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ASSESSMENT OF FLOOD AND ITS DAMAGE ON AGRICULTURAL YIELDS IN VULNERABLE AREAS OF UPPER AWASH, EJERE WOREDA, WEST SHEWA, OROMIA REGIONAL STATE, ETHIOPIA

BY: OLIYAD MESFIN SIYOUM

ADVISIOR: TILAHUN DERIB ASFAWU(PhD)

CO-ADVISIOR: ZELEKE AGIDE DEJAN(PhD)

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A Thesis Submitted to the School of Graduate Studies, Addis Ababa University, for portal Fulfillment of the requirement for the Degree of Masters of science in Water Resource Engineering and management.

By: Oliyad Mesfin Siyoum

Advisior: Tilahun Derib Asfawu(PhD)

Co-Advisior: Zeleke Agide Dejan(PhD)

DECLARATION

I hereby declared that this thesis entitled "Assessment Of Flood and Its Damage On Agricultural Yields In Vulnerable Areas Of Upper Awash, Ejere Woreda, West Shewa, Oromia Regional State, Ethiopia" was compose by myself with the under guidance of my advisor, that the thesis contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

This Thesis entitled "Assessment Of Flood and Its Damage On Agricultural Yields In Vulnerable Areas Of Upper Awash, Ejere Woreda, West Shewa, Oromia Regional State, Ethiopia" is approved by advisors, examiners and dean of the School of Civil and Environmental Engineering.

APPROVAL SHEET

Dr. Tilahun Derib Asfaw

______________________	______________	____________
Main supervisor	Signature	Date

Dr. Zeleke Agide Dejen

______________________	______________	____________
Co - supervisor	Signature	Date

______________________	______________	____________
Internal Examiner	Signature	Date

______________________	______________	____________
External Examiner	Signature	Date

______________________	______________	____________
School Dean	Signature	Date

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ABSTRACT

Floods are recurring natural events that can have both negative and positive consequences: however, their adverse impacts on agricultural activities particularly in areas with inadequate risk management are often devastating. Flooding in upper Awash River region has been a persistent problem for agricultural fields over an extended period. Therefore, attention should be focused on risk assessment, as well as on accurately analyzing and quantifying the flood occurrences. The objective of this research is to quantify and evaluate the impact of flood damage on wheat and barley yields in Bolengo kebele, Ejere woreda, Oromia regional state, Ethiopia. The area is frequently affected by flooding from the upper Awash River basin. Data on crop average, seasonal yields, flood levels, and community participation in the flood management were collected from woreda office, field observation, and focus group discussions.

Historical streamflow data was obtained from the Hombole station, the tributary of Awash River, which was recorded between 1999 and 2022. Floodplain mapping near the Awash River was developed based on the peak flow of the river for different return periods using the HEC-RAS model, the ArcGIS tool for spatial processing and HEC-GeoRAS to link ArcGIS with HEC-RAS. The basic assumptions in statistical flood frequency analysis include the independence and stationarity of the data series and that the data originated from the same distribution. Homogeneity and stationarity test at different significant level were conducted using Wald-Wolfowitz and Mann-Whitney methods. These tests confirmed that the flow data are independent, homogeneous, stationarity and no outliers at the 5% significant level. Flood quantile estimates were computed from return periods of 2, 5, 50, 100, and 500 years, with the discharge value ranging from 38.93 to 99.22m3/sec. The corresponding floodplain area was found in the range of 87.6 to 147 hectares, resulting in crop losses of 1,489.2 to 2,512.6 quintals of wheat and barley, respectively. The flood inundation map of the area indicated that the downstream parts of the cultivated land are more vulnerable to flooding. The most affected areas are located close to the awash main course. The results indicated a critical need for a flood risk management strategies both structural and non-structural to mitigate the economic impact of recurrent floods on agricultural land in the area.

Keywords: Flood Damage, Hydrological modelling, Upper Awash River Basin, Bolengo kebele.

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Abbreviations

APSIM	**A**gricultural **P**roduction System **Sim**ulator
DPPA	**D**isaster **P**revention and **P**reparedness **A**gency
DTM	**D**igital **T**errain **M**odel
E.C	**E**thiopian **C**alendar
FHM	**F**lood **H**azard **M**apping
FDC	**F**low **D**uration **C**urve
GIS	**G**eographical **I**nformation **S**ystem
GYGA	**G**lobal **Y**ield **G**ap **A**tlas
HEC-HMS	**H**ydrologic **M**odel
HEC-RAS	**H**ydraulic **E**ngineering **C**enter for **R**iver **A**nalysis **S**ystem
MARS	**M**onitoring **A**gricultural **R**esource
NASA	**N**ational **A**stronomy and **S**pace **S**cience
NMA	**N**ational **M**etrological **A**gency
USACE	**U**nited **S**tates **A**rmy **C**orps of **E**ngineers
USGS	**U**nited **S**tates **G**eological **S**urvey
WOFOST	**W**orld **F**ood **S**tudies **M**odel
W-W	**W**ald-**W**olfowitz
EWARDO	Ejere Woreda Agriculture and Development Office
EWFRMPO	Ejere Woreda Flood Risk Management and Preparedness Office
NRCS	The Natural Resources Conservation

1 INTRODUCTION

1.1 Background

Global Evidence demonstrates that disastrous natural events take place all over the Earth at a higher rate and in a larger area. Water-related disasters are the principal ones with the most deaths and damage among the recorded disasters. Water-related disasters include flooding as the leading one. Flooding is a situation in which the water level goes over the usual limit, and it happens mainly because of torrential rains, bad drainage, or the bursting of dams or breaches of flood control measures even in the areas that are generally supposed to be safe from water.(Dejenne, 2011)

Many damage estimate models are used to estimate flood damage. The WOFOST model from World Food Studies, referenced in Monteleone et al., (2023) was used to assess crop damage caused by flooding while Gashaw & Legesse, (2011) was applied to quantify crop physical damage in Ethiopia, floods happen at varied intervals, in multiple locations, and with varying degree of intensity. Approximately 80% of the country annual rainfall occurs during the month of July, August, and September. As this time of the year, major perennial rivers and many tributaries regularly experience their maximum water flow levels. As a result, the majority of rivers swell, overflow, or break through their banks, leading to flooding in adjacent low-lying area and flat farmland Ejigu, (2016).

The historical account of flooding in Ethiopia can broadly be classified into two groups: one being river floods and the other being flash floods. Intense rainfall leads to the rapid formation of flash floods in the upper section of a watershed followed by quick movement to the lower area. Such occurrences are usually very sudden and a large portion of them remains without any documentation. In Ethiopia, flood related disasters are frequently initiated by rives either overflowing or breaching through their banks, resulting in the inundation of nearby low-lying regions Lazzarin et al., (2024).

Flood damage in 2006, total of about 18,150 hectares of farmland was heavy affected in different parts of Ethiopia. Water joining on farmland was the main reason of the 20% decrease in agricultural yield Erena & Worku, (2018). Most of the flooding incidents in the country are due to the rivers overflowing their banks after a long period of heavy rains, which finally leads to the flooding of the adjacent low-lying areas. The most flood-prone locations in Ethiopia are the

SNNPR's lowland region, parts of the Somali region near Wabishebelle, Genale, and Dawa rivers, and the Baro, Gilo, and Akobo rivers in Gambella. The major floods in the Lake Tana flood plains affect the Awash River basin in the Oromia and Afar regional areas, as well as the upper and midstream of the Awash River plains, which are particularly vulnerable to flooding. Both the structural and non-structural methods can be applied to reduce flood damage. Despite being highly significant, the building of flood control infrastructure is still very costly and takes a lot of time. A public's awareness of the flood escaping strategy combined with the flood control measures' ongoing improvements and expansions can reduce the total flood-related losses dramatically. The flood damage maps are important for the local people to be educated and empowered about the flood hazard's extent in their community, their role in disaster prevention, and the correct evacuation procedures in case of flooding. To understand the physical features and spatial layout of flood is essential to comprehending its repercussions Lazin et al., (2021). Hydrodynamic models can be used to clarify the properties of floods.

Hydrodynamic models can be used to forecast the extent, depth, level, velocity, and timing of the floods with in the sizable simulated area over a certain period of time. Flood models analyse the flow parameters using the fundamental ideas of mass, energy, and momentum conservation Jafarzadegan et al., (2023). To validate that the model is capable of predicting the extent of the flood and its impact correctly, the data from the flooded area need to be analyzed. The image data captured from the affected area can help to extract information from the observed time series data. The data gathering for the flood plain survey involves collecting the topographic information. The topographic data of the river and floodplain landscapes were inputted in the model. The quality of mesh production is a very important consideration in hydrodynamic modelling.

In previous studies research analysis conducted by Dawit, (2015) with the title of identify flood inundation area in order to producing flood risk analysis for different magnitude of flood in Ilu flood plain, Upper Awash river basin. The study addressed significant gaps in the assessment of flood and its damage on agricultural yields in vulnerable areas of upper awash basin.

1.2 Problem Statement

Flooding has been recurring natural disaster in various regions of Ethiopia, particularly in the upper Awash River basin, where many cultivated lands are exposed to floods that lead to significant yield reduction. By Joint Government and Humanitarian Partners, (2006) approximately 75 districts across eight regions had been affected by flooding. The 2013 reported by Ethiopia's disaster prevention and preparedness agency showed that over about 500,000 people were displaced, approximately 200,000 people lost their property, and about 639 fatalities were registered. A large number of livestock were died, 228 tons of harvested crops were destroyed, 147 tons of export coffee beans were lost along with the machinery and nearly 42,229 hectares of cropland were flooded, resulting in a loss of productivity

The upper Awash river flood area include Illu, Sebeta, and Ejere excessive runoff from the upper catchments and isolated rainfall on the floodplain causes the flood to spill over in to the channel, ultimately affecting crops yields. Flooding in the upper awash basin of the Awash River affected 14 rural villages in Illu, Sebeta Hawas (Southwest Shewa), and Ejere woreda of the West Shewa zone as illustrated in Figure 1.1.

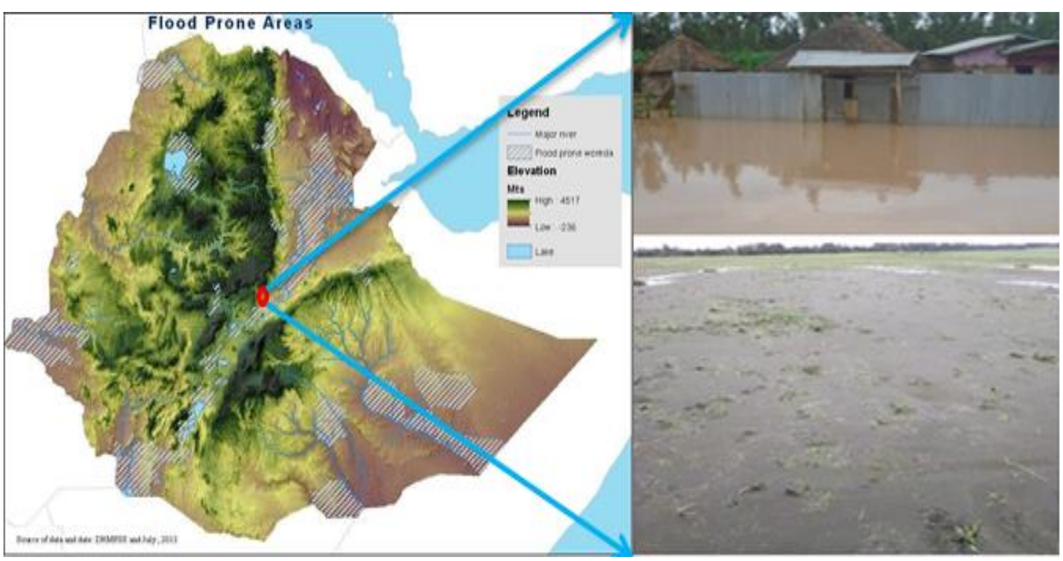

Figure 1-1 Flood incidence around Ejere

A 2006 study conducted by the National Disaster Prevention and Preparedness Committee reported that 2,052 people had to be relocated and were living in temporary housing facilities among the 14,790 individuals who had experienced the disaster in the worst-hit areas. The document referred to the Ejere woreda, where the floods had become so regular that even the residents' or their crops' movement to safer places lasted for two months. Eventually, crops on the floodplain would be lost or partly ruined, and this would be mainly due to the enormous accumulation of water inside the area. This had a severe impact on the inhabitants' socioeconomic conditions. Local farming practices indicated that around 75% of the flooded areas were mainly used for the cultivation of wheat and barley. The research examined the effects of floods on wheat and barley productivity, which are prominent crops in the area.

Every year, the area suffers from floods which damage up to 2,980 hectares of land, thus the region goes through significant social and economic hardships. The impact of these floods on the Bolengo Kebele crop yield was the subject of a study. Researchers looked into the relationship between the flood and the agricultural yields as well as the floodwater spread in the region. The determination of crop failure was based on factors like water depth, period of flooding, and water flow speed. The stage of crop growth, frequency of exposer, and sensitivity to flooding were the factors that all contributed to determining the impact on productivity. Flooding is one of the most annoying neighboring problems for agriculture, since among other things; it uproots the crops and losses the yields greatly.

Flooding has become a common occurrence in most cultivated areas and, thus, a major problem to farmers and agricultural planners. Generally, wheat and barley, which are the major cereal grains and most widely cultivated crops, are the most prone to losing their yield during floods. Yet, there is scant localized research that proves the claims of flood yield losses in these crops regardless of their economic and nutritional importance. The absence of precise data and analyses on the impact of flooding on wheat and barley production not only holds up the effective planning of agricultural practices but also affects the management of disaster risks and the building of resilient farming systems. Thus, it has become an absolute necessity to examine the floods' frequencies and patterns, as well as the losses suffered by the two crops. In bridging this knowledge gap, the study intends to facilitate the making of informed decisions in areas such as agricultural policy, flood damage yield reduction, and adaptation strategies for the affected farming communities.

1.3 Research Questions

The research questions include:

- What are the extent of flooding and its impact for different return periods?
- How are crop yields affected at different return periods?
- What are the mechanisms to reduce the impact of flood risk in the area?

1.4 Objectives

The main objective of the research is to analyze flooding and impact of flood damage on wheat and barley yields in Bolengo Kebele of Ejere Woreda, Oromia Regional State, Ethiopia.

1.4.1. Specific Objectives

The specific objectives of the research are:

- to identify the flood-prone areas, map the flood inundation with different return period.
- to estimate the amount of crop yield reduction due to floods of various return periods.
- to assess appropriate strategies that could help reduce the impact of flooding with the consideration of natural factors, and existing technologies and techniques

1.5 Significance of the Study

The purpose of this study is to assess and extent how flood damage, mostly from insufficient and ineffective flood management and control systems, affects crop production. The study's expected outcomes shall be used as crucial inputs in designing sustainable flood mitigation measures that can help reduce damage to yields and associated risks in the study area.

1.6 Scope of the study

The primary objective of this investigation is to assess the effects of flooding on Bolengo Kebele within Ejere Woreda and specifically examine the sole yield decrease of wheat and barley crops. Farmers that develop crops like beans, potatoes, and teff are not taken into account. Additionally excluded was the consideration of the hazards to public health and further property losses brought on by flooding.

2 LITERATURE REVIEW

2.1 Flood

Floods are the most common natural disasters worldwide. They cause environmental damage and threaten human lives. Flooding occurs when inland or tidal waters overflow or when runoff quickly accumulates, covering normally dry areas partially or completely.

According to Manandhar, (2010a)flooding happens when a river reaches an unusually high level due to excessive runoff from rainfall or snowmelt, exceeding its normal water surface elevation. This phenomenon comes from unusual weather conditions. The maximum flood that a structure can handle is called the design flood. It is set by balancing economic and hydrologic factors. The design flood changes based on the project's purpose. For example, the spillway design flood may be much greater than the flood control reservoir design flood or that of the temporary coffer dams.

When deciding on the design flood, it is important to consider the cost of building flood control structures and the benefits of reducing flood-related damages. These damages can include destruction of infrastructure downstream, disruptions in communication, loss of life and property, crop damage, and poor land use. Flood control aims to track the timing and flow of streams rather than use water directly. This can be achieved through land management practices like afforestation, which improves water absorption and reduces surface flow by increasing plant cover, and contour plowing, which decreases runoff by following the land's natural shape.

Flood control does not involve direct water usage but rather aims to regulate stream flow distribution over time. This can be accomplished through various land management strategies, such as afforestation and contour plowing Bezabeh & Tesfaye, (2021).

2.2 Flood Prone Areas in Ethiopia

In Ethiopia, flooding primary occurs during the Kiremt rainy season (July to September) in high risk flood disposed to areas Bhattacharya, (2010). Flooding in Ethiopia mainly happens when rivers overflow their banks. In Gambella, these overflows usually occur in August and

September. In the Somali region, floods during the Kiremt season are often caused by heavy rains in the nearby highlands of Oromia.

Flooding along the Wabe Shebelle and Genale rivers in Somalia, as well as the Oromia River in southern Ethiopia, can result from unusual or excessive rainfall that takes place from October to January. Similarly, the Awash River and its tributaries in Afar often overflow due to heavy rainfall in the highlands of Amhara, Tigray, and Oromia. Flooding in the Fogera and Dembia plains in the Lake Tana basin occurs because of backflow from the lake and overspill from its main tributaries during periods of intense rain. Additionally, areas that rarely experience strong Belg/Ganna seasonal rains from March to June may also see flooding.

According to the Wereda Agricultural and Rural Development Office report WARDO, (2021),flooding in the upper Awash river basin affected 14 peasant association across the Ejere. Illu and Sebeta Hawas woredas. Around 14,790 people were impacted, with 2,052 individuals displaced and mandatory to take refuge in temporary shelters.

2.3 Flood Damage Assessment on Crop Yields

The process of assessing flood damage is complex and depends on various factors, which can lead to different results. Performing an economic analysis is an essential first step in creating engineering plans at the broader management level. During the feasibility study, it is important to evaluate flood damage and include it in planning strategies. This provides a basis for making informed decisions. Engineering plans can estimates flood inundation areas for specific return periods: however, this estimates regularly overlook the cost-benefit ratio of flood mitigation actions Belina & Ababa, (2020).

The 1998 floods in Bangladesh caused wide damage to rice crops, harshly threatening the flood safety of tens of millions of people Onteleone et al., (2023). The floods resulted in significant agricultural losses, destruction of assets, and reduced job opportunities. This had an effect on market prices and household incomes, although government food aid helped ease the immediate impact on food access for households. The consequences of flooding on agriculture are not fully understood and are often downplayed. The depth, duration, and speed of floodwaters in agricultural areas affect yield losses, showing a clear negative link between crop growth and flooding. To understand the agricultural risks associated with floods, it is important to look at how crop damage assessments relate to the accuracy and complexity of hazard modeling.

Depth, duration, and damage function curves are valuable tools for estimating flood damage to rice crops. Once we identify rice fields affected in high-risk areas, we can assess potential damage using specific risk indicators. These indicators reflect how vulnerable each element is by demonstrating the relationship between the intensity of the hazard and the resulting damage, which is represented by a damage curve. Flood damage curves are crucial for accurate damage estimation. Typically, these curves are created using synthetic data, such as expert evaluations or survey responses. They may also be derived from hypothetical scenarios, survey responses, land cover data, and standardized property types Dejenne, (2011).

2.4 Test on Hydrologic Data

Statistical flood frequency analysis is based upon some major assumptions such as the series of data being independent and stationary. Besides, it assumes that the data is derived from a stable distribution homogeneity and does not neglect the presence of outliers. Various tests are commonly employed to assess stationarity, homogeneity, and independence, as outlined Short Communication Parameter Estimation for the Pearson Type 3 Distribution Using Order Statistics, (1994).

2.4.1 Test of Independence and Stationarity

The Wald-Wolfowitz (W-W) test, developed by Wald et al., (1943) s used to estimate the dataset's independence and identify any patterns in a sample of size N. For a dataset x1, x2, xn, the test statistic R is computed. When the sample elements are independent, R is said to have a normal distribution with a specific mean and variance. The variance indicates the degree of fluctuation in the value of the statistic R.

2.4.2 Tests of Homogeneity and Stationarity

Two samples of sizes p and q (where p equal to q) are related in this test. The merged dataset, which has a size of N (p + q), is arranged in ascending order. The Mann-Whitney (M-W) test Vogt, (2015) involves calculating the quantities V and W, where T and J represent the number of tied observations at each rank. For each set of linked observations in both samples, the value of T is added up. The hypothesis of homogeneity is then considered at a significance level α\alpha using the test statistic u, which is related to the equivalent critical value from the conventional normal distribution.

2.4.3 Test of Outliers

The Water Resource Council has proposed a method that implies adjusting data points significantly diverging from the overall trend of the dataset. The determination of statistical parameters can be greatly influenced by the choice of whether to keep or remove these outliers, especially in small sample sizes. The treatment of outliers requires meticulous scrutiny that considers both hydrologic context and mathematical criteria.

According to Hydrology Committee, (1967) if the station skewness exceeds +0.4, tests for high outliers should be prioritized; if the skewness is below -0.4, tests for low outliers take precedence. When the skewness falls between ±0.4, both high and low outlier tests should be showed before descending to eliminate any outliers from the dataset.

According to the Jain & Singh, (1987) recommend that if confirmation shows a high outlier represents the maximum event over an long period, it should be classified as historic flood data and omitted from the analysis. However, if such historic information is unavailable, high outliers should be retained within the systematic record. Low outliers identified among flood peaks are typically uninvolved, and a conditional probability adjustment, as described by Vogel & Kroll, (1989) may be applied to account for their exclusion.

