107 .739	.140 7.15	.169 6.98								
0.025 0.975	6		.143 5.99	.172 5.82	.195 5.70							
0.025 0.975	7			.176 5.12	.200 4.99	.221 4.90						
0.025 0.975	8				.204 4.53	.226 4.43	.244 4.36					
0.025 0.975	9					.230 4.10	.248 4.03	.265 3.96				
0.025 0.975	10						.252 3.78	.269 3.72	.284 3.66			
0.025 0.975	11							.273 3.53	.288 3.47	.301 3.43		
0.025 0.975	12								.292 3.32	.305 3.28	.328 3.21	
0.025 0.975	14									.312 3.05	.336 2.98	.355 2.92
		V_1:14	16	18	20	24	30	40	60	100	160	∞
0.025 0.975	V_2:16	.342 2.82	.362 2.76	.379 2.71								
0.025 0.975	18		.368 2.64	.385 2.60	.400 2.56							
0.025 0.975	20			.391 2.50	.406 2.46	.430 2.41						
0.025 0.975	24				.415 2.33	.441 2.27	.468 2.21					
0.025 0.975	30					.453 2.14	.482 2.07	.515 2.01				
0.025 0.975	40						.498 1.94	.533 1.88	.573 1.80			
0.025 0.975	60							.555 1.74	.600 1.67	.642 1.60		
0.025 0.975	100								.625 1.56	.674 1.48	.706 1.44	
0.025 0.975	160									.696 1.42	.733 1.36	
0.025 0.975	∞											1.00 1.00

(Source: Dahmen and Hall,1990)

Appendix-D: Percentile Points of the t-distribution t {V, p for the 5% level of Significance (Two-Tailed)}

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

(Source: Dahmen and Hall,1990)

Appendix-E: Result of hydrological data quality test for stationarity of stations time series data

Station name	Subset-I	Subset-II	V1,V2	Ft2.5%	Ft	Ft97.5%	V	Tt2.5%	Tt	Tt97.5%
Melka Guba	1986-2000	2001-2015	14,14	0.336	1.113	2.980	28	-2.04	1.93993	2.04
Megado	1985-2000	2001-2015	14,14	0.25	1.694	4.03	28	-2.060	1.172	2.060
Chenemasa	1985-1996	1997-2008	11,11	0.288	0.348	3.470	22	-2.060	0.832	2.060
Kolle bridge	1998-2003	2005-2008	6,5	0.169	1.359	6.980	11	-2.200	0.468	2.200
Halwey	1985-1997	1998-2009	12,11	0.301	1.953	3.430	23	-2.060	0.034	2.060
Gom-Goma	1990-1999	2000-2008	10,9	0.250	0.294	4.030	18	-2.100	-0.624	2.100
Melka Amana	1990-1999	2000-2009	9,9	0.269	0.997	3.720	18	-2.060	-0.916	2.060
Dello Mena	1990-1999	2000-2008	11,10	0.284	0.687	3.660	21	-2.060	1.179	2.060
Robe	1985-1996	1997-2008	11,11	0.288	0.365	3.470	22	-2.060	-0.211	2.060
Shallo village	1985-1996	1996-2008	11,11	0.288	0.928	3.470	22	-2.060	-0.359	2.060
Denbel	1986-1996	1998 -2008	11,10	0.288	0.339	3.470	21	-2.060	1.952	2.060
Alemkerem	1990-1999	2000-2009	9,9	0.248	2.329	4.030	18	-2.100	1.173	2.100
Agarfa	1985-1996	1997-2008	11,11	0.288	1.321	3.470	22	-2.060	0.899	2.060
Sofumer	1990-2000	2001-2010	10,10	0.269	0.328	3.720	20	-2.090	-1.311	2.090
Odda-shakiso	1997-2005	2006-2014	8,8	0.226	0.413	4.430	16	-2.120	1.172	2.120
Digatty	1997-2005	2006-2015	9,8	0.244	3.231	4.360	17	-2.060	0.328	2.060

Appendix-F: (Translated Matlab code for Discordancy Measure as provided by Hosking and Wallis, 1997)

U=xls. read ('c:\users\name of group\desktop\U.xls'); % File

% ratios ($\tau_2^i, \tau_3^i, \tau_4^i$) of the gauging sites in the region

U= number of gauging sites in the region (Enter the matrix of test statistics);

n=; % input ('enter the number of gauging sites in the group:');

Ubar= [0;0;0];

```
for i=1:n
Ubar=Ubar+1/n*(U(i,1:3)');
end
S=zeros (3);
for i=1: n
S=S+(U(i,1:3)'-Ubar)*(U(i,1:3)'-Ubar)';
end
for i=1:n
Di(i)=1/3*(U(i,1:3)'-Ubar)'*inv(S)*(U(i,1:3)'-Ubar);
End
disp ('The Di of U Statistics');
disp('Di, Di+1,….Dn');
```

Appendix-G: Candidate probability distributions of AMF for this study

To select the type of distribution which fit to the given data the following equations were used and obtained from Mishra *et al*. (2009).

- Normal distribution,

$$\tau 3 = 0, \tau 4 = 0.1226$$

- Logistic

$$\tau 3 = 0, \tau 4 = \frac{1}{6}$$

- Generalized pareto(GPA)

$$\tau 4 = 0.20196(\tau 3) + 0.95924(\tau 3)2 - 0.20096(\tau 3)3 + 0.04061(\tau 3)4$$

- Log Normal Distribution

$$\tau 4 = 0.12282 + 0.77518(\tau 3)^2 + 0.12279(\tau 3)^4 - 0.13638(\tau 3)^6 + 0.113638(\tau 3)^8$$

- Generalized Extreme Value (GEV)

$$\tau 4=0.10701+0.1109(\tau 3)+0.84838(\tau 3)^2-0.06669(\tau 3)^3+0.00567(\tau 3)^4-0.04208(\tau 3)^5 +0.03763(\tau 3)^6$$

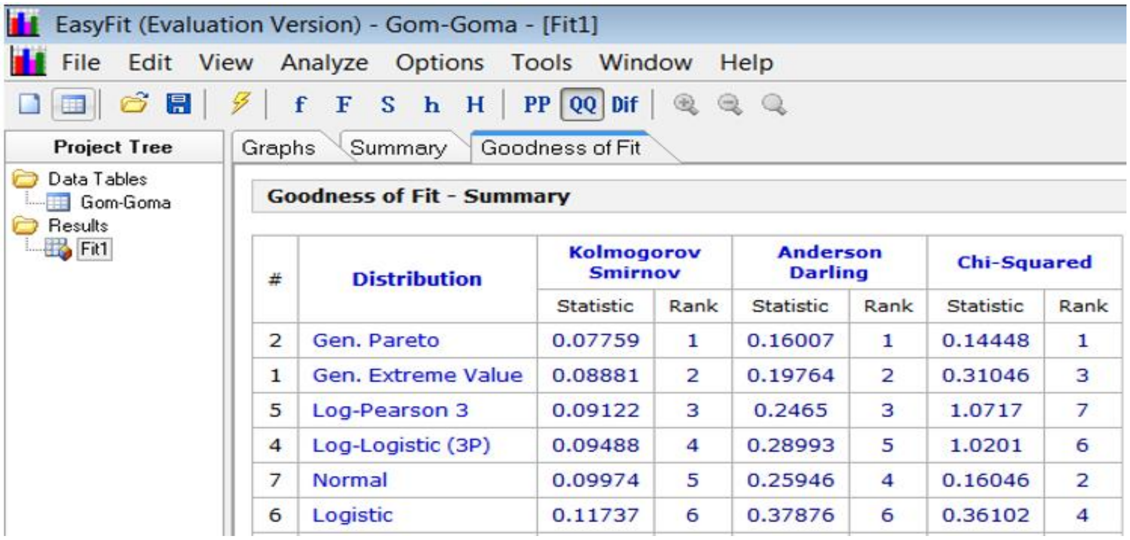
- Log-Pearson Type III

$$\tau 4 = 0.1224 + 0.30115(\tau 3)^2 + 0.95812(\tau 3)^4 - 0.57488(\tau 3)^6 + 0.19383(\tau 3)^8$$

- Generalized Logistic

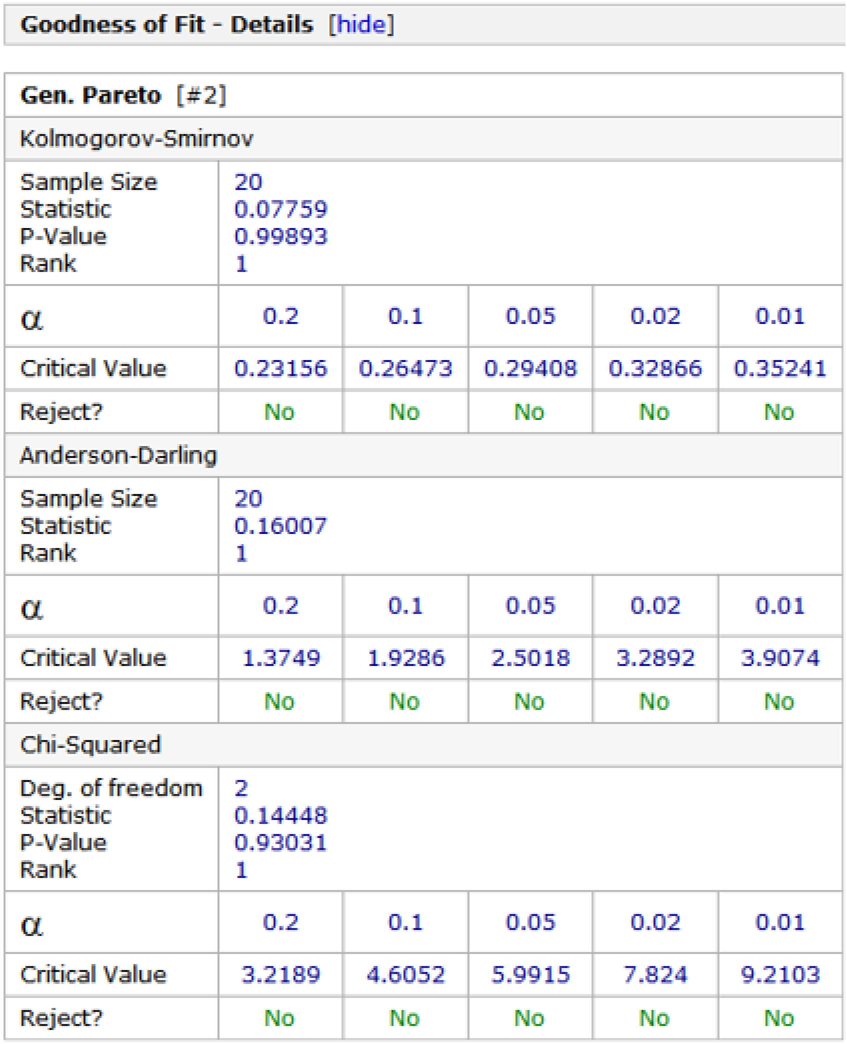
$$\tau 4 = 0.16667 + 0.83333(\tau 3)^2$$

