Jimma University

Jimma Institute of Technology

School of Graduate Studies

Faculty of Civil and Environmental Engineering

Hydrology and Hydraulic Engineering Chair

Master Program in Hydraulic Engineering

Flood Frequency Analysis; Case of Awash-Awash Sub Basin, Awash River Basin, Ethiopia.

By: Muhammedsalih Boru Bedaso

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

Nov, 2021

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Advisor: Mamuye Busier (Ass.Prof)

Co-advisor: Natnael Sitota (MSc.)

Nov, 2021

Jimma, Ethiopia

DECLARATION

I, the undersigned declare that the thesis entitled as “Flood Frequency Analysis; Case of Awash-Awash sub basin, Awash 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.

Muhammedsalih Boru Bedaso

______________________ ______________________

Signature Date

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

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APPROVAL

The thesis entitled " Flood Frequency Analysis: Case of Awash-Awash sub basin , Awash River Basin, Ethiopia" submitted by Muhammedsalih Boru Bedaso is approved and accepted as university supervisor in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

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ABSTRACT

This Flood Frequency Analysis aimed at analyzing flood magnitude and its probability of occurrence with fairly accurate not only aimed at preventing catastrophes but also at avoiding excessive costs in case of overestimating the flood magnitude or excessive damage while under estimating flood potential. The HEC-SSP software flood frequency analysis, MoM & L-Moment parameters estimation and KS and X^2 *distribution fitting test statistics were used to achieve the study objectives.*

The stream flow data record length was varying from 18 to 44 years (1970-2014). The extreme theory for annual maxima has been applied and the best fitted distribution generated by KS model test statistics values range from 0.074 to 0.115 which is considered as heavy tail distribution and also these KS values are within the highly acceptable range since KS test statistics value threshold is less than or equal to 0.5 dimensionless value. The MoM statistics for CV range from 0.299 to 0.627 and the Cs value range from 0.519 to 2.007 while the L-moment method generated ratio for L-Skew range from 0.011 to 0.366, the L-Kurtosis range from -0.014 to 0.300 which is the negative sign indicates the flat thin tail distribution and the L-CV value range from 0.184 to 0.319 which is the sample data are moderately variable. The shape parameters for all station data analyzed with GPA and Log pearson type III range from 0 to 2.15 which means the distributions have finite upper bound.

Finally, the software model has generated the quantile flood magnitude with very small (0.001 to 0.584%) percent difference among the observed and computed values of stream flow records for the return period of 2, 5, 10, 20, 50, 100, 200 and 500 years. At the inlet of the sub basin the model generated quantile flood magnitude of 513.8m3/sec is identified as lower bound and 1208.2m3/sec valued as upper bound while at the outlet of the sub basin 366.3m3/sec and 659.8m3/sec computed as the lower and upper bound respectively. The slope of a flood frequency curve (FFC) graphically represents the standard deviation of the flood frequency distribution. The higher the slope, the greater the standard deviation in flood discharges.

Keywords: Awash-Awash sub basin, Awash River Basin, Best fit distribution, Flood Frequency analysis, HEC-SSP, Return period.

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ABBREVIATIONS AND ACRONYMS

AMF	Annual Maximum Flow
AM	Annual maximum
AwBA	Awash Basin Authority
CC	Combined Coefficient of variation
CMS	Cubic Meter per Second
CV	Coefficient of Variation
DEM	Digital Elevation Model FFA Flood Frequency Analysis
DPPA	Disaster Prevention and Preparedness Agency
FFA	Flood Frequency Analysis
FFC	Flood Frequency Curve
GEV	Generalized Extreme Value
GIS	Geographical Information System
GP	Generalized Pareto
GUI	Graphical User Interface
HEC-SSP	Hydrological Engineering Corps Statistical Software Package.
K	Shape factor of parameters Estimation
KS	Kolmogrov Smirnov
LCL	Lower Confidence Limit
L-CV	Linear Coefficient of Variation
L-Cs	Linear Coefficient of Skewness
L-Ck	Linear Coefficient of Kurtosis
L-Mean	Linear Mean
σ	Location Factor of parameters Estimation
MADI	Mean Absolute Deviation Index
MML	Method of Maximum Likelihood
MoM	Method of Moment
MoWIE	Ministry of Water Irrigation and Energy

NMA	National Meteorological Agency
OFDA	Organization of Food & Development Agency
PD	Partial Duration
POT	Peak Over Threshold
PPCC	Probability Plot Correlation Coefficient
PWM	Probability Weighted Method
Q_T	Quantile Flood
R^2	Coefficient of Determination
RFFA	Regional Flood Frequency Analysis
RP	Return Period
RMSE	Root Mean Square Error
RRMSE	Relative Root Mean Square Error
S	Standard Deviation
S^2	Variance
T	Return Period
TE	Return Period in partial duration series
UCL	Upper Confidence Limit
μ	Scale Factors of parameters estimation
X^2	Chi-Square
X_T	Estimated flow quantiles value

1. INTRODUCTION

1.1 Background

Hazard is a potentially damaging physical event, phenomenon that may cause the loss of life or injury, property damage, environmental degradation, social and economic disruption. The hazard assessment is to identify the probability of occurrence of a specific hazard, in a specific future time, as well as its intensity and area of impact. Among the natural hazard drought and flood are rank the first and the second respectively (OFDA, 2012).

Flood is one of the most disasters that can lead to loss of life and property in many parts of the world (Zhang and You, 2014); (Mallakpour and Villarini, 2015); (Steinschneider and Lall, 2015); (Wu et al., 2015); (Komi et al., 2016). During the period of 2000-2008, near 99 million people worldwide were affected annually by flood (Kvocka et al., 2015). In Ethiopia, from 1980 to 2010, eighty six natural disasters were recorded and they results in a loss of 313,486 human lives and 57,382,354 people were affected and result in economic loss of US$ 31.7 million (DPPA, 2013), In this upper section of Awash River the flooding was usually caused by the release of water from the Koka dam's flood gates which are necessary when the reservoir reaches its maximum capacity. Unfortunately, in past years the reservoir authorities experienced difficulties in releasing water in controlled intervals, often causing flooding downstream (UNICEF, 1999).

The need for preventive action to reduce the unnecessary costs, economic losses and danger arising from overflow of water has become imperative and continued to engage the attention of water resources engineers and hydrologists (Ahmad U. N., et al., 2011). 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). 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).

1.2 Statement of the Problem

Floods are the most costly natural hazards that have ravaged different parts of the world destroying human lives and properties. 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.

In Ethiopian River Basins, different studies were undertaken related with flood frequency analysis of basin hydrology at large scale especially in Awash River basin. However, most of the studies tried to concentrate on upstream koka and at the lower sub basins of the river regarding to risk of flooding. But In the recent years; receiving the flood inundation in Awash-Awash sub basin is become familiar. For instance, according to (2020 government flood report); in Awash-Awash sub basin more than 25,000 people have been displaced and About 16,000 hectares large farms (both state and private farms) in Boset & Fentale Woredas of East Shoa Zone alone worst affected areas in the sub basin. Ambibara, Metahera town and Nurahera sites are seriously exposed.

The frequency of floods with various risks of exceedance is therefore needed in most engineering problems Vivekanandan, (2015). 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).

Therefore, flood frequency analysis is essential with 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, require a reliable estimation of flood quantiles with reliable flood records measured at gauging stations. The HEC-SSP software frequency analysis MoM & L-Moment parameters estimation methods and KS & chi square frequency distribution methods were used.

1.3 Study Objectives

1.3.1 General Objective

The general objective of this study is to analyses the flood frequency case of Awash - Awash Sub Basin in Awash River Basin,

1.3.2 Specific Objectives

- To estimate peak flow probability distribution and parameters of flooding events in the study area.
- To analyze the frequency of flood quintiles magnitude (Q_T) in the study area.
- To plot flood frequency curves of quantile floods for each station

1.4 Research Questions

1. How best-fit probability distributions and parameter estimation would be achieved?
2. How frequent are the flooding events of quantile flood (Q_T) in the study area?
3. What would be the flood frequency curves fitted with the quartile flood of interest produced?

1.5 Significance of the Study

The information generated by this study provide flood magnitude and its probable time of occurrence in the sub-basin primarily for Adama town, state farms, farmers, investors, flood control projects, planners, and designers of the basin water resources management and for policy initiators and decision-makers of the country. Also, this can be used as a referencing point for researchers intended to further investigate related studies in the sub-basin.

1.6 Scope of the Study

This study is essentially a sub-basin level case study using gaged hydrological stations data taken from on Awash Main River and significant gaged tributaries. The study limited to the characterization of the study area and stationary assumption to the flood frequency analysis at Awash-Awash sub-basin, Awash River Basin, Ethiopia.

2. LITERATURE REVIEW

2.1 General

Floods can be explained as excess flows exceeding the transporting capacity of river channel, lakes, ponds, reservoirs, drainage system, dam and any other water bodies, whereby water inundates outside water bodies areas Aris MM, (2003) . The flooding can be caused by, for instance, heavy rain, snow melt, land subsidence, rising of groundwater, dam failures. Moreover, since the industrial revolution, climate change has been clearly influencing many environmental and social sectors; in particular, it has been showing significant impact on water resources. The natural disaster related to the weather system variability, climate change, and environmental degradation have been frequently influencing human beings and their impacts seem to have greatly increased in recent decades Vincent (1997). Flood is one of the major natural disasters that have been affecting many countries or regions in the world year after year Dilley, Chen RS, Deichmann U., (2005). The river or flash flooding usually occurs in the low-lying flat topographic areas of the world. The intense rainfall in the highlands of the Awash River Basin causes flooding at its downstream and damages settlements close to any section of the river Abebe, Feyissa C (2007).

Flood frequency analysis (FFA) is most commonly used by engineers and hydrologists worldwide and basically consists of estimating flood peak quantiles for a set of non-exceedance probabilities. Flood frequency analysis is one of the most important studies of river hydrology. It is essential to interpret the past records of flood events to evaluate future possibilities in such occurrence. The estimation of the frequencies of the flood is important for the quantitative assessment of the flood problem. Knowing the magnitude and probable frequency of such recurrence is also required for the proper design and location of hydraulic structures and other allied studies Tanaka et al., (2017).

In flood frequency analysis, the major problems encountered by hydrologists are the period length of data records and selection of probability distribution and parameter estimation techniques, and shortage of experiences. On the other hand, the estimation of flood quintiles is complicated because both lack a physical basis for determining the form of the underlying flood frequency distribution and the necessity of evaluating flood risk for return periods that exceed the length of the observed record. Flood quintile estimates are strongly dependent on the form of a portion of the underlying flood frequency distribution, difficult to estimate from observed data Mengistu T.D., (2018) 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, A., (2014); Murphy et al., (2014). It indicates that flood frequency analysis is required hydrological data quantities and qualities to produce reliable predictions. It can be achieved by examining the recorded annual maximum discharge data using suitable software and probability distribution and parameter estimation methods. Then, flood frequency analysis plays a major role in the estimation of flood quintile at a project location for different return periods on a river system Vivekanandan, (2015); Tanaka et al., (2017).

2.2 Flood Frequency Models

In flood frequency modeling, the problems related to the choice of model type, choice of distribution to be used in the chosen model, and choice of method of parameter and quintile estimation have to be solved (Cunnane, C., 1989). Different magnitudes of flooding have a different probability of occurrence. According to Desalegn et al. (2016), in flood frequency modeling the problems related to the following points have to point out. 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 8 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 three different model types may be considered for this purpose. These models are the Annual Maximum series (AM) model, the Partial Duration series (P.D.) or Peaks over a Threshold (PoT) model, and the Time Series (T.S.) model, and their descriptions are discussed as follow.

A. Annual Maximum Series Model (AM)

Cunnane, C., (1989). has stated that a series of the annual maximum flood is assumed to form a random sample from a stationary population in which Q is a random variable with distribution P.R. $(Q<q)=F(q)$. In the annual maximum (AM) flow series, only the peak flow in each recorded year is considered. However, the use of an AM series may involve some loss of information. For example, the second or third peak within a year may be greater than the maximum flow in other years, and yet they are ignored (Kite, G.W., 1977). This situation is avoided in the partial duration (P.D.) or the peaks over a threshold (POT) models where all peaks above a certain base value are considered. The base is usually selected low enough to include at least one event each year (Kite, G.W., 1977). . However, the P.D. (or POT) model is limited by the fact that observations may not be independent. According to (Cunnane C. 1989)., the AM model is statistically more efficient than the P.D. model when λ is small (λ <1.65), where λ is the mean number of peaks per year included in the P.D. series. T E for a P.D. (or POT) model is related to the return period T of an AM model by the relative difference between T.E. and T is greatest for small values of T and converges to 0.5 as T increases.

The discussion here is based on the annual maximum series (AM) model. The variate values with exceedance probability 1/T are said to have return period T. Denoting this value Q.T.; it is such that: $1-F(Q_T) = 1/T$ In the annual maximum (AM) flow series, only the peak flow in each year of the record is considered, that may involve some loss of information.

B. Partial duration (P.D.) 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 statistical modeling and the case of identification of the values, which form the series, only the series of peaks exceeding an arbitrary threshold qo are considered. In particular, each of these showed that if the number of flood peaks exceeding some value qo (a threshold value) in some interval of time such as a year has a Poisson distribution with parameter l, the number of events exceeding a great value q is also Poisson distributed with parameter l = lp where p=PR 17 (q>q /q>qo). Here p is a conditional probability, being the proportion of all peaks exceeding qo, which also exceeds q

(Cunnane, C., 1989). To comprise a group of sites from which extreme flow information can be combined for improving the estimation of extreme flows at any site in the region (Hosking, J. R. M., and Wallis, J. R., 1997). There are several characteristics 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 (Mkhandi et al., 2000).

C. The Time Series (T.S.) Model

In the time series (T.S.) model (1975), the flow hydrograph is considered a time series in which the flows are represented by a series of ordinates at equally spaced intervals. Time intervals of days, months, and years are commonly used in hydrological time series, but most commonly, only days are used in flood frequency analysis. Ideally, if a hydrograph is considered a stochastic process in continuous time, the properties of such a series can be deduced from those of the parent process. If Q(t) is the flow on day t, a time series model may be written as the sum of trend, seasonal, and stochastic components. Estimating model formulation and parameters proceeded together through the three components beginning with the trend and ending with the stochastic component.

2.3 Model Selection for Flood Frequency Analysis

It should be noted that two separate aspects of such choice are important. These are the descriptive and predictive properties of the chosen 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 (Cunnane, 1989). Therefore, among the Annual Maximum (AM), Peak over Threshold (PoT) and Time Series (TS) models Annual Maximum Model has selected for this study.

But, 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). However, AMF is a universally used model by different investigators for the purpose of flood frequency analysis (Badreldin and Fengo, 2012).

In addition AM have widely accepted and applied, Simple and convenient to apply, Consistent, flexible or robust (low sensibility to outliers), theoretically well based, Documented in the guide & above all it accepts many probability distribution and also the HEC-SSP software is accept the annual maximum flow series data to produce flood frequency analysis report.

2.4 Flood Frequency Distribution Analysis Using HEC-SSP Software

Hydrologic Engineering Centers Statistical Software Package (HEC-SSP) is designed and developed by the U.S Army Corps of Engineers to perform statistical analysis of hydrological data. The first version of HEC-SSP software was released in August of 2008 while version 2.2 released in 2019 includes improvements to nearly all previously released analyses, two new analyses (distribution fitting and mixed population), a redesigned curve combination analyses and enhanced data usage and manipulation.

There are many distributions that have been suggested for AM series. Some of them are used for this particular study. When a theoretical distribution has been assumed, the validity of the assumed distribution may be verified or disproved statistically by goodness of test (Ang and Tang, 1975 a). The results of the goodness of fit tests are used to select a distribution for frequency analysis of stations. These parameters are used to calculate the quantiles related to return periods of T years and for this specific study HEC-SSP statistical software and L-moment method of parameter estimation were selected. Based on the selected distributions for each station, the quantile was calculated according to the formula provided in HEC-SSP for the selected distributions.

HEC-SSP software is designed for interactive use in a multi-tasking environment. The system is comprised of a Graphical User Interfaces (GUI), separate statistical analysis components, data storage and management capabilities mapping, graphics and reporting tools. Over a period of many years, HEC has supported a variety of statistical package that perform frequency analysis and other statistical computation and it is applicable in solving the analysis of short recorded data problems as short as seven year.

2.5 Statistical Probability Distribution of Peak Flow and Its Best Fit

After a detailed study of the gauges data and its descriptive parameters such as a measure of central tendency and dispersion characteristics are identified by applying probability theory, one can reasonably predict the probability of occurrence of any major flood events in terms of discharge or water level for specified return period (Jeonghwan., 2014). However, for reliable estimates of extreme events, long data records are required. There are no methods available that can determine the exact amount of flood. However, various methods available are either based on probability or empirical. In the hydrologic analysis, the annual discharge is considered a random variable; probability and statistical methods are employed to analyze random variables (Ojha., 2008).

The choice of distribution would be widely accepted, simple, and convenient to apply, Consistent, flexible, or robust (low sensibility to outliers), theoretically well based, and documented in the guide. No special method of parameter estimations referred and the graphical method is used as frequently, even more, as any other method. The choice of distribution is influenced by many factors such as the method of discrimination between distributions, method of parameters estimation, the availability of data, Etc. the method of parameter estimation goes parallel with distribution selection.

Many distributions have been suggested for AM series models. Some of them are Normal and related distributions (Normal distribution, Lognormal II parameter distribution, Lognormal III parameter distribution), The Gamma group (Exponential distribution, Two parameters Gamma distribution, Pearson III distribution, and Log Pearson III distribution), Extreme value distribution (Generalized extreme value distribution, Extreme value type I distribution, Extreme value type II distribution, Weibull distribution), Wake-by distribution (Five parameters wake-by distribution, Four parameters wake-by distribution and Generalized Pareto distribution) and Logistic distribution (Log-logistic distribution and Generalized logistic distribution)

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).

2.6 Goodness-of-Fit Test

According to (Biniyam and Kemal A., 2017) both rainfall and flood frequency analysis was performed with HEC-SSP using Log-pearson type III method for return period (T) of T= 2, 5, 10, 25, 50 and 100 years. HEC-SSP Software both offer graphical plots displaying scatter of sample data in addition to computed curve. Here, both intended to compare the result and the best plotting position and a theoretical curve of his choice. The graphical plot is a visual aid of broadly determining the worthiness of choice; therefore, a conclusion based on merely eye judgment is hugely subjective. To overcome this limitation, users can analyze the result distilled by software and employ any one of the D-index tests, Chi-square test, and / or Kolmogorov-Smirnov tests to measure fitness strength. Once a particular distribution is found the best, it is adopted to calculate peak floods in the future. A goodness-of-fit statistic tests hypothesis is:

H0: the series is random. The model specified distribution (M0) is fit.

H1: the series is not random model specified distribution (M0) does not fit (or, some other model M1 fits). As soon as a hypothetical distribution has been assumed, the strength of the implicit distribution may be confirmed or disproved statistically by the goodness of fit test. The goodness of fit tests such as the D-index test, Chi-Square (χ^2), and Kolmogorov-Smirnov (K.S.) are functional for checking the capability of appropriate probability distributions to the series of recorded annual maximum data Vivekanandan, N., (2015).

2.7 Parameters Estimation

There are various methods applied for statistical parameter estimation now a day such as the Maximum likelihood method (MLM), the Method of Moments (MOM), and the Probability Weighted Moments Method (PWM) and L-Moment methods.

2.8 Flood Quantile Estimation and Flood Frequency Curve Formation

After the distribution parameters are estimated, quintile estimates (Q_T.) which correspond to different return periods T, may be computed. The return period is related to the probability of non-exceedance (F) by the relation, F=1-1/T, where F= F (Q_T.) is the probability of having a flood of magnitude Q_T. or smaller. The problem then reduces to evaluating Q_T. for a given value of F Kumar and (Chatterjee, 2005). In practice, two types of distribution functions are encountered. The first type is that which can be expressed in the inverse form $Q_T = \varphi$ (F). In this case, Q_T. is evaluated by replacing ϕ (F) with its value from the above equation. In the second type, the distribution cannot be expressed directly in the inverse form Q_T. $=\varphi$ (F).

2.9 Previous Studies on Flood Frequency Analysis

Hydrological analysis plays the most important task to achieve a likelihood distribution of floods before estimation. Suitable historical data can predict this probability of events 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).

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 frequency analysis method involves fitting extreme value probability distribution functions to the historical record of maximum annual floods. This method relies upon the availability of observed stream flow to fit suitable probability distributions relevant to gauged sites (Kumar and Chatterjee, 2011; Vivekanandan, 2015). The derived techniques of flood frequency analysis involve quantifying the processes that govern flood behavior which is less dependent upon historical data (Badreldin and Fengo, 2012). According to (Ketsela et al., 2017).; Performed FFA on Awash River Basin using Statistical Distribution Technique; The Easy Fit Software was employed to select best-fit distributions and estimate parameters for stations. Kolmogorov–Smirnov test was used to choose a suitable distribution for estimation of maximum flood discharge. According to this study, the 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.

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 as having to be with geographical proximity. It mainly performs 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 the L-Moment ratio.