2.5 Flood Frequency Analysis

According to Singh & Singh, (1985) in hydrologic analysis, the annual peak discharge is treated as a random variable, and probability and statistical methods are used to analyze these variables. The report presents the probability distributions that are widely used in government decision-making processes in the field of hydrology, especially in the case of frequency analysis. For flood frequency analysis to be completely successful, there will be a need for certain assumptions to be met; the data must be a perfect representation of the random events under consideration; it should have high quality, be homogeneous, and be enough to enable population parameters to be estimated from the sample. Otherwise, the estimates would be regarded as unreliable. Besides that, the data must be accurate, valid and appropriate for the analysis. In general, a collection of yearly peak floods can be predominantly considered a random and independent sample of events. Notwithstanding, any non-randomness in the peak flood series raises the level of uncertainty attached to the resulting frequency analysis. Various statistical tests are available for determining whether or not the peak flow data are random. The given year typically has only one annual maximum flood peak, and hence the data is often treated as random. However, the presumption of independence is less assured if a partial duration series is being used. In such situations, careful selection of flood peaks is required to be certain they form a truly random sample. The word “applicable” signifies how critical the data is for the particular issue at hand. For example, if the problem involves flood duration, the data should comprise the period of flows above a certain threshold. In the same way, if the problem is of interior drainage, the data should be the volume of water above a certain point.

The word "acceptable" indicates the data's uniformity and precision, mostly in regard to discharge measurements. The dataset must not be affected by the relationships between humans. Any alterations in the stage discharge relationship can lead to a situation where the stage records are no longer homogeneous, thus, preventing them from being used for frequency analysis. For this reason, it is often preferred to use discharge data. In case of existence of stage frequency analysis, it should be based on the latest and the most reliable rating curve. Flood risk management begins with flood hazard assessment in a particular area. This can be done by looking at the factors that cause flooding and/or by analyzing the geographical extent of previous flood events, especially in terms of flood frequency and magnitude relationships Mohammadi et al., (2014).

A commonly used method for evaluating and quantifying flood frequency and flow variability is a probabilistic approach Bhattacharya,(2010). Gumbel’s extreme value distribution aims to form a relationship between the probability of an event's occurrence, its return period, and its magnitude. Jain & Singh, (1987) The two major approaches for the statistical analysis of extreme events in terms of flood frequencies are: one, concentrating on the calculation of peak and event flows; the other, applying simulation procedures based on parameter modelling, particularly in regions with a lack of data. The Pearson distribution is considered a powerful statistical method for the assessment of the suitability of the data and the simultaneous analysis of different observations with the same set of explanatory variable for the purpose of finding out the event magnitude and return period. The most appropriate probability distribution for peak flow analysis can be identified through statistical fitting and replication techniques Moore et al., (2009a).

According to Mosisa et al., (2023) the Characteristics hydrology consider the measured instantaneous flood peak discharges, which are derived from the well-known readings on autographic charts or digital recorders, as one of the most valuable datasets. This kind of records is quite valuable and gets even more so with time if the records are homogeneous and there are no missing peak events. But it is very seldom to get one such data record that lasts as long as most of the engineering projects requiring flood design predictably doing so. When flood frequency analysis is being done, it is very important to take into account all the peak flow observations possible. The hydrologists usually work with two kinds of peak flow data series - the annual maximum series and the partial duration series. When the peak discharge of a year is considered, there is no doubt that of the annual maximum series and the number of data points is the same as years in record. That is to say, the interdependence of these annual peak values is one of the conditions for their statistical validity. This interdependence is not easy to determine; it is challenging most when the flows are close in their maximum ranks e.g. an annual maximum in January may probably be connected to one from December of the previous year. To cope with this, it is frequently more favorable to use a "water year" instead of a calendar year. The water year's specification varies with the local climate and seasonal flow characteristics. The peak of partial duration series is that it includes all floods over a preset discharge threshold, and usually it is referred as the peak over threshold series. Compared to annual maximum series, the partial duration series normally includes a bigger number of data points for analysis. On the other hand, assuming independence in events is less reliable in this case as there is greater chance that some peaks might be related.

The occurrence of a sequence of annual maximum floods can usually be seen as a set of random, albeit possibly interconnected, events. The presence of non-randomness in the peak flow series adds to the uncertainty in the frequency analysis. Different statistical tests can be employed to test the peak flow data for randomness. In the scenario of the annual maximum series, with the average interval of recorded peaks being a year, the data can mostly be viewed as random. Nevertheless, the use of partial duration series does cause the independence of data points to be questioned. In such situations, the choice of peak events must be done with great care to obtain a sample that is fairly random. Furthermore, it is imperative to consider flood records and the watershed's past in detail to ascertain that no major changes such as land use changes or infrastructure construction have taken place during the time of data collection. It is only after the watershed conditions have been deemed comparatively stable that frequency analysis is performed on the dataset to ensure that the results are meaningful and accurate.

2.6 Probability Distributions of Hydrologic Variables

According to Mekonnen et al., (2023) various probability distributions are commonly used in hydrology to analyze the likelihood of streamflow events. These include:

2.6.1 Normal Distribution

The normal distribution is a consequence of the central limit theorem, which asserts that if a sequence of random variables Xi is indistinguishable in distribution (i.e. identical distribution) and independent with a mean μ and variance σ2, then the distribution of their sum will get closer to the normal distribution with mean μ and variance nσ2 when the number of variables n becomes large. In hydrology, yearly precipitation treated as the total of many independent events is frequently approximated to a normal distribution. Nevertheless, the normal distribution is not without its drawbacks when it comes to hydrology data. It covers an uninterrupted interval from [−∞, ∞] while most hydrological variables are very much nonnegative. Besides, the normal distribution is equally likely on both sides of the mean, and when hydrological data are often skewed then it becomes less suitable for such variables' accurate representation.

2.6.2 Lognormal Distribution

If the random variable Y which is normally distributed, then the variable X is said to flow a lognormal distribution. According to (Hagos, 2011)the lognormal distribution is particularly suitable for hydrologic variables that result from the product of several other variables. For instance, if X equal to X1 X2, X3,….Xn and each Xi is independent and identically distributed. Hailu, (2017) further supports the use of the lognormal distribution in hydrology, noting that it effectively describes variables such as raindrop size distributions during storms and hydraulic conductivity in porous media. The lognormal distribution's primary advantage is that it is dragged from the negative by zero, which makes it nonnegative hydrologic variables. Moreover, the process of the logarithmic transformation helps to get rid of positive skewness, which is often seen in hydrologic data, by compressing the large values more than the small ones. On the other hand, the lognormal distribution is not without limitations. One of such limits is that the lognormal distribution has two parameters and the form that the logarithms of the data be symmetric around their mean.

2.6.3 Gumbel Method

Gumbel extreme values distribution has two general characteristics: it has a positive skew, meaning it is biased towards the large flows or extreme values, the mean flow at a return time of T equal to 2.33 years.

2.6.4 Pearson Type III Distribution

The Pearson type III distribution which is a three parameter gamma distribution as well, adds a lower bound ϵ as the third parameter which allows for the conversion of the three sample moments (the mean, the standard deviation, and the coefficient of skewness) to the parameters of the probability distribution using the method of moments. This is a very versatile distribution which can assume extremely different shapes.

According to Singh & Singh, (1985) the probability distribution of the yearly maximum flood peaks was the first application of the Pearson Type III distribution in hydrology. When the data are very positively skewed, along transformation is used to reduce the skewness.

2.7 Flood Modelling Tools

2.7.1 HEC RAS (River Analysis System)

The HEC-RAS program was a must-have tool for hydraulic engineers and researchers and its capabilities in making real-time flood visualization, flood classification, and unsteady flood wave propagation simulation enabled it to perform many other tasks along with dam breach modeling. It can also be used to determine water surface profiles for both steady and unsteady flow, sediment transport, and water quality simulation as well. The method used to calculate water surface profiles can be based on various flow scenarios. Various flow regimes such as subcritical, supercritical, and mixed can be simulated for streams with a dendritic structure, a whole network of channels, or a single reach of a river. The River Analysis System (HEC-RAS) is software designed to perform water temperature analysis, sediment transport through mobile bed modeling, and two-dimensional steady and unsteady stream flow hydraulics approximations.

The HEC-2-river-hydraulics-package, which maintained its characteristics as a two-dimensional, steady flow water surface profiles program, was shadowed by HEC-RAS software as it replaced HEC-2. The Wide Water Resources Research Program (SWWRP) which was recognized and designed the water quality computational modules it is the output of the crops civil work system were established (U.S. Army Corps of Engineers, 2010).

2.7.2 Flood Mapping and damage Assessment in Ethiopia

Gebre SL, (2015) studied flood hazard mapping and damage analysis for Meki river using, HEC-RAS, and HEC-FDA models, the study establish flood hazard maps and damage analysis along the Meki river. The HEC-GeoHMS hydrological model's automatic elevation of the watershed was applied to the outflow of the catchment area using rainfall design to reduce the flow hydrographs for return periods of 2, 5, 10, 25, 50, and 100 years. Hydrographs corresponding to return periods of 2, 5, 10, 25, 50, and 100 years have been used to create flood hazard and inundation maps adjacent to the Meki River. The HEC-RAS model has simulated water surface profiles that delineate flood plains or flood plain areas of the Meki River with return periods of 2, 5, 10, 25, 50, and 100 years from Meki town to Lake Ziway.

Flood mapping and modelling on the Fogera flood plain: an analysis of the Ribb river case study by Bezabeh & Tesfaye, (2021). The historical data of the Ribb River are the bases on which the study outline the area’s flood depths and frequencies for the 2, 5, 10, 25, 50, and 100-year flow conditions. HEC-HMS is applied to the hourly time series data for return periods of 2, 5, 10, 25, 50, and 100 years and the hydrological model is calibrated accordingly. The HEC-HMS data value for each hour is linked to the diverse frequency analysis techniques. The research was performed using ArcGIS and the one-dimensional hydraulic model HEC-RAS in conjunction with the HEC-GeoRAS interface. The results were then compared with frequency analysis which made use of the Ribb River's event flow value. The flood map indicates that the areas inundated for the 2, 5, 10, 25, 50, and 100 years are 12.63 km2, 18.63 km2, 21.31 km2, and 22.5 km2 respectively. As per the classification of flood depth, most of the flood area was less than 1.5 meters bottomless. Conversely, 11.6 percent of agropastoral land, 88 percent of agricultural land, and 1.36% of rivers are submerged. Dawit, (2021) used HEC-FDA to analyse the flood damage in the upper Awash Sebeta Hawas woreda.

The analysis of both flood control strategy ecologically viable and flood damage management was done in a deep manner, and the study has revealed the technical method of flood risk evaluation through the statistical analysis of the flow at the Hombole gauging station, which included filling in the missing data, outlier, isolated, and stationary data. To determine the depth damage feature, a 1m interval contour Digital Elevation Model (DEM12.5m) was made. Flood mapping with ArcGIS and a field survey were helpful in evaluating property damages. However, field data was applied for inputting the cross-section. The boundary conditions and the manning number were involved in the estimate through the field. The HEC-RAS model was the one that determined the water surface elevation. The observed data is without outliers, which means they are independent. The Gumbel (Extreme I) model provided the following flood frequencies for 2, 5, 10, 25, 50, 100, 250, and 500 years - 42.36, 49.01, 53.41, 58.97, 63.10, 67.20, 72.59, and 76.66 m3/s respectively

Dejenne (2011) used a 2D hydrodynamic model to analyse the flood in the flood plain of Fogera. The main objectives of the research were to carry out a floodplain analysis and risk assessment for Fogera and its surrounding areas. The 2D Hydrodynamics Modelling technique with Geographic Information System (GIS) is employed in this study to propose a regional floodplain identification and representation model. The analysis shows the extent of flooding and the corresponding speed of water flow for different scenarios, which are derived from the historical flow data of the Gumera River. Flood frequency analysis, Gumbel method, and Long-Run Pearson Type III, along with the Gumbel distribution with R2 = 0.994, are applied to compute the peak flow for regular time series data. The river's peak flow is projected for the return periods of 2, 5, 10, 25, 50, and 100 years.

The upstream and downstream boundary conditions have been set. By conducting input boundary and steady flow analyses on the data, flood discharges for 2, 5, 10, 25, 50, and 100 return times were also registered. Based on Gumbel distribution results, for a return time of 2, 5, 10, 25, 50, and 100 years, flow values are 233, 281, 312, 352, and 411 m3/s, respectively. Two-dimensional computational hydrodynamic models and the detailed terrain data related to the area were used for the simulations. Six different scenarios with return periods of 2, 5, 10, 25, 50, and 100 years were tested to evaluate the results of the model. A flood map was finally made.

2.7.3 HEC-GeoRAS

HEC-RAS imports geometric data from HEC-GeoRAS. The ArcGIS extension tool HEC-GeoRAS was created specially to progress spatial data for use with HEC-RAS. The RAS team is the user who generates the major channel banks, streams centerline, flow path centerline, and cross sectional cut lines. Additionally, the RAS team imports storage areas, levee alignment, land usage, and places with failed flows Hamedi & Nazariha, (2015).

To create the HEC-RAS geometric data, the user produces several line themes. The created themes include the primary channel banks, steam centerline, flow path centerline, and cross-section cut lines. HEC-GeoRAS can perform GIS processing on water surface profile and velocity data obtained from HEC-RAS simulations, which are then used in floodplain mapping, flood damage assessments, ecosystem restoration and flood warning response, and preparedness. There are seven tools: Assign River name, Reach name, Assign from station to station, assign line type, create XS cutline, pilot cross section, and assign levee elevation; and four choices RAS Geometry, RAS mapping, ApUtilities, and help available in the HEC-GeoRAS toolbar.

2.7.4 Geographic Information System (GIS)

A Geographic Information System is one of the main tools for floodplain managers to identify and locate currently unprotected, or flood-vulnerable, areas in their community, as stated by consuguera Nigusse & Adhanom, (2019). In the GIS approach, the geographic data of various types are continuously processed in the database, where they can be mined and represented through visualization for analysis purposes. The confluence of different geographical layers allows the identification and selection of areas for flood control measures. The flood hazard maps, together with GIS and other data such as flood extent and population affected, are the basis for planning flood relief operations in the corresponding river basin. The maps might include the probabilities of flood heights being reached so that the risk in the floodplain can be appraised. Flood risk maps can now be utilized to calculate the rates for flood insurance based on the level of exposure to flooding more accurately.

In Lothar Khola, Manandhar, (2010b) used GIS technology to analyse the flood risk on 1,2017 hectares of land are submerged after two, ten, fifty, one hundred, and two hundred years of flood return times, respectively.

2.8 Previous Studies flood risk analysis on Upper Awash River Basin

Ejere woreda which is in the upper Awash River basin is location. An in depth analysis was essential because of the local flood situation. Flood risk analysis in Illu floodplain, upper Awash river basin Ethiopia was the tittle of the research study carried out by Dawit, (2015) and Bedilu, (2020) titled Flood Damage analysis for Teji area/Illu woreda. The flood risk analysis in Illu woreda revolved around the forecast of Awash River flow and the flood frequency analysis. The main aim of the study was to determine and evaluate the effect of flooding on crop productivity in the area. Steps such as testing the data series for independence and stationarity, confirming they came from the same distribution, are the main assumptions behind the statistical flood frequency analysis. At various significance levels, the tests for homogeneity and stationarity were performed using the Wald-Wolfowitz and Mann-Whitney tests. The system of moments of parameters approximation methods were employed to adjust the flow data time series to the extreme value of the first form (EVI). The HEC-GeoRAS and HEC-RAS tools were used to create the flood hazard map.

In the end, flood losses can be interpreted by comparing the expected crop production from the submerged area and the previously produced crop yield of one hectare of lands. This means that 1960-2010, the adjusted Awash Bello stream flow gauge station, constantly and reliably, collects flow data, resulting in precise flow statistics for that period. The flow data coming from the Awash Bello station were considered to be independent, homogenous, stable, and outlier-free at the 5% level of significance. In addition, quantile estimates for the location were given as 27.30, 38.38, 53.86, 60.39 and 76.34m3/s for the 2, 5, 50, 100 and 500-year return periods, respectively. The corresponding flood areas for these events were 1,959.50, 2,107.38, 2,299.16, 2,318.84, and 2,354.06 hectares of cropland. The crop losses for each of the events were recorded as 44,088.66, 47,415.96, 51,731.03, 52,173.84, and 52,966.25 quintals. As noted in the study, the highest part of the agricultural zone suffered from flooding more than the middle and lower portions. Flood-affected communities are located adjacent to the Awash River. Thus, the areas at risk of flooding, especially along the Awash River, should not have any agricultural activities, infrastructure, investments, or human settlements to lessen the risk.

3 MATERIALS AND METHODOLOGY

3.1 The Study Area

The Awash River Basin is considered the fourth largest basin in Ethiopia, with an area of catchment approximately 11,600 km². The Awash River has its source from the southern slope of Mount Warqe at a height of 3000m above mean sea level (m.s.l.) in the area, close to the town of Ginchi and proceeds to the Koka reservoir, which is at an altitude of about 1500m above m.s.l. The Upper Awash River is a river with the nature of wandering, where it takes about 200 km to reach the Koka reservoir. The highland area is partitioned into three parts; the upper basin or the Koka catchment, which is upstream of Koka Dam, and the eastern and western catchments based on their location within the basin. The research area lies in Ejere Woreda, which is directly in the upper Awash River Basin, approximately 50 km west of Addis Ababa, the capital city of Ethiopia. The area that is most vulnerable to flooding is in the West Shewa Zone, specifically in Bolengo Kebele, Ejere Woreda.

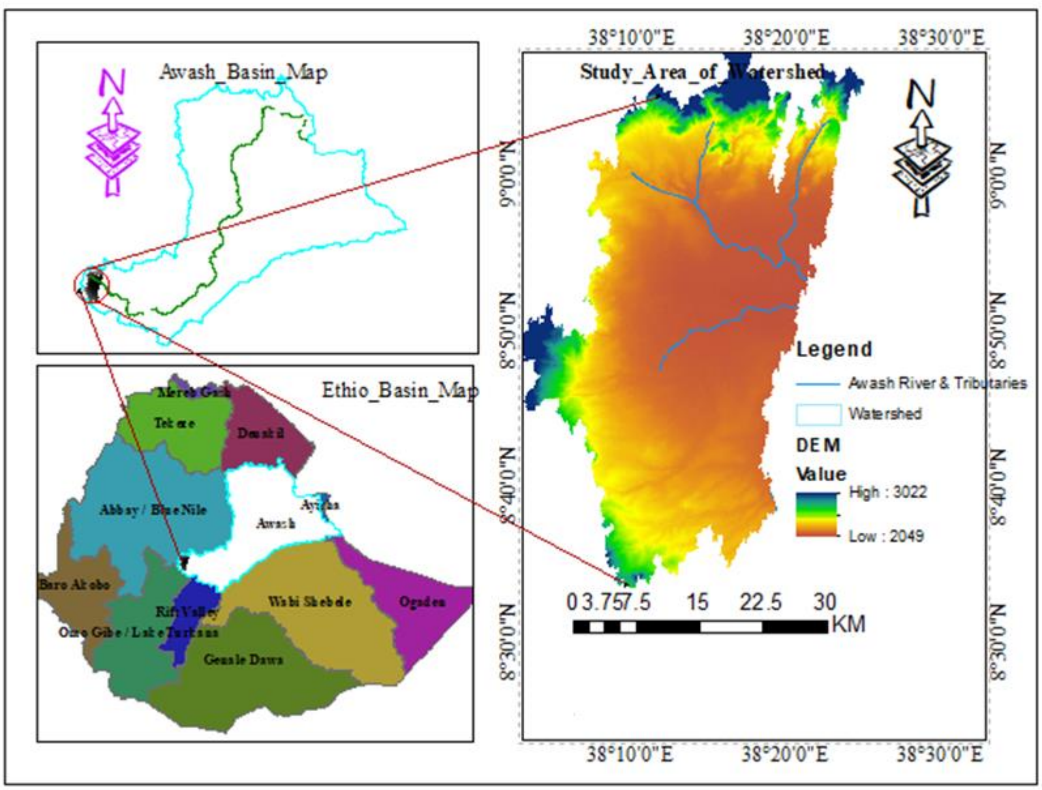

Figure 3-1 Location map of the study area.

The Woreda is made up of a total of 27 rural Kebeles and 3 towns which are Addis Alem, Kimoye, and Amaro. Addis Alem is located 50 km west of Addis Ababa, which is the capital town of the woreda, and it lies along the road to Ambo. The total geographic area is about 139,389 hectares, lying between the geographical coordinates of 08051'59" and 09001'20" north latitude and 38024'59.9' and 39040'59' east longitude. The Bolengo watershed occupies a space of around 4646.3 hectares. As shown in Figure 3.1, this area is characterized by its water divide or river catchment that is part of the upper awash basin.

3.1.1 Topography, Climate Type, and Rainfall Distribution in the District

The rainfall distribution in Ejere woreda is differed by place and time but the average annual rainfall is estimated to be from 900 - 1,200 mm. The major rainy season in the woreda is from June to September. The altitude of the area varies from 2049 m to 3022 m above sea level and has an annual temperature range of 15^0C - 25°C. The woreda has two agro-ecologies which are Dega(45%) and Weina Dega (55%) Hailu, (2017).

3.1.2 Land Use Land Cover

The region supplying water is very much inhabited and smallholder farmers have been doing crop and livestock production as the major agricultural activity extensively. The Woreda Agricultural and Rural Development Office report (2023) states that the two most important crops grown in the area are Wheat and Barley. The land cover in the study area, illustrated in Figure 3.2, is categorized as farming and coniferous forest.