Appendix-H: Goodness of fit test results and descriptive statistics for selected distribution of some stations



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
2	Gen. Pareto	0.07759	1	0.16007	1	0.14448	1
1	Gen. Extreme Value	0.08881	2	0.19764	2	0.31046	3
5	Log-Pearson 3	0.09122	3	0.2465	3	1.0717	7
4	Log-Logistic (3P)	0.09488	4	0.28993	5	1.0201	6
7	Normal	0.09974	5	0.25946	4	0.16046	2
6	Logistic	0.11737	6	0.37876	6	0.36102	4



Goodness of Fit - Details [hide]

Gen. Pareto [#2]

Kolmogorov-Smirnov

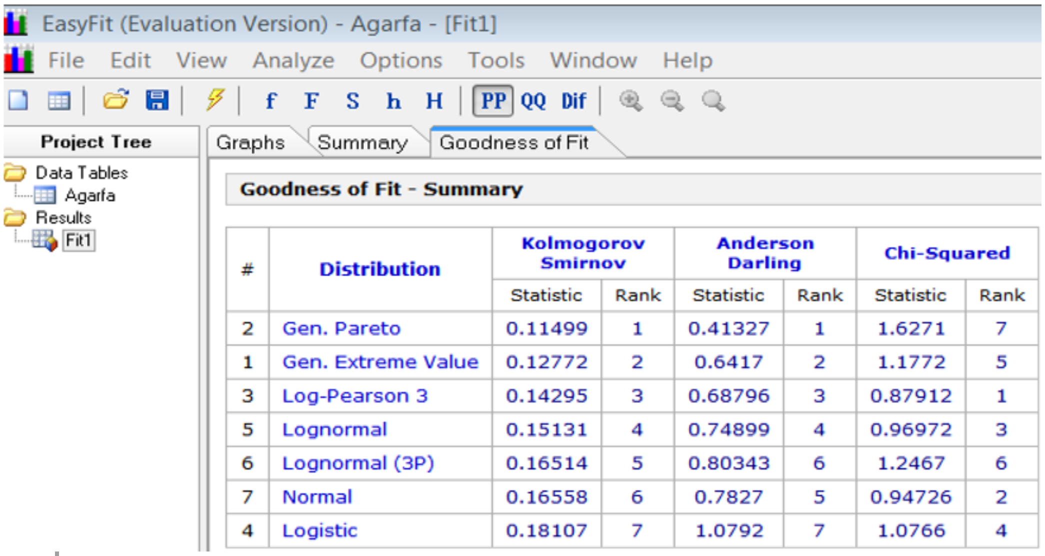
Sample Size Statistic P-Value Rank	20 0.07759 0.99893 1				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.23156	0.26473	0.29408	0.32866	0.35241
Reject?	No	No	No	No	No

Anderson-Darling

Sample Size Statistic Rank	20 0.16007 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

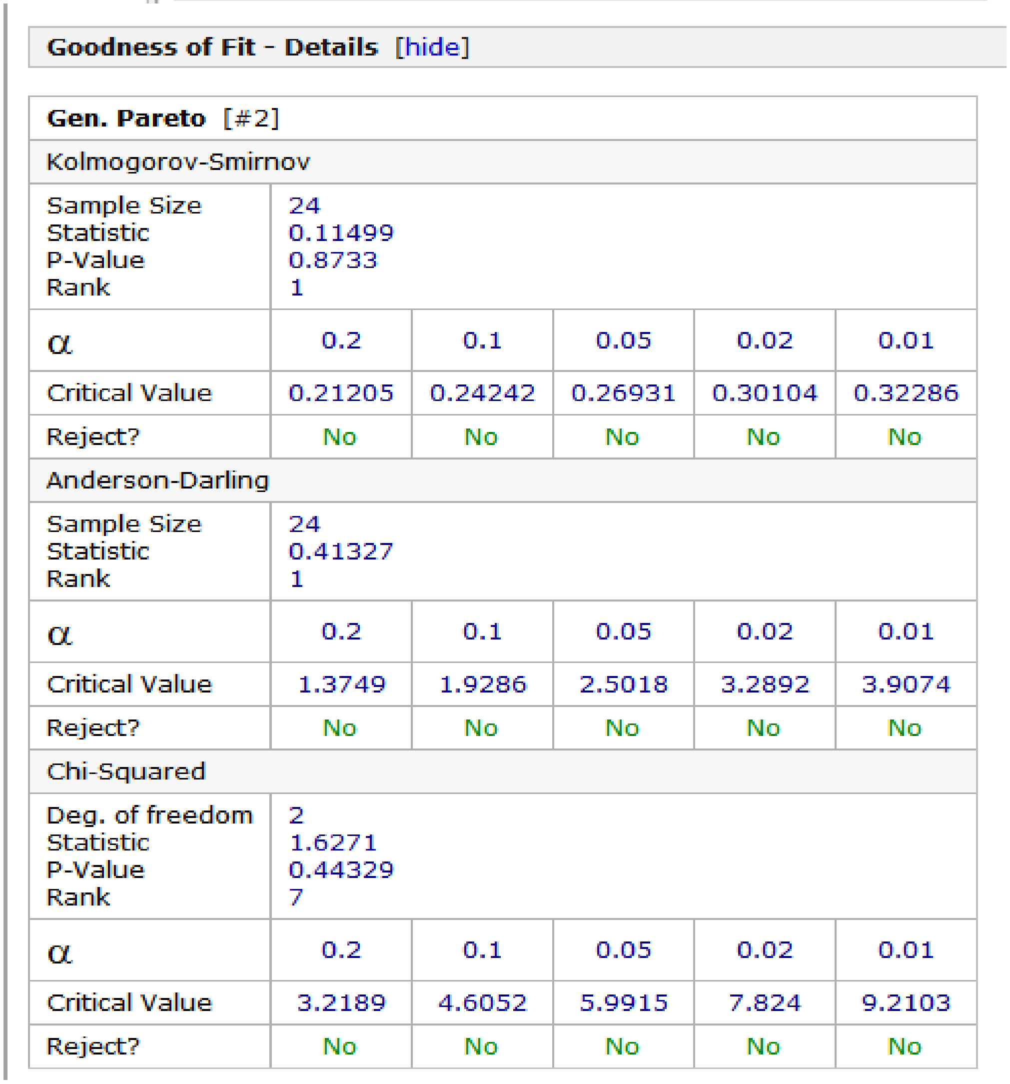
Chi-Squared

Deg. of freedom Statistic P-Value Rank	2 0.14448 0.93031 1				
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



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
2	Gen. Pareto	0.11499	1	0.41327	1	1.6271	7
1	Gen. Extreme Value	0.12772	2	0.6417	2	1.1772	5
3	Log-Pearson 3	0.14295	3	0.68796	3	0.87912	1
5	Lognormal	0.15131	4	0.74899	4	0.96972	3
6	Lognormal (3P)	0.16514	5	0.80343	6	1.2467	6
7	Normal	0.16558	6	0.7827	5	0.94726	2
4	Logistic	0.18107	7	1.0792	7	1.0766	4



Goodness of Fit - Details [hide]

Gen. Pareto [#2]

Kolmogorov-Smirnov

Sample Size	24
Statistic	0.11499
P-Value	0.8733
Rank	1

α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.21205	0.24242	0.26931	0.30104	0.32286
Reject?	No	No	No	No	No