The study recommended that the selection of best-fit single distribution and dynamic parameter estimation method require further investigation (Demissie and Michael, 2008; Mekoya and Seleshi, 2010).

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

Investigating and understanding the characteristics, variability, and the trend of hydro-meteorological variables for Awash River Basin is essential. High rainfall intensity and steep slopes, together with improper land use and sparse cover resulting from human activities, are responsible for erosion and subsequent river sedimentation, even flooding and potential loss of surrounding farmland. The major flood generating factors used for flood hazard assessment are slope, elevation, average rainfall, drainage density, land use, and soil type. According to previous studies, the flood generating raster layers have been classified based on their flooding capacity (Abebe, Chibssa F., 2007).

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1 Location of the Study Area

Awash-Awash sub basin is the catchment area immediately from Koka reservoir outlet to Awash @ Melka sedi hydrological station. This area cover 8111km^2 including flash flood producing catchments around Adama watersheds & Dodota catchments, Beseka lake watersheds, keleta, Arba and Bedeyi rivers watershed areas of high potential discharge in perennial bases from the south eastern escarpments of Arsi - Bale high lands. Geographically, Awash-Awash sub basin is found at 7^0 50' to 9^0 20' latitude and 39^0 00' to 40^0 50' longitude as the part of Awash River basin.

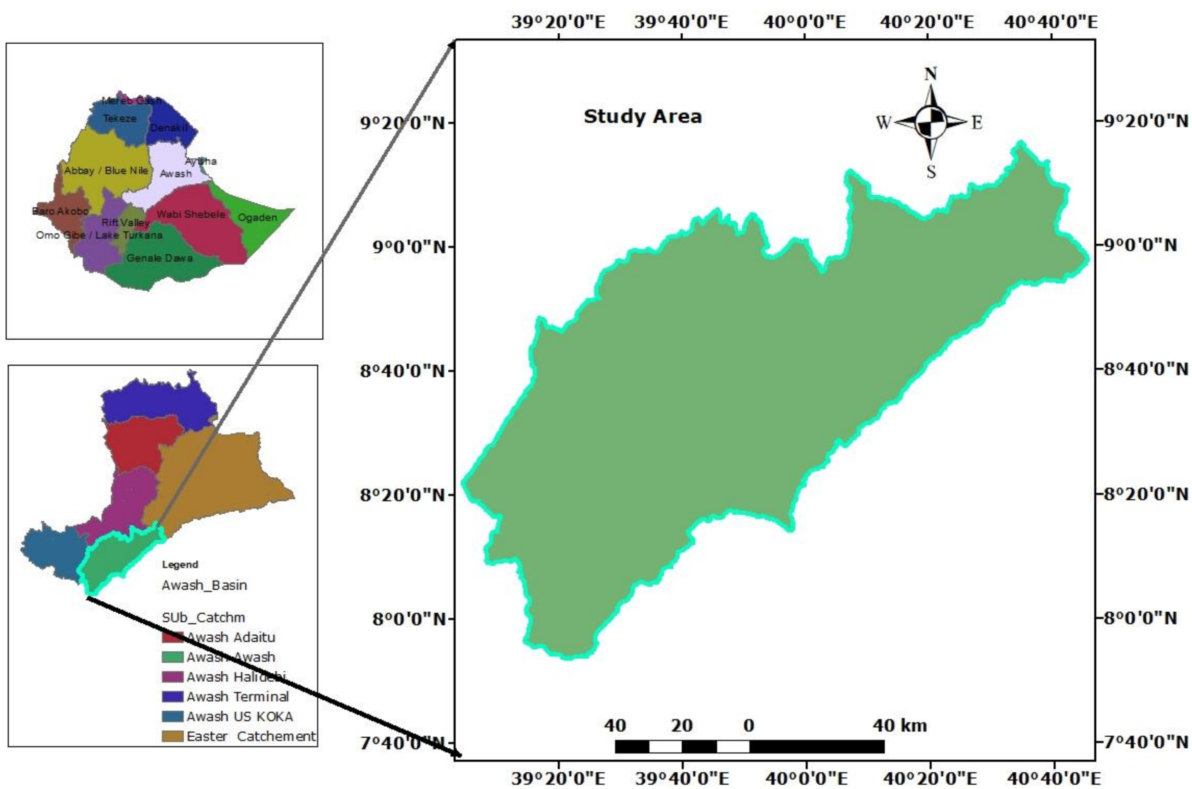


Figure 1 Location Map of the Study Area

3.1.2 Climate and Topography of the Study Area

The annual rainfall distribution in the basin is exhibited most clearly in two distinct rainy seasons, the spring and the summer rain seasons. In the sub basin's Dega, Woyna dega and Kola agro-climatic zones are familiars. The mean monthly temperature varies from about 8.6 ^{0}C in February in the highlands to 24.9 ^{0}C in June the lowlands and the long term average annual temperature of the basin is 14.6 ^{0}C.

Topographically, the Awash-Awash sub basin shows variation with altitude ranging from around 800 masl to 3200 masl. This is confirming that the presence of low land areas around Melka sedi and high land at the Arsi-Bale massive areas.

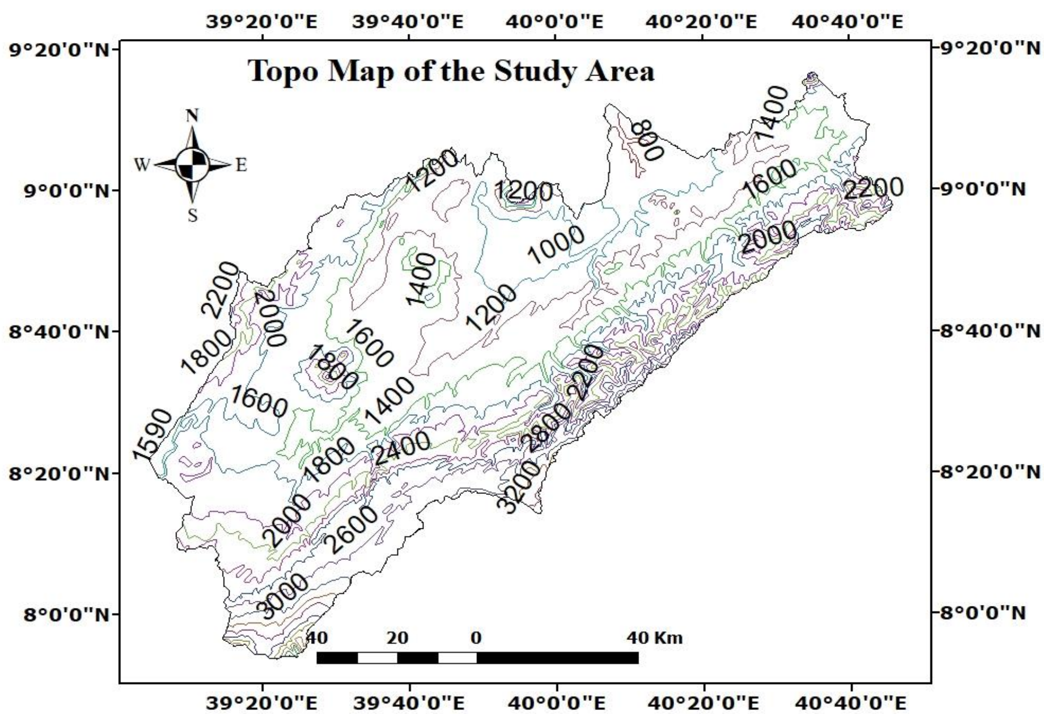


Figure 2 Study Area Topographic Map

3.1.3 Land Cover

Awash – Awash sub basin was analyzed for general land cover classes using Arc GIS software. As the analysis result indicated Cultivated Land, Dispersed Shrubs and grass land are the major land cover types among others.

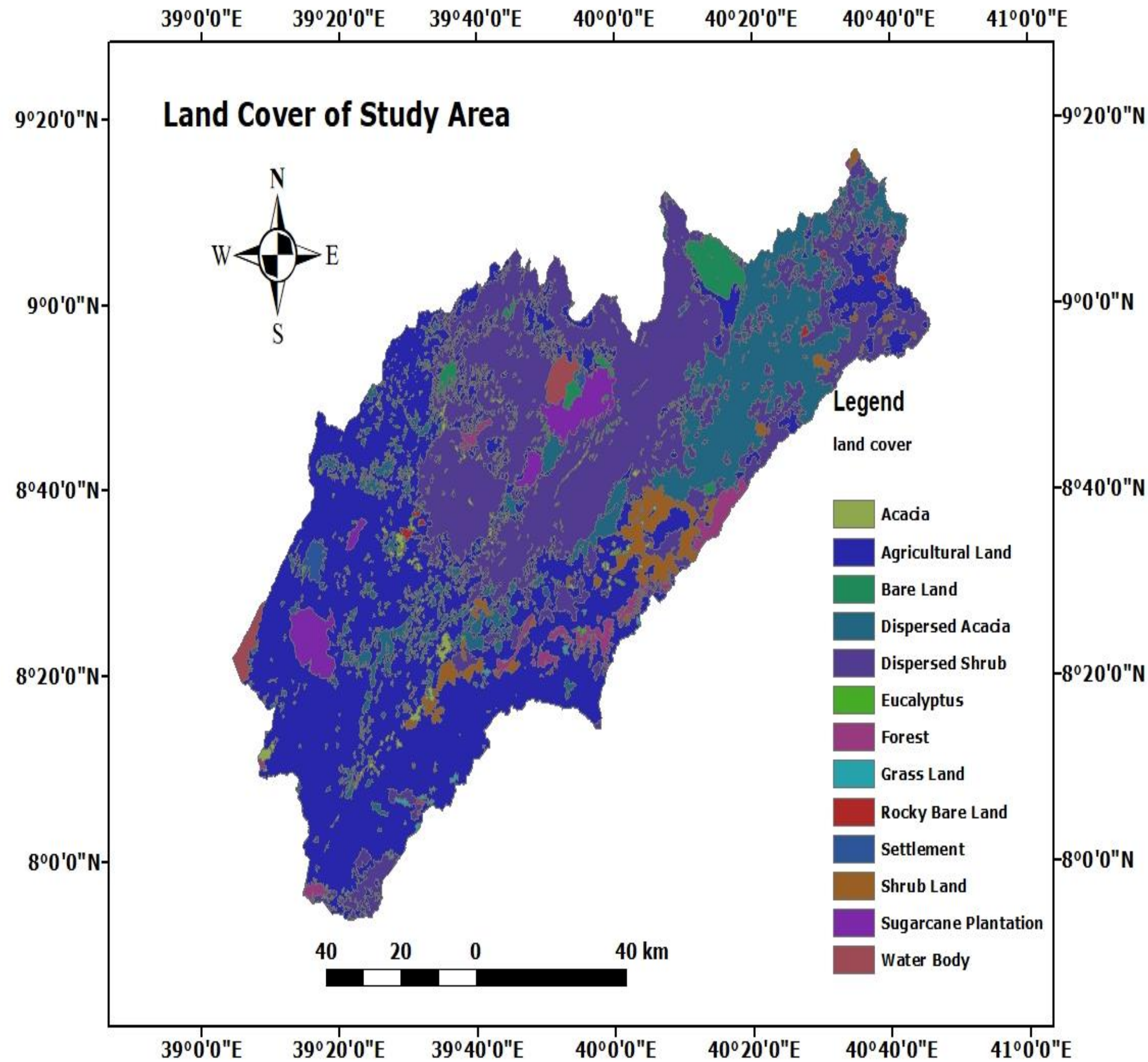


Figure 3 Land Cover of the Study Area

3.1.4 Land Use

In the study area land use data analysis applied and the result indicated cultivation lands, grass land and shrub land are the dominant land use form while the others shares minor parts of the sub basin areas. In fact now a day land use is the most changing parameter in the sub basin that is from forest or bush to cultivation, cultivation to construction due to urbanization and industrialization pushing effect.

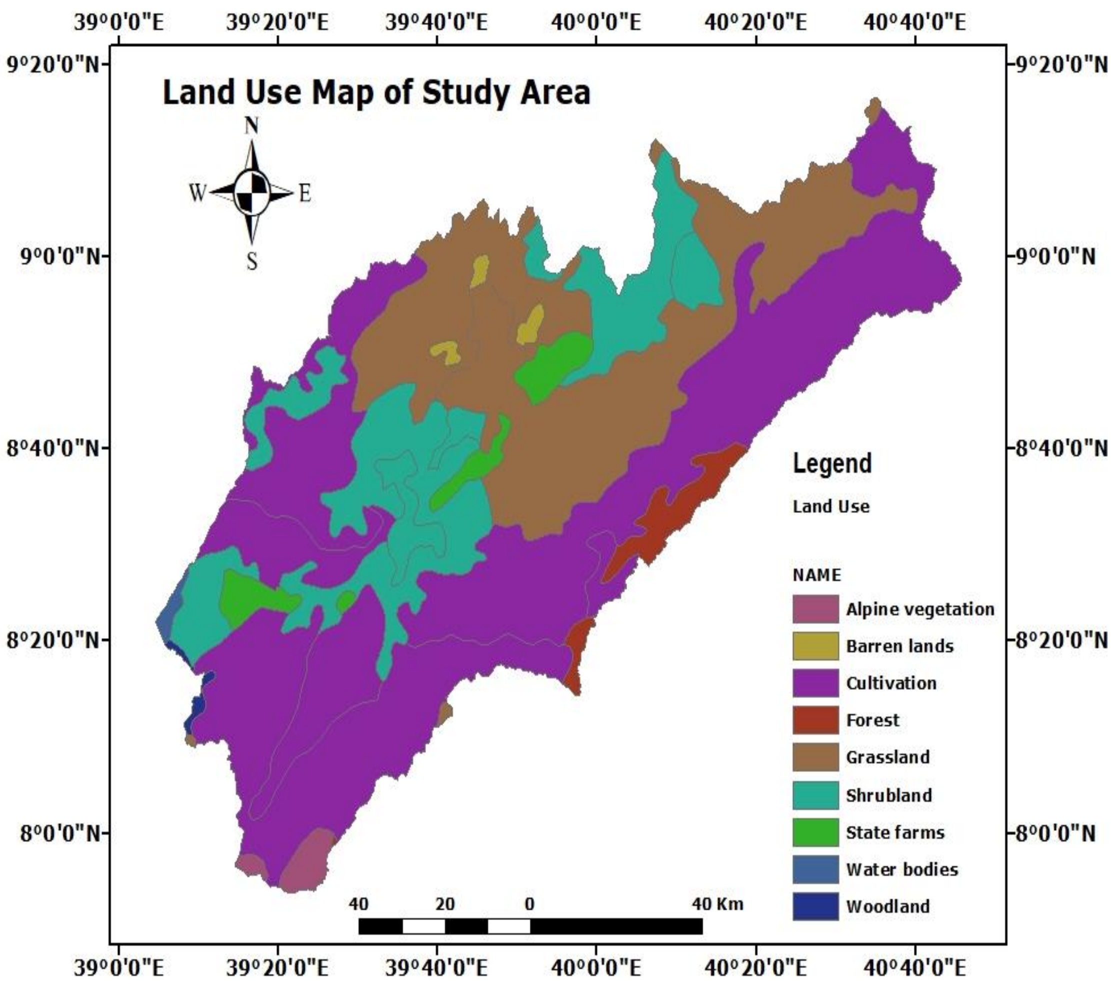


Figure 4 Land Use Map of the Study Area

3.1.4 Soil

In this study soil data analysis was made based on FAO soil calassification and Awash-Awash sub basin constitutes about twenty four (24) types of soils in which Eutricsols, Chromicsols, No soil and Leptosols domains are dominant soils which cover larger parts of the sub basin among others.

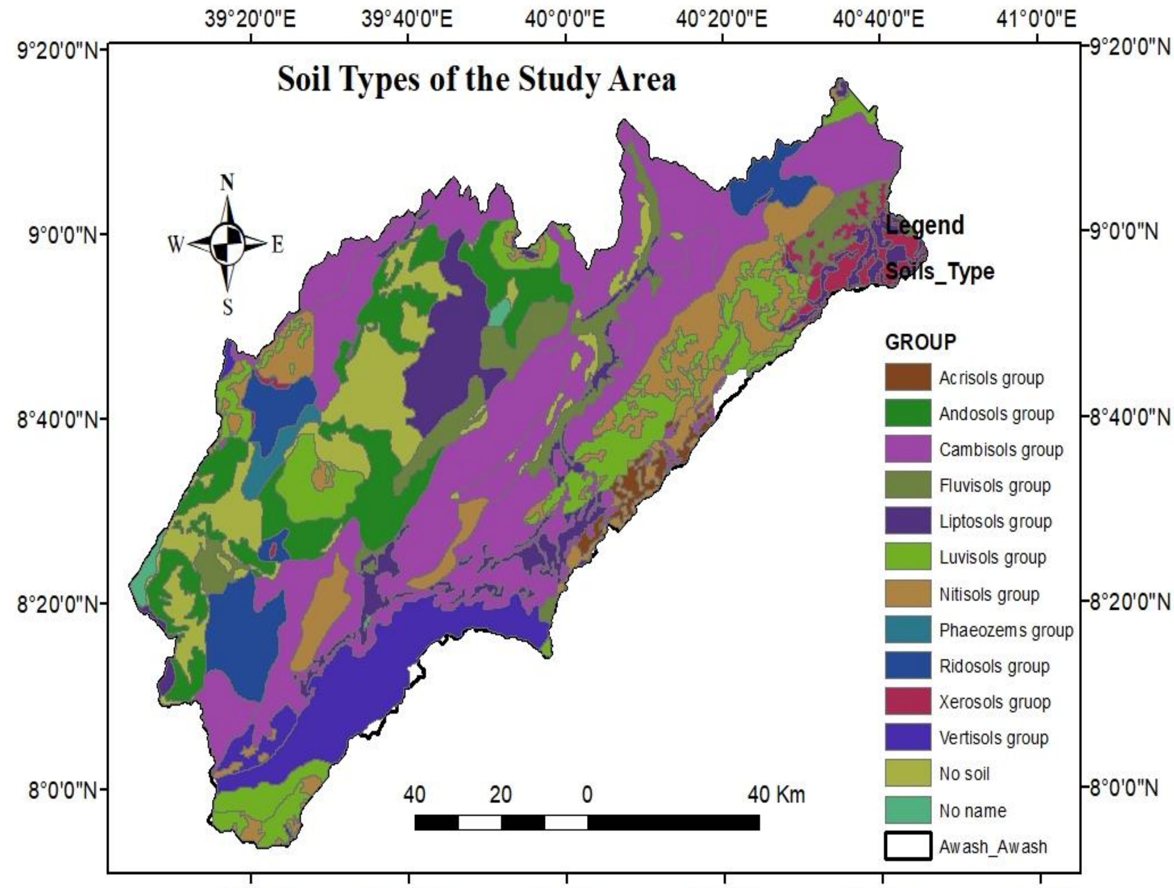


Figure 5 Awash-Awash Subbasin Soil Map

3.2 Materials Used

In this study the author used different computer programming tools:

- ❖ Microsoft Excel Spread sheet was used for organizing raw data and processing for statistical analysis.
- ❖ Arc GIS 10.4 version software was used for processing spatial data and delineation of the study area and mapping study area location map, topographic map, land use map, land cover map and soil of study area map development
- ❖ Ethiopian Basins, Awash River basin and Awash- Awash Sub basin as well as FAO soil shape files used for location map, land use map, land cover map, soil map, Meteorology and Hydrology stations map
- ❖ Ethiopian DEM (30 by 30) resolution used in topographic map development
- ❖ HEC-DSSVUE version 2.0.1 software used to import flow data to data storage system and HEC- SSP version 2.2 software was used for the statistical analysis, parameter estimation, generation of best fit distribution, describe outliers and develop frequency curves

3.3 Data collection

In this study, secondary data of rainfall and stream flow were used. The hydrological data and GIS/ DEM, basins shape file, soil shape file, land use land cover shape file, stations shape file data were collected from Ministry of Water, Irrigation and Energy. Meteorological data (rain fall and temperature) were collected from National Meteorological Agency. The meteorological data was used for characterization of the study area where as hydrological data was manipulated for flood frequency analysis. Generally, this study work used the following Work Frame.