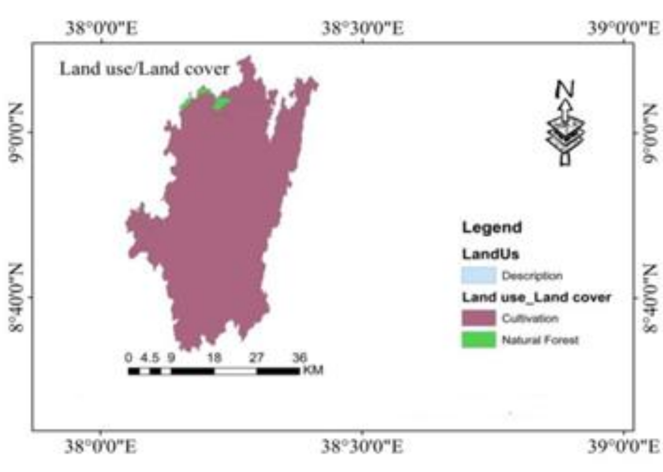

Figure 3-2 Land use/land cover of the kebele.

Although the human activities and land use within a watershed vary over time, they still significantly influence the consequences of a runoff event. A watershed's expected runoff rate and volume depend on a number of variables, such as drainage density, slope, and vegetation cover. When establishing the parameters of each runoff hydrograph, the study considered the current land usage. Currently, only 0.52%, or 24.1 ha, of the land is utilised for building and other purposes, while roughly 99.48% of the cultivated area, or 4,622.2 ha, is covered by different crops.

3.1.3 Land Cover and Cultivation

The crop coverage of agricultural land in 2023 was represented by Table 3.1. The five crop types that cover the study area were given in percentage terms for their average yield per hectare. It was shown that barley and wheat together occupy nearly 50% of the total land area, with wheat alone covering about 35%. Also, wheat does produce twice the amount of barley, which is about 40 quintal per hectare.

Table 3-1 Crop production in the study area during the 2023 season (EWARDO, 2023)

Crop	**Barley**	**Wheat**	**Teff**	**Bean**	**Potato**
(%) of Crop Coverage	15	35	20	10	10
Average crop yield per hectare (quintal)	20	40	15	10	60

3.1.4 Climate

According to the Woreda Agricultural and Rural Development Office report of 2015, the mid-range annual precipitation in the area of study is between 700 mm and 800 mm and the temperature is in the range of 15 ˚C to 25 ˚C. Hombole station, the placed that measured the catchment's water flow, was the leading station for hydrological gauging in the region of the study. This investigation considered 50 years' worth of stream flow data that had been recorded daily from 1965 to 2015. The period of June to August is characterized by heavy rainfall in the woreda while February to April has light rainfall.

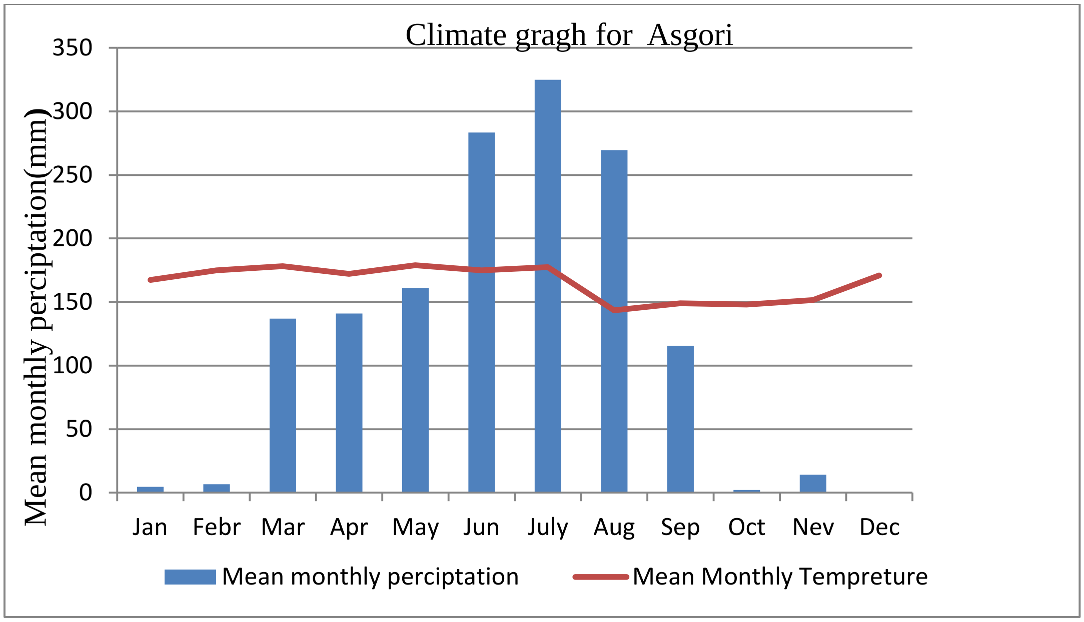

Figure 3-3 Climate and rainfall characteristics in the study area.

3.1.5 Soil Type

Soil type is a significant factor in determining the discharge rates of a runoff hydrograph. The permeability of soil is the major factor in the infiltration rate of the rainwater; thus, the soil type has a direct influence on it. The Natural Resources Conservation Service (NRCS) is an excellent source of soil information. The soil groups in the study area are depicted in Figure 3.4 as B, C, and D in rank order.

Group B: loam or silt loam. These soils have a moderate low potential for runoff as they have moderate penetration rates. Examples of such soils are Orthic Luvosols, Chromic Cambisols, Vertic Cambisols, Eutric Fluvisols, Eutric Nitisols, Calcic Xerosols, and Orthic Solonchaks.

Group C: sand clay-based loam. These types of soils are characterized by slightly higher runoff potential due to the moderate infiltration rates prevailing in this category. Luvic Phaeozems can be a case in point.

Group D consists of clay loam, silty clay, sandy clay, silty loam, and clay. The infiltration rates of these soils are very slow, leading to a high potential for runoff. Chromic Vertisols, Pellic Vertisols, Leptosols are a few examples of such soils.

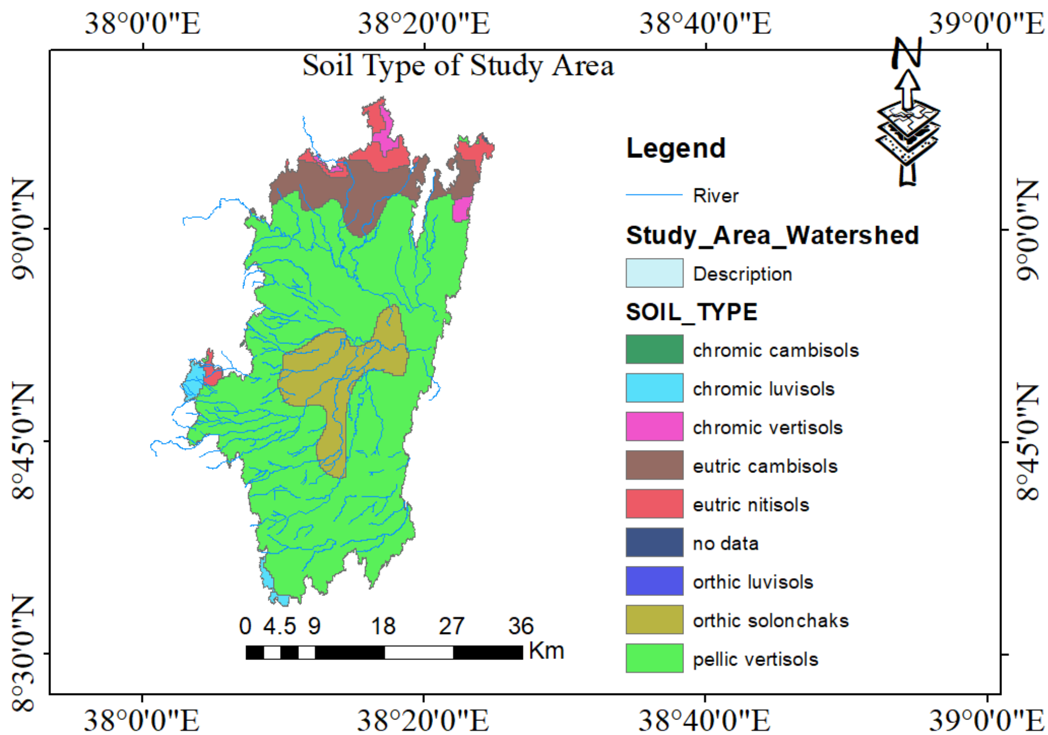

Figure 3-4 Soil type in the study area.

3.1.6 Demographic Characteristics of the Study Area

Ejere Woreda has 27 Rural Kebeles and 3 towns, the towns are (Addis Alem, Kimoye and Amaro). The urban and rural populations were indicated under Table 3.2.

Table 3-2 Total number of people in woreda (The Woreda Flood Risk Management and Preparedness Report, (2023).

Rural population			**Urban Population**			**Total population in the Woreda**		
M	F	Total	M	F	Total	M	F	Total
28,282	28,304	56,586	8,357	12,330	20,687	36,689	40,692	77,381

3.1.7 Socio-Economic Characteristics in the Study Area

The 2023 Ejere Woreda Agricultural and Rural Development Office Report states that 73.1% of the population resides in rural areas. Consequently, the economy of the woreda is primarily made up of varied agricultural practices, Crop Cultivation, and Animal production, which account for more than half of the population. The farming activities provide food, income, and raw materials for the industries.

3.1.8 The Flood damage

The flood-vulnerable area identification is the most challenging part of flood damage analysis. Element at-risk indicators illustrate the count of economic, social, or ecological systems that could be impacted by different hazards in a particular area. The example of agricultural production, especially at the household level, as well as the growing of wheat and barley, is in a risky zone.

Table 3-3 Population data and agricultural land under flood risk in Ejere Woreda at Bolengo Kebele according to EWARDO, 2023

Household Family			(ha)
M	F	Total	Total
1,504	1652	3,156	4,622.2

Conceptual Framework

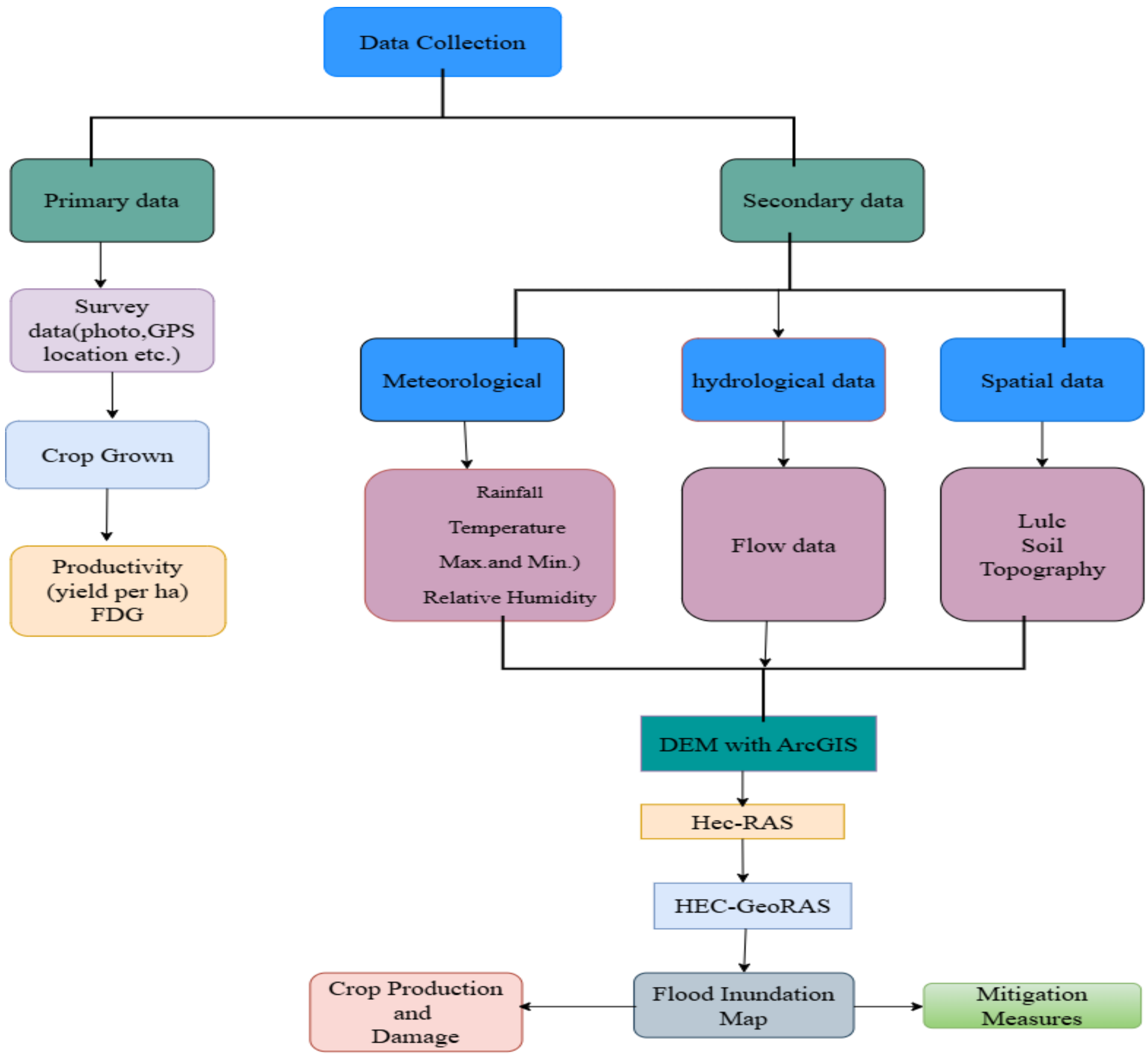

Figure 3-5 Conceptual frame-work of the Research.

3.2 Methodology

3.2.1 Watershed Delineation

The identification of a specific area contributing to a certain control point or outlet by means of a border is called watershed delineation. The boundaries of the research region were determined to indicate its borders and/or divide it into smaller, more delicate sub-areas or sub-basins. The accurate watershed borders are essential in the production of HEC-RAS simulations and Su-watershed characterization reports. For this research, Digital Elevation Model-based automatic delineation was used, meaning that ArcGIS or the machine was responsible for the automatic creation of the border. Subsequently, the study river, its drainage system, the catchment pattern, and the locations of the gauge and meteorological station were all demarcated through the ArcGIS software.

3.2.2 Data Collection

Data which are important in this study consist of flow data, cross-section data, production data, topographic and land use, land cover data. The Ministry of Water, and Energy's hydrology department provided the cross sectional data, while a through on-site study of the Awash River provided the cross sectional data. A variety of sources were used to collect data on soil, land cover, land use, and the Digital Elevation Model (DEM). For example: the ALASKA satellite facility website (https://vertex.dac.asf.alska.edu) provided high resolution DEM (12.5m x 12.5m), while the United States Geological Survey (USGS) provided DEM (30m x 30m) at https://earthexplorer.usgs.gov/. Moreover, a 30m x 30m DEM was gathered from (MoWE) and examined in ArcGIS to extract the physical and hydrological characteristics of the watershed.

In this digital model, different elevation levels from 2049 to 3022 m above sea level were indicated in the form of a digital model. The data on land usage, land coverings and soil were obtained from the Ministry of Water, and Energy in Ethiopia. The flood risk management and preparedness office of the Ejere woreda gives the socio-economic data, including the data on flood damages, which are collected through field observations, focus group discussions (FDG), interviews, and surveys. Moreover, the crop statistics were provided by the woreda agricultural and rural development office, which included the average yield per hectare and the percentages of wheat and barley, and a survey of the river cross-section, was carried out.

3.2.3 Digital Elevation Model (DEM)

Among the manifold digital products that have been produced due to the fast progress of digital technologies and associated sciences, DEM (digital elevation model) is one of them. Many domains like soil mapping, hydrology, surveying, mapping, and agricultural planning have made extensive use of this product. SRTM with a 12.5-meter resolution was used to develop a digital elevation model of the Awash River fit to the study area; this was aimed at providing more precise and better results for this research.

The results are shown in Figure 3.6.

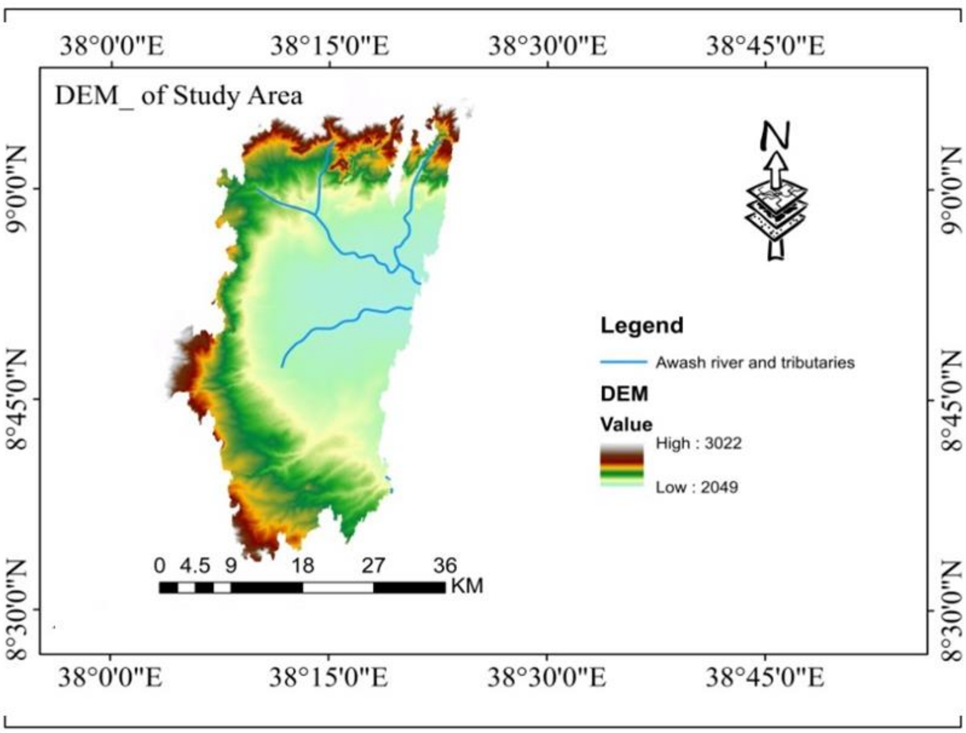

Figure 3-6 Digital Elevation Model 12.5m resolution for Awash River at study area.

3.2.4 Cross-sectional Data

The edge or the geometric boundary of the river is illustrated by the information derived from the river's cross-sections. The cross-sections are to be located at the most important places along the stream, especially when the discharge, slope, and surface roughness differ. A lot of data, such as the distance of the downstream reach, the key channel bank stations, the names and IDs of the river stations, the description of the x and y coordinates (stations and elevation points), and the coefficients of expansion, are required for the cross-section. The lengths of the downstream reaches were distinguished at every 50 to 600 meters along the river station of cross sections. The water depth in the wide cross-sections during the summer dry season is usually between 0.5 m and 1.5 m; the study was conducted over two visits in May and August of 2023. Look at the longitudinal and cross-section profiles of the Awash River, as the river's morphology is a big factor in creating the flood. The analysis presented in this paper heavily depends on the Awash River, which is only 5 km long and cuts through the research area, for its data.

3.2.5 Crop Production Data

The significance of this data was to measure how much the flood risk affected the agricultural output. In other words, the flooded territory has its own yield potential. Thus, the volume of crops harvested from the flooded area was estimated in order to assess the loss caused by the water.

Table 3-4 Production data of wheat and barley within five years (2019-2023) GC from (EWARDO).

Year	**Unit**	**2019**	**2020**	**2021**	**2022**	**2023**
Total Cultivated land	ha	522.2	636.4	578.5	630.6	748
Flood Area Covered	ha	329	426	353.7	386	494.4
Wheat Production per ha	quintal	32	33.64	36.18	39.11	42.7
Barley Production per ha	quintal	18	31.56	37.86	41.19	44.1

According to Ejere Woreda Agricultural and Rural Development Office Production Department report on the main crop production, percent of each crop coverage and average crop yield per hectare. Therefore, the yield loss of inundated area for different return period was analysis using:-

$$\text{Cl} = Av.y \text{ per hectare } x \text{ \% of } CC \text{ } x \text{ } Fa \text{ of different return period} \ldots\ldots 3.1$$

Where:

Cl - Crop Loss**,** in quintal

Av.y Average Yield per hectare, quintal

CC - Crop Coverage and in percent

Fa - Flood Inundated Area of different return period in ha.

The average crop yield per hectare and percentage of crop coverage for selected crops (wheat and barley) depicted

The Relative Yield Loss (RYL) is a widely used metric to quantify the percentage reduction in crop yield due to stress factors such as floods, droughts, or pests. According to Monteleone et al., (2023) RYL is calculated using the formula:

$$RYL = \left(\frac{Yp - Ya}{Yp}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where Yp represents the potential yield under ideal, stress-free conditions, and Ya is the actual yield gained under the influence of stress. The resulting percentage indicates how much of the potential yield has been lost. An RYL of 0% implies no yield loss, while an RYL of 100% indicates complete crop failure. The higher the RYL, more severe the impact of the stress factor.

3.2.6 Test on Hydrologic data

In statistical flood frequency study, the data series independence and stationarity are important assumptions. Additionally, it is expected that series independence and that the data are homogeneous (from the same distribution). The following tests, which are also defined by Mosisa et al., (2023) are commonly used to verify that the data is independent, homogeneous, and stationarity. There are other (similar) tests in Bobee et al., (1991).