Anderson-Darling

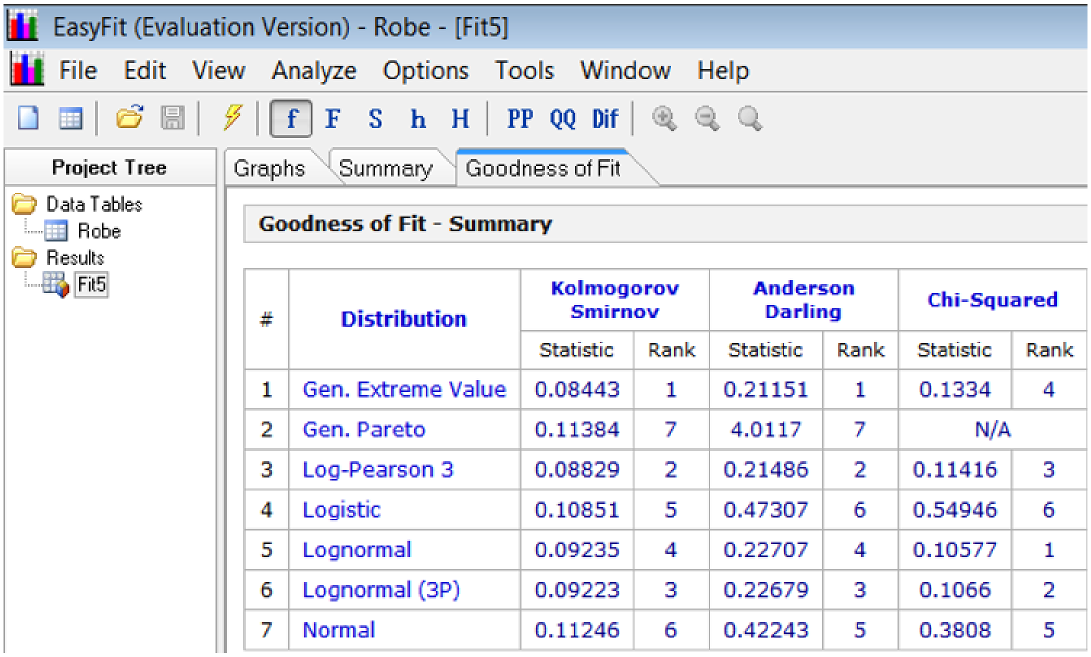
Sample Size	24
Statistic	0.41327
Rank	1

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

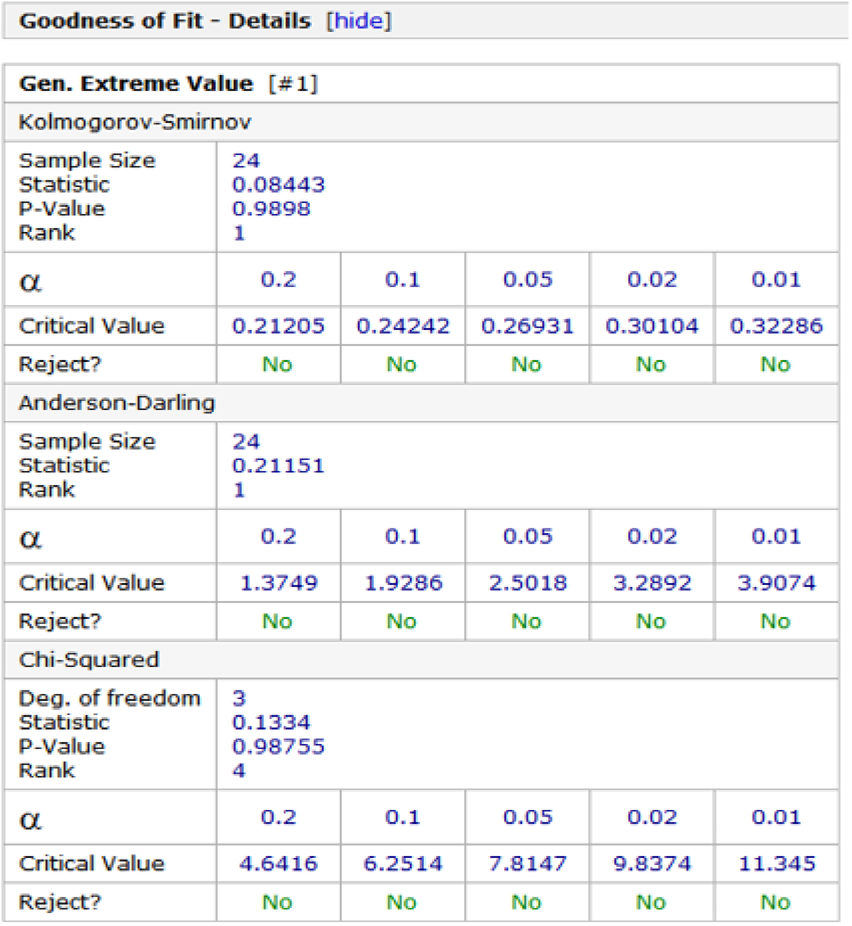
Deg. of freedom	2
Statistic	1.6271
P-Value	0.44329
Rank	7

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



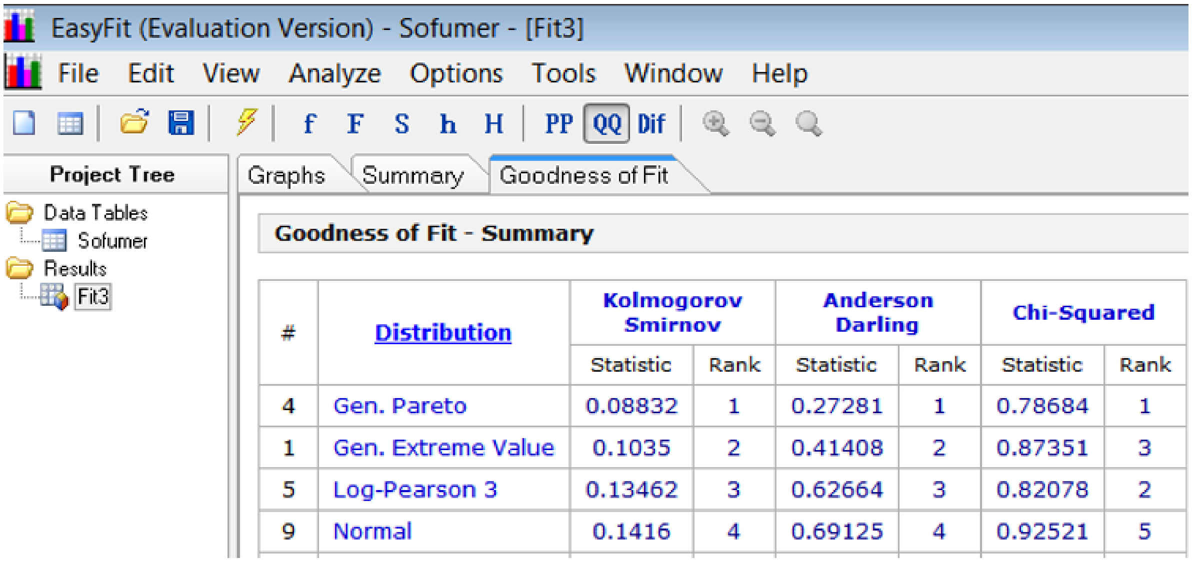
Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gen. Extreme Value	0.08443	1	0.21151	1	0.1334	4
2	Gen. Pareto	0.11384	7	4.0117	7	N/A	
3	Log-Pearson 3	0.08829	2	0.21486	2	0.11416	3
4	Logistic	0.10851	5	0.47307	6	0.54946	6
5	Lognormal	0.09235	4	0.22707	4	0.10577	1
6	Lognormal (3P)	0.09223	3	0.22679	3	0.1066	2
7	Normal	0.11246	6	0.42243	5	0.3808	5



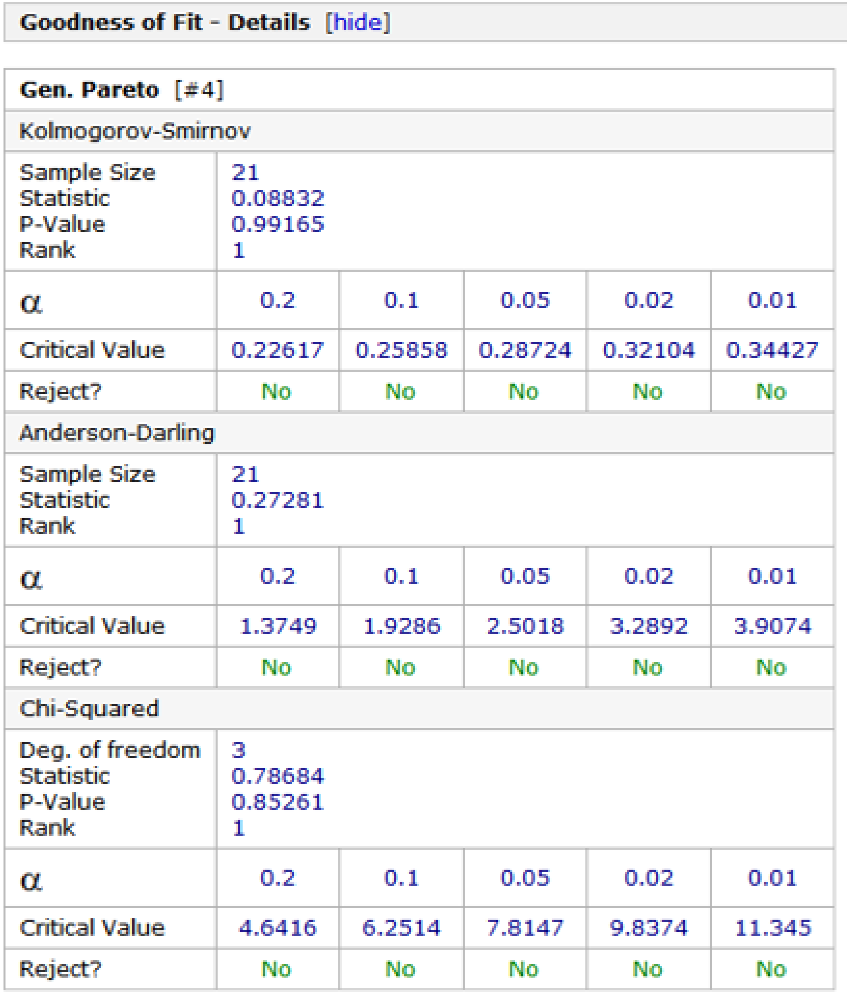
Goodness of Fit - Details [hide]

Gen. Extreme Value [#1]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	24 0.08443 0.9898 1				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.21205	0.24242	0.26931	0.30104	0.32286
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	24 0.21151 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	3 0.1334 0.98755 4				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
4	Gen. Pareto	0.08832	1	0.27281	1	0.78684	1
1	Gen. Extreme Value	0.1035	2	0.41408	2	0.87351	3
5	Log-Pearson 3	0.13462	3	0.62664	3	0.82078	2
9	Normal	0.1416	4	0.69125	4	0.92521	5



Goodness of Fit - Details [hide]

Gen. Pareto [#4]

Kolmogorov-Smirnov

Sample Size	21
Statistic	0.08832
P-Value	0.99165
Rank	1

α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.22617	0.25858	0.28724	0.32104	0.34427
Reject?	No	No	No	No	No