Study work flow chart

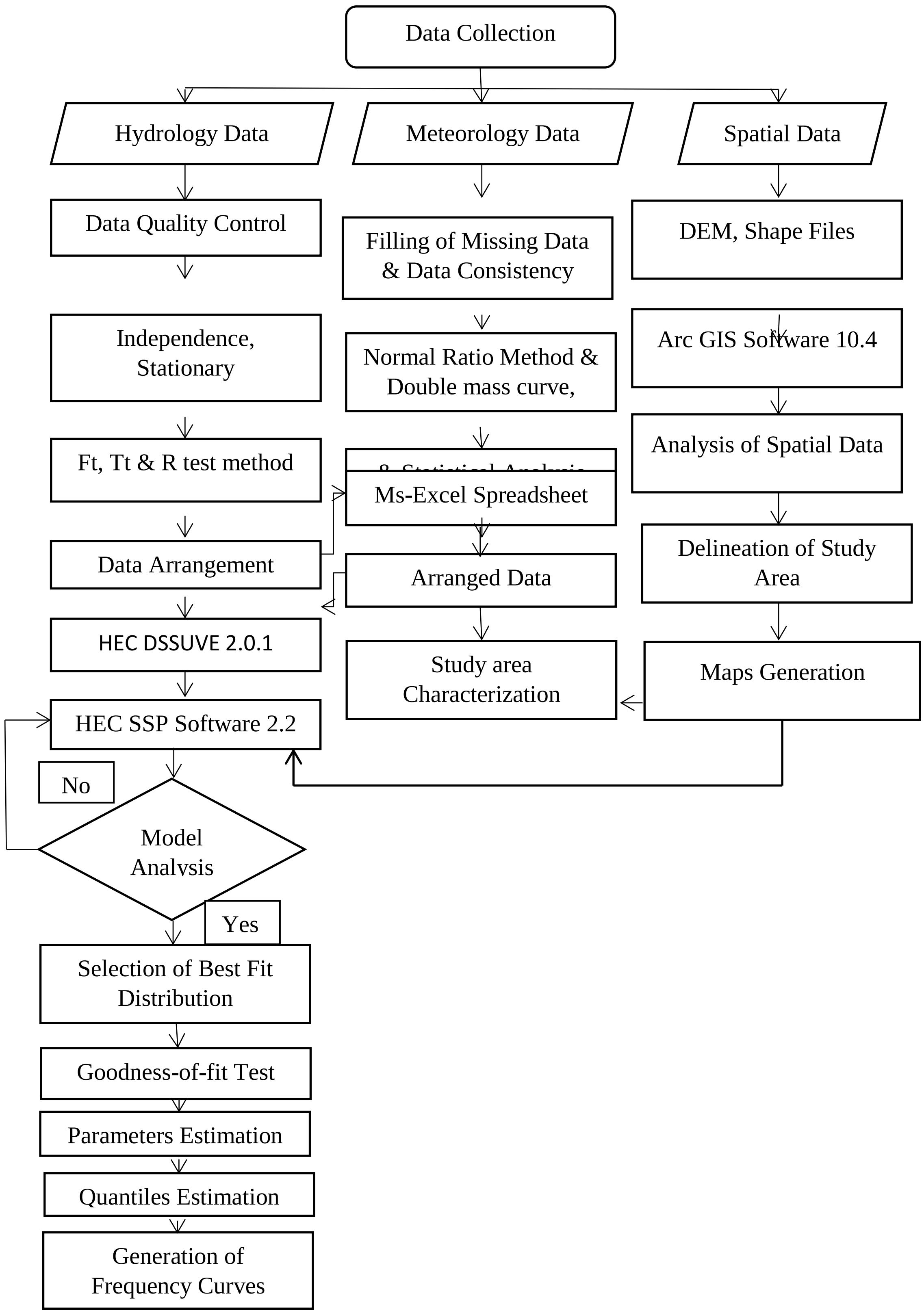


Figure 6 Flow Chart of the Study Work

3.4 Data Analysis

3.4.1 Meteorological Data

The Meteorological station selected based on the stations representativeness of the study area, the long term data availability and percentage of missing data. Based on data availability Adama, Robe Arsi, Kullumsa, Awash 7 kilo and Nura hera meteorological stations data were used. The rainfall and temperature data have 30 years (1990 to 2019) record lengths. For the purpose of this study sites with less than 10% missing data were selected.

Table1 Selected Meteorological Stations Missed Record Percentage

Station Id	Station name	UTM Coordinate system		Length of record	Total recorded year	Missed Record (%)
		Latitude	Longtude			
SHNAZE 11	Adama	945887	531253	1990-2019	30	1.67
SHAWAS 13	Awash 7kilo	993858	628062	1990-2019	30	7.5
ARKULLU 11	Kullumsa	886070	517521	1990-2019	30	1.11
ARROBE 21	Robe Arsi	871304	568896	1990-2019	30	2.5
SHNURA 11	Nura hera	958456	585262	1990-2019	30	6.11

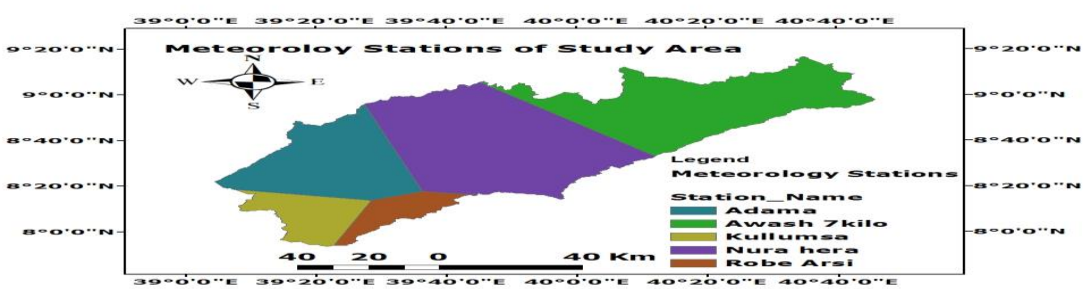


Figure 7 Map of selected Meteorological stations in the study area

A. Filling of missing rain fall data

The analysis focused on rainfall and temporal and inter-annual variability of the sub-basin. Missing data was filled using normal ratio method. The normal ratio method was used to compute missing data a rainfall stations in relation to the data of a nearby rainfall station.

$$Px = \left(\frac{px}{n}\right)\sum_{i=1}^{n}\left(\frac{Pi}{pi}\right) \text{ --- } (3.1)$$

Where Px is missed value of rainfall, px and pi are annual average rainfall at a station with missing value and neighboring gauges respectively, Pi is the rainfall in the neighboring gauge and n is the number of neighboring stations.

B. Rainfall data consistency test

After the filling of missing data were performed at all meteorological stations data consistency have tested using double mass curve analysis method. Double mass curve is the best method to test data for consistency; this method is applicable by comparing the cumulative of multiple stations average of annual flow with that of the cumulative of single station and drawing the graph by putting cumulative of single station on Y-axis and cumulative of multiple stations average of annual flow on X-axis, and checking whether they aliened in a single straight line or not. In this study for the consistency test similar data record was deployed.

Accordingly all meteorological stations double mass curves analysis result were aliened in a single straight line with coefficient of determination (R^2) value 1. The consistency requirement means that each rain fall occurs under more similar hydrological conditions.

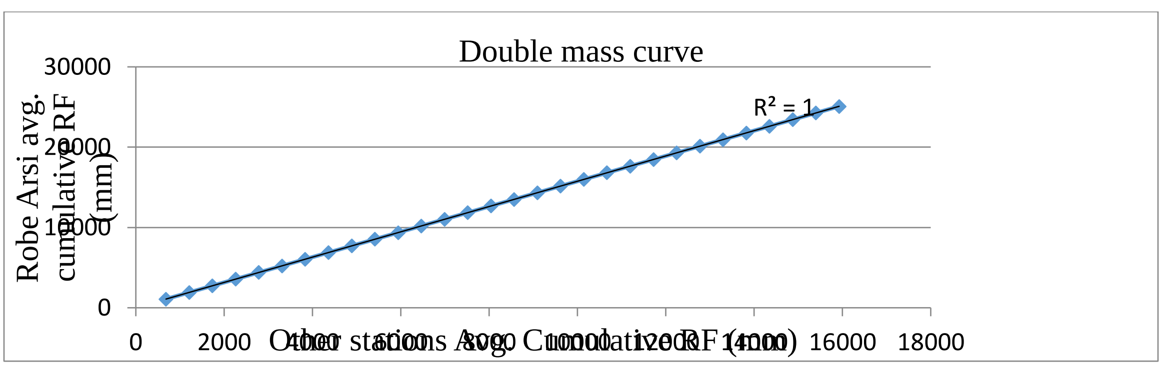


Figure 8 Robe Arsi rainfall data Vs other stations consistency test result

C. Rainfall of the study area

The mean monthly rainfall of the selected representative stations in the Awash-Awash sub basin varied from 7.4 to 251.3 mm in the period 1990–2019. Comparatively, the monthly rainfall was low from October to February, but started to increase in March. Moreover, relatively intensive rainfall was received between June and September, with the maximum mean monthly rainfall received in July at the Robe Arsi station. The minimum monthly rainfall was recorded at Nurahera station in December and in all stations the lowest rainfall occurred in November and December.

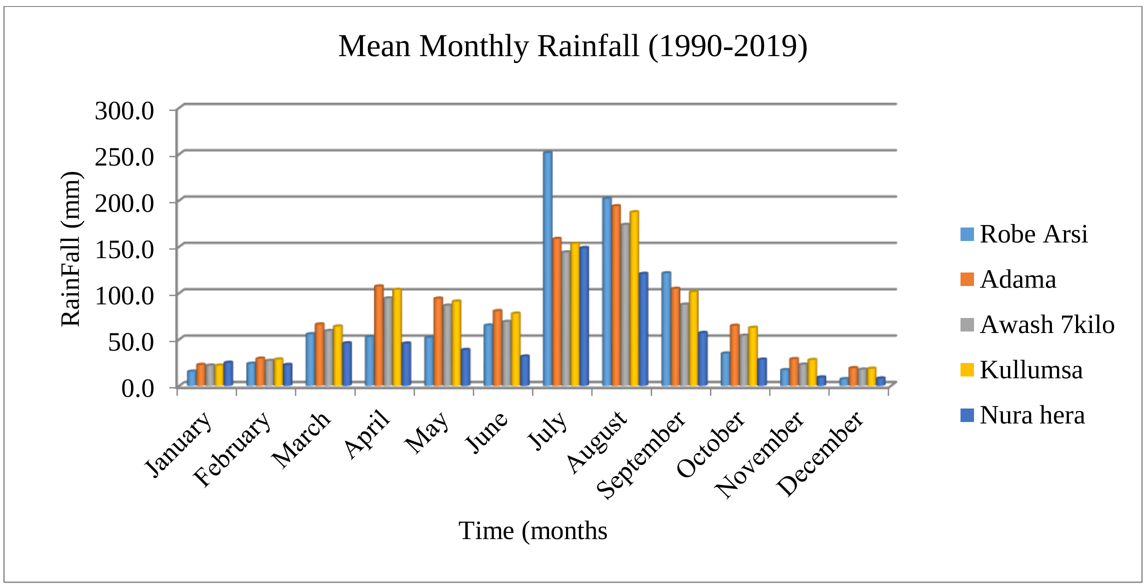


Figure 9 Mean Monthly Rainfalls (mm) of the Study Area (1990-2019)

As shown below on the figure 8, the annual rainfall variability of the selected rainfall stations in Awash-Awash sub basins are varied from 1310.1mm to 103.3 mm. the highest value is recorded at Robe Arsi meteorological station in 1998 and lowest value is recorded at Awash 7kilo meteorological station in 2019 respectively. The general 30 years observed annual rainfall trend shows decreasing but the occurrence of high magnitude rainfall shows continueing.

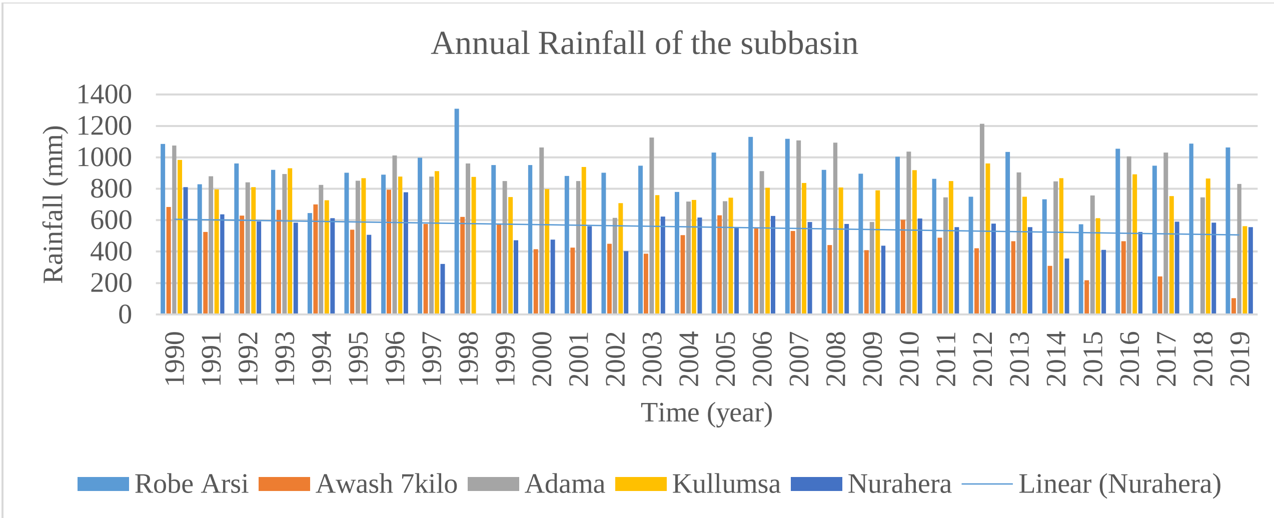


Figure 10 Annual Rainfalls (mm) of Selected Meteorological Stations

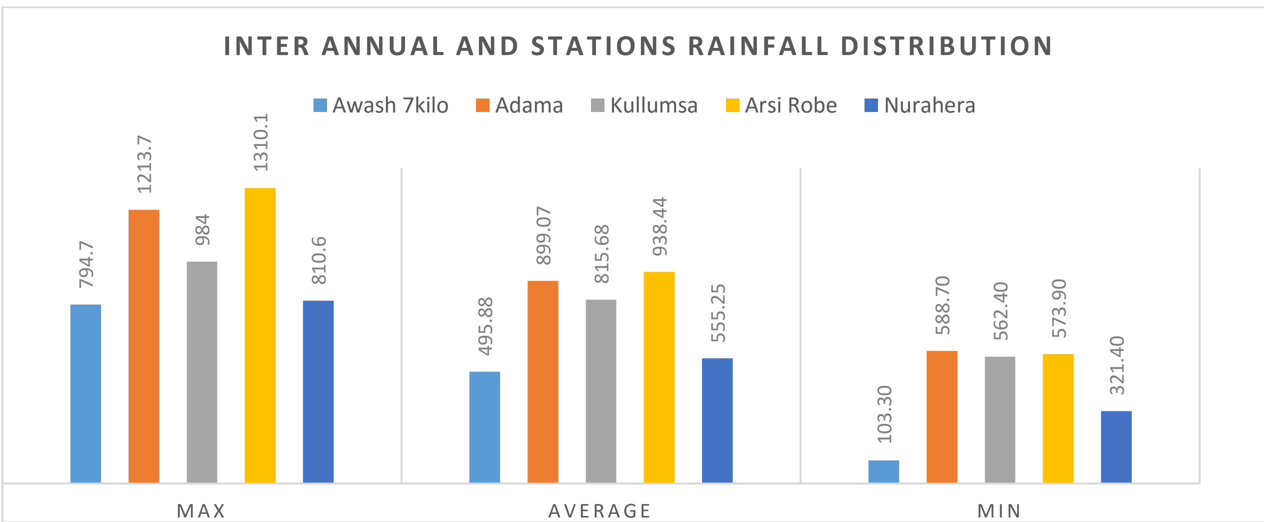
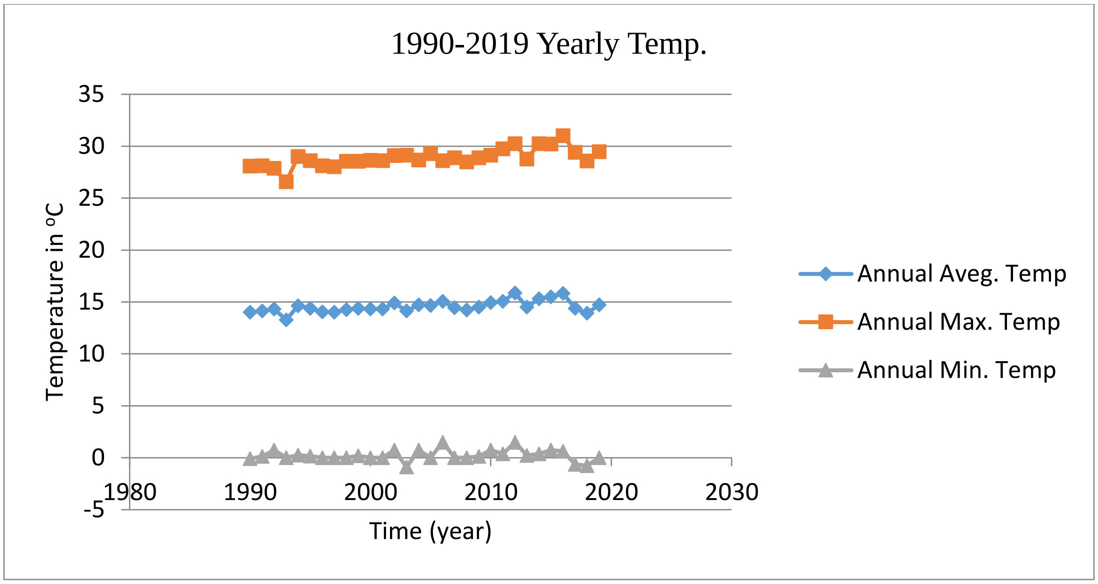


Figure 11 Rain fall Statistics of Selected Meteorological stations throughout the study Area Since (1990-2019)

D. Temperature of the study area

In the study area, the minimum yearly temperature record is -1.2 ^{o}C during 2003 at Robe Arsi and the maximum yearly temperature record more than 30 ^{o}C during 2016 at Awash 7kilo, Adama and Nurahera. The general trends of the temperature analysis result indicate increasing in both tips (- & +). This may result unfamiliar day time hot and night time cold during the extreme temperature.



While the long term (1990-2019) all stations monthly average temperature of the study area summarized as the figure below

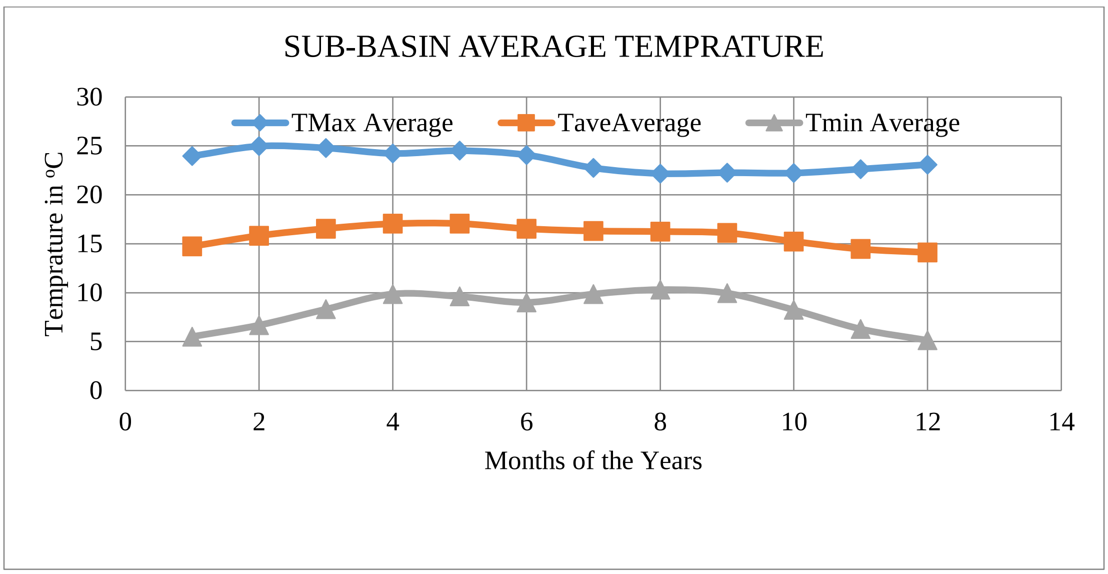


Figure 12 Monthly average temperature of the sub basin

3.4.2. Hydrological Data

Awash below Koka, Awash @ wenji, Awash @ metahera, Awash @ Awash 7kilo, Awash @Melka sedi, Arba @ Abomsa and Keleta @ Sire hydrological stations were selected based on the stations representativeness of the study area, the long term data availability and percentage of missing data.