3.2.7 Test of Independence

Given a sample of size N, the Wald et al., (1943) (W-W) test is used to test for the independence of a dataset and to test for the existence of trends in it. For a data set x1, x2...xn the statistic R is calculated.

$$R = \sum_{i=1}^{N-1} X_1 X_{2+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

R has a mean and variance and follows a normal distribution when the sample's components are independent.

$$R = \frac{S_1^2 S_2^2}{N-1} \text{...} 3.5$$

$$\text{var}(R) = \frac{S_1^2 S_2^2}{N-1} - R + \frac{S_1^4 - 4S_1 S_2 + 4S_1 S_3 + S_2^2 - 2S_4}{(N-1)(N-2)} \text{.................................} 3.6$$

Where:

R is determinant

Var(R) is the variance of determinant

3.2.8 Test of Homogeneity and Stationarity

In this test two sample of size p and q with p is less than or equal to q are compared. The collective data set of size N equal to p+q is ranked in increasing order Whitney, (1947) (M-W) test considers the quantities V and W in

$$V = R - \frac{(p(p+1))}{2} \text{..} 3.7$$

$$W = pq - v \text{...} 3.8$$

V and W are computed from R, p, and q, and R is the sum of the rankings of the elements of the first sample (size p) in the pooled series (size N). V is the number of times an item in sample one is ranked after an item in sample two. Likewise, W can be calculated for sample two after sample one. The smaller of V and W defines the M-W statistic U. under the null hypothesis that the two samples were drawn from the same populations, U is roughly normally distributed with mean and variance var (u) when N > 20 and p, q > 3.

$$U = \frac{pq}{2} \text{...} 3.9$$

$$Var(u) = \left(\frac{pq}{N(N-1)} \right) \left(\frac{N^3 - N}{12} - \sum T \text{......................} 3.10 \right.$$

$$T = \frac{J^3 - J}{12} \quad \ldots\ldots 3.11$$

Where T and J is the number of observations tied at a given rank. T is summed over all groups of tied observations in both samples of size p and q. The statistic u is used to test the hypothesis of homogeneity at significance level α by relating it with the standard normal variate for that significance level.

3.2.9 Estimating of Missing Flow Data

Restoration or filling of hydrological flow records such as water level, streamflow, or river discharge that are characterized by missing, insufficient, or distorted data is called hydrological data recovery. Records that are continuous and comprehensive being essential for precise analysis, modelling, and decision making, this is a typical task in hydrological studies and water resource management. The stream flow data should be verified before it is used as it is the basis for the control of the river's peak flow for the year. The method of linear regression is employed to fill in the missing data.

3.2.10 Regression Method

In many cases, flow data for some rivers are either not available for the upstream or downstream points. In such situations, the flow data of nearby streams can be utilized to infer the missing flows. The method that is mostly applied to solve this matter is regression analysis. The independent variables consist of the flows recorded at nearby stations that possess drainage basins with similar hydrological characteristics.

3.2.11 Linear Regression Analysis

If X, as well as Y, is two related variables, then linear regression analysis helps us to calculate Y value for a known X value or vice versa, expressed through

$$Y = \beta x + \alpha \quad \ldots\ldots 3.12$$

Where β and α are the slope and y-intercept respectively

In my case, Awash at Hombole gauging station is used as a dependent variable to estimate the miss of the Awash River adjacent to Ejere woreda.

3.2.12 Estimating Missing Rainfall Data

Oftentimes, a day or days' rainfall that was supposed to be reported at a certain station might be guilty of non-reporting due to an observer's absence or equipment failure. In such a scenario, the missing rainfall amount would have to be estimated by making use of neighboring stations' data. Hydro-metrological data analyses should only be done after data preparation and missing values evaluation have been completed. Nowadays, different methods exist for calculating missing data values. By those methods, multiple regression techniques were applied to predict the missing rainfall data. However, the linear regression method was chosen for checking data consistency, and the Long-Pearson type III test was employed for data outlier detection.

Multiple regressions were used in this study.

This helps to estimate the Y values for given values of X1, X2, X3,…PX worth. Established values PX. Expressed hereunder

$$PX = a_0 + a_1 P_1 + a_2 P_2 + \ldots + a_n P_n \ldots\ldots 3.13$$

PX = estimated rainfall at the station with missing data

P1,P2,…, Pn = rainfall data from n near stations (for the same time period)

a_0 = regression constant (intercept)

a_1,a_2,…,an = regression coefficients (slopes)

Meteorological Rainfall stations used for the study are:-

3.2.13 Peak flow Estimation

Flood frequency analysis and HEC-HMS are the two approaches used to estimate peak flow in this study. Additionally, we may use the distribution approach to guess flood frequency analysis.

3.2.14 Testing of Outliers

The clustering based methods, the distance based methods, the statistical based methods and the supervised or unsupervised learning algorithms are among the techniques used. The outlier test is one way to evaluate the amount of data that might be problematic due to collection and recording errors. Outliers are data points that are significantly different from the overall trend of the data. The inclusion of these outliers can greatly affect the size of the statistical parameters calculated from the data, particularly for small samples. Outlier consideration procedures necessitate a decision that integrates both mathematical and hydrological aspects.

The Water Resource Council, (1981) states that high outliers can be found using the following formula.

$$Yh = y + Knsy \quad \text{.......... 3.14}$$

Where: Yh is the high outlier threshold in log units and Kn is given from sample size n.

The Kn values are used in the one-sided tests that locate outliers in normally distributed data at the 10 percent significance level. According to the earlier equation, high outliers are identified when the logarithms of a sample's values exceed Yh. The floods that are classified as high outliers should be compared with historical flood data and flood knowledge in nearby areas. Historical flood data contain information on specific severe events that are not part of the systematic record. If no trustworthy historical data exists to connect high outliers, then the outliers should remain in the systematic record.

A similar equation can be used to detect low outliers:

$$Yl = Y - Knsy \quad \text{.......... 3.15}$$

Where: Yl is the low outlier threshold in log units. Flood peaks considered low outliers are erased from the record and a conditional probability adjustment described by the Hydrology Committee, (1967) can be applied.

Figure 3.8 shows how the value of a statistic or correction factor denoted as "Kn" varies with sample size. As the sample size increases, Kn also increases, suggesting that Kn accounts for changes in variability or distribution behavior with growing sample sizes. The curve approaches a plateau, showing diminishing change in Kn at larger sample sizes.

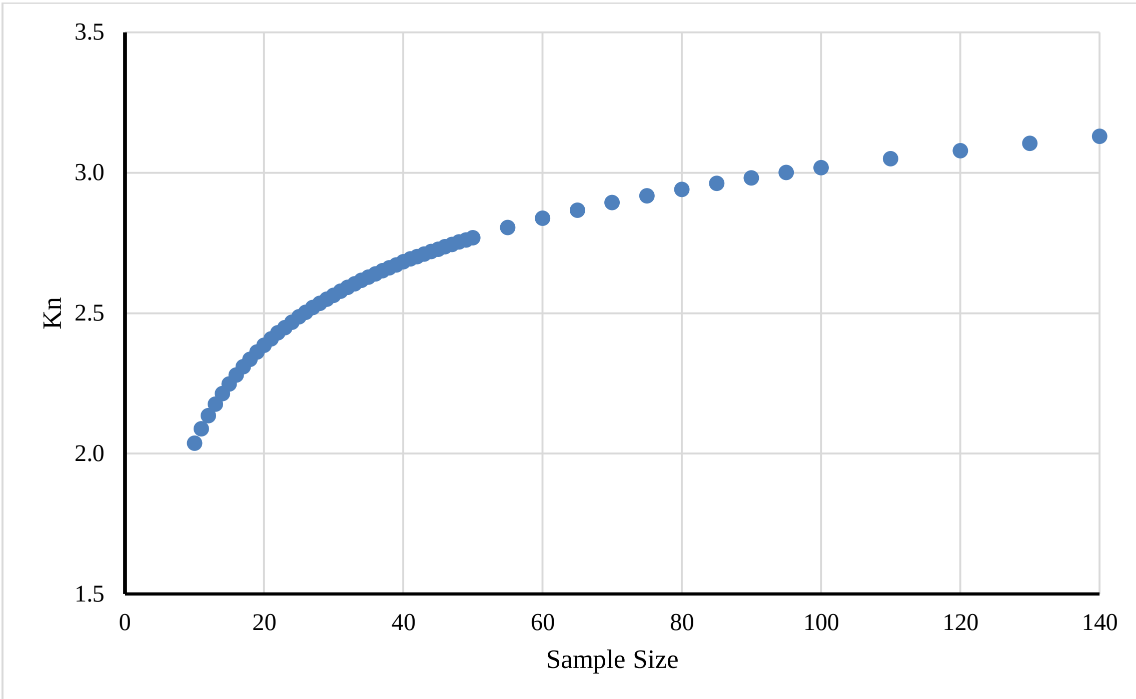

Figure 3-7.Variability or distribution behavior of sample size.

3.2.15 Flood Frequency analysis

Strong steps also impact hydrological processes Costa & Amato Neto, (2017) such as major hurricanes, drought, and floods.

An extreme event's degree is inversely proportionate to how often it occurs, thus the very serious events are less frequent than the mild less serious ones. The hydrological data frequency analysis aims to set up a correlation between the frequency rate of recurrence and the severity of extreme events through chance distributions. The hydrological process that produces the studied hydrological data (e.g., storm rainfall mechanism) is referred to as stochastic, location independent, and time independent. The data are assumed to be uniformly distributed and independent.

This is also done through the process of exercising the assumption of independence of the subsequent observations of the variable from one year to another by selecting the annual limit of the variable to be evaluated, where the annual maximum discharge is the largest instance. The outcomes of flood flow frequency analysis have been widely adopted in various engineering sectors. For instance, they have facilitated designation of floodplains, valuation of flood mitigation projects, and the use of bridges, culverts, dams, and other flood control structures, and they have also helped to assess the impacts of encroachments on the flood plain. The possible number of floods forecast is the flood's respective or equal probability to occur in that year or to be surpassed in that year. An annual percentage probability of 20% for flood would mean that the flood occurrence would be around every 5 years for quite a long time. Therefore, not every flood occurring on or after the 5-year mark is taken as a 5-year flood. The reason is that the previous flood's height or volume has a 20% probability that it will be matched or surpassed; thus, the five-year flood may happen in several successive years.

According to Mazimwe, (2019) asserts that the same is true for flooding and other return periods. The likelihood of a flood happening is also determined by the flood frequency, which is 2, 5, 10, 25, 50, and 100 years. A 100-year flood, for instance, is occasionally called a 1% flood. Several frequency distribution functions are frequently employed to estimate extreme flood values, including: The Gumbel extreme-value distribution has the following general features: it has a positive skew (i.e., it is biased towards the large flows or extreme values), the mean flow occurs at the return time, and T is taken as 2.33 years.

$$XT = \overline{X} + KTrSn - 1 \quad \text{...} 3.16$$

Where: X_T is Maximum flood peak discharge

$\overline{X}$ The Average values of discharge.

Sn-1 Standard deviation of sample size.

Lognormal Distribution: - If the accidental variable Y equal to log X is normally scattered, then X is assumed to be log-normally scattered.

$$Y = \log X = \sum_{i=1}^{n} \log X_i = \sum_{y=1}^{n} Y_i \quad \text{...} 3.17$$

Gumbel Method

The general features of the Gumbel extreme–value distribution are; the mean flow occurs at the return time of T equal to 2.33 years and it has a positive skew (i.e. it is biased towards the large flows or extreme values).

$$X_T = \overline{X} + K_{Tr} S_{n-1} \qquad 3.18$$

The Extreme Value Type I (EVI) (Gumbel's distribution) probability distribution function is given by:-

$$f(x) = Exp[-\frac{x-\mu}{\alpha} \qquad 3.19$$

The parameters μ and α are determined by the method of moments as the following formula:

The magnitude XT (quantile estimation) of a hydrologic event is therefore represented as

$$XT = Xi + K_T S \qquad 3.20$$

Where KT is the frequency factor and is given by

$$KT = -\frac{ln[-ln(1-1/T)] - 0.5772}{1.2825} \qquad 3.21$$

Where:

XT = value corresponding to return period T (e.g., rainfall or flood magnitude)

X= sample mean

S = sample standard deviation

KT= **frequency factor** (depends on the distribution and return period)

3.3 Flood damage analysis

The first step involves identifying the areas that are prone to flooding. In order to predict the areas that will be flooded based on the changing hydrological parameters, it is necessary to have a digital elevation model (DEM) with a sufficiently fine grid resolution for estimating the river channel geometry (for instance, the width and depth of the channel across). The difficulties attached to these models are that they require huge amounts of data, including the topology of the stream channel. A rough estimate of the areas close to the stream channel can still be made by using the SRTM DEM, even though the regions to be flooded are likely to change along the river course, depending upon the river's reach and rainfall event's location.

At the continental and even regional sizes, the SRTM DEM provides excellent resolution. In the flood risk assessment established by Manandhar, (2010a) who offers its own method, the flood risk is divided into the hazard element and its likelihood. The flood risk assessment includes the results obtained from these two evaluations. The vulnerability assessment is simplified by the binary approach that considers only if a flood of certain intensity takes place in the particular land use type. The risk assessment procedure is automated by a graphical user interface designed specifically for ArcGIS.

Chang et al., (2018) state that the usual definition of flood risk as a product of hazard (natural event) and its likelihood of incidence will also serve as the basis for its evaluation and measurement. Flood risk maps are created by overlapping the grids of flood extent with the map. If the water floods, both banks will be affected since almost the entire risk area is flat and has various crops. Consequently, the risk is now measured in quintals of the crop yield from the area. The price of the crop, however, changes with time, which makes it hard to determine its money value. Thus, it is better to assess the risk connected to crop production rather than the crop itself.

3.4 Flood Hazard Analysis

Flood depth, flood magnitude, and the likelihood of a flood event can be used to describe the level of hazard. When approximating the flood threat and potential damage, the size of the flood is a critical element. According to Pistrika & Tsakiris, (2007) the hazard component of flood risk is influenced by hydraulic and hydrological features. The weighted spatial coexistence model enables the study by categorising the degree of hazard based on the magnitude of the flood. This means that a large flood also has a higher level of hazard, whereas a little flood conveys a lower level of danger.

Additionally, According to Chang et al., (2018) state that information on the frequency and intensity of flood incidents ought to be the starting point for identifying and assessing flood hazards. Usually, the axis locational setup of both flood flow depth and flow velocity is needed to be taken into account. The flood flow depth was chosen as a flood identifier and evaluator for the study. The very low land flooding can be pictured as a shallow water movement with a speed distribution that is vertically integrated. Consequently, the two-dimensional hydraulic model (flood inundation model) is the foundation for defining flood hazard. It is necessary to use a GIS to produce a flood hazard map for the presumed flood events with various recurrence intervals.

3.5 Agricultural Damage

The damage categories are used to consolidate large numbers of structures in to specific categories with alike characteristics for analysis and reports (U.S. Army Corps of Engineers, 2010). Based on field observations and the report from the woreda flood risk management and preparedness office, this study was conducted.

The most recorded damage per year is farm damage. The land is inundated from the water surface profile in hectares by Arc-GIS. The land inundated from the water surface profile in hectares by ArcGIS.

$$CT \ birr = Z * W \ \% \, cultivated \ * AT \text{..............................} 3.22$$

Where: CT in (Birr) is the damage cost of cultivated land at a given elevation AT land inundated due to the rise of water in the river (ha)

Z is yield per ha in kg

Flood inundated area per crop type equal to total inundated area * per area crop inundated * per crop planted

W is (birr) cost of one Kg (cultivated land yield) or birr qi$untal$ percent cultivated is the percent of different crops shown in Table 4.4.

Figure 3-8 The right is a focused group discussion in May, 2023 and the left is river cross section measure in July, 2023.

4 RESULTS AND DISCUSSION

4.1 Upper Awash River Characteristics

4.1.1 Stream Centerline

The river and reach network are displayed by the stream centerline layer. The stream centerline was drawn from the upper side (upstream) to the lower side (downstream) of the study area along the Awash River channel. The producers were giving the river name and reach name. The stream centerline is a mapped line that moves along the central axis of the stream or river, indicating the general flow path of the water. It is widely applied in hydrological studies, river engineering, and GIS applications to analyze water flow, erosion patterns, and watershed management. A stream centerline feature class has been created in the Output Geo-database based on the centerline location in HEC-RAS.

River and *Reach* attribute information were added as shown in figure4.1.

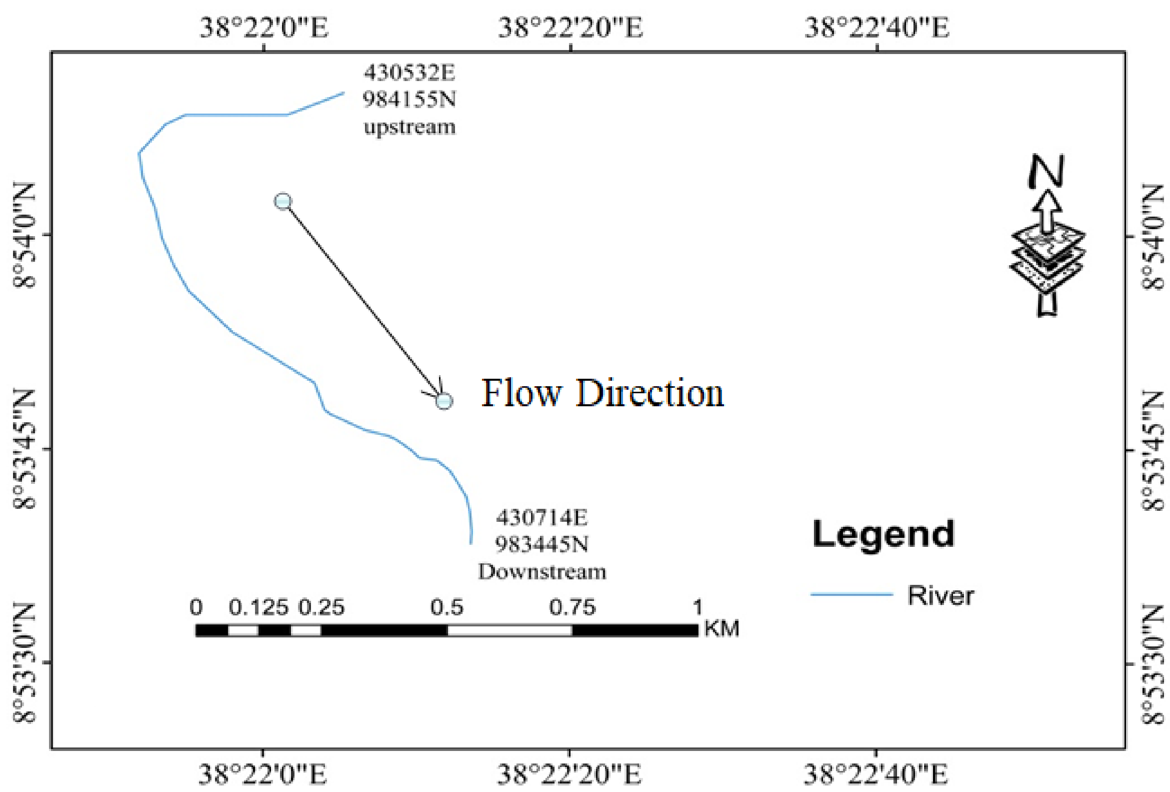

Figure 4-1 River centerline of Awash River at study area.

4.1.2 Bank lines

The Bank lines layer marks the primary flow from the river into the overbank areas. For each cross-section, bank stations were determined where the bank lines and cut lines intersected. It would be better to bypass this layer and carry out the work in HEC-RAS using the graphical cross-section editor as shown in Figure 4.2. At point A, the river's cross-section is deep and narrow, but at point B, it is wide. The cross-section of the river indicated that the bank is widening from section A to section B, which is the downstream direction. This development results in overtopping.

Table 4. 1. Awash river cross section with depth.

River cross section(m)	0	0.5	1	2	2	2.5	3	3.5	4	4.5	5	5.5	6
Depth(cm)	0	20	23	25	35	44	52	38	31	26	21	15	0

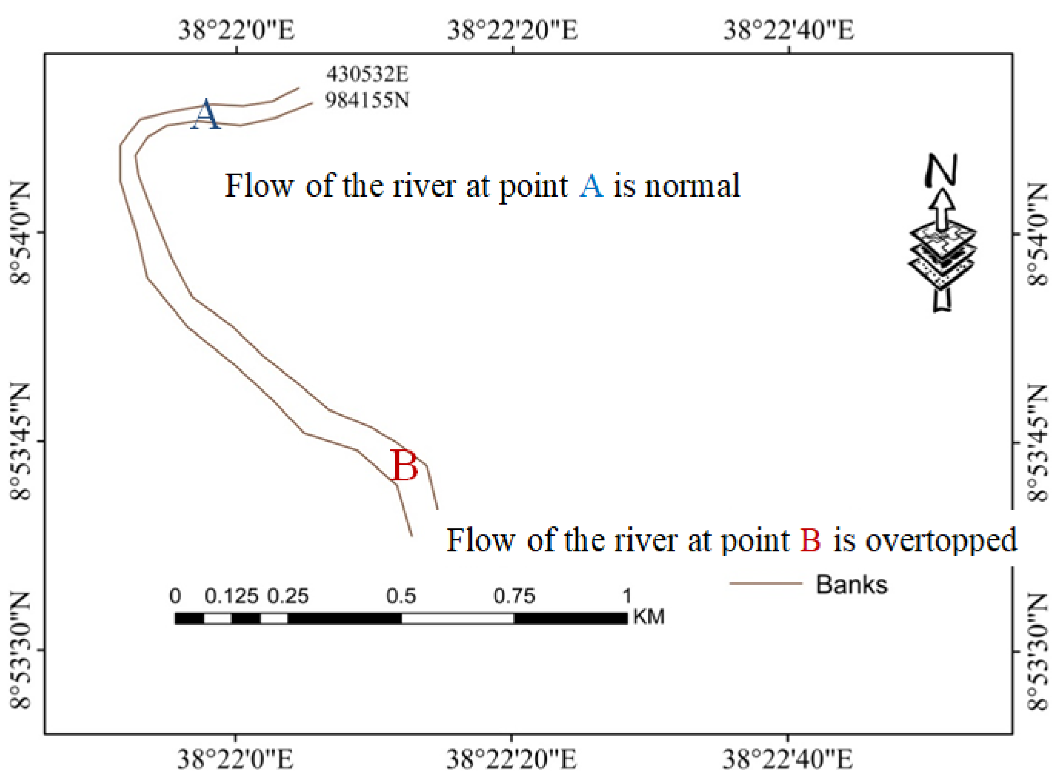

Figure 4-2 Schematization of Bank lines of Awash River

4.1.3 Cross-section cut lines

Cross-sections are highly important inputs for HEC-RAS, among others. Elevation data is extracted from the terrain by means of cross-section cut lines, and a ground profile is constructed where channel flow occurs. HEC-RAS attributes like bank stations (places that separate the main channel from the floodplain), downstream reach lengths (cross-section distance), and Manning's coefficient, n, are computed by joining the cut lines with other RAS layers such as the stream centerline and flow path lines. Thus, it is essential to generate a sufficient number of cross-sections to effectively portray the channel bed and floodplain, as shown in Figure 4.3. In this dissertation, the interpretation of the river crossing is based on the green XSCutLines (cut lines) shown across the river. These cross-sections indicate the locations of measurement points for river and flooding assessments, which are part of hydrological and hydraulic studies. A river crossing is a term that usually indicates a location where the river can be crossed, such as a bridge, culvert, or ford. Nonetheless, in the presented figure, the XSCutLines seem to be more relevant for modeling and analysis rather than indicating actual crossing structures.