Anderson-Darling

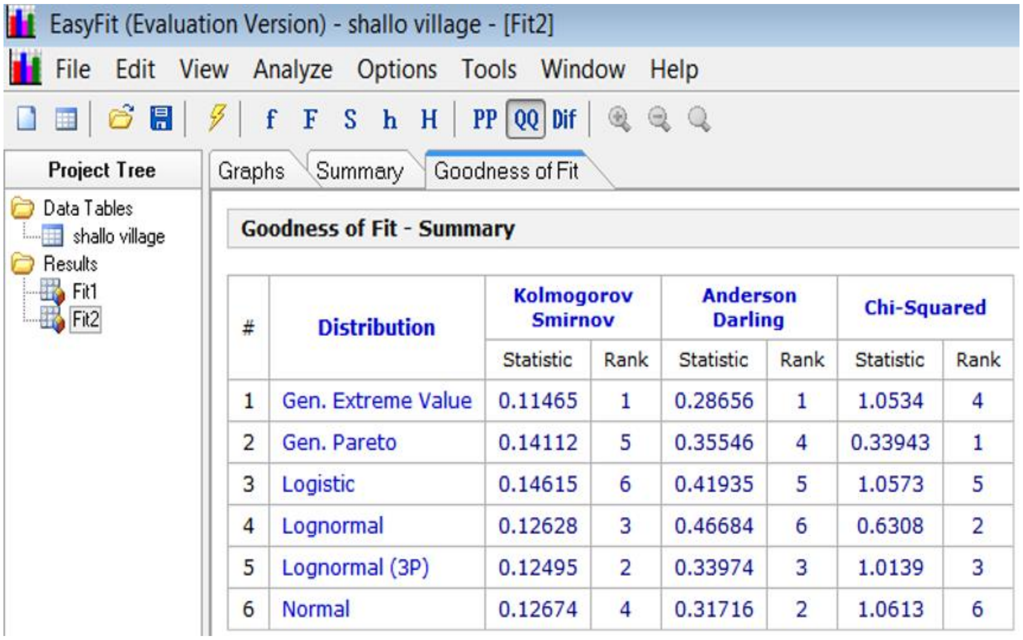
Sample Size	21
Statistic	0.27281
Rank	1

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

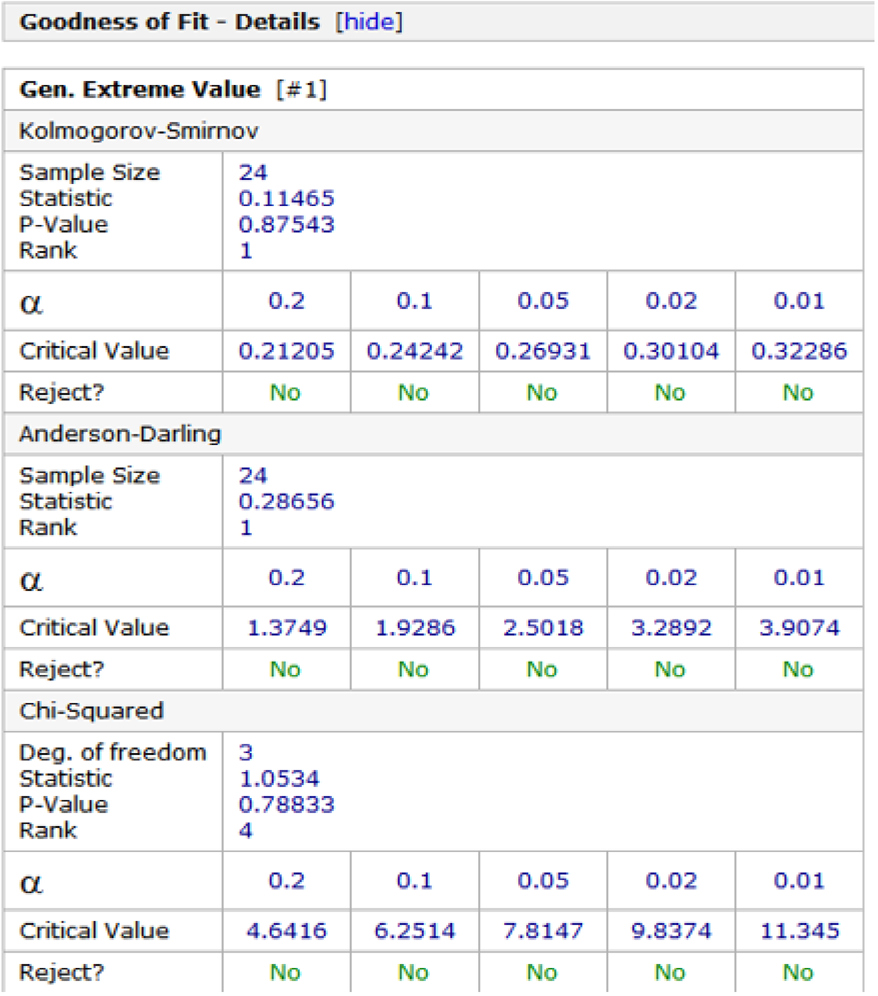
Deg. of freedom	3
Statistic	0.78684
P-Value	0.85261
Rank	1

α	0.2	0.1	0.05	0.02	0.01
Critical Value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gen. Extreme Value	0.11465	1	0.28656	1	1.0534	4
2	Gen. Pareto	0.14112	5	0.35546	4	0.33943	1
3	Logistic	0.14615	6	0.41935	5	1.0573	5
4	Lognormal	0.12628	3	0.46684	6	0.6308	2
5	Lognormal (3P)	0.12495	2	0.33974	3	1.0139	3
6	Normal	0.12674	4	0.31716	2	1.0613	6



Goodness of Fit - Details [hide]

Gen. Extreme Value [#1]

Kolmogorov-Smirnov

Sample Size 24
Statistic 0.11465
P-Value 0.87543
Rank 1

α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.21205	0.24242	0.26931	0.30104	0.32286
Reject?	No	No	No	No	No

Anderson-Darling

Sample Size 24
Statistic 0.28656
Rank 1

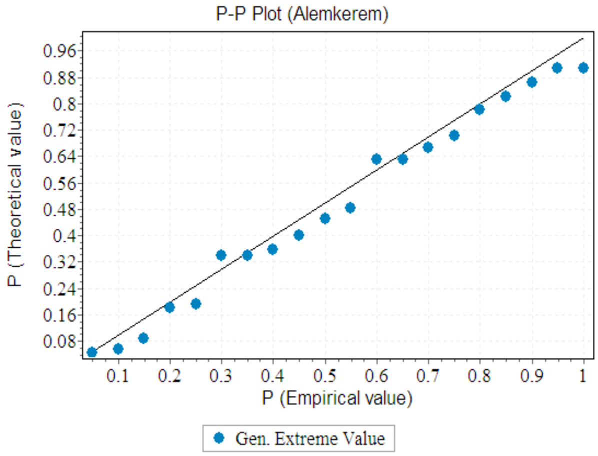
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No

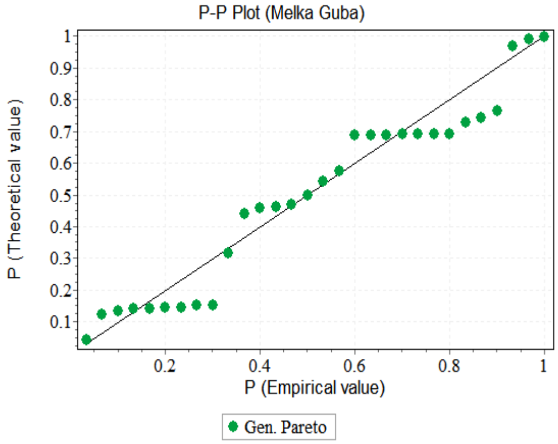
Chi-Squared

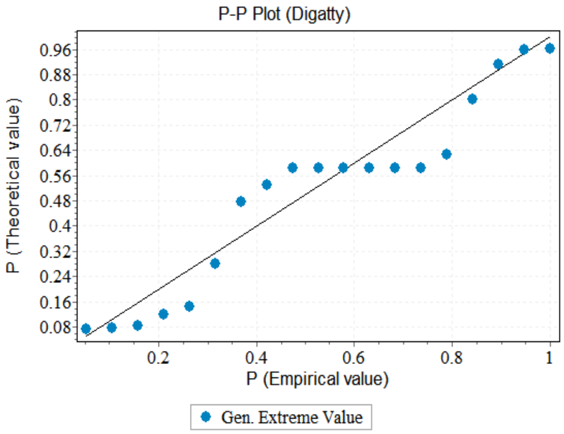
Deg. of freedom 3
Statistic 1.0534
P-Value 0.78833
Rank 4

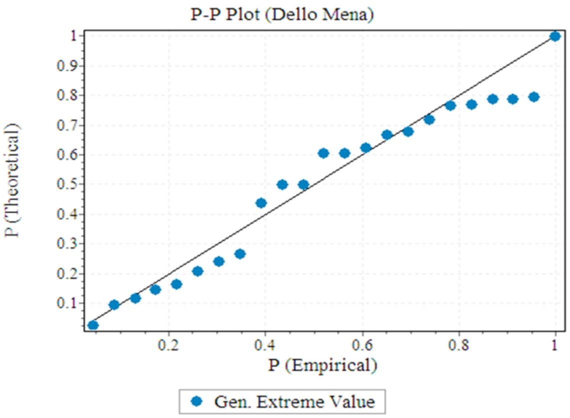
α	0.2	0.1	0.05	0.02	0.01
Critical Value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No

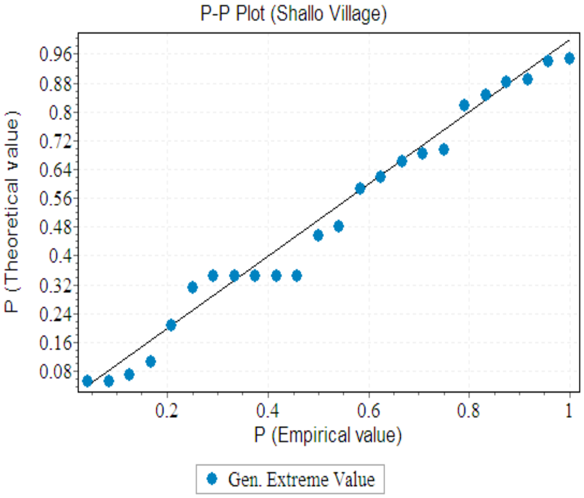
Appendix-I: Probability-probability plots of stations