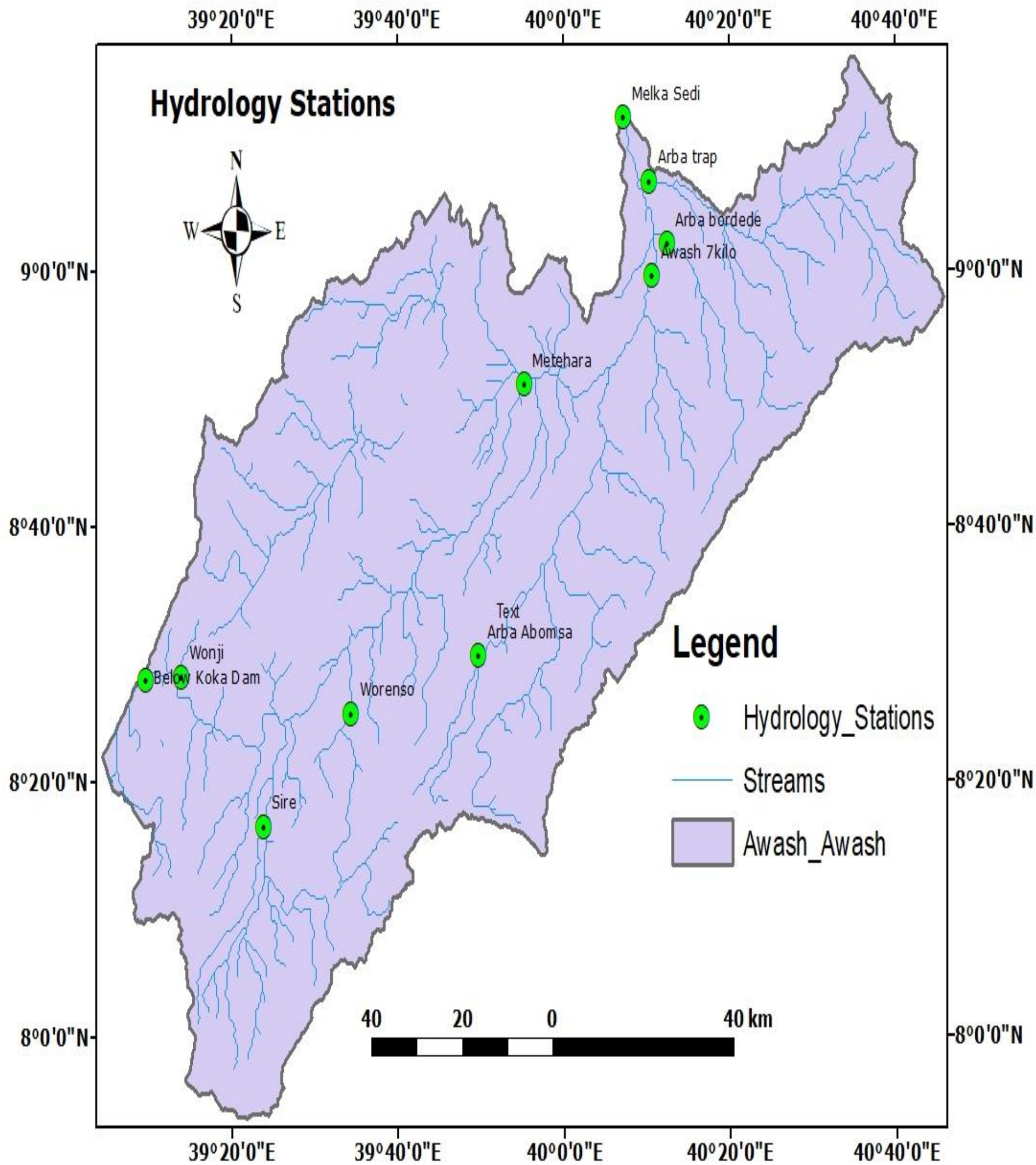


Figure 13 Hydrology Stations Map

The stream flow data record length was 18 to 44 years (1970 to 2013). For the purpose of this study sites with less than 10% missing data were used.

Table 2 Selected hydrological stations missed data percentage

Station name	Number of data in year	Missed daily data record	Daily recorded data count	Missed data percentage
Awash @ 7kilo	39	187	14236	1.31
Arba @ Abomsa	18	210	6574	3.19
Awash @ Metahera	32	442	12078	3.66
Awash @ Wenji	32	499	11681	4.27
Keleta @ Sire	21	134	7666	1.75
Awash Below Koka	44	663	16054	4.13
Melka sedi	27	630	9720	6.48

Table 3 Selected Hydrological stations

Station Selected on Awash Main River						
Station Id	River Name	Hydrological Station name	UTM Coordinate System		Length of record	Total recorded year
			Latitude	Longtude		
32003	Awash	Awash @ Metahera	629815	994848	1982-2014	32
32004	Awash	Awash @ 7kilo	518127	936637	1975-2013	39
31016	Awash	Awash @ Wenji	601325	978626	1985-2016	32
32015	Awash	Melka sedi	384446	100425	1983-2009	27
31017	Awash	Awash below koka	525361	938001	1970-2013	44

Stations on Selected Tributary Rivers						
Station Id	River Name	Hydrological Station name	UTM Coordinate System		Length of record	Total recorded year
			Latitude	Longtude		
32002	Arba dima	Arba @ Abomsa	589870	947040	1993-2010	18
31015	Keleta	Keleta@sire	543760	914817	1990-2010	21

3.4.2.1 Hydrological Data Quality Analysis

The error of standardized quantile estimation may not be significant since the sub basin is proved to be hydrological homogeneous. The correctness of the estimation of the at site mean flood value depends highly on the sample size. In most cases risk is associated with insufficient data or small sample size. The availability of data is very crucial in the sub basin perspective for the water resource planning, development and management. The stream flow data quality assessed using screening of the daily flow observations allow visual detection of whether the observations have been consistently or accidentally credited to the wrong day, or whether they contain misplaced decimal points. Visual observation of the daily flow records implied on minor errors such as overstated numbers, misplaced decimal points, and very high flow records during dry months and/or very low flow records during rainy months.

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

$De = Cv/N^{0.5}$……..….…….…………….....……………………..………………. (3.2)

Where, De - Standard error

Cv - Coefficient of variation and

N - Number of yearly data in the series

The accuracy of statistical mean is a function of the sample size. The data taken for analysis were checked for its adequacy and reliability. Accuracy and adequacy of data were checked and the data series could be regarded as reliable and adequate if De is less than 10% significance level. The results were summarized in the table below.

Table 4 Recorded Flow Data in accuracy and Adequacy analysis Result

Site name	Cv	N	De	Remark
Arba @ Abomsa	0.40	18	0.099	Below 10%
Awash @ Awash 7kilo	0.293	39	0.059	Below 10%
Awash @ Metahera	0.29	32	0.058	Below 10%
Awash @ Wenji	0.191	32	0.039	Below 10%
Awash Below Koka	0.256	44	0.051	Below 10%
Awash @ Melka sedi	0.316	27	0.063	Below 10%
Keleta	0.438	21	0.098	Below 10%

Hence, the data of stations are found accurate, adequate and reliable as De value for all of the stations is less than 10% of standard error.

I. Randomness or Independence Test

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 FFA 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 inter-site correlation has a considerable effect on the variance of 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 test was applied to verify the independence of the data of the selected hydrological stations. According to (Dahmen and Hall, 1990), the lag-1 serial correction coefficient, R1, defined as follows:

$$R1 = \left[\left(\frac{\sum(\mathrm{Xi-Xm})(\mathrm{Xi+1-Xm})}{\sum(\mathrm{Xi-Xm})^2}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where

Xi is an observation,

Xi+1 is the following observation,

Xm is mean of observed data and

n is the number of data.

After computing R1, the test hypothesis is that H0: R1= zero (that there is no correlation between two consecutive observations) against the alternative hypothesis, H1: R1<> 0.

Anderson (1942) defines the critical region, R1 at the 5% level of significance as: (−1, (LCL) R1 (UCL), 1) and equation 3.4 gives:

The upper confidence limit, UCL, for R1 as:

$$UCL\ (R1) = \frac{[-1+1.96*(N-2)^{0.5}]}{N-1} \quad (3.4)$$

The lower confidence limits, LCL, for R1 as:

$$LCL\ (R1) = \frac{[-1-1.96*(n-2)^{0.5}]}{n-1} \quad (3.5)$$

To accept the hypothesis H0: R1=0, the value of R1 should fall between the UCL and LCL. Applying this condition to the time series, we see that the condition: LCL (R1) <R1< UCL (R1) is satisfied for the all stations.

Table 5 Independence Test Results of Flow Data

Station Name	R1	UCL (R1)	LCL (R1)
Awash Wonji	0.09638032	0.32315	-0.39212
Awash Metahera	0.302577	0.309776	-1.36099
Awash 7kilo	0.11748915	0.287427	-0.34006
Awash Melka sedi	0.307270429	0.338462	-0.41538
Arba Abomsa	0.380369687	0.402353	-0.52
Awash Below Koka	0.01117039	0.272145	-0.31866
Keleta sire	0.354724836	0.377172	-0.47717

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 Awash Below Koka station -0.31866<0.0112<0.272 and the other stations are given in Table 4 and the results show that the annual maximum flow series for all stations were independent.

II. Data Stationary Test

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.

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 stream flow 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:

$$\mathrm{Ft} = (\text{Variance of time series 1})/(\text{variance of time series 2}) \ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

According to this method, the variance of the time series is stable if and only if: F (V1, V2, 2.5%) < F < (V1, V2, 97.5%),

Where

V1= n1-1, V2=n 2-1, and n1= n2 is 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 nonoverlapping subsets of the time series (Dahmen and Hall, 1990). The same subsets from the Ftest are used for calculations of the t-test values. The statistic t-test (Tt) is given as:

$$Tt=((Xm\ series1-Xm\ series2) / (n1-1)S_1^2+(n2-1)S_2^2)*1/(n_1+n_2-2)*(1/n_1+1/n_2)^{0.5} \ldots (3.7)$$

Where

$\bar{x}$ = Xm: 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%) < Tt< 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 {V1, V2, 2.5%} and F {V1, V2, 97.5%} values for 5% significance level as Appendix-B. For the station having year are listed using V1, V2 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 here and shows that mean and variance of the time series data was stable. This properties or characteristics of the samples do not fluctuate with time. Linear trend test determined this property of sample.

Table 6 Table 6 Hydrological Data Stability Analysis Result

Station Name	**Series1**	**Series 2**	**V1,V2**	**Ft 2.5%**	**Ft**	**Ft 97.5%**	**V**	**Tt 2.5%**	**Tt**	**Tt 97.5%**
Awash Below koka	1970-1991	1992-2013	21,21	0.206	0.351	2.46	44	-2.02	-4.739E-07	2.02
Awash @ Wonji	1985-1999	2000-2014	14,14	0.336	0.715	2.98	30	-2.04	3.166E-06	2.04
Awash @ Metahera	1982-1998	1999-2014	16,15	0.379	0.670	2.71	33	-2.04	-8.893E-03	2.04
Awash 7kilo	1975-1994	1995-2013	19,18	0.385	1.161	2.6	39	-2.02	-1.464E-06	2.02
Melka sedi	1983-1994	1995-2009	13,12	0.309	0.750	3.21	27	-2.04	-7.851E-07	2.04
Arba @ Abomsa	1993-2001	2002-2010	8,8	0.226	3.914	4.43	18	-2.1	1.108E-04	2.1
Keleta @ sire	1990-2000	2001-2010	10,9	0.265	2.586	3.96	21	-2.09	1.175E-05	2.09

As the analysis result indicated that, the F-test for variance stability and T- test for mean stability values are laid with in the accepted range settled both for F-test and T-test of 2.5% and 97.5% confidence limit as per (Dahmen and Hall, 1990).

3.4.2.2 Test for Outliers

An outlier is an observation that deviates a lot from the bulk of the data may be due to errors in data collection, daily flow records implied no minor errors such as inflated numbers, misplaced decimal points, very high flow records during dry months and or low flow record during rainy months or due to natural causes. The presence of outliers in the data causes difficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis

Outliers can be identified visually by plotting the data or by a variety of statistic tests like Grubbs T- test, Grubbs and Beck (G-B) test, Dixon's test of ratios and Youden's rank test. For this study used the Grubbs T-test.

Grubbs' test can be used to test the presence of one outlier and can be used with data that is normally distributed (except for the outlier) and has at least 7 elements (preferably more).

Here, the author tests the null hypothesis that the data has no outliers vs. the alternative hypothesis that there is one outlier. The Generalized Extreme Student zed Deviate Test (ESD test) should be used if there is the possibility of more than one outlier. If you suspect that the maximum value in the data set may be an outlier you can use the test statistic

$$G = \frac{x_{max} - \bar{x}}{s} \quad \text{--- (3.8)}$$

If you suspect that the minimum value in the data set may be an outlier you can use the test statistic

$$G = \frac{\bar{x} - x_{min}}{s} \quad \text{--- (3.9)}$$

The critical value for the test is

$$G_{crit} = \frac{(n-1)t_{crit}}{\sqrt{n\left(n-2+t_{crit}^2\right)}} \text{ --- (3.10)}$$

Where t_{crit} is the critical value of the t distribution T $(n-2)$ and the significance level is α/n. Thus the null hypothesis is rejected if $G > G_{crit}$.

There is also a two-tailed version of the test where G is the larger of the two G values described above and G_{crit} is defined as above except that the significance level for t_{crit} is $\alpha/(2n)$. Alternatively, G can be calculated using the formula

$$G = \frac{\max|Xi - xm|}{s} \text{ --- (3.11)}$$

Statistic Grubbs T test is calculating as:

$$G = \left(\frac{X - \bar{X}}{S}\right) \text{ – (3.12)}$$

Where X - observed mean monthly flow,

$\bar{X}$ - Mean of observed monthly flow, and

S - Standard deviation.

As the outliers analysis result indicated there is no outliers in the data series and significant variation in the data records of the study area. in data collection, daily flow records implied no minor errors such as inflated numbers, misplaced decimal points, very high flow records during dry months and or low flow record during rainy months or due to natural causes. The presence of outliers in the data causes difficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis

Outliers can be identified visually by plotting the data or by a variety of statistic tests like Grubbs T- test, Grubbs and Beck (G-B) test, Dixon's test of ratios and Youden's rank test. For this study used the Grubbs T-test.

Grubbs' test can be used to test the presence of one outlier and can be used with data that is normally distributed (except for the outlier) and has at least 7 elements (preferably more).

Table 7 Significance level of data outliers

Parameters	Awash @ Melka sedi	Awash @ Awash 7kilo	Awash Below Koka	Awash @ Metahera	Awash @ wenji	Keleta	Arba @ Abomsa
Mean	230.67	354.10	186.01	174.56	154.33	124.87	25.04
St.dev	97.75764	179.12	146.46	52.56	79.58	80.23	15.71
Minimum	104.59	123.61	42.47	91.22	59.35	38.31	8.43
Min Outlier G=	1.289736	1.29	0.98	1.59	1.19	1.08	1.06
Alpha =	0.05	0.05	0.05	0.05	0.05	0.05	0.05
sample size	27	39.00	44.00	33.00	32.00	21.00	18.00
Sig value(p)	0.000926	0.00	0.00	0.00	0.00	0.00	0.00
Deg. Freedom	25	37.00	42.00	31.00	30.00	19.00	16.00
t-critical	3.480946	3.23	3.25	3.22	3.21	3.20	3.20
G-critical	2.858923	2.86	2.91	2.79	2.77	2.58	2.50
significance	No	No	No	No	No	No	No

As the analysis result indicated that, $G_{critical}$ value is greater than minimum outlier (G) therefore the null hypothesis has accepted and the p values for all stations are zero. This means the data collected in the hydrological stations are highly correlated to each other. Since as a statistical rule thumb the significance value (p) should be less than or equal to alpha value (i.e 0.05).

3.5 Methods of Flood Frequency Distribution and Best fit distribution

HEC-SSP software has its own frequency distribution (i.e probability-probability plot and Quantile-Quantile plots) and its own distribution fitting methods in frequency analysis system using standard product moments (MoM) method and L- moment method with Kolmogrov Smirnov and Chi square goodness of best fit test statistics.

a) **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 may reveal a systematic 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.

b) 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 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.

Based on the above plots the behavior of the tail can be described as normal or heavy or light tail depending on the shape of the distribution. In the case of Awash sub-basin flood frequency analysis distributions in upper tails are identified as normal and heavy ones. The tail of the distribution can be identified by the plots of the above mentioned relationships taking in consideration the following conditions.

3.6 Distribution Tail Analysis

Normal tail - Exponential Q-Q plot - upper tail points tend towards straight line - Pareto Q-Q plot - upper tail points tend to bend downwards - UH plot - the slope in the upper tail becomes towards the zero value.

Heavy tail - Exponential Q-Q plot - upper tail points tend towards straight line - Pareto Q-Q plot - upper tail points tend to bend downwards - UH plot - the slope in the upper tail becomes towards the zero value

When a theoretical distribution has been assumed, the validity of the assumed distribution may be verified or disproved statistically by goodness of test (Ang and Tang, 1975 a). The results of the goodness of fit tests are used to select a distribution for frequency analysis of hydrological data. These parameters are used to indicate the fitness of the distribution the variables to the line of best fit.

3.7 The Model Frequency Distribution Test Tools

A. Kolmogorov-Smirnov Test

The test statistic in the Kolmogorov-Smirnov test is extremely simple; it is now the maximum vertical distance among the empirical cumulative distribution functions of the two samples. The empirical cumulative distribution of a sample is the proportion of the sample values that are a lesser amount or equal to a known value.

Kolmogorov-Smirnov (KS) test is a different and commonly used goodness-of-fit moreover Chi square test.

A Statistic based on the deviations of the sample distribution function FN(X) is use in this test. The test statistic DN is defined in equation;

$$DN = \max |Fn(xi) - FO(xi)| \quad \text{--} \quad (3.13)$$

$$1 \leq I \leq n$$

The values of FN (x) are predictable as Nj/N where Nj is the cumulative number of sample events in class j. F0(x) is then 1/K, 2/k…..etc, Similar to the chi-square test. The value of DN must be less than a tabulated value of DN at the specified confidence level for the distribution to be received (Dessalegn, 2016).

Hypothesis Testing

The Kolmogorov-Smirnov test is a hypothesis test method for formative if two samples of data are from the similar distribution. The test is non-parametric and completely nonbeliever to what this distribution really is. The truth that by no means have to know the distribution the samples come from is extremely helpful, particularly in software and operations where the distributions are durable to convey and complex to compute through.

B. Chi-Squared Test

Chi-Square 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 Chi-Square goodness of fit test, the word goodness of fit is used to contrast the observed sample distribution with the estimated probability distribution. Chi-Square goodness of fit test determines how fine theoretical distribution (such as normal, binomial, or Poisson) fits the experimental distribution. In Chi-Square goodness of fit test, sample data is separated into intervals. Then the numbers of points that lay into the interval are compared, with the predictable numbers of points in every interval.

Procedure for Chi-Square Goodness of Fit Test: Put up the hypothesis for Chi-Square goodness of fit test:

i. Null hypothesis: In Chi-Square goodness of fit test, the null hypothesis assumes that there is no importantly variation between the observed and the expected value.

ii. Alternative hypothesis: In Chi-Square goodness of fit test, the alternative hypothesis assumes that there is an importantly variation between the observed and the expected value.

$$X^2 = \sum \left(\frac{(O-E)^2}{E}\right) ------------------------ 3.14$$

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

O= observed value

E= expected value

Degree of Freedom: In Chi-Square goodness of fit test, the degree of freedom depends on the distribution of the sample.

Hypothesis testing: Hypothesis testing in Chi-Square goodness of fit test is the unchanged as in other tests, like t-test. The considered value of Chi-Square goodness of fit test is compared with the table value. If the considered value of Chi-Square goodness of fit test is bigger than the table value, will throw out the null hypothesis and conclude that there is an important differentiation between the observed and the expected frequency. If the considered value of Chi-Square 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.

Intended for a chi-square goodness of fit test, the hypotheses take the following form

H0: The data are dependable with a specified distribution

Ha: The data are not dependable with a specified distribution.

Characteristically, the null hypothesis (H0) specifies the amount of observations at each level of the definite variable. The alternative hypothesis (Ha) is that at smallest amount one of the specified proportions is not true.

P-value: The P-value is the probability of observing a sample statistic as great as the test statistic. As the test statistic is a chi-square, employ the Chi-square distribution to review the probability related with the test statistic.

C. The Coefficient of Determination (R^2)

R^2 is used to analyze how differences in one changeable can be explained by dissimilarity in a second variable. The coefficient of determination is comparable to the correlation coefficient R. The correlation coefficient procedure will tell you how well-built of a linear association there is among two variables. R Squared is the square of the correlation coefficient r (hence the term r squared).

The goodness-of-fit was well supplementary tested applying Coefficient of determination (R^2) test on the fitted distribution to choose the best fit distribution.

3.8 Evaluation of Model performance for Goodness-of-fit Tests

HEC-SSP employs Kolmogrov Smirnov and Chi square methods of distribution fitting as a software package. So the adequacy of the selected probability distribution models in fitting the observed peak discharge data were evaluated by goodness of fit tests or criteria. The methods are Root Mean Square Error (RMSE), Relative Root Mean Square Error (RRMSE), Mean Absolute Deviation Index (MADI) and Probability Plot Correlation Coefficient (PPCC). The first three methods assess the fitted distribution applied to a site by summarizing the deviation between observed discharges and predicted discharges while the last gives the correlation between the ordered observations and corresponding fitted quantiles determined by a plotting position Abdul Karim, M. et al., (1995). The result of the tests enabled ascertaining how sufficiently close a given distribution fits the observed data and hence the choice from the candidate distributions the one that best fits the observed data.

I. Root Mean Square Error (RMSE)

The root mean square error of a distribution fitted to the observed discharge data at a site is the square root of the sum of the squares of the differences between the observed and predicted values. It is computed using the equation

$$\mathrm{RMSE} = \left(\frac{\sum(\mathrm{xi}-\mathrm{yi})^2}{\mathrm{n}-\mathrm{m}}\right)^{1/2} ------------------------(3.15)$$

where xi , i=1--- n are the observed values and yi, i=1,--,---,n are the values computed from the assumed probability distributions, the number of parameters estimated for the distribution is denoted by m.