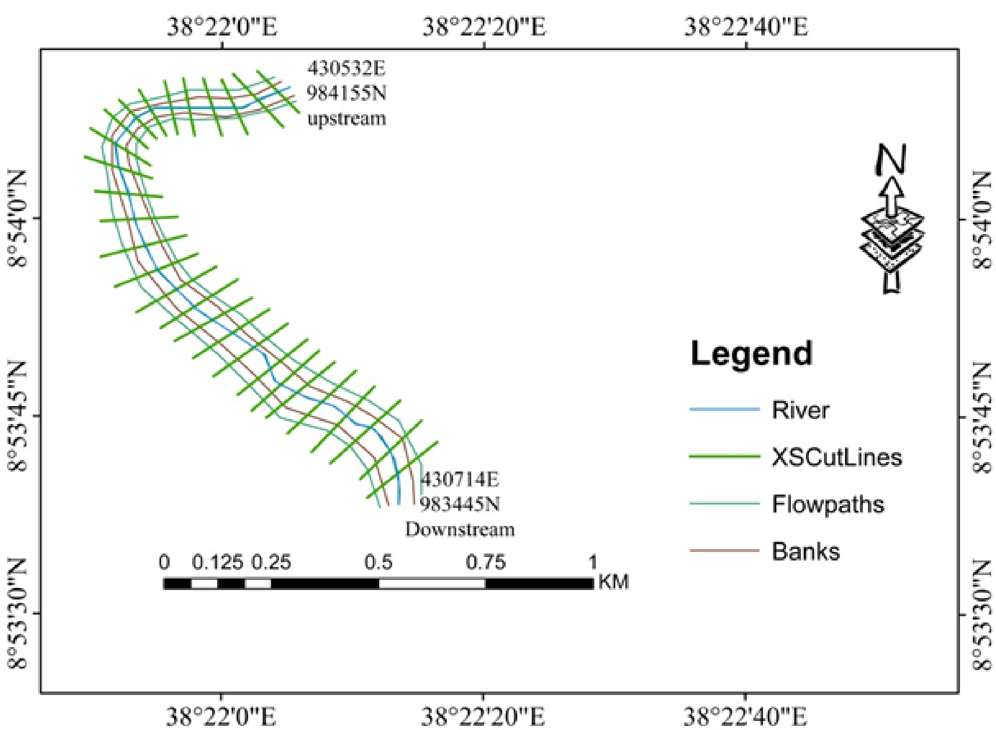

Figure 4-3 Cross-sectional cut line of Awash River.

4.2 Hydrological Data Test Results

A hydrological data test collects, processes, and interprets information relating to the movement of water in a river system or watershed. Its target is to evaluate the general hydrologic condition of a given area, flood hazards, and water supply. The tests are critical in the area of water resources, flood simulation, and environmental studies. Such tests are very valuable in the areas of environmental protection, flood- and infrastructure-related problems handling.

4.2.1 Stationary and Independence (W-W) Test

By the computation, the critical value at the 5% significance level, u0.025 = 1.96, is greater than the u-value test of 1.32 with 3.5 as the test value. Reject the null hypothesis that the Awash River flow data is independent and stationary at the 5% level of significance.

4.2.2 Homogeneity and stationary (M-W) Test

As per the equation 3.7, the test value u is determined as 0.0054, however, the critical value at the 5% significance level, u0.025 which is 1.96, is greater. Hence, the hypothesis that the flow data of the Awash River is reliable and stable at the 5% significance level is accepted. Consequently, the flow data received from the Hombole gauging station is considered to be independent, homogenous, and stationary at the 5% significance level.

4.3 Quantile Estimation

The Extreme Value Type I (Gumbel) methods was used to calculate quantile estimates (Xtr) that correspond to various return periods after the parameters of a distribution were estimated using annual maximum flow data using the technique of moments.

Table 4. 2. Quantile estimates for different return periods of the Awash River at the station.

Return Period(years)	2	5	50	100	500
Standard deviation	0.37	1.5	3.9	4.6	6.21
Frequency Factor	0.16	0.81	2.86	3.46	4.83
Quantile Estimation(m^3/s)	38.93	50.62	75.39	82.59	99.22

4.4 Peak Flow Estimation

The EasyFit curve fitting method that was used for the forecast of peak flow indicated the Extreme Value Type I (Gumbel) distribution as the best suitable model. The annual maximum flow data were used in the Gumbel equation to get the distribution parameters and consequently, the peak flows for different return periods were obtained. The data are presented by an Exceedance Probability Curve, which is also called a Flood Frequency Curve or a Flow Duration Curve at times. It reflects the association between peak streamflow (m^3/s) and the chance that a certain flow rate was overrun in a specified year. This curve is a very useful hydrological study tool as it tells about the probability and frequency of flood occurrences.

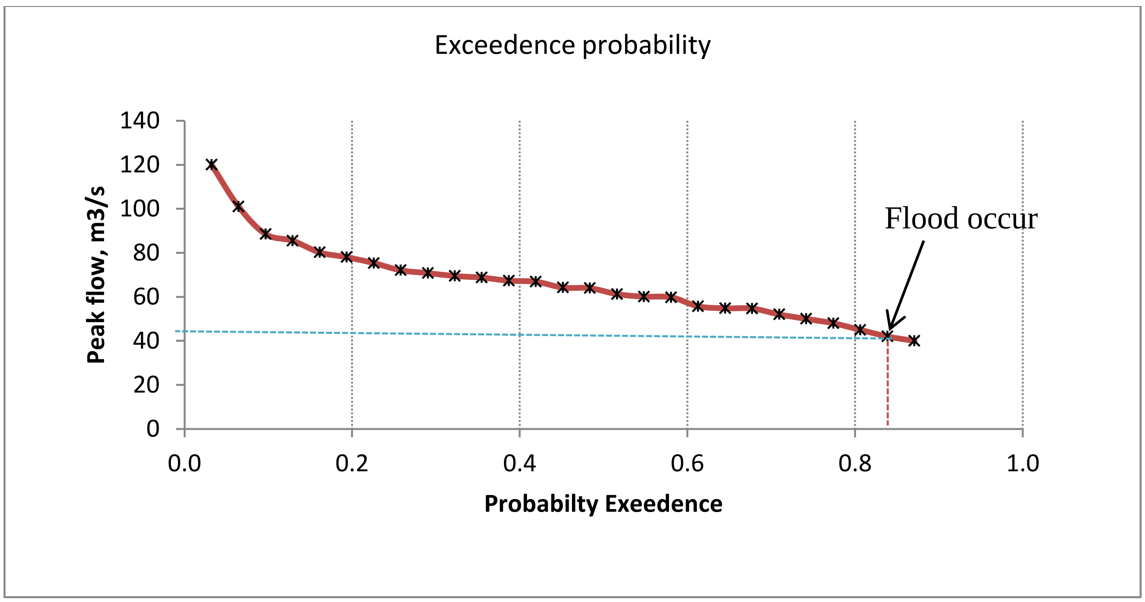

Figure 4-4 Flow duration curve of Awash River at the Hombole station

The flow duration curves of the upper Awash River exhibit minimal flow system fluctuation due to the reducing effects of enormous storages. A highly variable discharge, usually from small catchments with little storage where the stream flow directly reflects the rainfall pattern, is what causes the sharply sloping curve.

4.5 Flow data

Using the flow data, the flood's extent and the areas it covered were mapped out. The daily discharge data for the specific stations are considered as the main data source characterizing the study region. It is believed that the discharge gauge's downstream end, which is located near Ejere, is susceptible to flooding. In this research, a period of sixteen (16) years of daily discharge data is used, as depicted in Figure 3.7. The flow data serve to indicate the flood's dimensions and to create its inundation area map. Generally, it is a must to forecast the flood for different return intervals. The Awash River traverses the upper awash sub-basin along with its tributaries. The river takes its source from the Warke upper highland of the Becho basin.

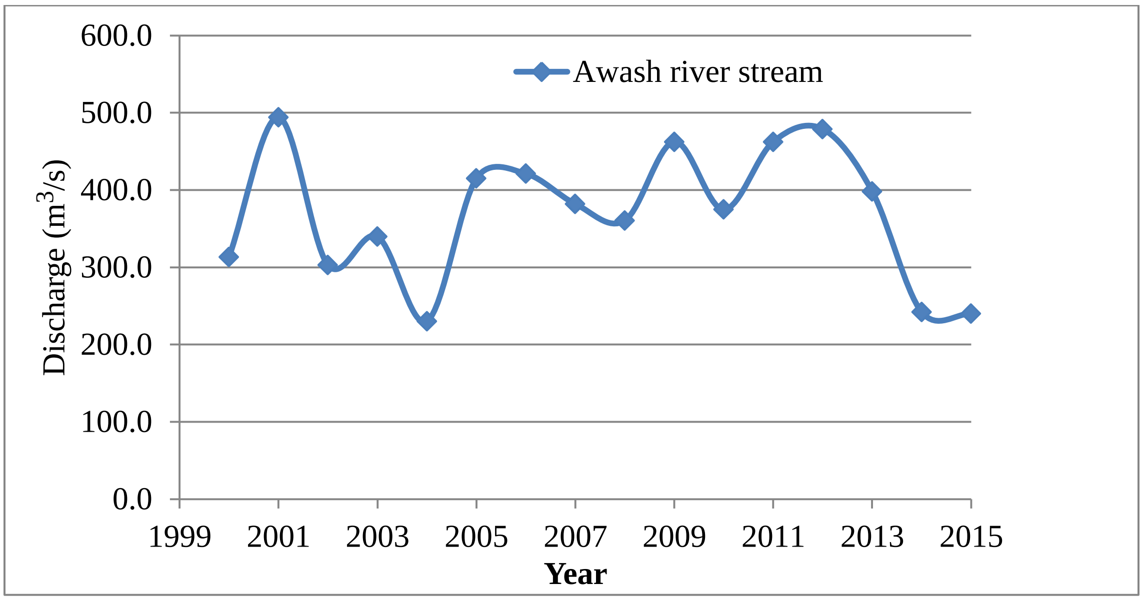

Figure 4-5Annual maximum flow data of Awash River at Hombole station.

4.6 Flood damage protection strategies and measures.

Flood protection strategies and measures play a key role in minimizing the impact of flooding on human settlements, physical assets, and nature. Flood protection strategies and measures are the main factors responsible for the reduction of impact of flooding on communities, infrastructure, and ecosystems.

4.6.1 Flood damage protection/measures.

Flood risk can be minimized by designing buildings that keep water out of occupied areas. Flood control structures consist of dams, dikes, levees, weirs, seawalls, reservoirs, pump stations, embankments, tidal gates, and diversion channels. The intention is to reduce the risk of flooding by keeping people safe and well away from water sources. Flood control measures encompass legislation, public education campaigns, flood prediction systems, evacuation procedures, and more zoning and land reclamation laws, insurance, financial aid and subsidies, comprehensive flood management plans, as well as other initiatives. Design measures that keep water out of occupied areas can help to reduce flooding dangers. Flood control structures include dams, dikes, levees, weirs, seawalls, reservoirs, pump stations, embankments, tidal gates, and diversion channels among others.

The aim is to minimize the risk of flooding by getting people far enough away from the water in the first place. Flood control systems include legislation, public education campaigns, flood prediction systems, evacuation protocols, training programs, zoning and land reclamation regulations, insurance alternatives, financial aid and subsidies, comprehensive flood management plans, and many others. Thus, it is necessary to conduct a flood risk assessment and then apply the appropriate flood management plans to the area before disaster strikes. The plans should involve both flood managers and non-professionals. Not only the pools of water are seen as a irritation but also on the whole declining floods are essential to ecosystem based management in many natural systems because they preserve biodiversity and basic ecosystem services. One such example is the fish spawning grounds that get preserved through the flooding cycles, besides, their movement is facilitated and even their silt and debris removal is helped. Frequent floods may be very important for a wide range of plant and animal species, including agricultural crops. The restoration of rivers and floodplains is associated with the ecological services that floodplains provide, for the repairing of damaged ecosystems and the exploiting of the positive societal impacts of flooding management.

Flood resistance encompasses:

a) Keeping and restoring the natural adaptable capacity of wetlands to reduce flood levels and the time they last.

b) The capacity to regain, which consists of improving the effort of reconstruction and increasing the coping mechanisms of people living in flood-prone areas.

c) The possibility to shift all the time with capacity change, which includes the impacts of climate change. One of the ways to reduce the risk of river floods is to lower the peak runoff of the watershed area into the river and the maximum river discharge or flood levels.

4.6.2 Dam Site

According to the feasibility study document prepared by Oromia Water Works Construction (OWWC, 2017 EC), the proposed dam site is located on the Berga River, a tributary of the Awash River. The dam axis has been aligned nearly perpendicular to the Berga River stream, taking into consideration the suitability and stability of the abutments. The final alignment of the dam is illustrated in Figure below.

The spillway is located on the left abutment and is formed by excavating the left bank. Excess floodwater passing over the spillway will be safely conveyed back to the main river channel through the chute spillway and its associated components, as shown in Figure 2, which presents the layout of the dam and appurtenant structures.

This research was conducted in support of the Oromia Water Works Construction Office's plan to improve the dam site for irrigation purposes to serve Ejere Kebele. Google Earth software was used to observe and analyze the Berga water reservoir area. Site topography was examined, an optimal construction site was identified, and the dam alignment was defined using the "Add Path" tool. The dam location was then saved in KML format for further analysis.

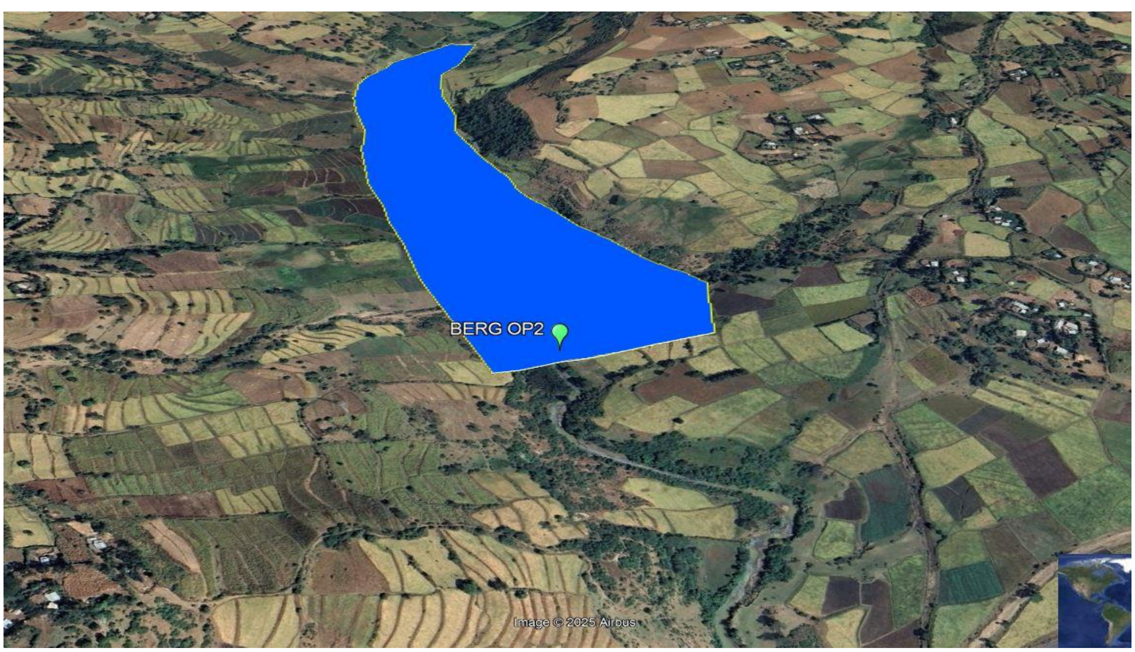

Figure 4-6 Study site of medium scale irrigation project in Ejere woreda.

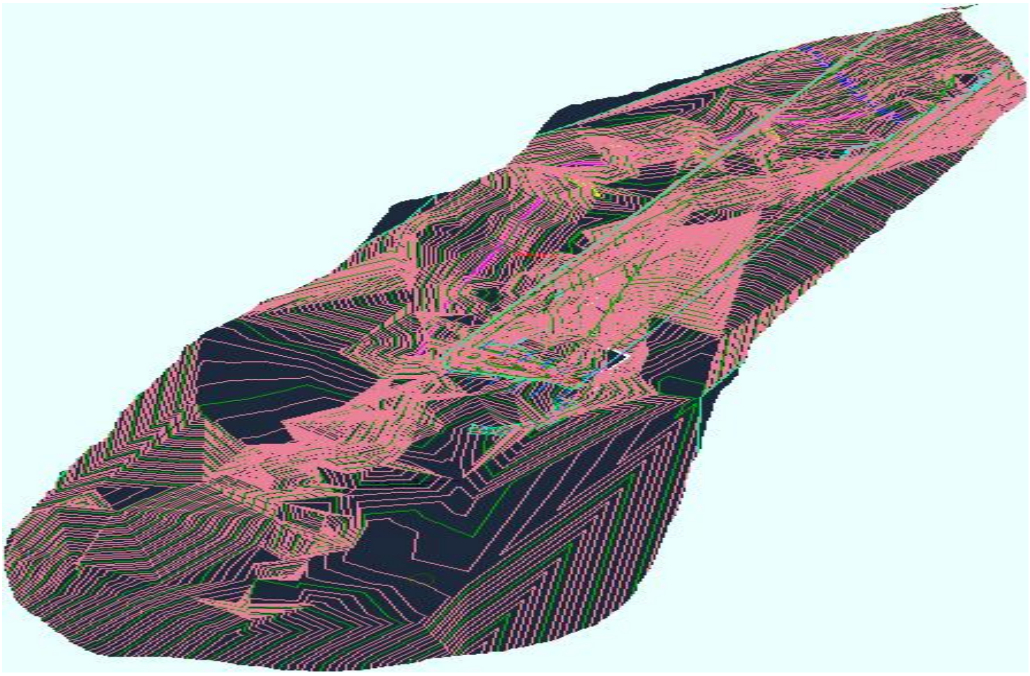

Figure 4-7 Dam and spill way axis alignment.

Dam location section (KML file) is saved in Global Mapper program and the site relief digital model obtained using Shuttle Radar Topography Mission (SRTM) is downloaded from online database (Fig. 4.8).

Using water reservoir digital model, along with determining reservoir total water surface area and its volume, water areas and volumes for each contour was analyzed, sections to be closed with dams for maximal water storage were determined and cross sections were developed.

Having built dam location site cross section with 3D Path Profile command dam location section data such as dam length, mean height can be obtained from Show Path Details option in Option menu

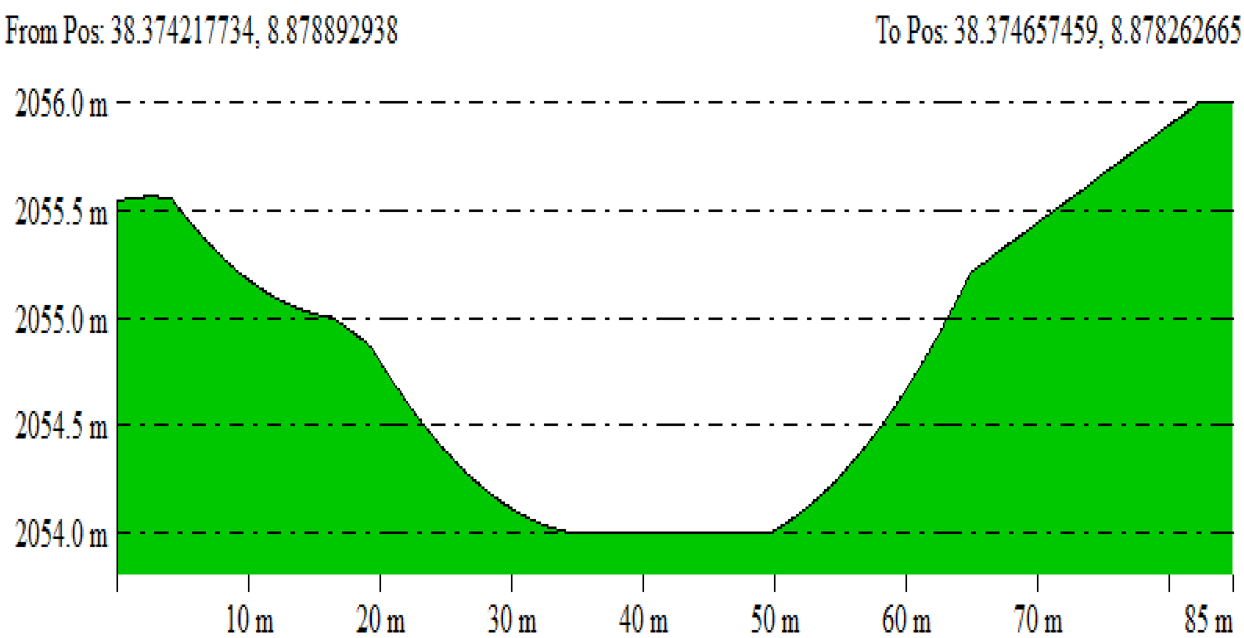

Figure 4-8 Longitudinal profile along the bottom of the dam.