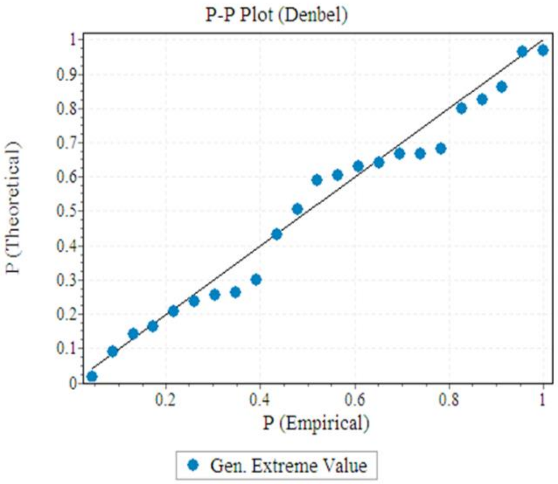


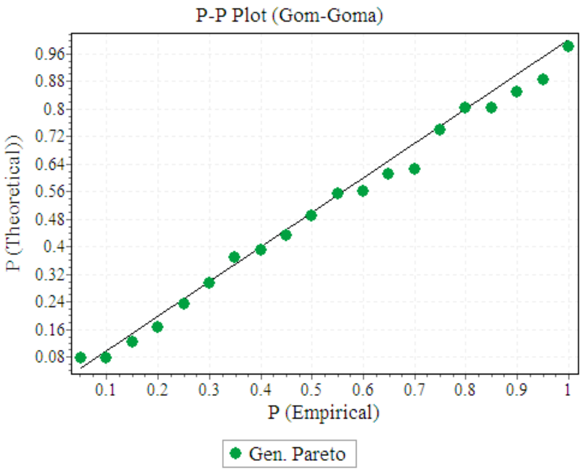


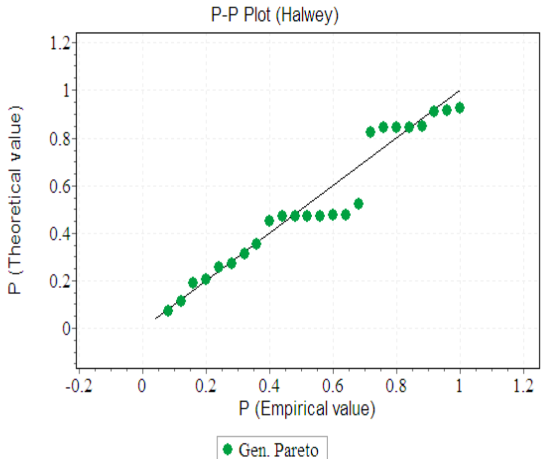


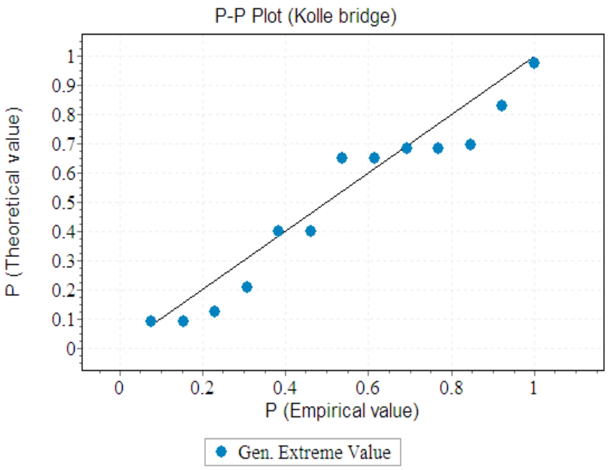


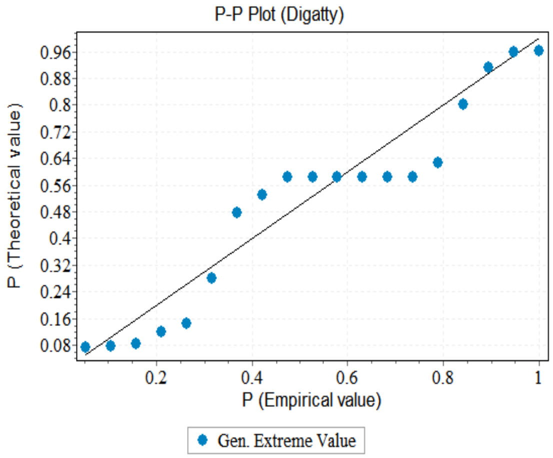


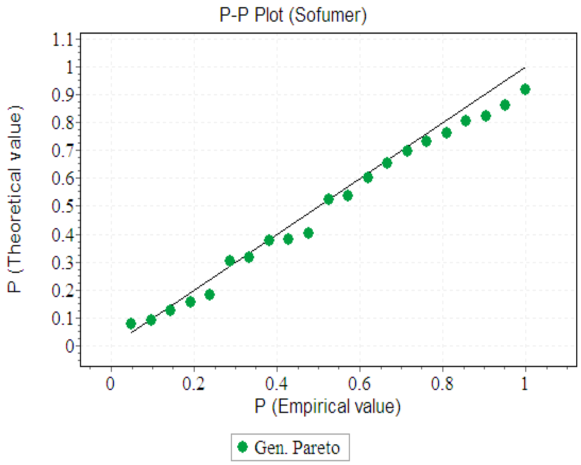


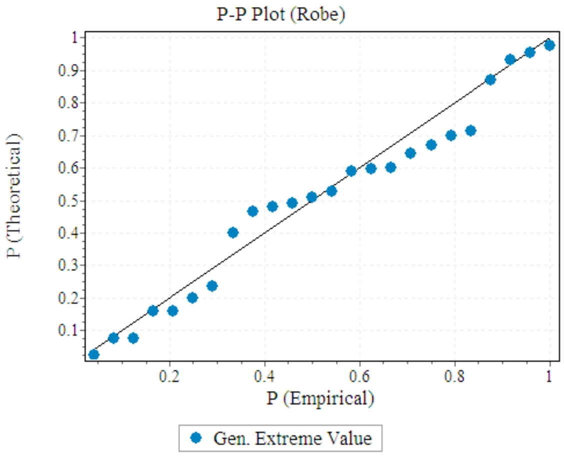

P-P Plot (Gom-Goma)
P (Theoretical))
0.96
0.88
0.8
0.72
0.64
0.56
0.48
0.4
0.32
0.24
0.16
0.08
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
P (Empirical)
● Gen. Pareto


P-P Plot (Halwey)
P (Theoretical value)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
P (Empirical value)
● Gen. Pareto

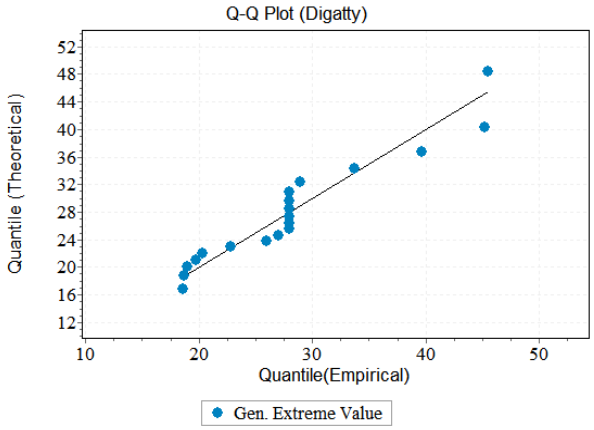

P-P Plot (Kolle bridge)
P (Theoretical value)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
P (Empirical value)
● Gen. Extreme Value

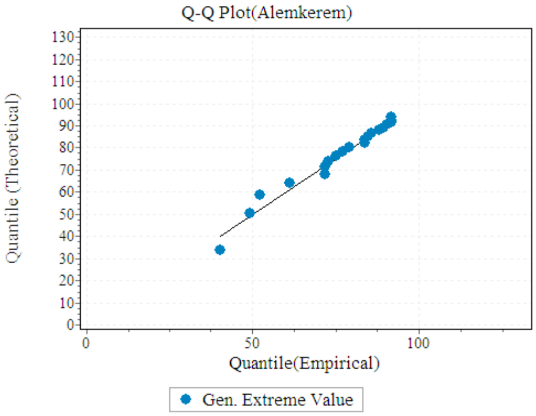

P-P Plot (Digatty)
P (Theoretical value)
0.96
0.88
0.8
0.72
0.64
0.56
0.48
0.4
0.32
0.24
0.16
0.08
0.2
0.4
0.6
0.8
1
P (Empirical value)
● Gen. Extreme Value

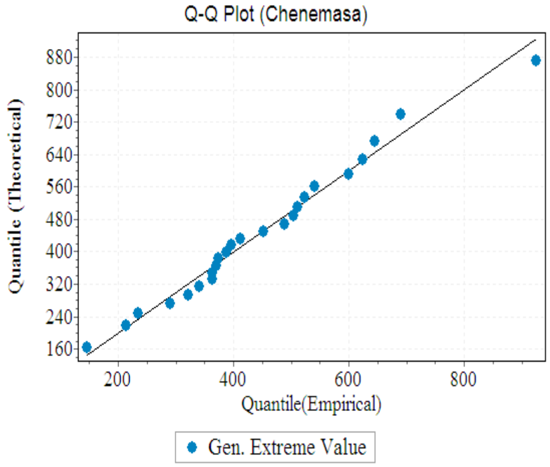

P-P Plot (Sofumer)
P (Theoretical value)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
P (Empirical value)
● Gen. Pareto

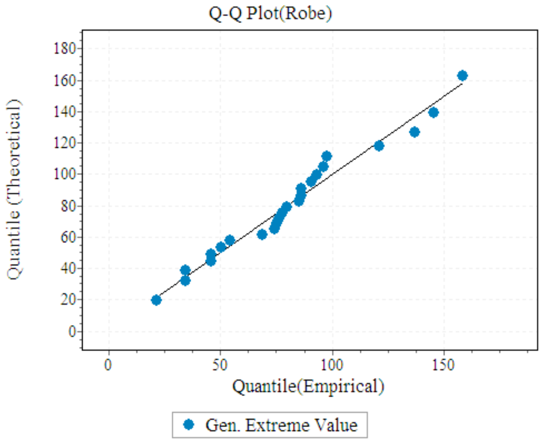

P-P Plot (Robe)
P (Theoretical)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.2
0.4
0.6
0.8
1
P (Empirical)
● Gen. Extreme Value

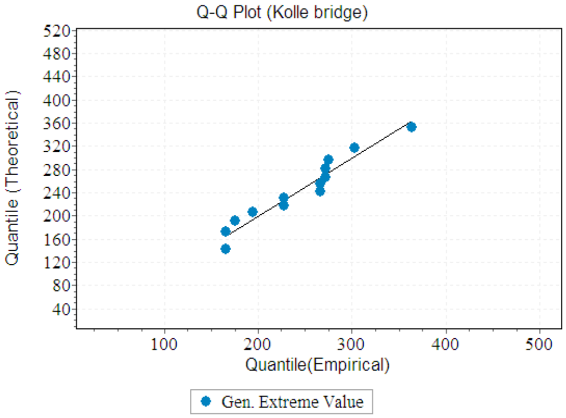
Appendix-J: Quantile-Quantile plots of stations