II. Relative Root Mean Square Error (RRMSE)

The relative root mean square error (RRMSE) provides a better picture of the overall fit of a distribution. It calculates each error in proportion to the size of observation thereby reducing the influence of outliers which are common features of hydrological data (Tao, D.V., et al., 2008). It is defined as

$$\mathrm{RRMSE} = \left(\frac{\sum\left(\frac{\mathrm{xi}-\mathrm{yi}}{\mathrm{xi}}\right)^2}{\mathrm{n}-\mathrm{m}}\right)^{1/2} ----------------------- (3.16)$$

III. Mean absolute deviation index (MADI)

The MADI is calculated by (Ahmad, U. N. et al., 2011):

$$\mathrm{MADI} = \left(\left(\frac{1}{\mathrm{N}}\right)\left(\sum\left|\frac{xi-yi}{\mathrm{xi}}\right|\right)\right) --------------------------(3.17)$$

Where xi are the observed values, yi the predicted values and N the number of data points. The smaller the value obtained for MADI is for a distribution, the more fitting it is for the actual data Ahmad, U. N. et al., (2011). Thus the distribution with smaller values of MADI indicates that it is more fitted to the observed data.

IV. Probability plot correlation coefficient (PPCC)

The probability plotting correlation coefficient (PPCC) is a measure of the linearity of the probability plot Filliben, J.J., (1975). It gives the correlation between the ordered observations and corresponding fitted quantiles determined by a plotting position (Abdul Karim, M. et al., 1995).PPCC is defined mathematically as Abdul Karim, M. et al., (1995).

$$PPCC = \left(\frac{[\sum(Xi-Xm)(Yi-Ym)]}{[\sum(Xi-Xm)^2\ (Yi-Ym)^2]^{\frac{1}{2}}}\right) ---------------------- (3.18)$$

Where Xm and Ym represents the mean values of the observed and predicted quantiles respectively

A value of PPCC near 1 suggests that the observed data could have been drawn from the fitted distribution at a site.

3.7 Parameters Estimation

There are various methods applied for statistical parameter estimation now a day such as, the Maximum likelihood Method (MLM), the Method of Moments (MOM), and the Probability Weighted Moments Method (PWM), L-Moment methods. However, among the above listed methods of moment; Standard product moment (MoM) and L-moment were used for analyzing the statistical distribution and parameters for this specific study.

3.8.1 Method of Moment

MOM is a natural and relatively easy method but its estimates are usually inferior in quality and are generally not efficient for distributions with large number of parameters (3 or more) because higher order moments are more likely to be highly biased in relatively small samples.

3.8.2 L-moment Method for Flood Frequency Analysis

The L-moments and probability weighted moments are used to summarize theoretical distributions and observed samples thereby making them liable for use in parameter estimation, interval estimation and hypothesis testing (Vogel et al., 1993b). L-moments and L-moment ratios are however more convenient than probability weighted moments because they are more easily interpretable as measures of distribution scale and shape (Hosking, J.R.M.,1994). L-Moment method is a method used to compute statistical distribution and parameters.

L-moment can be written as function of probability-weighted moments (PWMs), L-moments are linear combinations of probability weighted moments and are defined as:

$\lambda 1 = M100$ -- (3.19)

$\lambda 2 = 2M110 - M100$ --- (3.20)

$\lambda 3 = 6M120 - 6M110 + M100$ -- (3.21)

$\lambda 4 = 20M130 - 30M120 + 12M110 - M100$ -------------------------- (3.22)

Where, M100 is the zero[th], M110 is the first, M120 is the second, and M130 is the third probability weighted moments. The L-mean, λ1, is a measure of central tendency which is the same as the conventional mean and the L- moment standard deviation, λ2, is a measure of dispersion, as λ3 and λ4 are third and fourth L-moments. M110 is the expected value of the random variable, x, weighted by its probability of non-exceedence, Pnex. M120 and M130 are the expected values of x weighted by (Pnex)2 and (Pnex)3, respectively. The dimensionless L-moment ratios are defined by Hosking, (1997). as:

$\tau 2=\lambda 2/\lambda 1$ (L-coefficient of variation, L-Cv) ------------------------------ (3.23)

$\tau 3=\lambda 3/\lambda 2$ (L-skewness, L-Cs) --- (3.24)

$\tau 4=\lambda 4/\lambda 2$ (L-kurtosis, L-Ck) -- (3.25)

Estimates of the parameters of the selected distributions were obtained following the Lmoment procedures. ξ is the location parameter, α the scale parameter and k the shape parameter.

3.9 Flood Quantile (Q_T) 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. After the parameters of a distribution are estimated, flood quantile estimates (Q_T) which correspond to different return periods were computed. The major problem of flood quantile estimation stems from type of distribution and availability of observed data for short period of time as compared to extrapolation usually made by upper part of the theoretical curve. The probability that Q_T is equaled or exceeded in any year is assumed to be 1/T. From this follows that the probability of non-exceedence of Q_T for each year takes the form

4. RESULT AND DISCUSSION

4.1 Flood Magnitude

As indicated on figure 15, Extreme stream flow was recorded at Awash 7kilo hydrological station in 2004 and 2011, respectively. A similar increase in flow during these years was shown in all the other stations following the increase of koka dam water release, increase in land use change from forest/bush/grass land to cultivation and settlement both at urban and rural areas and contribution of high volume of flow by Keleta and Arba tributary rivers to Awash river above Awash 7kilo hydrological station. Generally the stream flow hydrograph of almost all station which is derived from observed / real time data series show increasing trends of peak flow magnitude and occurrence.

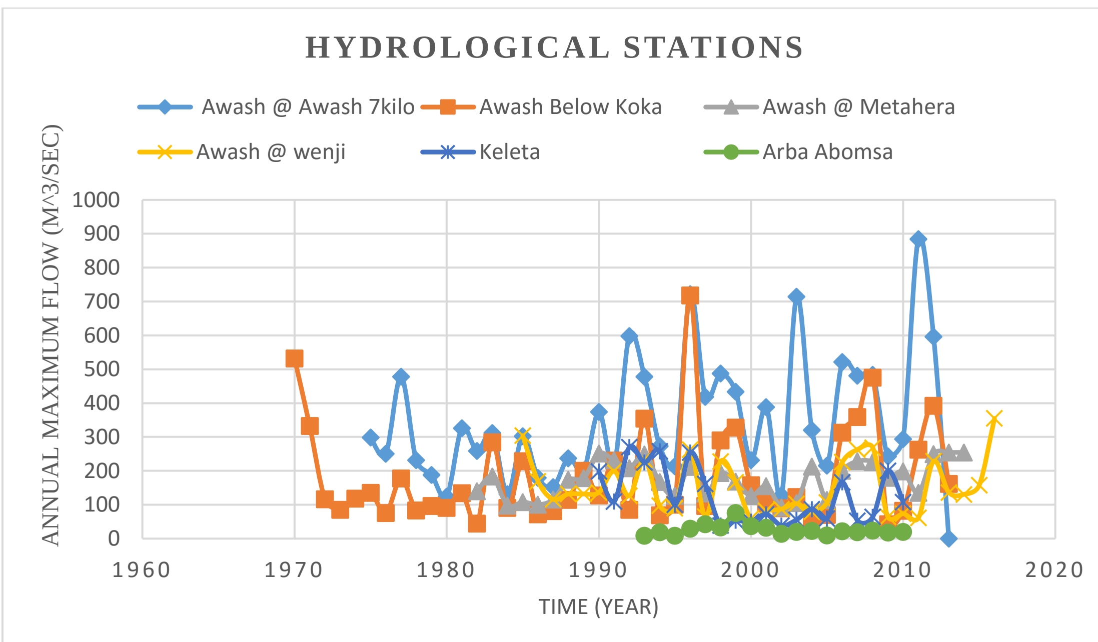
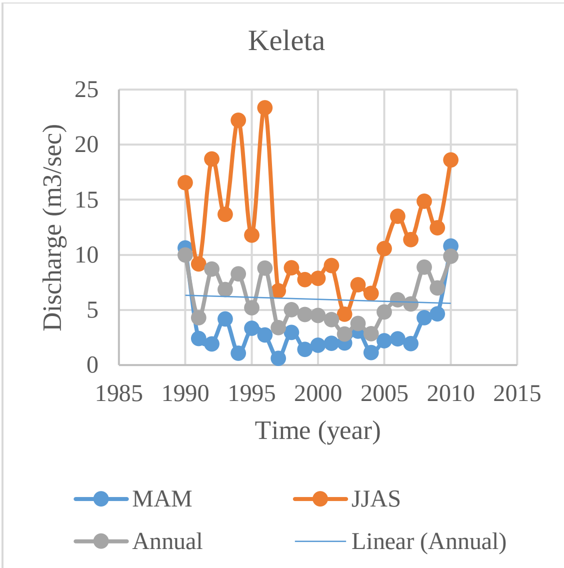
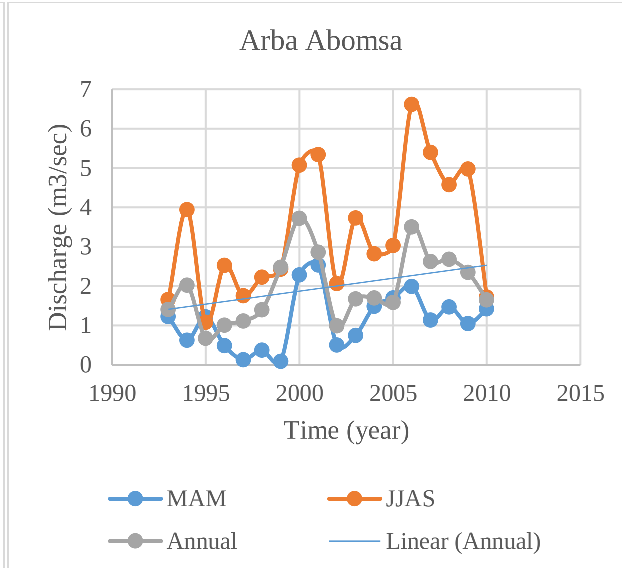
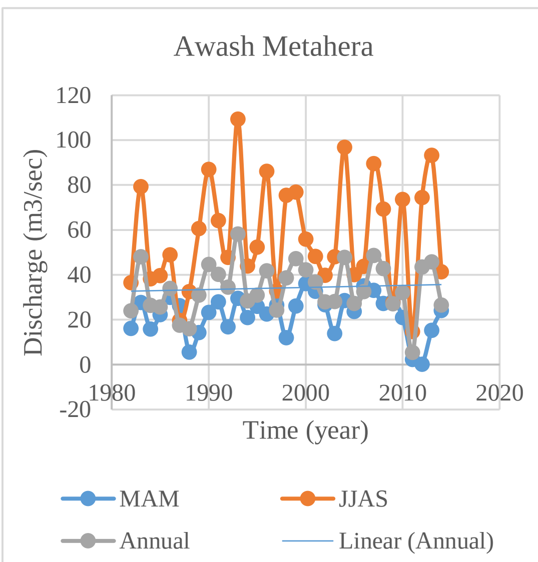


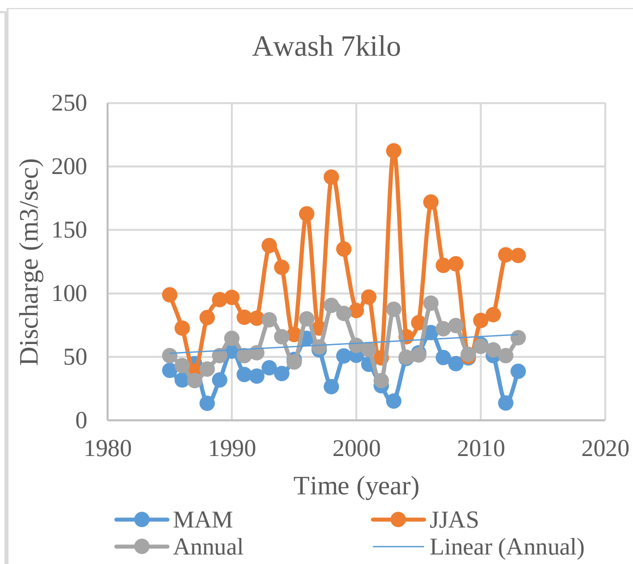
Figure 14 Plots of annual maximum discharges of stations in the Awash-Awash Sub basin

The hydrographs had a similar pattern on annual and kiremt that is June-July-August-September (JJAS) season and belg that is March-April-May (MAM) rainy season river discharge, except for a few years with extremely high flow records.


Keleta
Discharge (m3/sec)
25
20
15
10
5
0
1985 1990 1995 2000 2005 2010 2015
Time (year)
MAM
JJAS
Annual
Linear (Annual)


Arba Abomsa
Discharge (m3/sec)
7
6
5
4
3
2
1
0
1990 1995 2000 2005 2010 2015
Time (year)
MAM
JJAS
Annual
Linear (Annual)


Awash Metahera
Discharge (m3/sec)
120
100
80
60
40
20
0
-20
1980 1990 2000 2010 2020
Time (year)
MAM
JJAS
Annual
Linear (Annual)


Awash 7kilo
Discharge (m3/sec)
250
200
150
100
50
0
1980 1990 2000 2010 2020
Time (year)
MAM
JJAS
Annual
Linear (Annual)

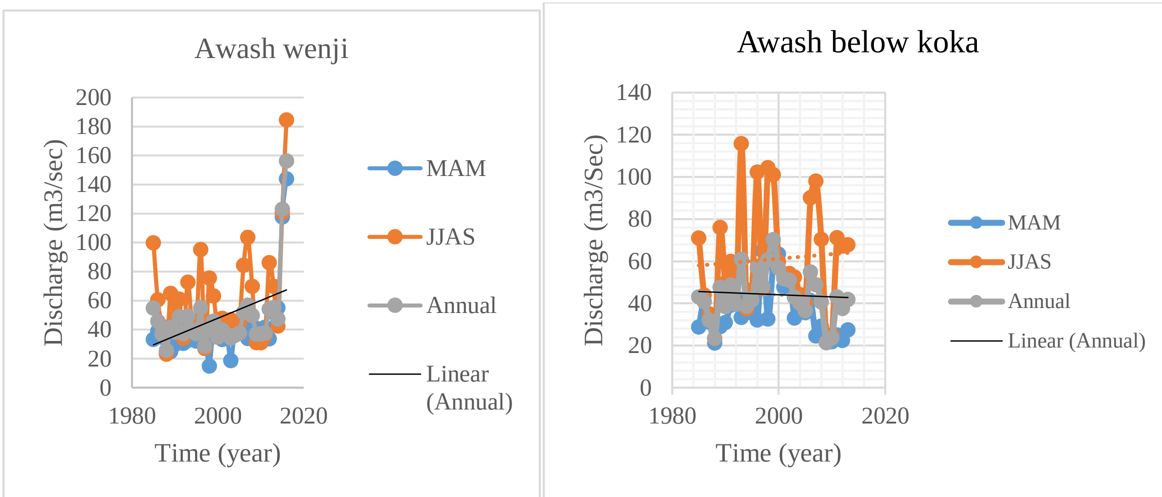


Figure 15 Shows Stream flow variability at all stations

4.1.3 Rain Fall Vs Stream Flow Interaction

The mean monthly rainfall of the selected representative stations in the Awash-Awash sub basin varied from 7.4 to 251.3 mm in the period 1990–2013 while the mean monthly stream flow is varied form 20.22 m3/sec in November to 140.77m3/sec in August in the period of 1990 to 2013. Comparatively, the monthly rainfall and Stream flow were low from October to February, but started to increase in March. Moreover, relatively intensive rainfall and high stream flow were received between June and September, with the maximum mean monthly rainfall received in July at the Robe Arsi met-station while the maximum stream flow recorded at Awash @ Awash7 hydrological station on August. The minimum monthly rainfall was recorded at Robe Arsi in December and in all stations the lowest rainfall occurred in November and December while the minimum monthly stream flow was recorded at Metahera in November and in all stations the lowest stream flow observed in between November to January.

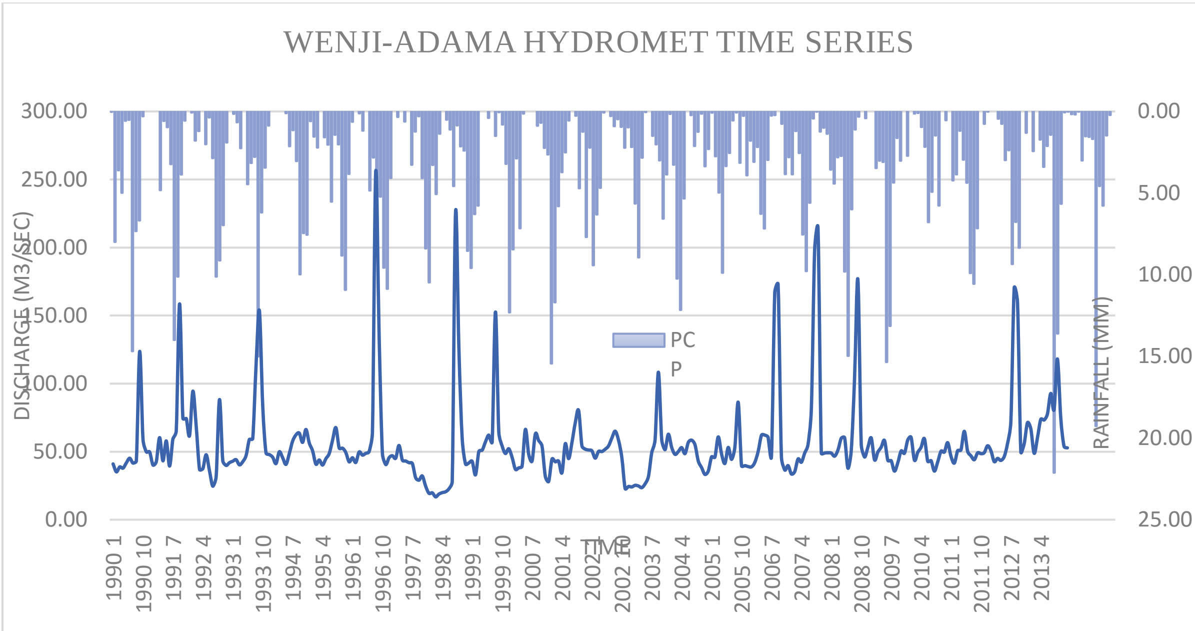


Figure 16 Adama - Wenji Rainfall and stream flow interrelation

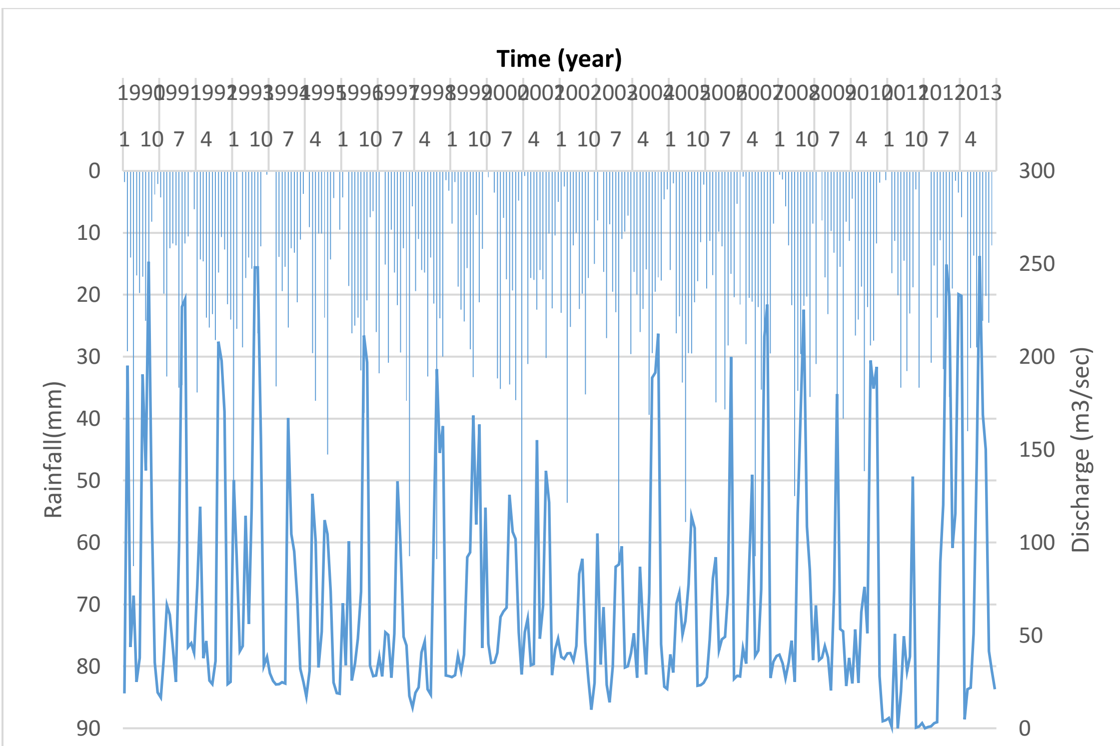


Figure 17 Nurahera - Metahera Rainfall and stream flow interrelation

As the rainfall and stream flow interaction analysis result between Adama meteorological station and Wenji hydrological station as well as Nurahera meteorological station and Metahera hydrological stations indicated that the high stream flow peak follow the high magnitude of rainfalls at both Adama and Nurahera meteorological stations. The stream flow at Metahera hydrology station more likely compatible with Nurahera meteorology station rainfall record while the Adama rainfall data has no more influence on Wenji stream flow peak. This means the wenji site inundation is highly dependent on the koka reservoir water release and upstream koka catchment rainfall influence.