Table 4. 3. Type of spill way based on the inflow and outflow ogee spillway .

Dam Height, m	Flood event year	Max. Inflow Discharge, (m3/s)	Spillway Length, (m)	Spillway Head (m)	Max. Outflow Discharge, m^3/s
29.5	100	273.87	0	2158	0
			5	2164	162.4
			10	2162.95	243.39
			15	2161.9	250.42
			20	2161.25	253.02
			25	2160.8	251.96
			30	2160.45	254.25
			35	2160.25	261.06

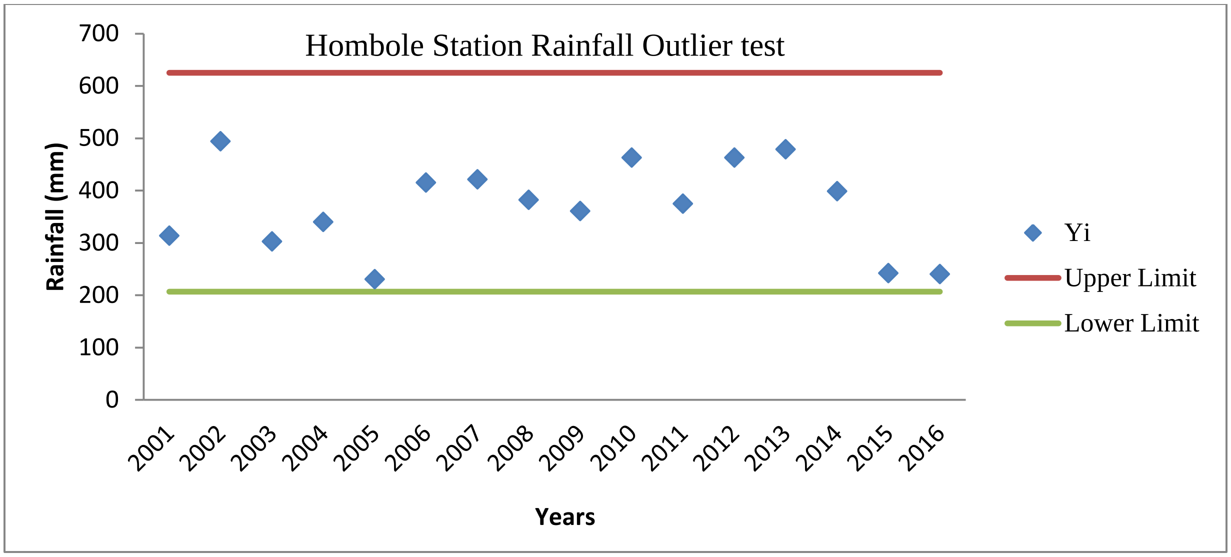

Figure 4-9 Quantile test for Hombole station.

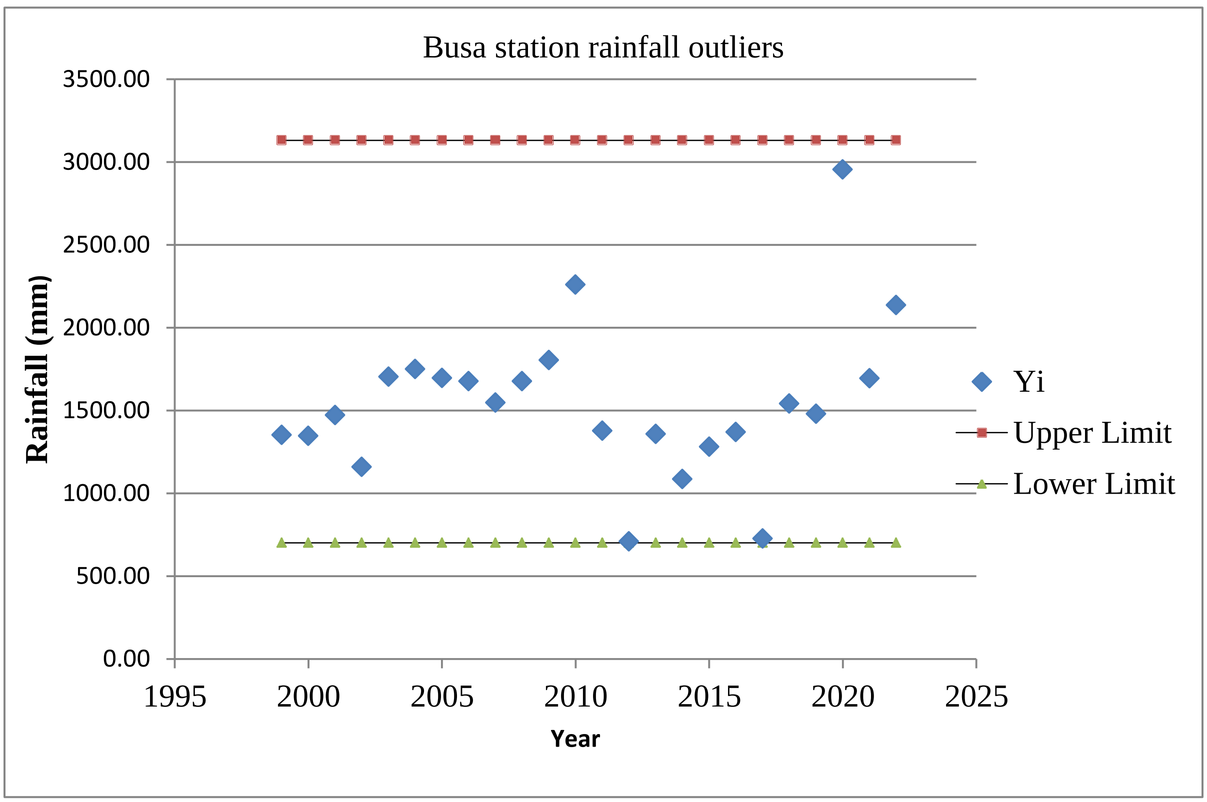

Figure 4-10 Busa station annual rainfall data outlier test.

The above Figure4.7 implies that there is no outlier problem for stream flow for this specified period awash at Busa station.

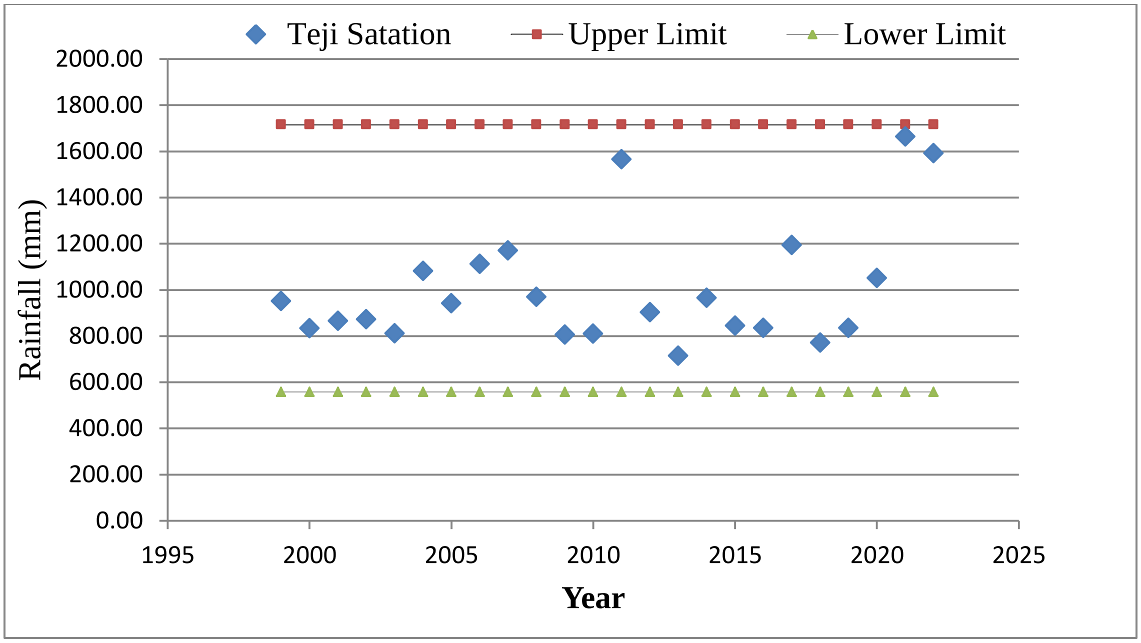

Figure 4-11 Quantile test for Teji station

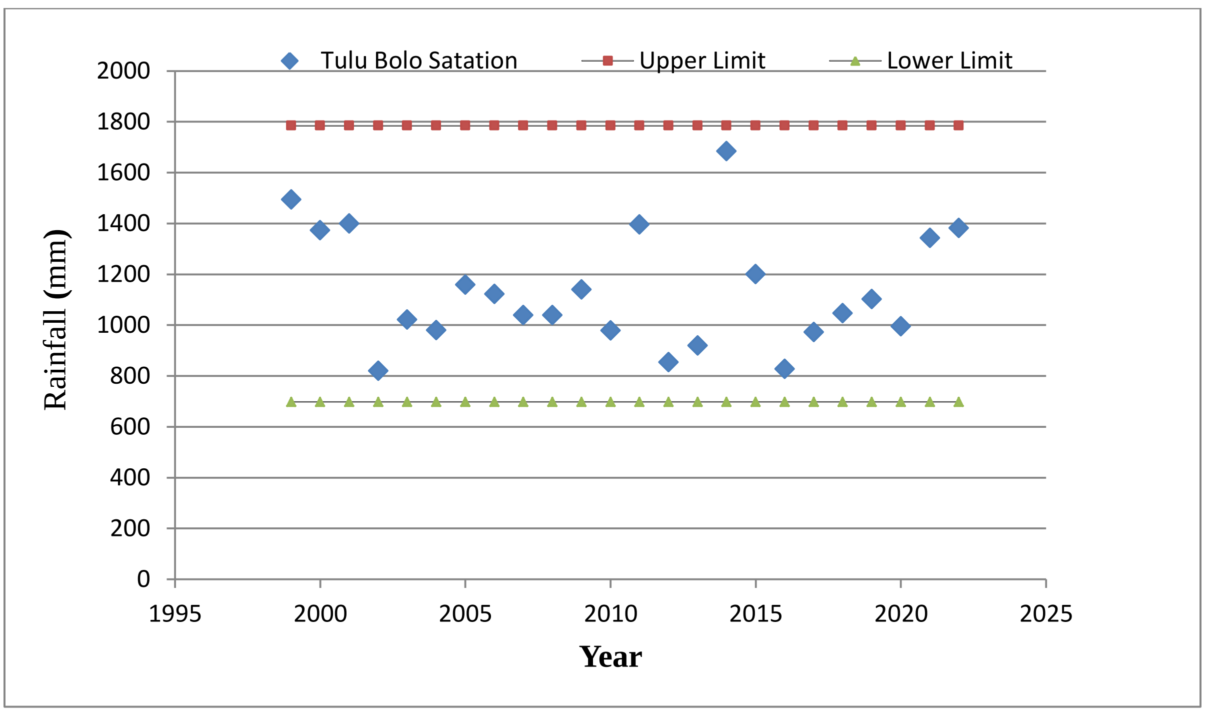

Figure 4-12 Quantile test for Tulu Bolo station.

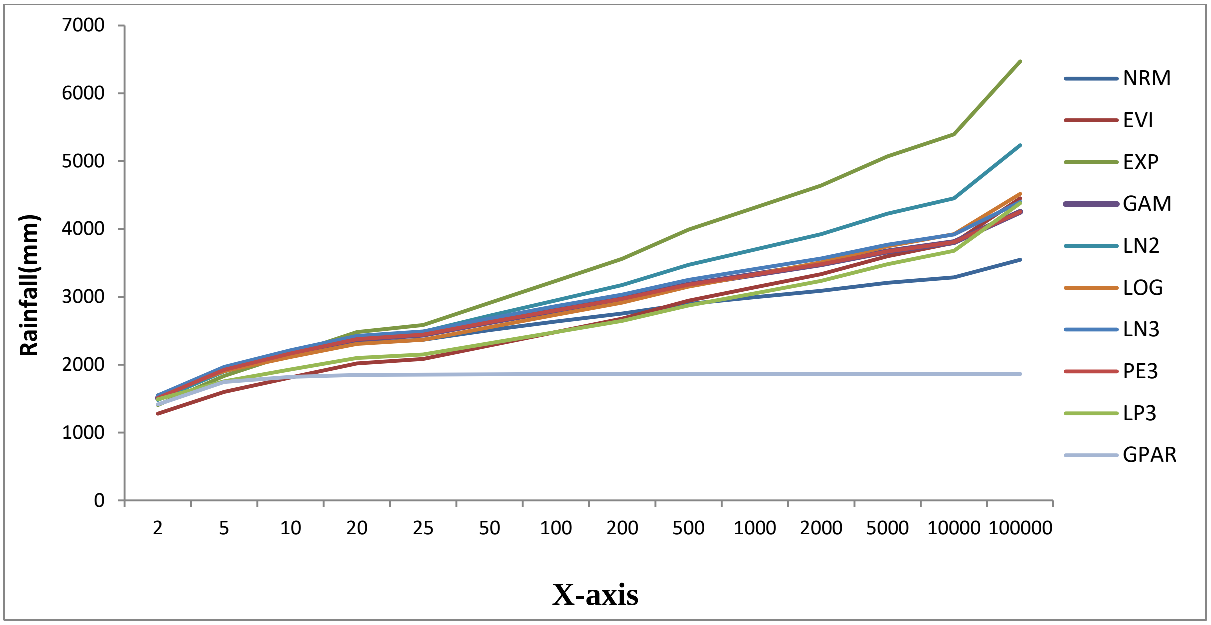

Figure 4-13 Quantile at Busa station.

Figure 4.13 implies that quantile test for Busa station. And the other stations are shown in Appendix.

The quantile plot reveals the extreme alterations in the statistical distributions that were utilized to predict rainfall for various return periods. For the shorter return periods (like, 2 to 50 years), the rainfall estimates given by the majority of the models are quite close to each other and there are just minor discrepancies. However, with the gradual increase of the return period (especially after 1,000 years), the estimates start to show large deviations, thus indicating that each distribution extrapolates in a different way under simple conditions. The Log-Pearson Type III (LP3) model is the one that predicts the least, producing the highest rainfall amounts during the extreme return periods 10,000–100,000 years.

Therefore, LP3 is the ideal tool for dealing with critical infrastructure, because it is better to be safe than sorry. Meanwhile, the Generalised Pareto (GPAR) model shows a very strange pattern and almost a flat curve, which may indicate that it does not fit the data well statistically or is not suitable for the dataset at all. In addition, GPAR is also less affected by longer return periods. Huddled around the middle of the ranges are NRM, GAM, LN2, LN3, PE3 and LOG models, whose rainfall estimates are unvarying and discreet but nevertheless moderate across the board.

Hence, they are still rather broadly appropriate for hydrological modelling of any kind. Ultimately, the risk assessment of hydrology is at the mercy of the choice of the distribution. On the one hand, conservative models such as LP3 can only be used in high-risk applications, while the other hand, models like GAM or PE3 can be suitable for typical design scenarios. No matter which model is selected, thorough validation preceding reliance on these models for long-term planning or infrastructure design by means of historical rainfall data is a must.

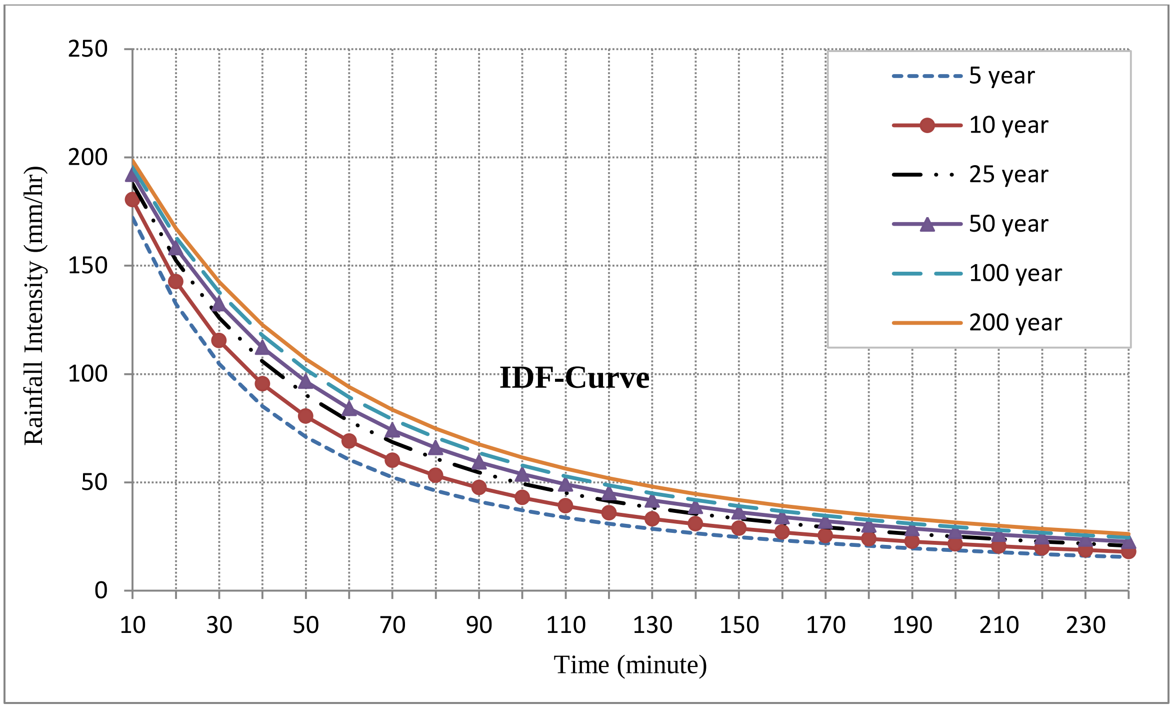

Figure 4-14 Rainfall Intensity-Duration-Frequency curve.

Figure 4.14 implies that there is the best fit, PE3 and used to develop the IDF curve for Busa station.

The diagram is an IDF (Intensity-Duration-Frequency) Curve, which represents the relationship between rainfall intensity, duration, and return period (frequency of occurrence).

- X-axis: Time (minutes) representing the duration of rainfall.
- Y-axis: Rainfall Intensity (mm/hr)   the rate at which rain falls.
- Curves: Represent different return periods (5, 10, 25, 50, 100, and 200 years).

The IDF curve clearly illustrates two major trends in rainfall behavior: the first one being that the intensity decreases when the duration increases, and the second one that the intensity increases with the increase in return periods. The rainfall intensity decreases continuously with the storm duration over all return periods and this indicates that the shorter storms are the ones that usually produce more intense rainfalls than the longer ones. However, on the other hand, the longer return period (i.e., less frequent) storms display much higher intensities for any fixed duration. For example, the 200-year storm has much more intense rainfall during a 30-minute period than the 5-year storm, which highlights the severe nature of infrequent risky weather occurrences. It is also worth noting that intensity is going to be going down really quickly at shorter durations but when the duration gets longer it will be rather stable, this phenomenon actually implies that intensity will not be decreasing that much over longer periods. These patterns are very important for grasping the concepts of storm water design, flood risk, and infrastructure planning.

4.7 Water Level Fluctuation of Upper Awash River

The HEC-RAS hydraulic modeling program was applied to notice the water level variations of the Upper Awash River. The study aimed to model and evaluates the behavior of floods at different flow rates. Figure 4.11 presents a representative river cross-section featuring flood-prone areas and inundation extents during floods. The results not only enrich the flood risk analysis and the corresponding prevention measures but also provide significant insights into the river's hydrology during flood events.

4.8 Cross-sectional View

The respective sample cross section at stations can be found in Table 4.1. The floods with return periods of two and five years (38.93 m3/s and 50.62 m3/s, respectively) did not produce any significant changes because of the depth of the cross-section. On the other hand, floods with a return period of 50, 100, and 500 years had higher magnitudes of 75.39, 82.59, and 99.22 m3/s, respectively. These discharges completely fill the whole cross-section, and the adjacent floodplains are also inundated.