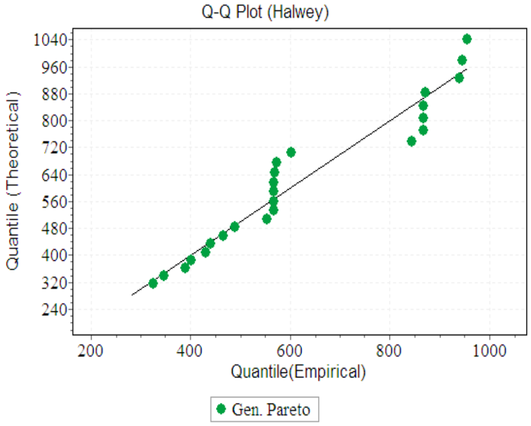


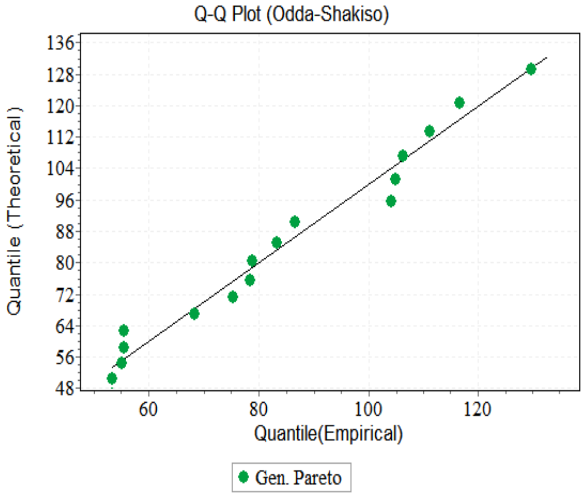


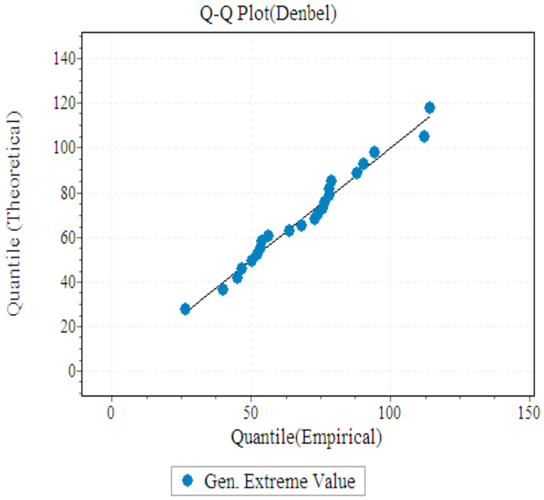


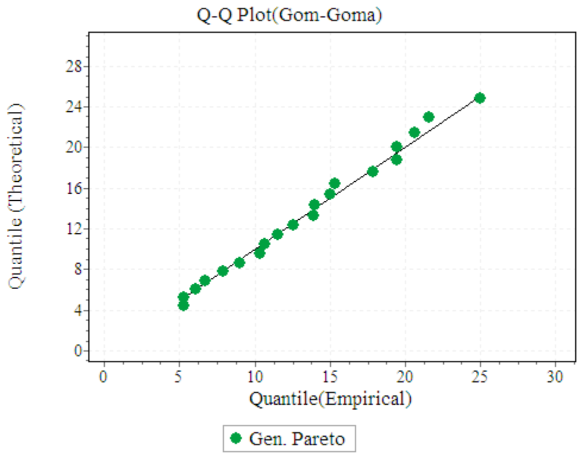


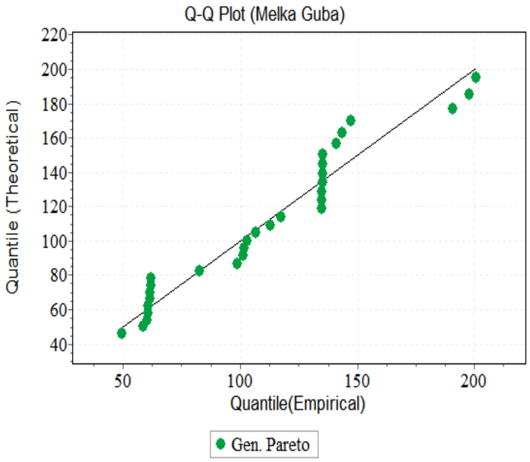


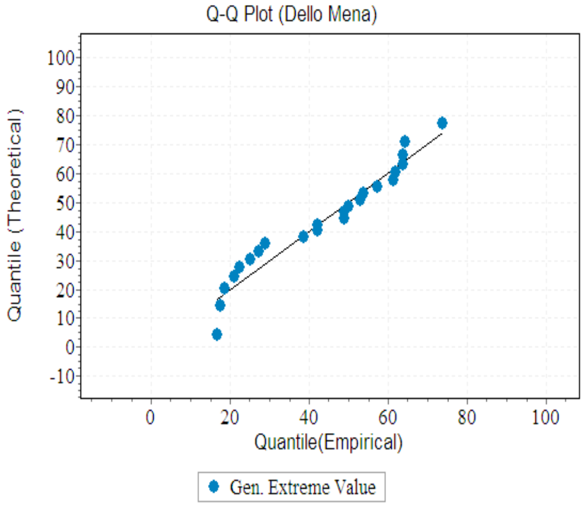


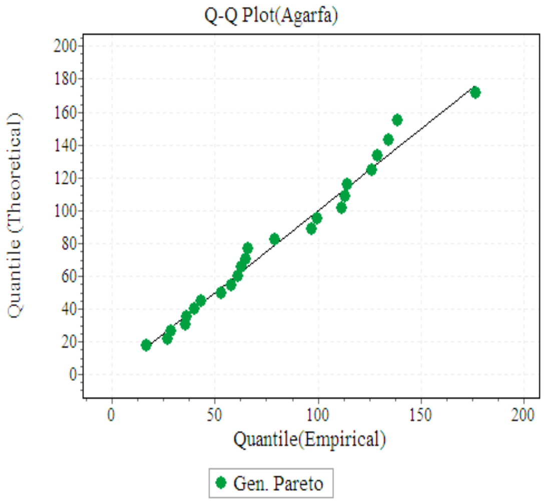

Q-Q Plot (Odda-Shakiso)


Q-Q Plot(Denbel)


Q-Q Plot(Gom-Goma)


Q-Q Plot (Melka Guba)


Q-Q Plot (Dello Mena)


Q-Q Plot(Agarfa)

Appendix-K: Estimated standardize flood quantiles of stations

Gumbel reduced variate	Robe	Shallo-village	Agarfa	Denbel	Alemkerem	Sofumer	RGC-C
0.37	0.97	1.05	1.32	1.03	1.08	1.69	1.19
1.50	1.29	1.64	3.57	2.06	1.58	4.17	2.38
2.25	1.52	2.21	6.51	3.25	2.25	7.00	3.79
3.20	1.83	3.19	13.33	5.95	3.86	12.71	6.81
3.90	2.08	4.20	22.23	9.45	6.07	19.24	10.54
4.60	2.34	5.51	36.57	15.06	9.78	28.59	16.31
5.30	2.62	7.22	59.66	24.07	16.02	42.00	25.27
6.21	3.02	10.32	113.11	44.87	31.28	69.00	45.27
6.91	3.34	13.50	182.93	71.98	52.24	99.89	70.65
7.60	3.67	17.66	295.36	115.54	87.56	144.14	110.66
8.52	4.16	25.19	555.65	216.16	173.84	233.30	201.38
9.21	4.55	32.95	895.63	347.30	292.44	335.27	318.02

Gumbel reduced variate	Melka Guba	Megado	Odda-Shakiso	Digatty	RGC-B
0.37	1.26	1.71	1.21	1.01	1.30
1.50	3.00	3.41	2.74	1.63	2.69
2.25	5.00	5.27	4.66	2.24	4.29
3.20	9.02	8.91	8.94	3.28	7.54
3.90	13.64	12.93	14.33	4.28	11.30
4.60	20.25	18.53	22.73	5.53	16.76
5.30	29.75	26.31	35.81	7.08	24.74
6.21	48.93	41.45	64.94	9.71	41.26
6.91	70.90	58.18	101.58	12.27	60.73
7.60	102.43	81.46	158.69	15.45	89.51
8.52	166.08	126.76	285.80	20.84	149.87
9.21	239.01	176.84	445.74	26.09	221.92

(RGC: Regional Growth Curve)

Appendix-L: Estimated quantiles and confidence limits of stations (m^3/s)

Station	Chenemasa			Kolle Bridge			Halwey		
T	FFC	UCL	LCL	FFC	UCL	LCL	FFC	UCL	LCL
2	553.47	622.22	484.71	303.60	329.27	277.93	809.57	894.20	724.94
5	739.18	807.93	670.43	405.99	431.66	380.32	1153.96	1238.59	1069.33
10	869.75	938.50	800.99	491.19	516.86	465.52	1426.95	1511.58	1342.32
25	1043.92	1112.68	975.17	623.79	649.46	598.12	1833.28	1917.91	1748.65
50	1180.13	1248.88	1111.37	744.04	769.71	718.37	2186.38	2271.01	2101.75
100	1321.51	1390.27	1252.76	885.70	911.37	860.03	2587.44	2672.07	2502.80
200	1468.80	1537.55	1400.04	1053.06	1078.73	1027.39	3044.34	3128.97	2959.71
500	1673.39	1742.15	1604.64	1322.24	1347.91	1296.57	3748.69	3833.32	3664.06