In general view, the sub basin meteorological and hydrological real time series data analysis result indicated that the temperature, precipitation and stream flow peak occurrence are increased. Especially, high magnitude rainfall and stream flow peak event in the sub basin show increasing trend as cause and effect relationship. This means that the increase in rainfall magnitude and peak stream flow are not means the change on the whole system of hydrology cycle in the area. It may be the change on rainfall intensity and distribution both spatially and temporally as the human interference in natural environment increases from time to time in the area.

4.2 Flood Frequency Distribution Result

Hydrological Engineering Corps Statistical Software Package encompasses all frequency distribution (Emperical, gamma, generalized extereme value, generalized pareto, generalized logistic, normal, Ln-normal, Log_{10}-normal, pearson III and Log pearson) analyzing room. Kolmogrov smirnov and Chi square test statistics methods were used as testing and the kolmogrov smirnov produced best fitted result than chi-square methods. 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 the flood models for the basin with both KS and X^2 positive test statistics values which are heavy tail distributions.

Table 8 Comparison of KS & X2 test statistics Result

Name of Stations	Parameters distributions	Kolmogrov Smirnov test statistics	Chi-square test statistics	Degree of freedom (N-2)
Awash below koka	Log-Normal	0.099	9.091	42
Awash Wenji	Log-Pearson III	0.103	2.552	30
Awash Metahera	Generalized pareto	0.074	2.875	30
Awash 7kilo	Generalized pareto	0.083	4.4615	37
Melka sedi	Generalized pareto	0.090	2.074	25
Arba Abomsa	Generalized pareto	0.155	2.327	16
Keleta Sire	Generalized pareto	0.122	3.190	19

The extreme value theory for annual maxima has been applied to discriminate the distribution in the upper tail where the model generated value = 0 classified as the normal tail distribution, while the model generated value > 0 the tail is considered as heavy and the light tail is encountered when the model generated value < 0 as explained in (Willems P.1998). In most cases extreme situations are distinguished either normal or heavy tail as far as hydrological application is commonly concerned. Therefore since the value of KS is less than 0.5 for all the observed data at all stations the distributions were confirmed the acceptable range of Kolmogrov Smirnov threshold.

So that, the (P-P) and (Q-Q) plots results confirmed the upper tail distributions as the models generated values are more than zero in both P-P plots and Q-Q plots results.

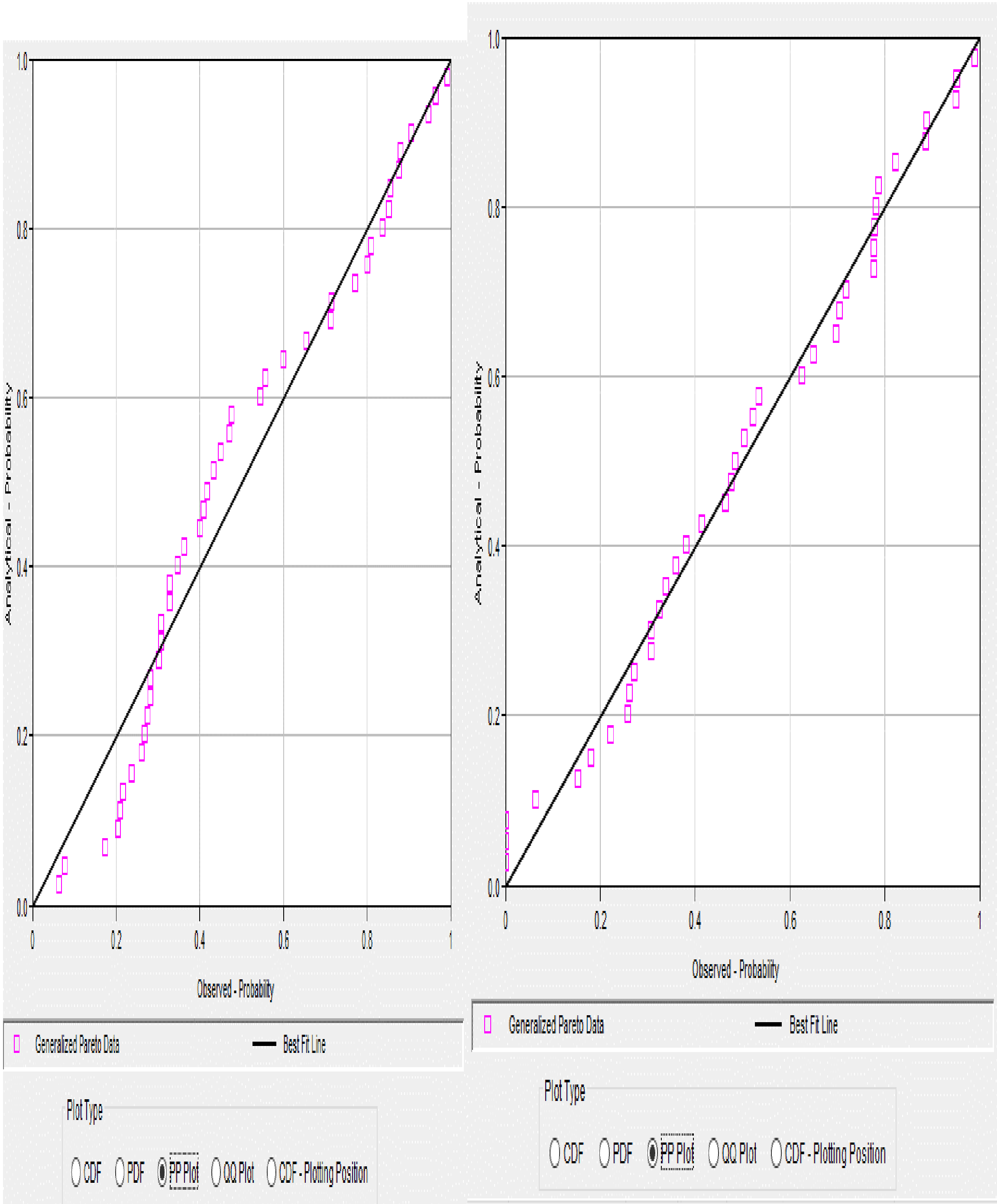


Figure 18 Awash below koka and Awash @ 7 kilo hydrological stations P-P plot

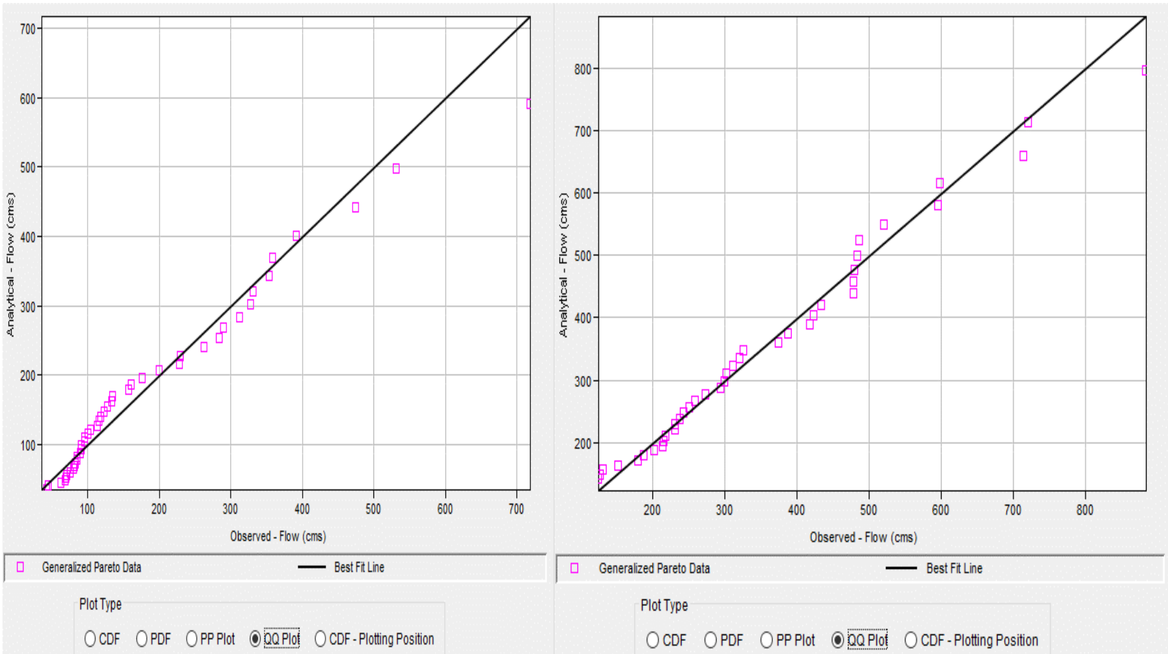


Figure 19 Awash Below koka and Awash @ 7 kilo hydrological stations Q-Q plot

The competence of the selected probability distribution models in fitting the observed peak discharge data were evaluated by goodness of fit tests or criteria.

Table 9 Goodness-of-fit Test Result

Stations Name	Distribution types	Test criterion			
		RMSE	RRMSE	MADI	PPCC
Awash Blow Koka	Log-Pearson III	13.2591	0.02143	3.04812E-05	0.9994
Awash wenji	Generalized Pareto	18.4074	0.04696	0.000155	0.9995
Awash Metahera	Generalized Pareto	21.5304	0.08230	0.0001556	0.9752
Awash 7kilo	Generalized Pareto	30.0321	0.03081	0.0137511	0.9994

Melka sedi	Generalized Pareto	17.7432	0.03460	5.97408E-05	0.9963
Arba Abomsa	Generalized Pareto	1.40846	0.00000	0.00184315	0.9976
Keleta Sire	LN-Normal	23.0896	0.06710	9.78239E-05	0.9926

As the test results indicated in table 7 for all stations data the Mean Absolute Deviation Index (MADI) are very small that is 0.00003 to 0.01. So that, as per Ahmad, U. N. et al., (2011); the distribution with smaller values of MADI indicates that it is more fitted to the observed data. The result of Probability Plot Correlation Coefficients (PPCC) is near to 1 that is (0.98 to 0.99) for all stations as indicated in the table 7. Therefore the selected distribution model is best fitted to the observed data. Thus agree with (Abdul Karim, M. et al., 1995); a value of PPCC near 1 suggests that the observed data could have been drawn from the fitted distribution at a site.

4.3 Parameters Estimation

In this study the observed data has evaluated for statistical parameters descriptively with Method of Moment and L-moment method. The synthesized statistical parameters by method of moment are summarized in table 5. As the standard product moment (MoM) results indicated the distributions are positively skewed which mean the distribution for maximum annual series has confirmed the upper tail end. The negative values of kurtosis indicated that the distribution for Wenji, Keleta and Metahera stream flow of flat distribution with thin tails while the positive values for Awash Below Koka, Awash 7kilo, Melka Sedi and Arba Abomsa stream flow distributions are indicate a platy kurtic distribution analysis result.

Table 10 Statistical Product Moment

Station Name	Product moment				
	Mean	St.dev	Cv	Skewness	Kurtosis
Melka sedi	219.167	84.535	0.386	1.019	0.291
Awash @ Awash 7kilo	354.105	179.120	0.438	0.549	0.850

Awash Below Koka	217.835	102.240	0.506	1.654	1.401
Awash @ Metahera	172.069	51.391	0.299	0.519	-1.256
Awash @wenji	143.837	74.650	0.519	0.571	-0.816
Keleta	111.535	48.868	0.438	0.859	-1.179
Arba @Abomsa	25.044	15.715	0.627	2.007	5.516

So that all the parameters in this study such as the Coefficient of Variation (CV) are ranges from 0.299 to 0.627 and skewness (Cs) are ranges from 0.519 to 2.007. These observation takes together suggests that Annual Maximum Flood are from the population of positively skewed distributions with in allowable range. These observations taken together suggest that annual maximum floods are from population with positively skewed distributions. According to (Leulseged, 2002). Annual Maximum Flood series in general skewed with observed average skewness (Cs) values to the range 0.5 to 3.0 and Coefficient of Variation (CV) values which vary from 0.1 in tropical rainfall climate to around 1 to semi-arid areas.

The L-moment analysis indicate at all stations the observed sample data L-skew values are range from 0.011 to 0.366 thus the positive values of L-skew indicate that the right tails are long compared to the left. The L-kurtosis values are -0.014 to 0.300. The negative value of L-kurtosis at Metahera station (-0.014) is indicates the sample data has flat distribution with thin tail while the positive values indicate heavy tail distribution. Also the L-CV values of all stations data are 0.184 to 0.319 which means the sample data from station to station are moderately variable. As most studies indicate that the L-CV value more than 0.4 the data is susceptible for outliers. Therefore, the sample data is homogenous, independent and stationary to produce reliable flood frequency distribution, parameter and flood quantile estimation.

Table 11 Analysis Result L-Moment Ratios of the software

Name of the stations	L-moment Ratios

	L-Mean	L-CV	L-Skew	L-Kurtosis
Awash below koka	183.165	0.246	0.322	0.186
Awash @ Wenji	146.216	0.296	0.183	0.025
Keleta @sire	116.830	0.251	0.181	0.052
Awash @metahera	168.541	0.175	0.008	-0.014
Arba @ Abomsa	25.044	0.319	0.321	0.300
Awash @ 7kilo	338.523	0.279	0.223	0.118
Melka Sedi	219.167	0.213	0.263	0.133

According to (L-RAP User's Manual, 2011)**.** The negative value of L-skew indicates that the left tail is long compared to the right tail and the fact that if computed L-skewness value lies in the range 0.05 < |L-skewness| ≤ 0.150 suggests that the observed or sample data is moderately skewed (L-RAP User's Manual, 2011)**.** Also, for instance L-CV value of 0.2918 indicates that the sample data is moderately variable (L-RAP User's Manual, 2011)**.** The parameters of location (ξ), scale (μ) and shape (k) of the selected distributions computed using the relevant equation.

Table 12 Results of at-site Estimated Parameters for Best fitted distributions in the sub basin

Name of stations	Best-fitted distribution	Values of parameters			Kolmogrov smirnov test statistics
		Shape (k)	Location (ξ)	Scale (μ)	
Awash Below koka	Log-Pearson III	Mean log 2.15	Stdev log 0.32	Skew 0.22	0.091
Awash @ Wenji	Generalized pareto	0.50	40.60	158.08	0.103

Awash @ Metahera	Generalized pareto	0.96	77.77	177.57	0.074
Awash @ Awash 7kilo	Generalized pareto	0.510	127.250	319.180	0.083
Melka sedi	Generalized pareto	0.262	114.778	131.786	0.090
Arba @ Abomsa	Generalized Pareto	0.00	9.35	15.68	0.155
Keleta @ Sire road	Generalized Pareto	0.254	74.882	104.243	0.122

As indicated in table 10 the shape parameters for all stations with generalized pareto and Log-pearson type III analysis range from 0 to 2.15 which means the distributions have finite upper bound.

It can be seen that for the three distributions (GEV, Log pearson III, Generalized Pareto), the shape parameter (k) values are greater than zero indicating that the distributions have finite upper bound (Hosking, J.R.M and Wallis, J.R., 1997).

4.4 Estimation of Flood Quantile (Q_T)

In most of the recent study, the parameter estimation was done by using the Hydrological Engineering Corps Statistical Software Package (HEC- SSP). Since all the parameters for each station is estimated, then it is possible to determine the quantile with different return periods using HEC-SSP software (Biniyam and Kemal A., 2017).

After all the stations frequency distribution and parameters were determined, the flood quantiles (Q) having a return period of T year were estimated. The observed and simulated data compared and the model has generated the quantile flood values with very small percent differences from the observed data values range from 0.001 to 0.584% but at the sub basin inlet (0.033 to 0.241%) and at out let (0.008 to 0.367%).

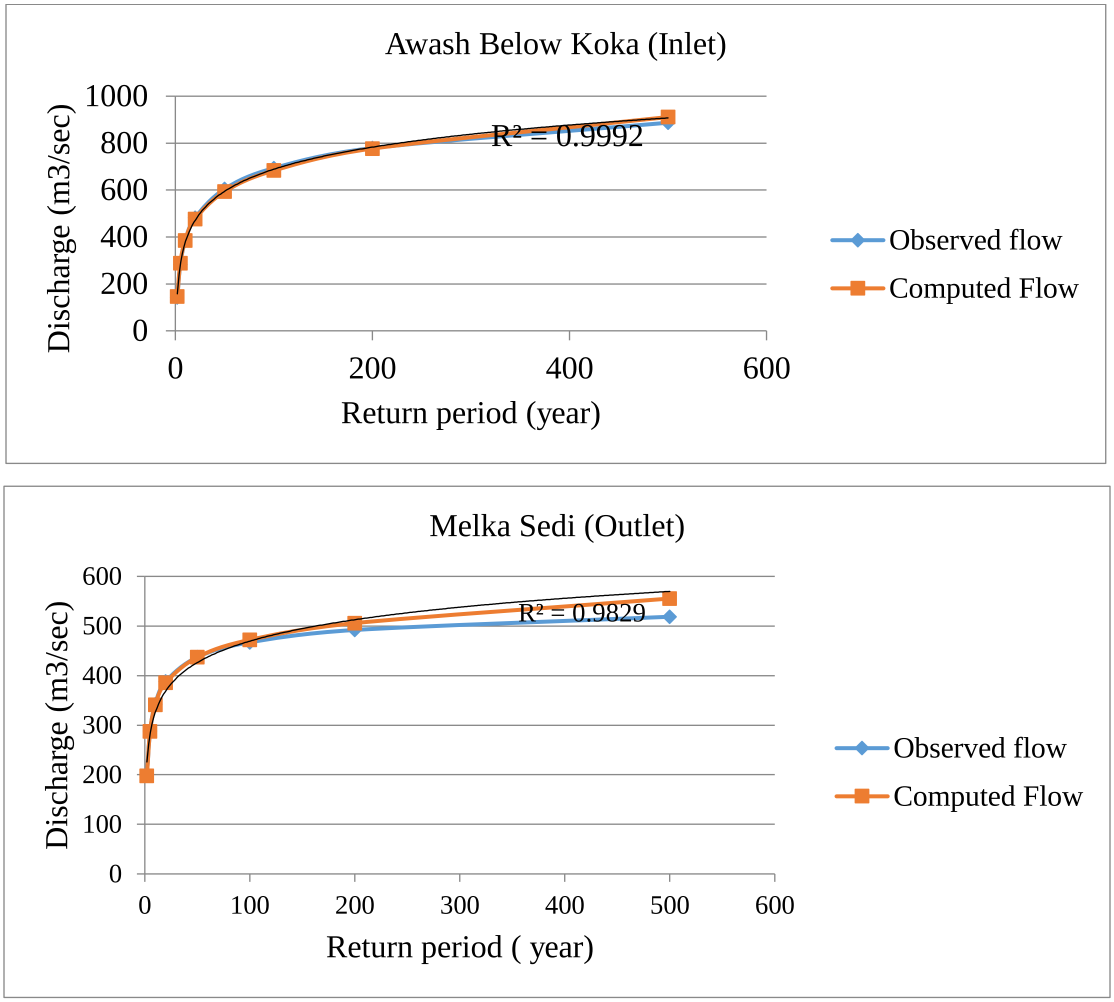


Figure 20 Comparison of Observed and Simulated Flood Magnitude at Inlet &Outlet of the Sub Basin

For all stations, the quantiles of different return periods were determined using HEC-SSP software. Flood quantiles estimation was performed corresponding to the required return periods of 2, 5, 10, 20, 50, 100, 200 and 500 years.