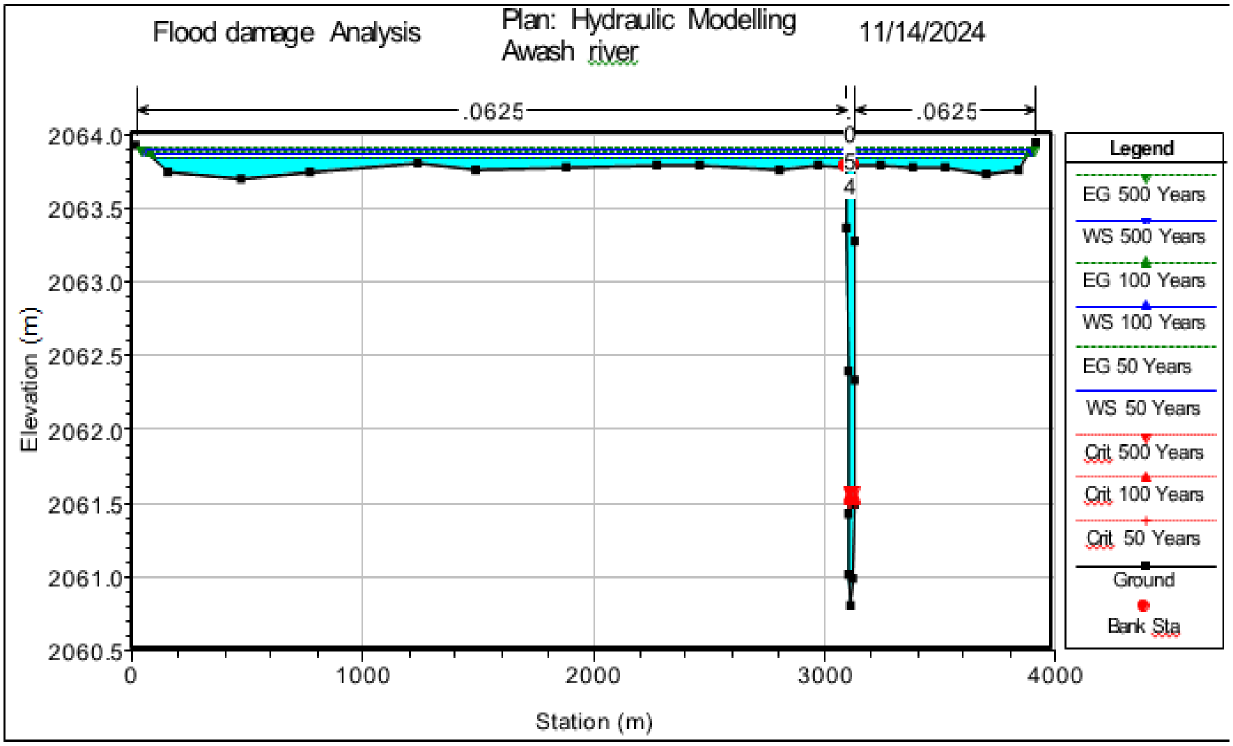

Figure 4-15 Cross sections view of Awash River.

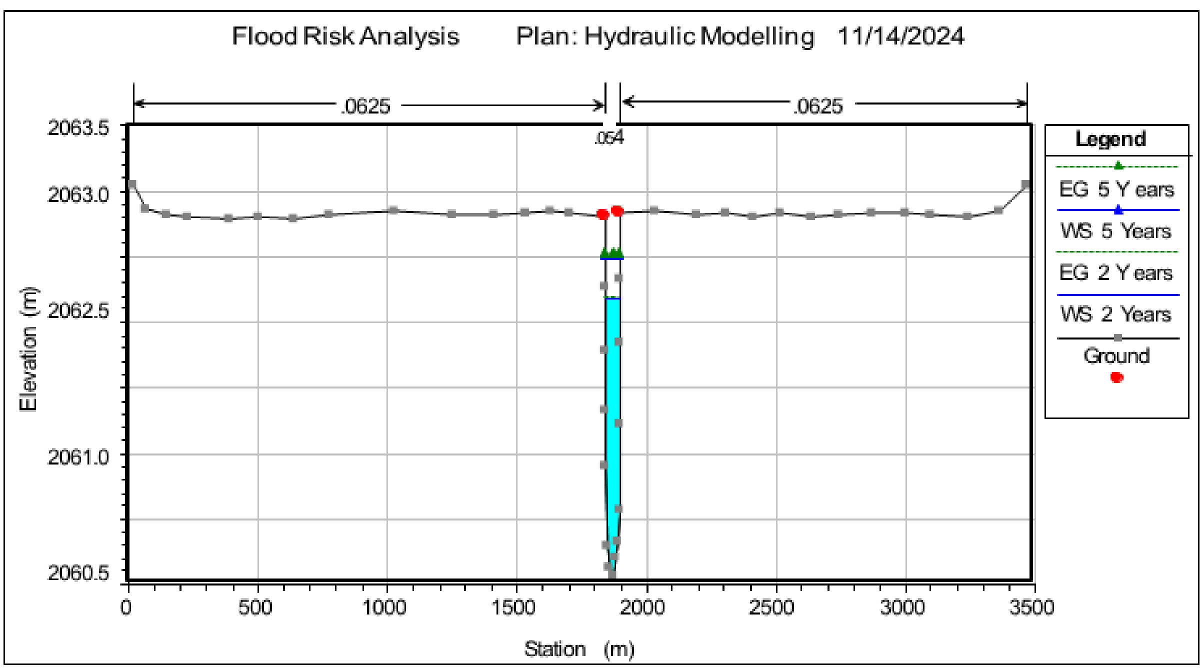

Figure 4-16 Cross sections view of Awash River at study area.

Table 4. 4. Water surface profile for different return 2-Year Flood, 10-Year Flood, and 50-Year Flood

Feature	2-Year Flood	10-Year Flood	50-Year Flood
Return Period Probability	60%	70%	>80%
Flood Severity	high	very high	Highest
Bank Overtopping Risk	high	very high	Highest
Water Surface Elevation	high	very high	Highest
Impact on Floodplain	high	very high	Widespread inundation/dam design

The diagram shows the gradual decline in the production of wheat and barley in the Awash River basin due to flooding over a period of two, ten, and fifty years. The most effectual flood that can be termed 'mild' takes place, with adjacent areas just slightly flooded and only a small part of the banks overflowing, during a two-year flood that has a 60% chance of happening each year. The water levels rise even more in a 50-year flood, with an incidence of 80% annually. This leads to moderate overflowing and a considerable increase in the area that has been flooded. The flooding could partly damage barley because it is at critical growth stages then and, hence, most sensitive to extreme wetness. The 50-year flood is a catastrophic event at times, with extensive flooding and a very high risk of total crop death. The situation creates a scenario where wheat and barley experience prolonged flooding while massive tracts of arable land are submerged, resulting in either complete loss of the crop or harsh reduction of the output. Thus, the aforementioned figures point to the urgent need for flood resilient agricultural planning, prompt alert systems and targeted evacuation practices in order to secure the production of crops in the flood-prone areas.

4.8.1 Water surface profile

The water surface profiles of the different return periods, i.e. 2, 10, 50,100 and 500 years are shown in Figure 4.13.

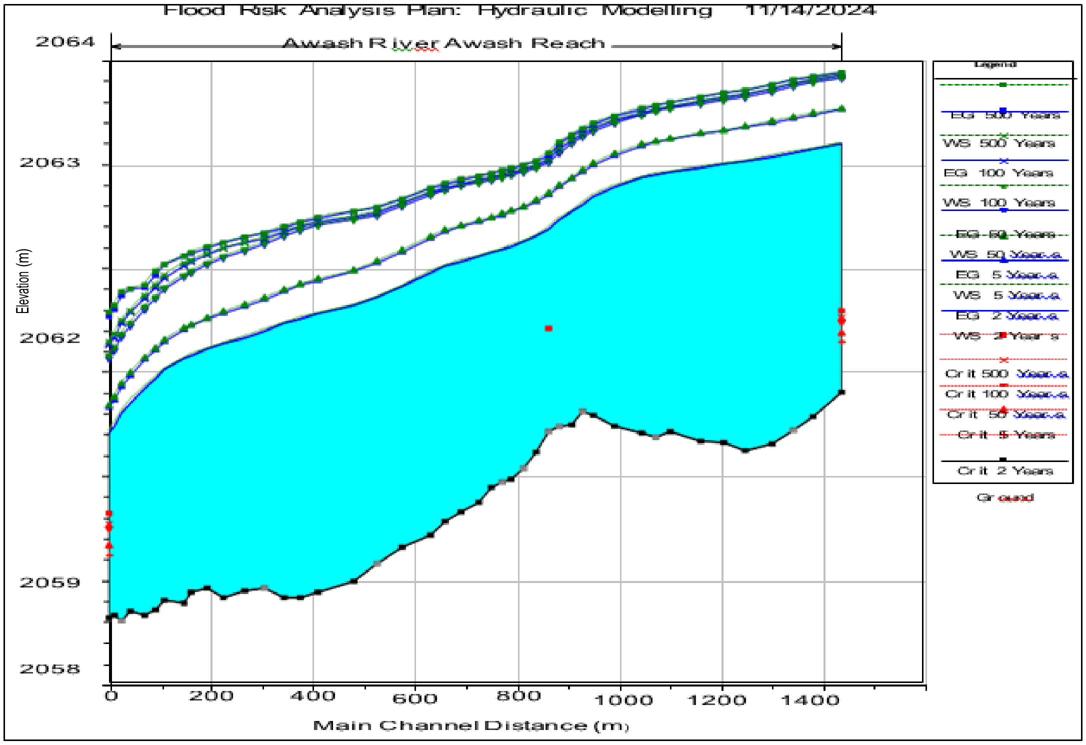

Figure 4-17 Water surface profile for all return periods of Awash Reaches.

4.9 Flood Inundation Mapping

4.9.1 Water Surface TIN generation

A single water surface TIN was generated for each water surface profile chosen. The TIN was created using the water surface elevation at each cross-section and the data of the bounding polygon from the RAS GIS export file, as illustrated in figure 4.14. The land surface was not included in the process of water surface TIN creation. The water surface TIN created by concatenating "t" with the name of the water surface profile (for instance, t equals 500 years) was considered and existing in the output directory specified in the layer configuration. The elevation of the selected profile water surface is raised and thus a water surface TIN is made and shown on the map to indicate the area without flooding risk.

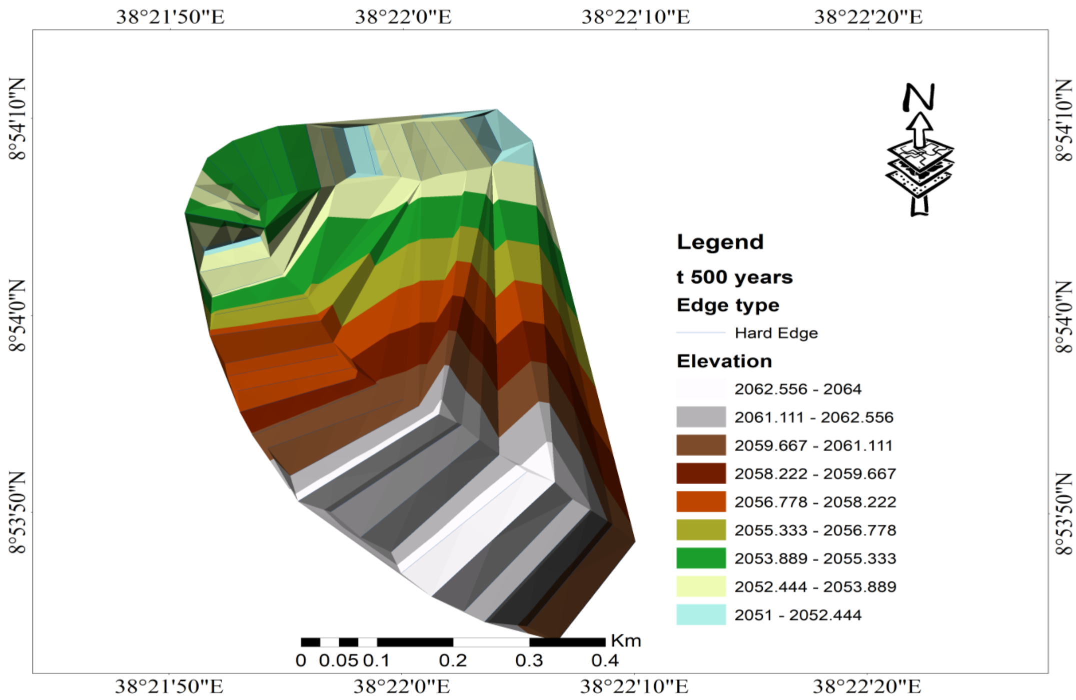

Figure 4-18 Water surface TIN generated using cross-sectional cut line.

4.9.2 Floodplain Delineation using Raster

Floodplain delineation using the topography model and water surface TIN, recognized the floodplain boundary and depth of inundation. At this stage, the DTM GRID was decreased by from the water surface grid after the water surface TIN was transformed into a GRID. Positive results indicate that the water surface is above the terrain while negative results imply that the area is not flooded. The water surface grid's final flood inundation polygon was created by converting all cells that have positive values after deduction into a forest. A quality assessment of the inundation polygon was performed after the creation of the inundation map. To evaluate the topography and flood inundation polygon quality, it is necessary to have experience and knowledge with the research area.

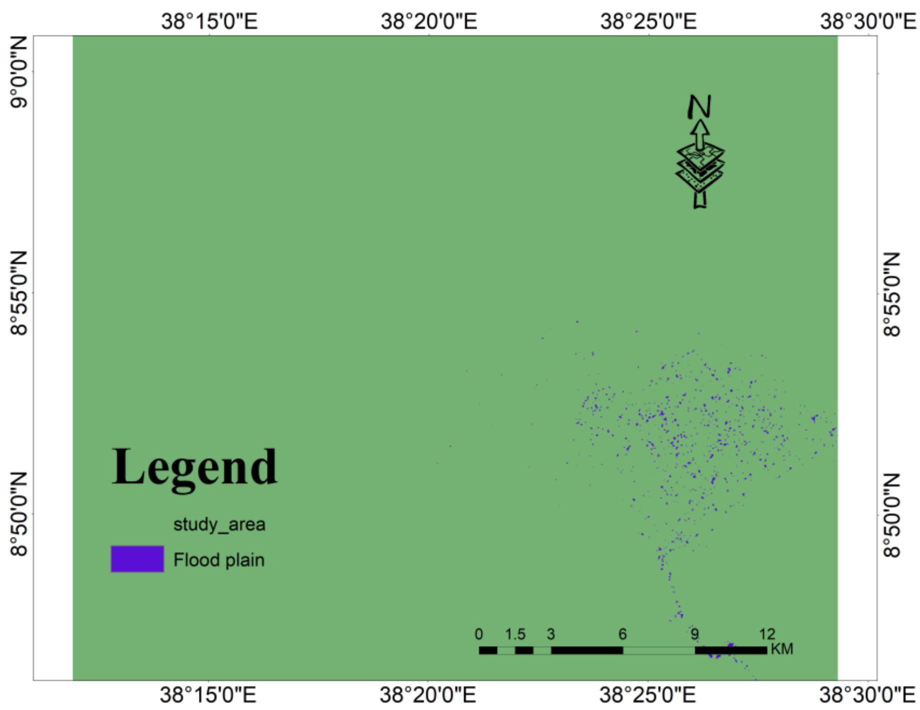

Figure 4-19 Flood inundation map for 2 years return period.

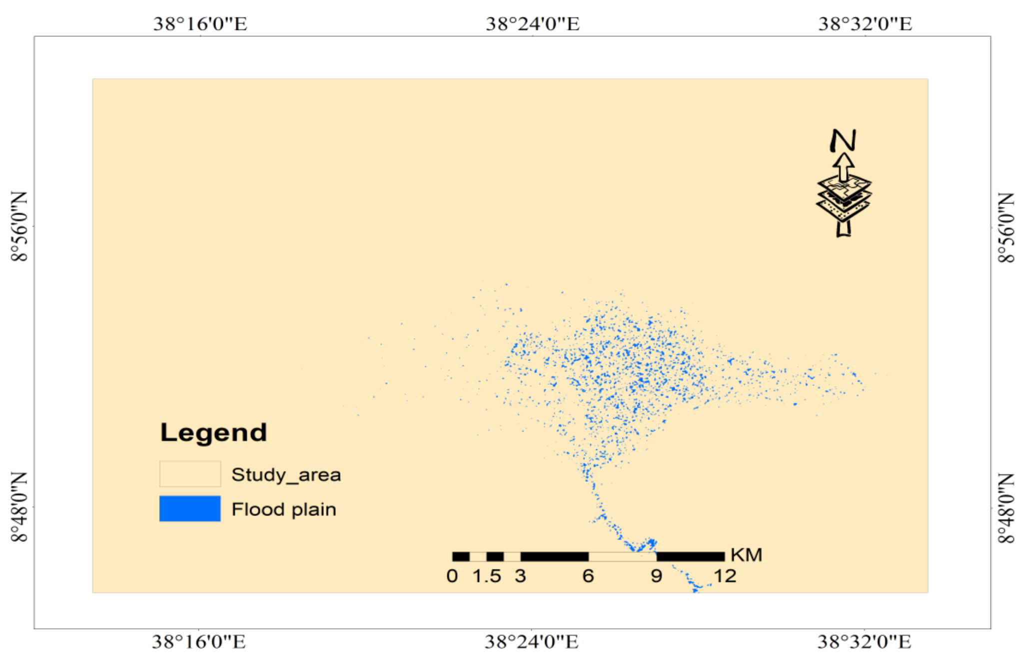

Figure 4-20 Flood inundation map for 5 years return period.

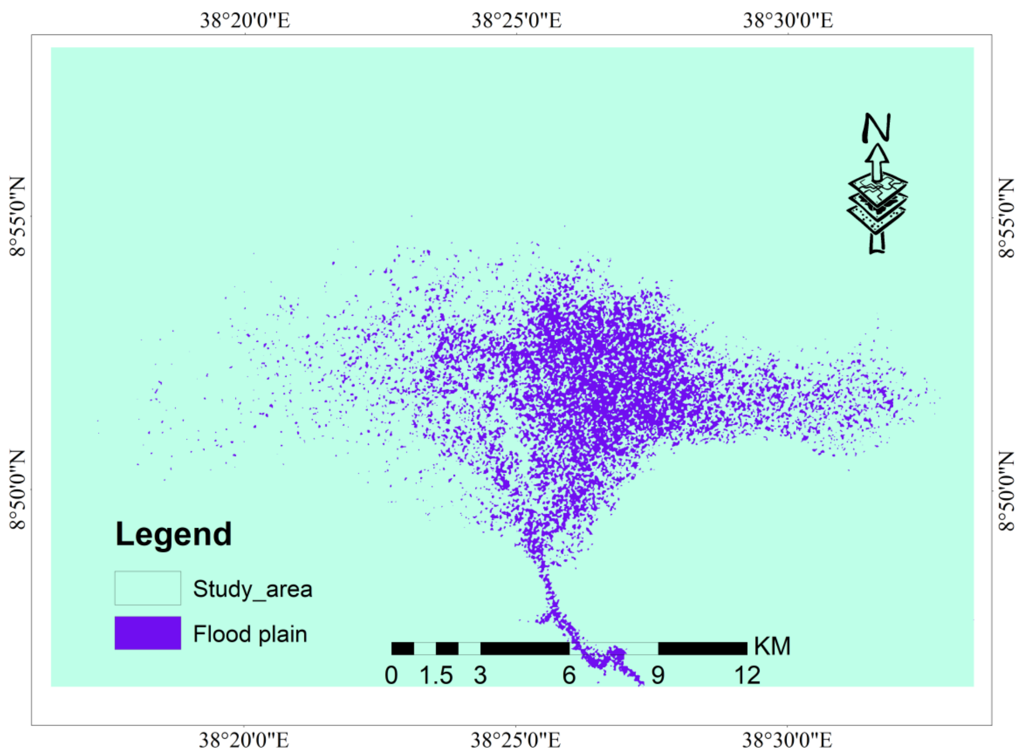

Figure 4-21 Flood inundation map for 50 years return period.

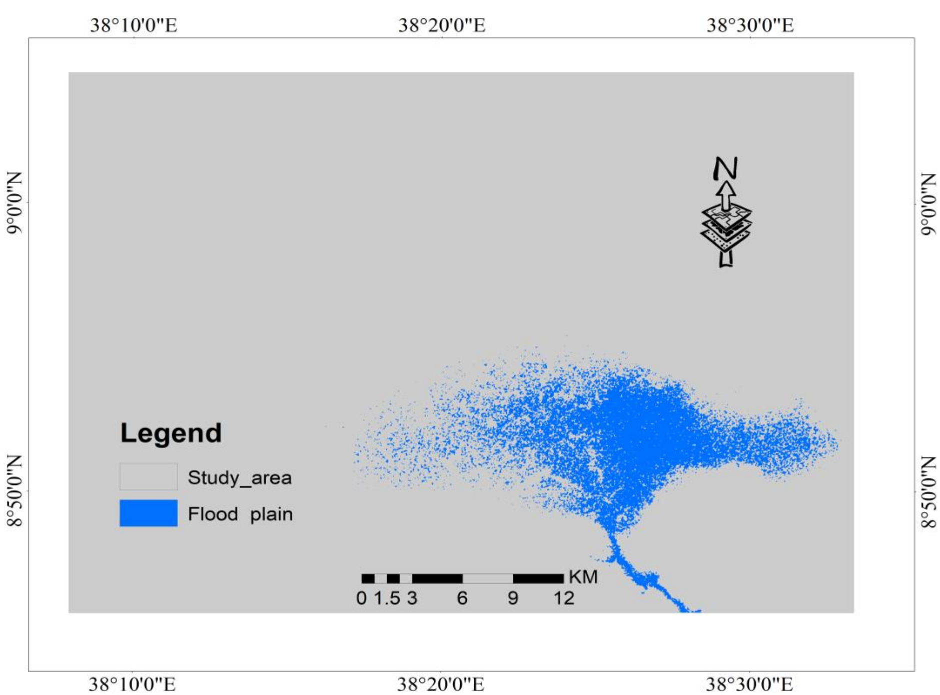

Figure 4-22 Flood inundation map for 100 years return period.