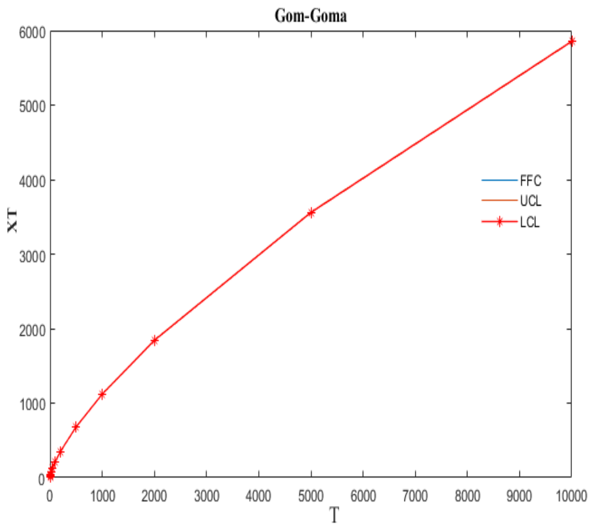
1000	1836.18	1904.93	1767.43	1569.74	1595.41	1544.07	4369.89	4454.52	4285.26
2000	2006.28	2075.03	1937.53	1862.86	1888.53	1837.19	5079.46	5164.10	4994.83
5000	2242.97	2311.72	2174.21	2334.93	2360.60	2309.26	6174.90	6259.53	6090.27
10000	2431.43	2500.18	2362.68	2769.26	2794.93	2743.59	7141.65	7226.29	7057.02

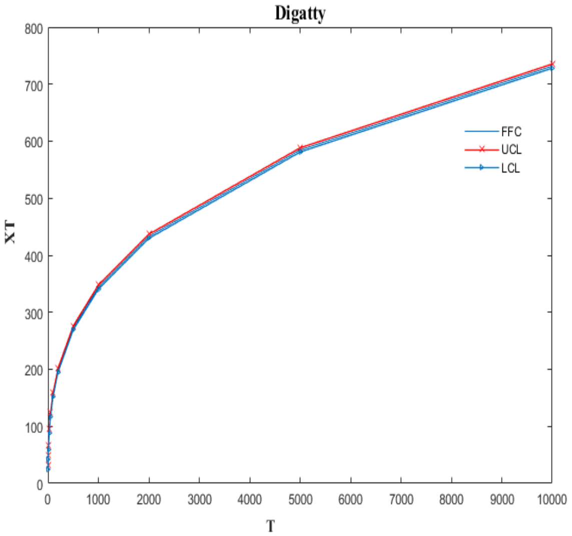
Station	Digatty			Megado		
T	FFC	UCL	LCL	FFC	UCL	LCL
2	28.20	31.85	24.55	108.89	122.13	95.66
5	45.79	49.44	42.15	228.48	241.71	215.25
10	62.87	66.52	59.22	362.76	375.99	349.53
25	91.92	95.57	88.27	628.19	641.42	614.96
50	120.12	123.77	116.47	926.23	939.46	913.00
100	155.12	158.77	151.47	1346.38	1359.61	1333.15
200	198.56	202.21	194.91	1938.67	1951.90	1925.44
500	272.46	276.11	268.82	3109.42	3122.65	3096.19
1000	344.20	347.84	340.55	4424.02	4437.25	4410.79
2000	433.23	436.88	429.59	6277.22	6290.46	6263.99
5000	584.70	588.35	581.05	9940.36	9953.59	9927.13
10000	731.73	735.38	728.08	14053.61	14066.84	14040.38

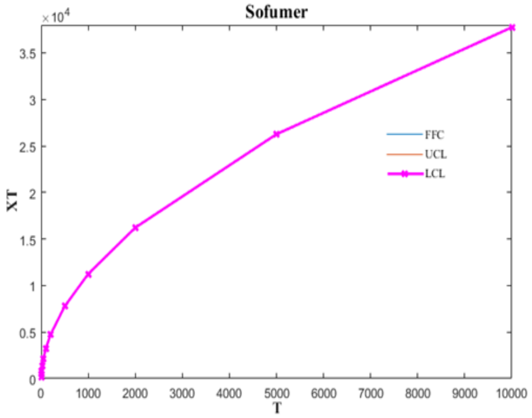
Stations	**Denbel**			**Alemkerem**			**Sofumer**		
T	**FFC**	**UCL**	**LCL**	**FFC**	**UCL**	**LCL**	**FFC**	**UCL**	**LCL**
2	73.02	79.84	66.20	80.19	87.27	73.12	190.02	202.16	177.88
5	146.19	153.01	139.37	117.87	124.94	110.80	469.03	481.18	456.89
10	230.32	237.14	223.50	167.71	174.78	160.63	788.15	800.29	776.01
25	421.72	428.54	414.90	287.98	295.06	280.91	1431.11	1443.25	1418.96
50	669.71	676.53	662.89	452.55	459.62	445.47	2166.48	2178.62	2154.34
100	1067.43	1074.25	1060.61	729.32	736.39	722.24	3220.01	3232.15	3207.87
200	1706.03	1712.85	1699.21	1195.24	1202.32	1188.17	4729.38	4741.52	4717.24
500	3180.14	3186.96	3173.32	2332.94	2340.01	2325.87	7770.43	7782.57	7758.29
1000	5101.02	5107.84	5094.20	3896.53	3903.60	3889.45	11248.60	11260.74	11236.46
2000	8188.45	8195.27	8181.63	6530.83	6537.91	6523.76	16231.64	16243.78	16219.50
5000	15319.24	15326.05	15312.42	12966.09	12973.16	12959.02	26271.41	26283.55	26259.27
10000	24613.46	24620.28	24606.64	21812.03	21819.10	21804.96	37754.28	37766.42	37742.14

Stations	Robe			Shallo Village			Agarfa		
T	**FFC**	UCL	LCL	**FFC**	UCL	LCL	**FFC**	UCL	LCL
2	83.30	93.33	73.27	21.68	23.73	19.64	100.30	113.22	87.37
5	110.85	120.89	100.82	33.90	35.95	31.86	272.02	284.94	259.09
10	130.65	140.68	120.62	45.50	47.54	43.46	496.31	509.24	483.39
25	157.59	167.62	147.55	65.90	67.94	63.85	1015.55	1028.47	1002.62
50	179.06	189.09	169.02	86.67	88.72	84.63	1693.76	1706.69	1680.84
100	201.71	211.74	191.68	113.72	115.77	111.68	2786.03	2798.95	2773.10
200	225.70	235.73	215.66	149.02	151.06	146.98	4545.10	4558.03	4532.18
500	259.65	269.68	249.61	212.79	214.84	210.75	8617.21	8630.14	8604.29
1000	287.17	297.20	277.13	278.48	280.53	276.44	13936.18	13949.10	13923.25
2000	316.39	326.42	306.36	364.37	366.41	362.33	22502.31	22515.24	22489.39
5000	357.82	367.86	347.79	519.72	521.76	517.68	42332.17	42345.09	42319.24
10000	391.43	401.47	381.40	679.82	681.86	677.77	68233.78	68246.71	68220.86

Appendix-M: Flood frequency curves of sites with confidence limits



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2
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3
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2000
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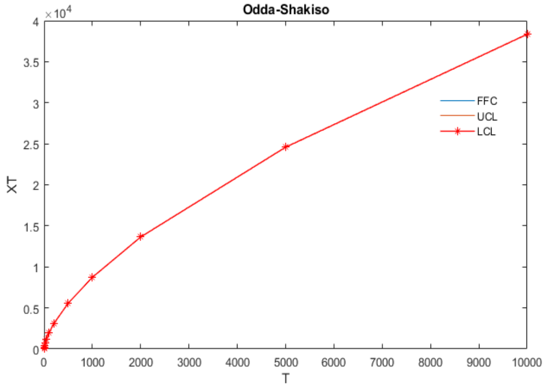
4000
5000
6000
7000
8000
9000
10000
T
FFC
UCL
LCL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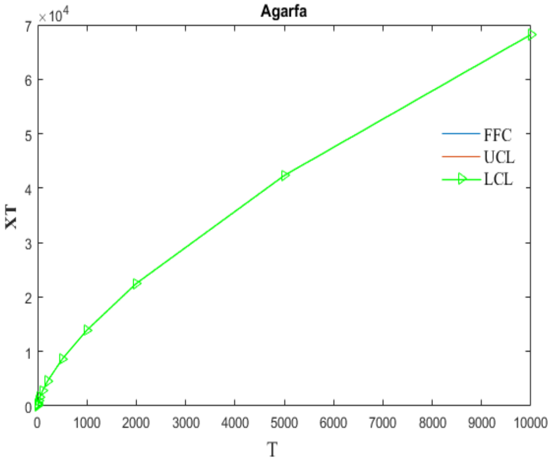
8000
9000
10000
T
FFC
UCL
LCL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8000
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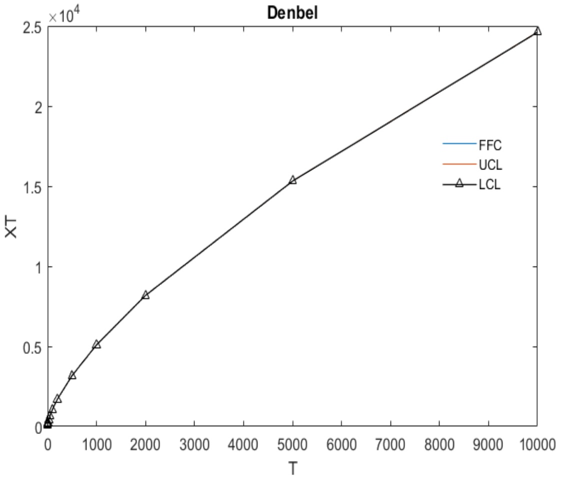
10000
T
FFC
UCL
LCL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UCL
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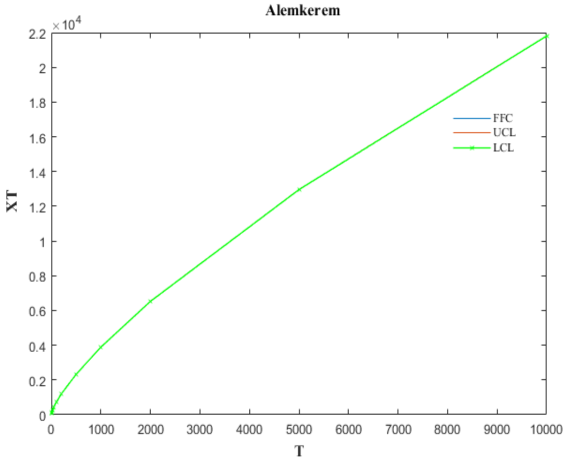
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UCL
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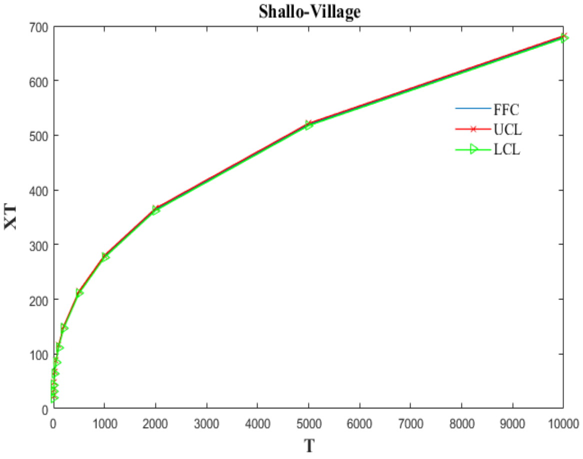
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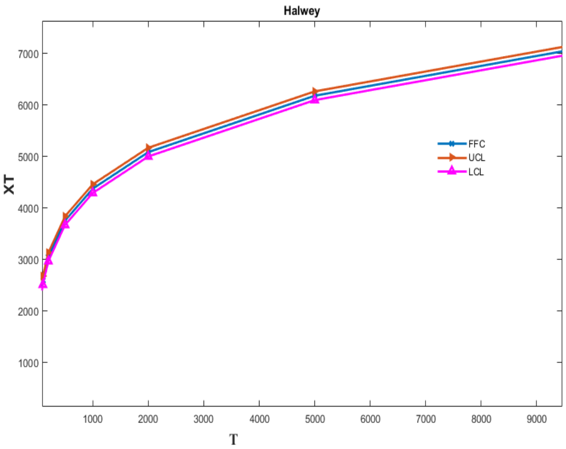
T
FFC
UCL
LCL