Table 13 Return Period Vs Flood Magnitude in the Sub basin

Return Period	Keleta	Awash Below Koka	Arba Abomsa	Awash Metahera	Awash 7kilo	Awash Wenji	Melka Sedi

2	96.5	145.8	20.7	165.3	311.2	133	197.8
5	167	287.8	35.5	223	478.5	215.8	287.9
10	219.9	385.5	45.7	245.5	559.5	257.5	341.4
20	277	476.7	55.8	259.3	615.8	287.8	386.3
50	371.1	593.2	69.6	271.3	668.5	317.7	438.4
100	457	683.1	81.1	279.8	706.7	336.3	477.2
200	545.9	776.8	93	286.4	741.1	353.9	558.8
500	695.3	911	110.6	295.9	781.4	377.5	595.7

Table 14 Awash Below Koka station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow(cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	142.5	145.8	180.2	115.9
5	20	282.6	287.8	353.6	228.2
10	10	384	385.5	474.3	302.1
20	5	481.4	476.7	594.8	363.8
50	2	604.4	593.2	756.6	426.3

100	1	693.4	683.1	884.6	461.2
200	0.5	778.9	776.8	1019.8	487.8
500	0.2	886.9	911	1208.2	513.8

Table 15 Melka sedi station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow(cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	198.3	197.8	231.2	173.8
5	20	287.8	287.9	336.1	244
10	10	342.5	341.4	395	285.9
20	5	388.2	386.3	447.9	316.1
50	2	437.1	438.4	511.2	341.6
100	1	467	477.2	557.1	353.2
200	0.5	491.9	558.8	601	360.1
500	0.2	518.6	595.7	659.8	366.3

4.5 Derivation & Confidence level of flood frequency curves

Plots of Q/Q_m against the Generalized Pareto and Log-Pearson type III growth curves were generated for each station and used in the derivation of the at-site growth curves. The median plotting position method used for developing the frequency growth curves to represent the frequency curves of at-site stations. For those of entrant distributions, the goodness of fit measure takes place with a significance level of α=0.05 which is a confidence level of 95%. In this study, the confidence limit of the study area at 5% (UCL) and 95% (LCL) of quantile values were determined. At the inlet of the sub basin the quantile flood magnitude 513.8m3/sec is identified as lower bound and 1208.2m3/sec valued as upper bound while at the outlet of the sub basin 366.3m3/sec and 659.8m3/sec are the lower and upper bound respectively. The slope of a flood frequency curve (FFC) graphically represents the standard deviation of the flood frequency distribution. The higher the slope, the greater the standard deviation in flood discharges. 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 and when Both UCL and LCL were far from FFC at their significance level.

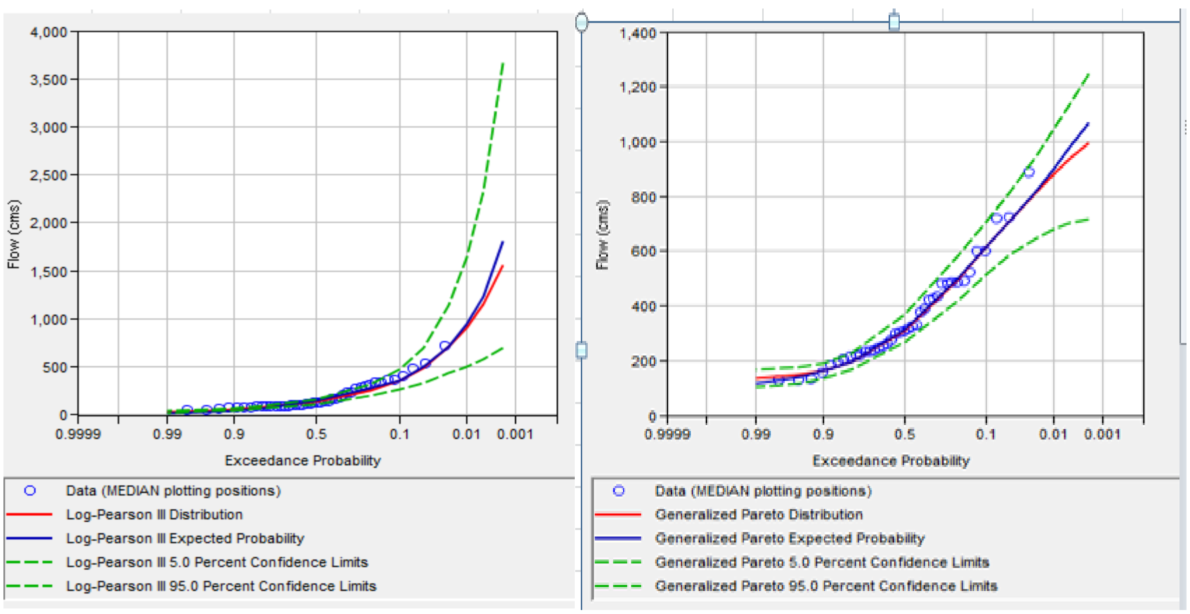


Figure 21 Awash Below koka and Awash @ 7kilo CDF Curv

5. CONCLUSION

The main challenge of flood from water resources development and management point of view are its recurrent interference and activities made by society. These uncontrolled human activities and intervention cause tremendous damage to enormous loss of life and property due to the frequency and magnitude of flooding occurrences. This study aimed at analyzing flood magnitude and its probability of occurrence with fairly accurate not only intended at preventing catastrophes but also at avoiding excessive costs in case of overestimating the flood magnitude or excessive damage while under estimating flood potential. The HEC-SSP software flood frequency analysis, MoM & L-Moment parameters estimation and KS and X^2 distribution fitting test statistics were used to achieve the study objectives.The highest magnitude of flood observed at Awash Below Koka and Wenji recorded during 1985 with gaged value of 480m3/sec and 304m3/sec around the inlet of the sub basin while the highest flood magnitude are recorded at Awash 7kilo and Melka Sedi stations during 1996 with gaged value of 721.5m3/sec and 426.628m3/sec around the outlet of the sub basin respectively. The extreme theory for annual maxima has been applied and the best fitted distribution generated by KS model test statistics values range from 0.074 to 0.115 which is considered as heavy tail distribution and also these KS values are within the highly acceptable range since KS test statistics value threshold is less than or equal to 0.5 dimensionless value. The MoM statistics for CV range from 0.299 to 0.627 and the Cs value range from 0.519 to 2.007 while the L-moment method generated ratio for L-Skew range from 0.011 to 0.366, the L-Kurtosis range from -0.014 to 0.300 which is the negative sign indicates the flat thin tail distribution and the L-CV value range from 0.184 to 0.319 which is the sample data are moderately variable. The shape parameters for all station data analyzed with GPA and Log pearson type III range from 0 to 2.15 which means the distributions have finite upper bound.Finally, the software model has generated the quantile flood magnitude with very small (0.001 to 0.584%) percent difference among the observed and computed values of stream flow records for the return period of 2, 5, 10, 20, 50, 100, 200 and 500 years. At the inlet of the sub basin the model generated quantile flood magnitude of 513.8m3/sec is identified as lower bound and 1208.2m3/sec valued as upper bound while at the outlet of the sub basin 366.3m3/sec and 659.8m3/sec computed as the lower and upper bound respectively.

6. RECOMMENDATION

The study directed that, the flood frequency analysis of hydrological time series data on the basis of statistical Analysis of gauged sites could be considered an acceptable method of flood frequency analysis using Annual Maximum series model. HEC-DSS storage system and HEC-SSP hydrological Software Package can use for other related studies. The methodological framework of this study can be suitable for other similar study in river basins.

Since this study assume stationary concept of flood frequency analysis, the next study should elaborate the result using non-stationary variables and analyses the effects of climatic variables, land use and land cover change scenarios, Urbanization and industrialization impact using Annual Maximum Flow models in the study area.

In this study data analysis, the rainfall of the study area indicated decreasing trend when comes from 1990 to 2019 while formation of peak stream flow is increasing. So that it is essential to assess local climate variability using Statistical down Scaling Climate Model to estimate the declining of rainfall in terms of amount, intensity or distribution wise.

At the upstream of the sub basin, recently Koka reservoir is the main cause of year to year flooding in the study area may be due to increasing of dead storage. So, in line with other mitigation measures considering the removal of sediments or introducing inter basin transferring of excess water during rainy season is essential rather than releasing excess water to downstream.

There are some potential ungagged tributary rivers and missing data due to manual collection system. This is very difficult to have instantaneous time series data. Therefore, it is essential to establish new station in the study area and upgrade the existing stations to automate hydrology data collection.

Finally, this study has provided updated quantile flood magnitude with probable return period. Therefore, it is essential to use the information in the design of hydraulic structures, project planning and flood hazard mitigation & management of the study area by the actors and stakeholders.

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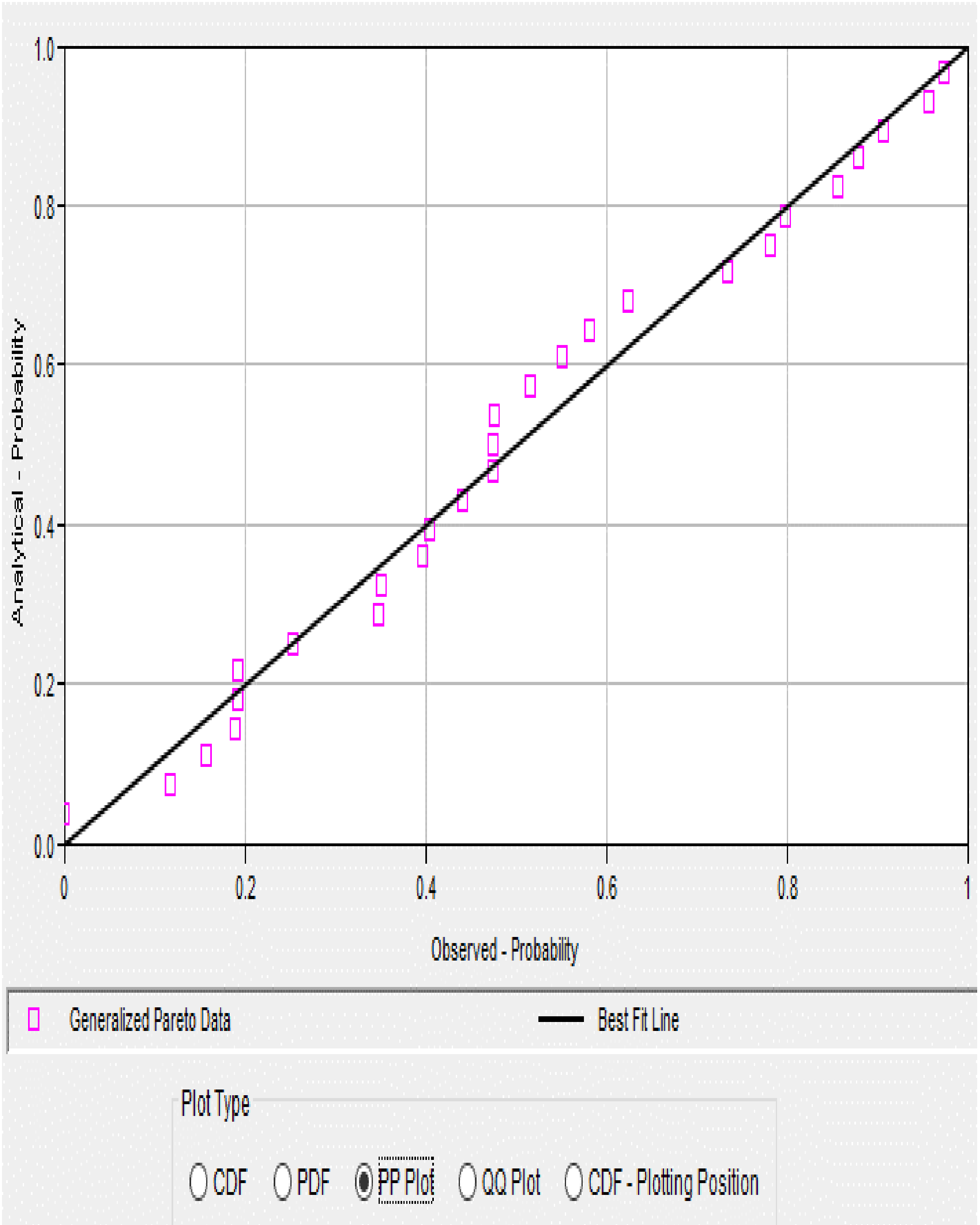
ANNEXES