Halwey
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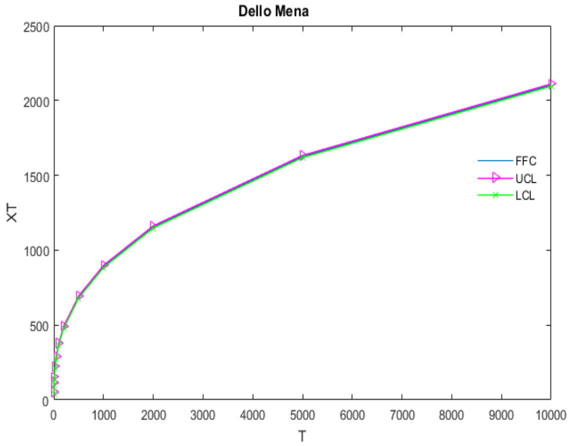
Dello Mena
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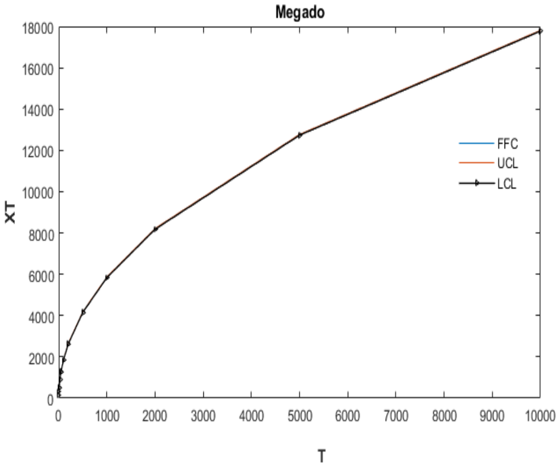
Megado
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FFC
UCL
LCL
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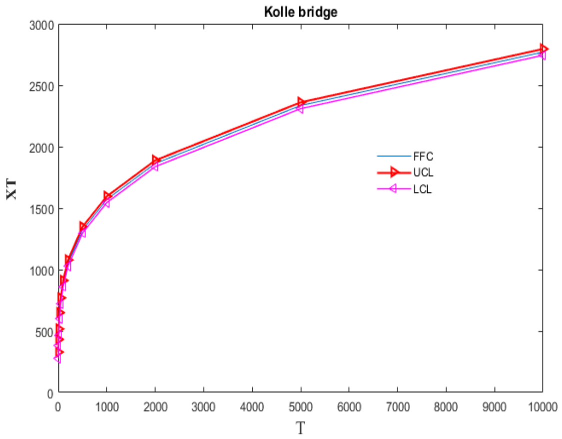
Kolle bridge
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T
FFC
UCL
LCL
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2000
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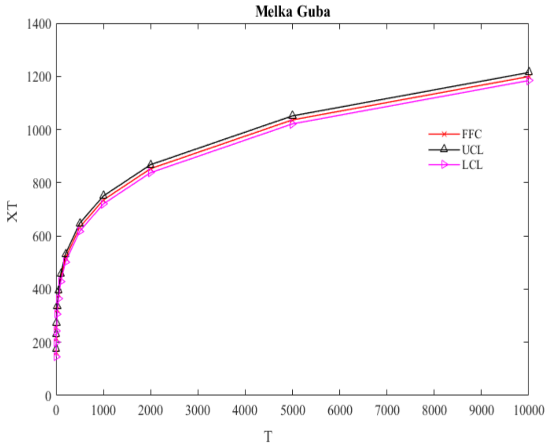
7000
8000
9000
10000


Melka Guba
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T
FFC
UCL
LCL
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800
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4000
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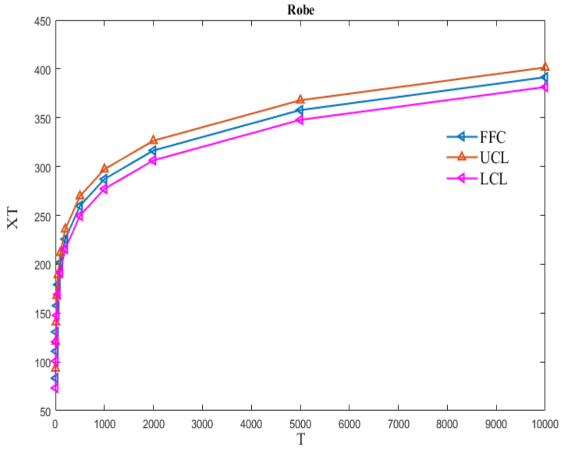
Robe
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T
FFC
UCL
LCL
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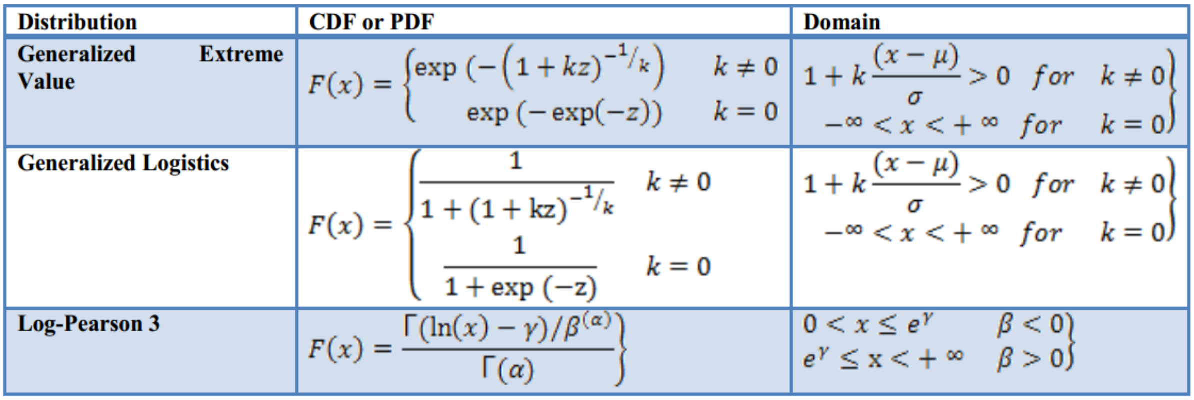
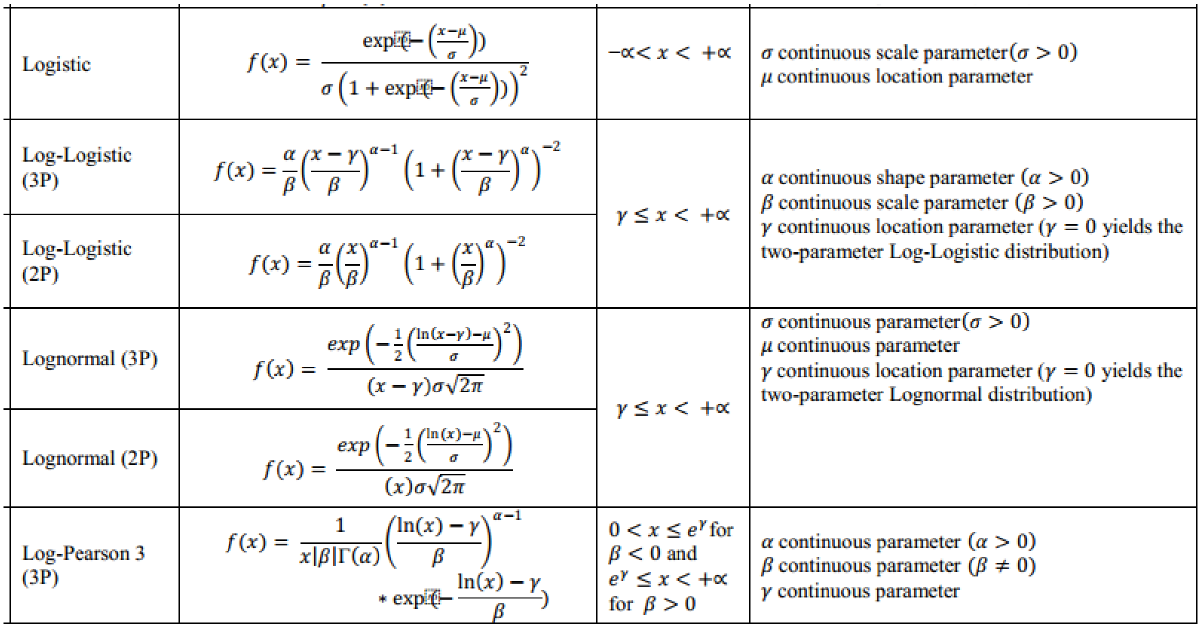
10000

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



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



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