Annex A: P-P Plot Figures



22 Melka sedi hydrological Station P-P Plot

Figure 23 Awash @ Metahera and Arba @ Abomsa hydrological station P-P plot

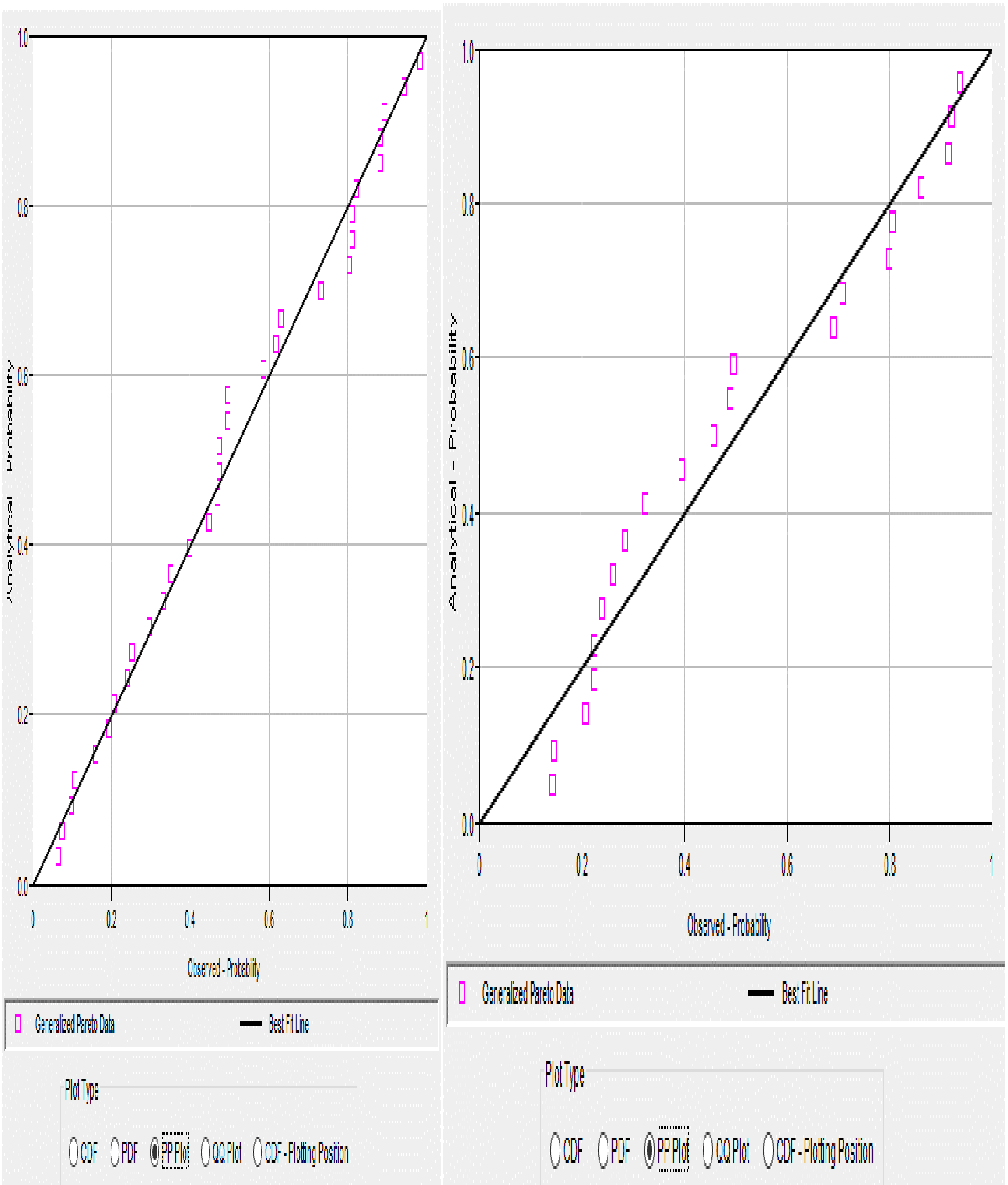


Figure 24 Awash @ Wenji and Keleta @ sire hydrological stations P-P plot

Annex B: Q-Q Plots

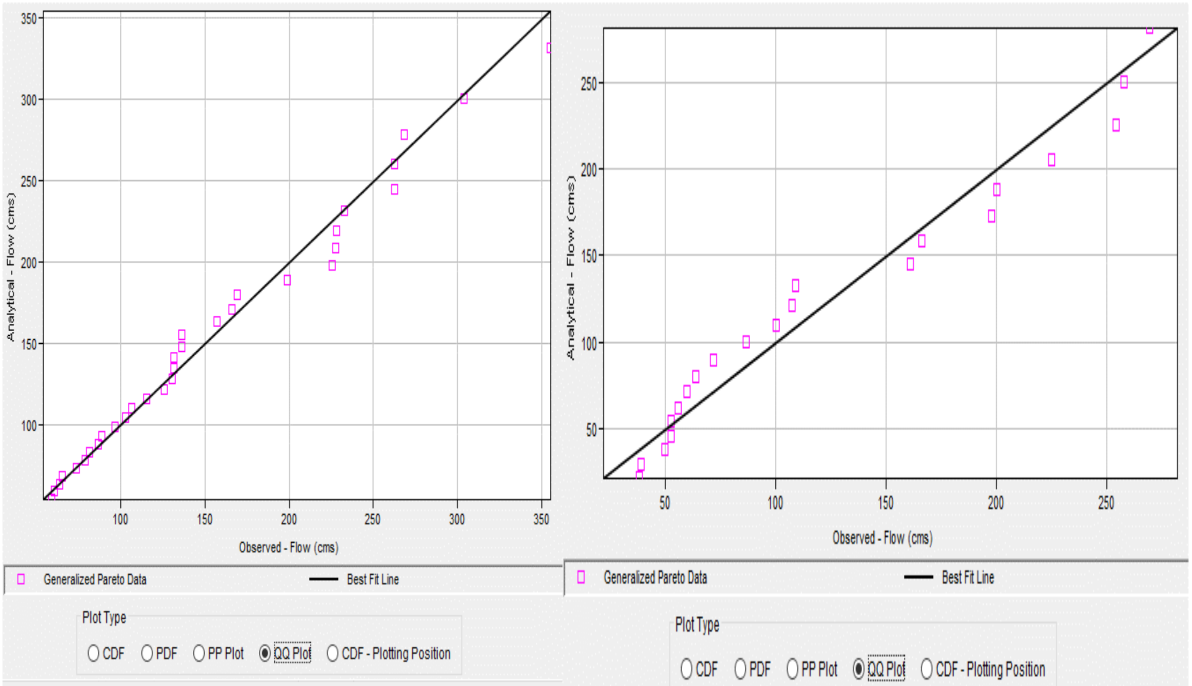


Figure 25 Awash @Wenji and Keleta @ sire Hydrological stations Q-Q plot

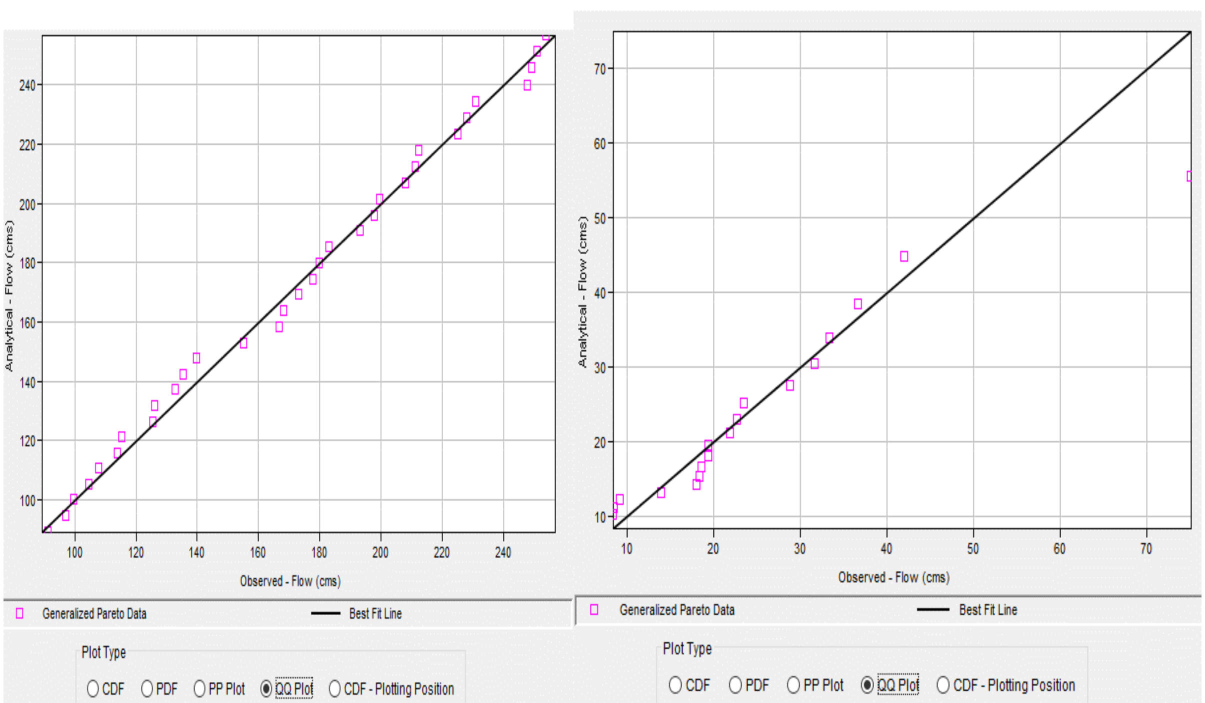


Figure 26 Awash @ Metahera and Arba @ Abomsa hydrological staions Q-Q plots

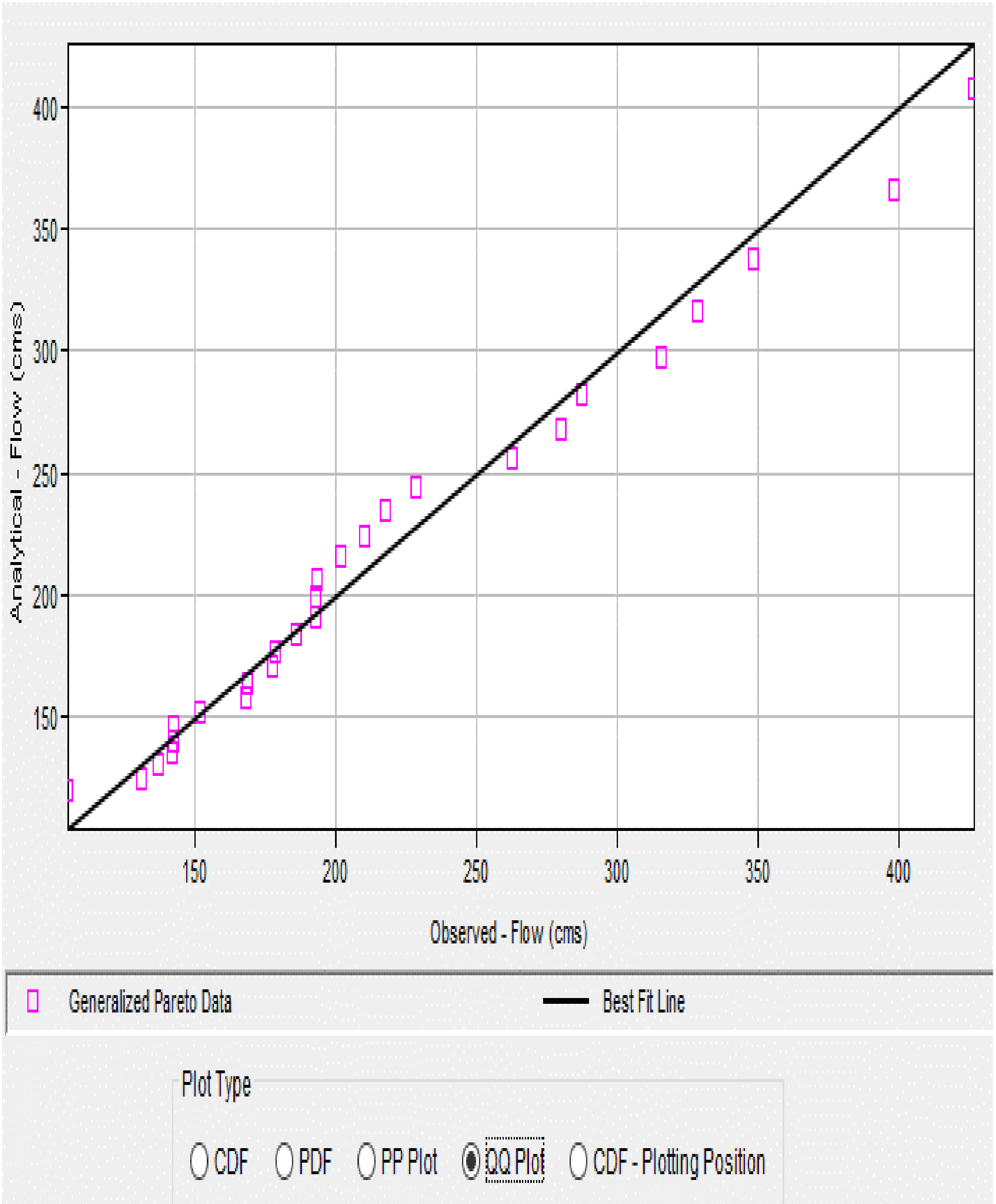


Figure 27 Melka sedi hydrology Stations Q-Q plot

Annex C: Return Period Vs Flood quantiles

Table 11 Awash @ Wenji station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow(cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	133.3	133	163.6	107.7
5	20	215.8	215.8	251	177.7
10	10	257.4	257.5	291.6	215.7
20	5	287	287.8	321.5	241.3
50	2	313.3	317.7	354.7	259.8
100	1	326.5	336.3	376	266.9
200	0.5	335.9	353.9	395.8	271.1
500	0.2	344.3	377.5	419.6	273.8

Table 12 Awash @ Metahera station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow(cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	167.8	165.3	179.1	146.1
5	20	223.6	223	237.4	201.8
10	10	242.9	245.5	263.3	225.7
20	5	252.9	259.3	279.1	239.1
50	2	259.1	271.3	293	247.2
100	1	261.2	279.8	298.7	249.9
200	0.5	262.3	286.4	304.1	251.4
500	0.2	263	295.9	308.1	252.3

Table 13 Awash @ 7kilo station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow (cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	313.6	311.2	365.5	268.1
5	20	477.5	478.5	538.6	411.8
10	10	559.4	559.5	617.1	489.7
20	5	616.9	615.8	674.7	541.5
50	2	667.5	668.5	735.7	580.4
100	1	692.7	706.7	775.6	594.6
200	0.5	710.5	741.1	811.4	603.1
500	0.2	726.1	781.4	848.7	609.3

Table 14 Arba @ Abomsa station Estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow(cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	20.2	20.7	26.9	16.4
5	20	34.6	35.5	47.6	26.1
10	10	45.5	45.7	62.5	31.8
20	5	56.4	55.8	77.6	36.1
50	2	70.8	69.6	98.2	40.1
100	1	81.7	81.1	114.5	42
200	0.5	92.7	93	131.5	43.4
500	0.2	107.1	110.6	155.5	44.6

Table 15 Keleta @ sire station estimated Quantiles

Return period (year)	Probability of exceedence (%)	Mean flow (cms)	Expected flow (cms)	Confidence limit	
				5%	95%
2	50	96.5	96.5	121.7	76.4
5	20	164.4	167	214.6	124.4
10	10	217.2	219.9	295.4	156.9
20	5	273.4	277	388.5	188.8
50	2	354.2	371.1	530.9	231.3
100	1	421	457	655.8	264.1
200	0.5	493	545.9	796.6	297.6
500	0.2	597.1	695.3	1009.1	343.8

Annex D. Flood Frequency Curves

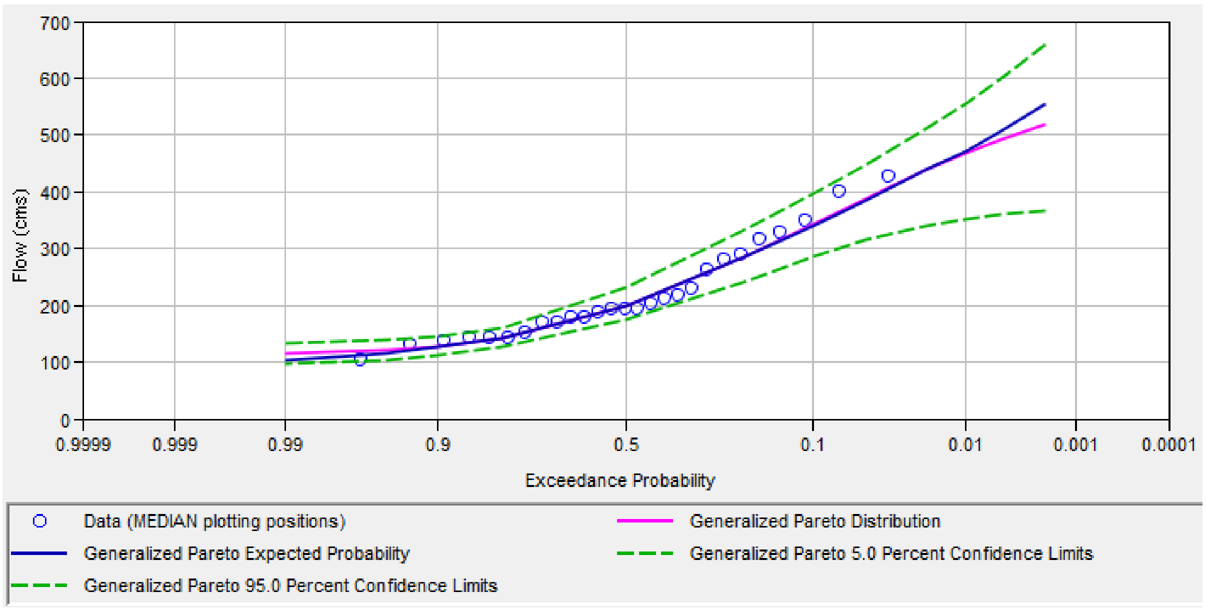


Figure 28 Melka Sedi CDF Curves

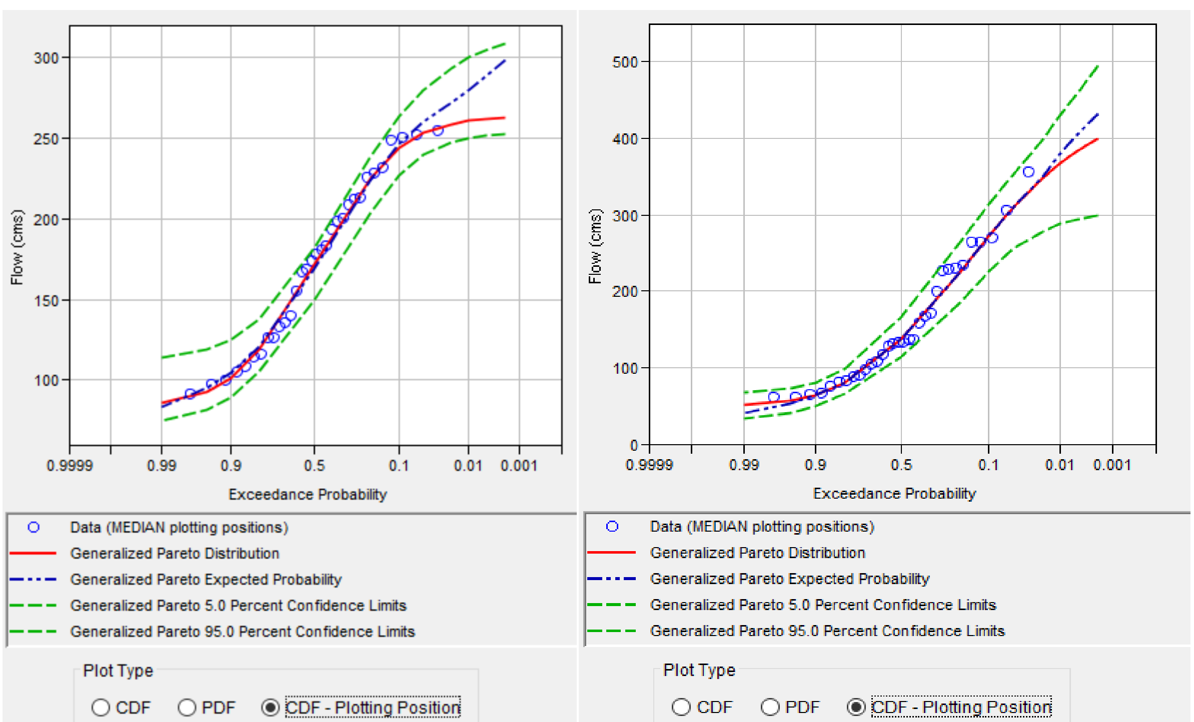


Figure 29 Awash @ Metahera and Awash @ Wenji CDF Curves

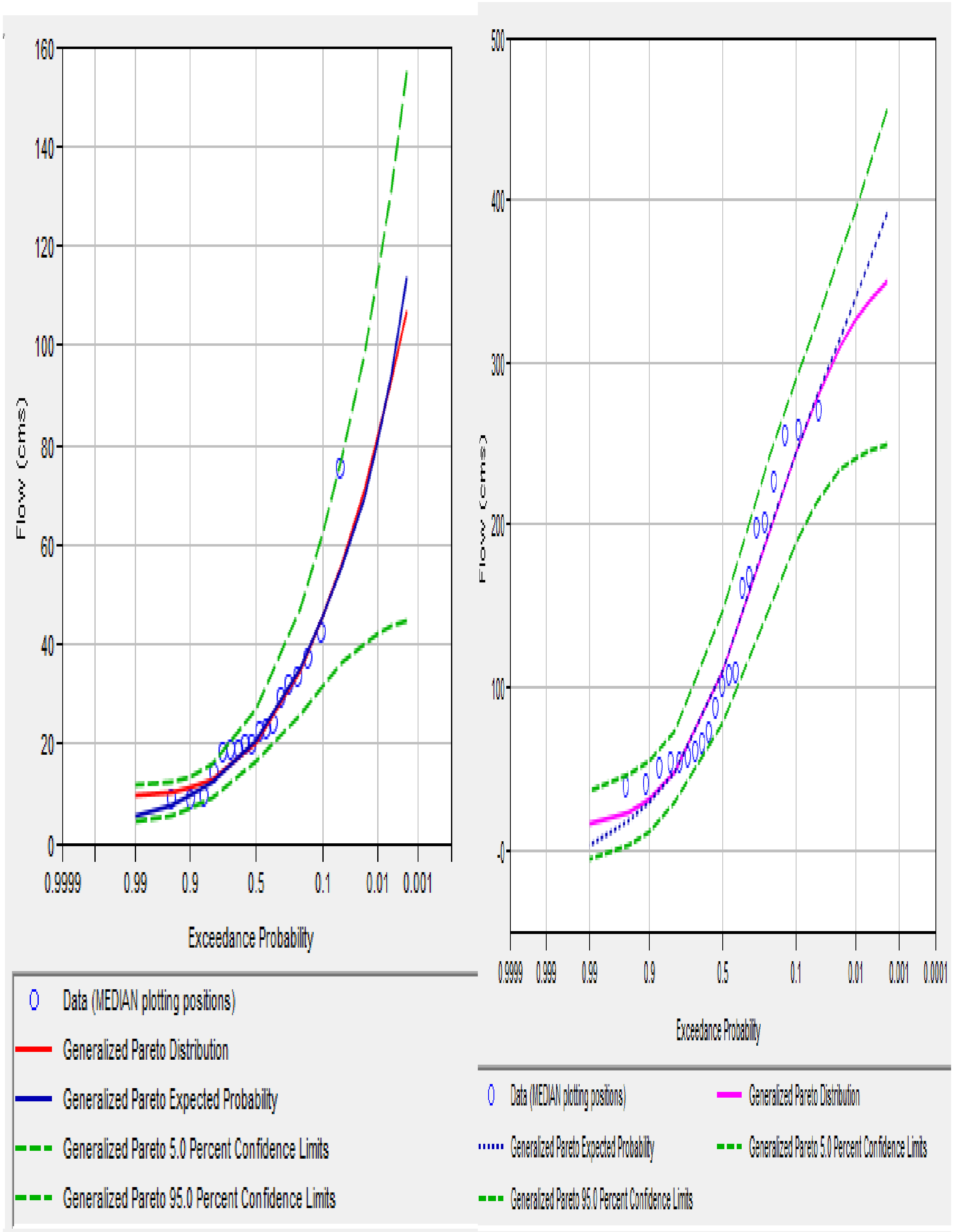


Figure 30 Arba @ Abomsa and Keleta @ sire CDF Curves

Annex E. Statistical Summaries of Time Series Data

Awash Below Koka Statistical summary

Statistic	Original Data	Processed Data
Min	100.539	100.539
Max	531.786	531.786
Median	184.428	184.428
Mode	185.350	185.350
Sample Size	44	44
Mean	217.835	217.835
St Dev	102.240	102.240
Skew	1.369	1.369
Kurtosis	1.401	1.401
0.2%	531.8	531.8
0.5%	531.8	531.8
1.0%	531.8	531.8
2.0%	531.8	531.8
5.0%	461.0	461.0
10.0%	375.7	375.7
20.0%	312.8	312.8
50.0%	184.4	184.4
80.0%	135.1	135.1
90.0%	117.3	117.3
95.0%	106.6	106.6
99.0%	100.5	100.5
L-Mean	217.835	217.835
L-CV	0.246	0.246
L-Skew	0.322	0.322
L-Kurtosis	0.186	0.186

Keleta Hydrological station statistical summary

Statistic	Original Data	Processed Data
Min	55.814	55.814
Max	200.384	200.384
Median	100.230	100.230
Mode	55.814	55.814
Sample Size	21	21
Mean	111.536	111.536
St Dev	48.868	48.868
Skew	0.530	0.530
Kurtosis	-1.179	-1.179
0.2%	200.4	200.4
0.5%	200.4	200.4
1.0%	200.4	200.4
2.0%	200.4	200.4
5.0%	200.1	200.1
10.0%	192.4	192.4
20.0%	164.5	164.5
50.0%	100.2	100.2
80.0%	63.4	63.4
90.0%	59.9	59.9
95.0%	56.2	56.2
99.0%	55.8	55.8
L-Mean	111.536	111.536
L-CV	0.251	0.251
L-Skew	0.181	0.181
L-Kurtosis	-0.052	-0.052

Awash @ Wenji Station Statistical Summary

Summary Statistics

Statistic	Original Data	Processed Data
Min	42.053	42.053
Max	304.000	304.000
Median	128.950	128.950
Mode	131.800	131.800
Sample Size	30	30
Mean	143.837	143.837
St Dev	74.650	74.650
Skew	0.623	0.623
Kurtosis	-0.816	-0.816
0.2%	304.0	304.0
0.5%	304.0	304.0
1.0%	304.0	304.0
2.0%	304.0	304.0
5.0%	284.6	284.6
10.0%	263.0	263.0
20.0%	227.6	227.6
50.0%	129.0	129.0
80.0%	75.7	75.7
90.0%	61.3	61.3
95.0%	51.6	51.6
99.0%	42.1	42.1
L-Mean	143.837	143.837
L-CV	0.296	0.296
L-Skew	0.183	0.183
L-Kurtosis	0.025	0.025

Awash @ Metahera Statistical Summary

Summary Statistics

Statistic	Original Data	Processed Data
Min	91.221	91.221
Max	254.155	254.155
Median	175.703	175.703
Mode	91.221	91.221
Sample Size	32	32
Mean	172.069	172.069
St Dev	51.391	51.391
Skew	0.025	0.025
Kurtosis	-1.256	-1.256
0.2%	254.2	254.2
0.5%	254.2	254.2
1.0%	254.2	254.2
2.0%	254.2	254.2
5.0%	252.3	252.3
10.0%	249.1	249.1
20.0%	226.5	226.5
50.0%	175.7	175.7
80.0%	114.9	114.9
90.0%	101.4	101.4
95.0%	95.1	95.1
99.0%	91.2	91.2
L-Mean	172.069	172.069
L-CV	0.175	0.175
L-Skew	0.008	0.008
L-Kurtosis	-0.014	-0.014

Awash @ 7kilo Station Statistical Summary

Summary Statistics

Statistic	Original Data	Processed Data
Min	123.610	123.610
Max	883.930	883.930
Median	302.550	302.550
Mode	231.110	231.110
Sample Size	39	39
Mean	354.105	354.105
St Dev	179.120	179.120
Skew	1.040	1.040
Kurtosis	0.850	0.850
0.2%	883.9	883.9
0.5%	883.9	883.9
1.0%	883.9	883.9
2.0%	883.9	883.9
5.0%	721.5	721.5
10.0%	598.2	598.2
20.0%	483.6	483.6
50.0%	302.5	302.5
80.0%	213.8	213.8
90.0%	152.2	152.2
95.0%	127.3	127.3
99.0%	123.6	123.6
L-Mean	354.105	354.105
L-CV	0.279	0.279
L-Skew	0.223	0.223
L-Kurtosis	0.118	0.118

Statistical Summary of Melka Sedi Hydrology Station

Summary Statistics

Statistic	Original Data	Processed Data
Min	104.589	104.589
Max	426.628	426.628
Median	192.995	192.995
Mode	104.589	104.589
Sample Size	27	27
Mean	219.167	219.167
St Dev	84.535	84.535
Skew	1.019	1.019
Kurtosis	0.291	0.291
0.2%	426.6	426.6
0.5%	426.6	426.6
1.0%	426.6	426.6
2.0%	426.6	426.6
5.0%	415.4	415.4
10.0%	358.7	358.7
20.0%	298.9	298.9
50.0%	193.0	193.0
80.0%	142.3	142.3
90.0%	135.7	135.7
95.0%	115.2	115.2
99.0%	104.6	104.6
L-Mean	219.167	219.167
L-CV	0.213	0.213
L-Skew	0.263	0.263
L-Kurtosis	0.133	0.133

Arba Abomsa Statistical Summary

Summary Statistics

Statistic	Original Data	Processed Data
Min	8.400	8.400
Max	75.100	75.100
Median	20.750	20.750
Mode	19.500	19.500
Sample Size	18	18
Mean	25.050	25.050
St Dev	15.702	15.702
Skew	2.005	2.005
Kurtosis	5.516	5.516
0.2%	75.1	75.1
0.5%	75.1	75.1
1.0%	75.1	75.1
2.0%	75.1	75.1
5.0%	75.1	75.1
10.0%	45.4	45.4
20.0%	34.1	34.1
50.0%	20.8	20.8
80.0%	13.1	13.1
90.0%	8.6	8.6
95.0%	8.4	8.4
99.0%	8.4	8.4
L-Mean	25.050	25.050
L-CV	0.318	0.318
L-Skew	0.321	0.321
L-Kurtosis	0.300	0.300

Annex F: 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)

Annex G: 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				

Annex H: 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)