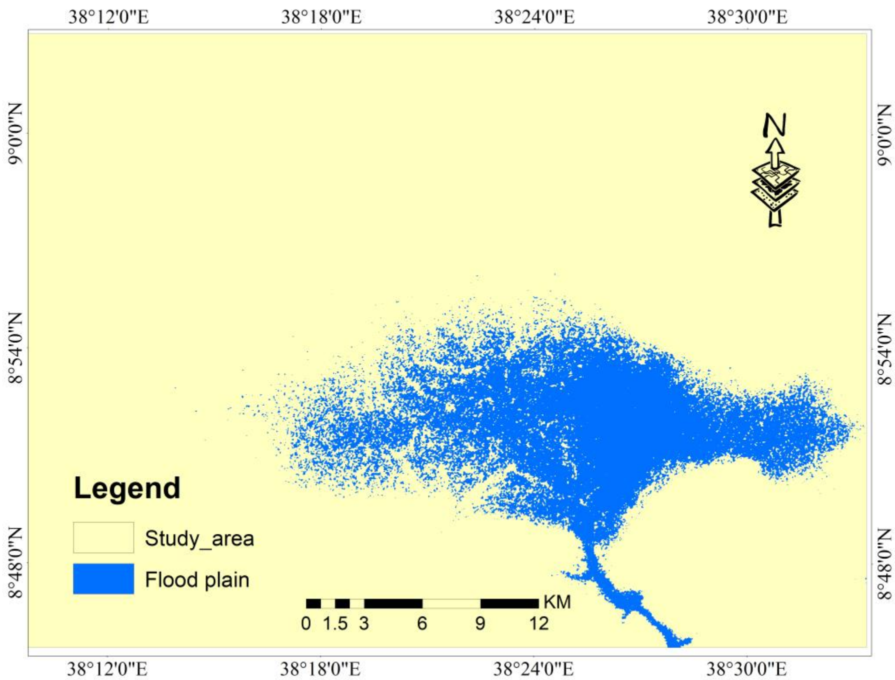

Figure 4-23 Flood inundation Map for 500 years return period.

Table 4. 5. Flood inundation depth

Flood Inundation Depth (m)	Color	Notes
Less than 0.5	Brown	Areas with very shallow flooding
0.5 – 1.0	Yellow	Moderate inundation
1.0 – 1.5	Green	Significant inundation
Above 1.5	Blue	Deep flooding zones

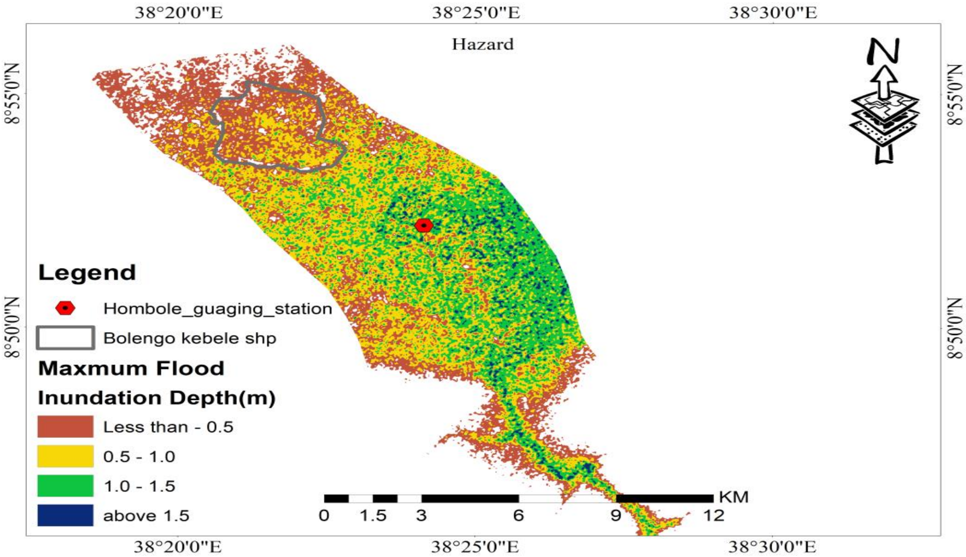

Figure 4-24 Flood inundation depth for 2 years return period.

Flood velocity, as illustrated in Figure 4.22, represents the speed at which floodwater moves across the landscape during a 50-year return-period flood. It is a critical parameter in flood-hazard assessment because the rate of water movement typically measured in meters per second (m/s) directly influences erosion, scour, structural stability, evacuation safety, and overall damage potential. The map shows that low-velocity zones (0 m/s) appear in green, generally corresponding to wider floodplains or shallow overbank areas where water spreads out and slows down. In contrast, high-velocity areas, reaching up to approximately 9.95 m/s and shown in dark blue, occur mainly in narrow channels, deeper sections, or steeper terrain, where floodwater accelerates and becomes more destructive. This spatial variation in flood velocity highlights the differing levels of hazard across the floodplain and underscores the importance of understanding flow dynamics for effective flood risk management.

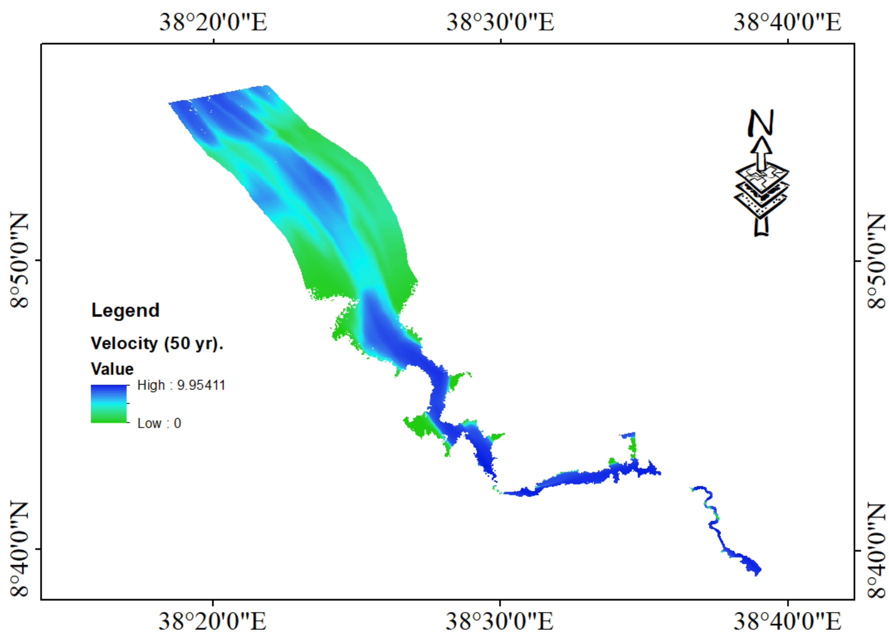

Figure 4-25 Flood Velocity for 50 year return period

4.10 Flood Exposers and damage Assessment

In considering drainage, agriculture in areas that are prone to flooding was included in the evaluation. Among the main crops of the Awash River Basin, wheat and barley are the two most important ones. Consequently, the crop damage of wheat and barley was calculated as agrarian damage in this investigation. Thus, the estimation of wheat and barley crop damage during the flood that occurred in July and August 2015 was taken into account. After detecting the wheat fields at risk located in a hazardous area, the potential damage can be estimated via depth duration damage functions curves and risk indicators. Each risk indicator represents the level of susceptibility to the current developments in flood risk management for each item and illustrates this relationship via showing the extent of the damage determined by the damage curve. This means that flood damage curves are crucial for flood damage estimation. Depth-duration-damage function curves are usually applied in assessing the flood damage to wheat and barley crops. The flood damage curves were derived either from the artificial data produced through questionnaire surveys or expert estimation. The damage curves were developed based on certain typical property types, land use, data from the survey, or theoretical analysis.

Table 4. 6. Flood damage matrix for wheat-crop damage Shrestha et al., (2021)

Growth stage of wheat and barley crops	Days of submergence at 0.5m flooding depth			
	1-2 days	3-5 days	6 days	>7 days
	Estimated yield loss (%)			
Seedling	60-70	80-90	90-100	100
Vegetative stage	60-70	80-90	95-100	100
Reproductive stage	15-30	40-70	40-85	40-85
Maturity stage	5	10-20	15-30	15-30

The extent of flood damage to wheat crops differs greatly depending on the stage of growth. The precise growth phase of wheat during a flood event can be identified by using the cropping calendar and knowing how long each stage lasts. This allows the use of the proper damage curve. According to Equations [3.2] and [3.3], production losses for the reproductive and mature periods are computed using a farm gate price of 50 birr/kg and an average yield of 4,000 kg/ha (EWARDO, 2023).

On the other hand, in the case of the seedling, newly planted, and vegetative stages, which are not marked by any harvest, losses are estimated based on input costs (EWARDO, 2023). From the field studies and the consultations with local experts and farmers, it is indicated that the damage takes place when the floodwaters are 0.3 meters higher than the ground level in the early stages and 0.5 meters during the reproductive and maturity stages. In the research, a wheat field was deemed completely flooded when the leaves of 10–15 cm height were hidden under the water surface.

Table 4. 7. The relationship between yield loss and flood sensitivity with depth of flood.

Growth Stage	Flood Depth Sensitivity	Duration Sensitivity	Max Yield Loss (%)	Notes
Seedling	Very High (>0.5 cm)	Very High	~100%	Most vulnerable stage
Vegetative	High (>0.5 m)	High	~100%	Still vulnerable, but more tolerant than seedling
Reproductive	Moderate (>0.5 m)	Moderate	~50%	Most tolerant stage

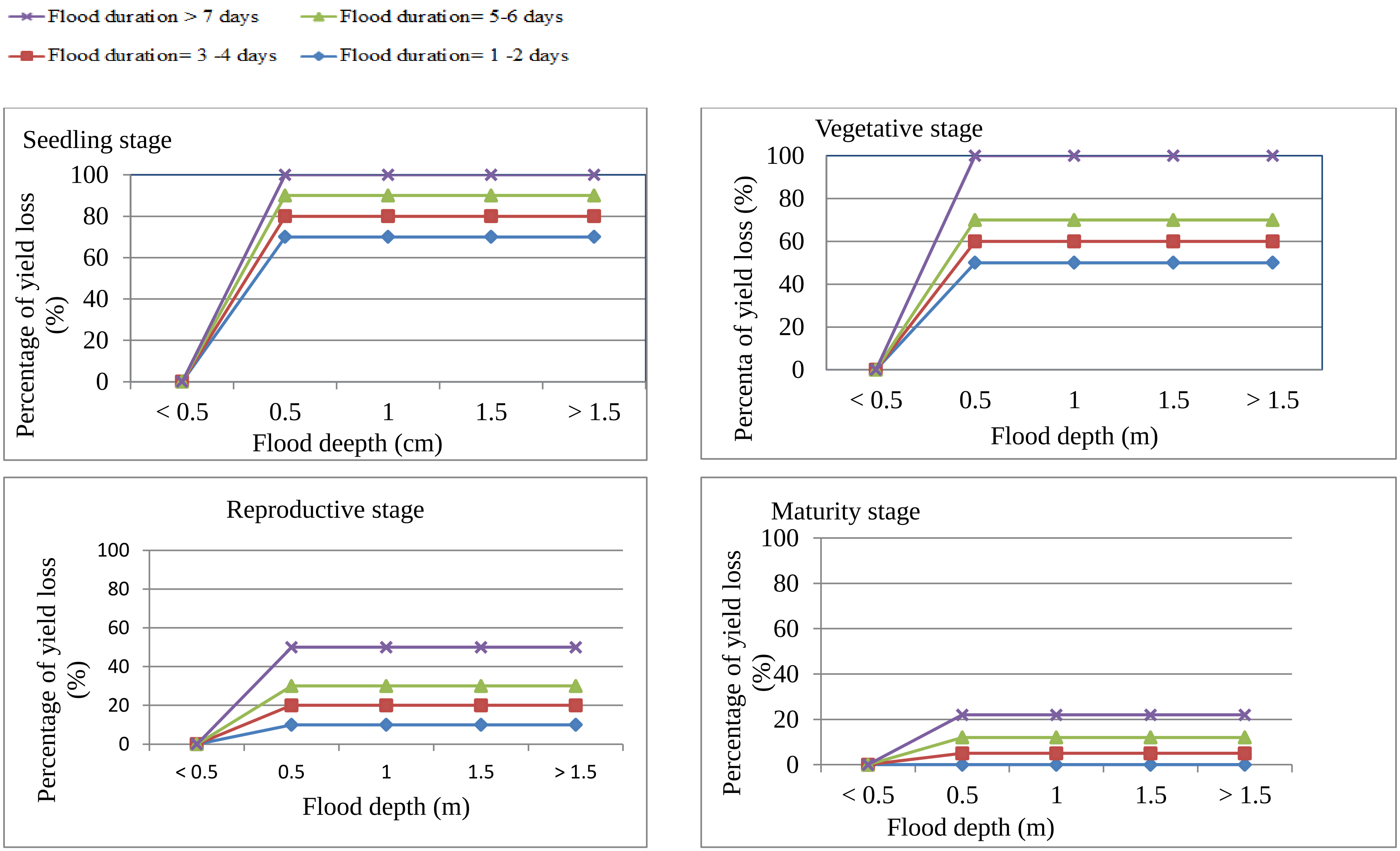

Figure 4-26 Depth-duration-damage function curves for wheat-crop damage Kumar et al., (2022).

In the attribute table of the polygon of the flood extent, the inundation area was displayed and used for analysis of the flooding effect on crop yield.

The extent of inundation areas for the floods of different return periods floods are indicated in Table 4.5

Table 4. 8. Flood magnitude and corresponding inundated area.

Return period (years)	**2**	**5**	**50**	**100**	**500**
Flow (m^3/s)	38.93	50.62	75.39	82.59	99.22
Inundated area (ha)	18.6	105.2	127.04	137.3	147.8

Floods that correspond to longer return periods have high flows which can submerge and damage a large amount of cropland. Also this flood can bring in water logging in the area which consequently can result in yield reduction.

4.11 Flood damage on crop

Floods that correspond to longer return periods have high flows which can submerge and damage a large amount of cropland. Also this flood can bring in water logging in the area which consequently can result in yield reduction. The estimated crop loss due to flooding for different return periods is indicated in Table 4.7

Table 4. 9. Crop loss due to flood in different return periods.

				Flood Inundated Area for return period				
				2 yrs	5 yrs	50 yrs	100 yrs	500 yrs
No.	Crop	Average	% of Coverage	87.6	105.2	127.04	137.3	147.8
2	Wheat	40	35	1,226.40	1,472.80	1,778.56	1,922.20	2,069.20
3	Barley	20	15	262.80	315.60	381.12	411.90	443.4
Total Crop Loss				1,489.20	1,788.40	2,159.68	2,334.10	2,512.60

Using Equation 3.1, crop losses for wheat and barley under a two-year flood return period were estimated. The analysis, summarized in Table 4.6, presents data on crop damage resulting from floods of varying return periods specifically 2 year, 5 year, 50 year, 100 year, and 500 year events. It highlights the extent of flood inundation and its impact on two major crops, wheat and barley.

For the 2-year return period, wheat production was reduced by approximately 1,226.40 quintals, with floodwaters covering 87.6 hectares of farmland. Considering an average market price of 6,000 Birr per quintal, the total financial loss for wheat amounted to 7,358,400 Birr. Similarly, barley production decreased by 262.80 quintals across the same inundated area. At an average price of 8,000 Birr per quintal, the estimated financial loss for barley reached 735,840 Birr. These results demonstrate the significant economic impact of even relatively frequent flood events on agricultural productivity in the area.

Table 4. 10. Flood inundated area for different return period per crop planted.

crop type	Average crop yield per hectare	percentage of Coverage (%)	Flood inundated area (Ha) for different return period				
			2	5	50	100	500
			87.6	105.2	127.04	137.3	147.8
wheat	40	35	30.66	36.82	44.464	48.055	51.73
Barley	20	15	13.14	15.78	19.056	20.595	22.17

The data displayed in this table show the impacts of flood inundation on different crop types (wheat and barley) under different flood return periods (2, 5, 50, 100, and 500 years). For each return period, the table lists the average yield per hectare, the percentage of area planted, and the area flooded (in hectares). Flood return periods refer to the probability of a flood of a certain size occurring, with a 2-year flood indicating a frequent and small event and a 500-year flood being infrequent and catastrophic. As the return period increases, the total area affected by floodwaters also increases - from 87.6 hectares in the case of a 2-year flood to 147.8 hectares in the case of a 500 year flood. This pattern of flooding not only indicates the increasing severity but also widespread geographical impact of rare but extreme flood events. In terms of losses due to flooding, wheat accounts for a larger share of the total cultivated area (35%) than barley (15%).

The area under water for barley goes up from 13.14 to 22.17 hectares in the same period and the area under water for wheat goes up from 30.66 hectares in a 2-year flood to 51.73 hectares in a 500-year flood. The extent of each crop is always represented by these figures. They have great implications for agricultural planning: more fertile land is threatened with extinction due to the increase of flood intensity, and more importantly for wheat, which not only covers larger areas but also yields twice as much as barley (40 t/ha vs. 20 t/ha). This means that wheat might suffer from large crop loss and hence, have a great economic impact, thus, the need for flood mitigation measures in the high-risk agricultural zone becomes more compelling.

Table4. 11.Yield difference.

Type of Crops	Total Yield within five years at normal condition(2019-2023)kun/ha	Yield difference	Total yield within five years during flooding (2019-2023)kun/ha	% of losses	% of Recovery
Wheat	16918	6259.66	10658.34	37	63.0
Barley	3619.8	1176.44	2443.37	32.5	67.5
Sum	20537.8	7366.60	13171.21	35.9	64.1

The research conducted in this paper was centered on the flooding areas next to the Awash River, with special emphasis on the Bolengo area in Ejere Woreda, which due to its geographical position and shape is very prone to flooding. A five-year-long (2019-2023) data collection has unveiled the considerable damage caused by the floods that came repeatedly on the yields of wheat and barley. The normal production of wheat was 16,918 quintal/ha and barley 3,619.8 quintal/ha, respectively, which made the total yield of cereal crops 20,537.8 kun/ha. But, the flood years did not allow the growers to enjoy the entire yield. Wheat, for instance, lost large part of its production up to 6,259.66 quintal/ha and remained at 10,658.34 quintal/ha which was a drop of 37% with only a 63% recovery rate. Barley, being the minor crop, was also fed upon but less drastically by 1,176.44 quintal/ha which meant that the yield during floods was 2,443.37 quintal/ha indicating a decrease of 32.5% and a recovery rate of 67.5%.

The two crops in total suffered a loss of 7,366.6 quintal/ha due to flooding, resulting in a combined yield of 13,171.21 quintal/ha. This indicates an average yield loss of 35.9% and a total recovery rate of 64.1%. Wheat was significantly more affected than barley, both in terms of absolute yield loss and lower recovery percentage, which revealed its greater susceptibility. In summary, the results signal that flooding is a very serious threat to crop cultivation, especially for those with high yields but sensitivity to floods like wheat. Floods with a long return period are not common but their annihilating power and impact on agriculture can be disastrous. The data represented in Table 4.8 makes it clear that there is an urgent need for targeted mitigation measures, crop-specific flexibility strategies, and long-term adaptive planning. In other words, these are the measures that will ensure agricultural productivity, food security, and the survival of farm communities in those flood-affected areas.

4.12 Strategies to reduce flood damage on agricultural yield reduction

Structural: Preventing water from reaching populated areas to mitigate flood risks. Structures used for flood control include dams, levees, dykes, reservoirs, embankments, and diversion channels.

Non-structural: the objective is to keep populations at a safe distance from water bodies in order to reduce flood vulnerability. Strategies for flood control encompass public education campaigns, flood prediction systems, training programs, and insurance options, financial support and subsidies, comprehensive flood management plans, and other initiatives.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In the Ejere woreda region, the main cause of the flood is the over flooding of Berga and Holeta rivers, which is the result of rain in the upper catchment area. The combination of increased rain and the sloping of the upper catchment area causes the flood. The main objectives of these studies were mapping the flood hazard area, assessing the impact of flood damage on crop production at various return periods and proposing suitable strategies to minimize the flooding impact. The hydrological record at Hombole gauging station has been deemed to be of high quality, homogenous and stationary. Flood zones were identified for both 2-year and 500-year return periods when maximum flood discharges were 38.93m3/s and 99.22m3/s, respectively. One-dimensional numerical model HEC-RAS was used along with ArcGIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcGIS. The flood hazard map produced indicated that Bolengo in Ejere woreda was the area most impacted by floods.

There were plans put forward for the total flooding of the land which area was calculated at 87.6 hectares for the years 2 return period. Such a flood would lead to the loss of 1,489 quintals of crops. In case of a flood with a 500-year return period, the affected area was 147.8 hectares with a loss of 2,512.60 quintals of crops estimated. A deluge of the area with different return periods may result in a loss of crops but at the same time, it will positively impact the land and thus the farmers through the buildup of fertile soil from the upstream of the river. The agricultural activity for the increased production will depend on the floods and the flood management measures should therefore be identified and practiced.

Merging different flood protection mechanisms would lead to a comprehensive coverage of the infrastructure, the enhancement of community resilience, and the saving of ecosystems from flood destruction. The mixture of practical solutions, community involvement, green infrastructure, non-structural infrastructure, and structural elements results in a very strong framework for efficient flood management. Thus, floods are natural calamities that are quite evident and cannot be completely avoided but rather minimized through advanced planning and the application of both structural and non-structural management strategies.

5.2 Recommendation

The area under investigation is mainly for agriculture but it is also very prone to flooding, mostly in summer (July and August) every year. Hence, it is of utmost importance to come up with non-structural flood mitigation management that is effective and timely in the case of the research area e.g., agricultural crop calendar and soil and water conservation operations. Since floods are most likely to happen in the study area, it is recommended that flood-affected areas that are covered by the 100-years return period flood should not be devoted to agriculture or any other investment projects during the rains, thus minimizing the flood damage.

Depending on the outcomes of this study, following specific recommendations are also forwarded.

- The government should support the affected community to distribute seed and agricultural inputs to communities whose crops have been eroded away by the floods.
- The study only examined the impact of flood risk on wheat and barley crop yield due to financial and data limits. Further study into the likelihood of flooding on other homes is advised.
- The development of flood protection structures and non-structure practices should be acceptable out in the upstream and downstream part of the site to decrease the magnitude of flood, sediment transport, and siltation.
- The responsible bodies of the woreda and the region should include the flood hazard and flood risk assessment studies in their development strategies.
- To lessen the negative effects, implement suitable land use planning techniques in areas that are prone to flooding.

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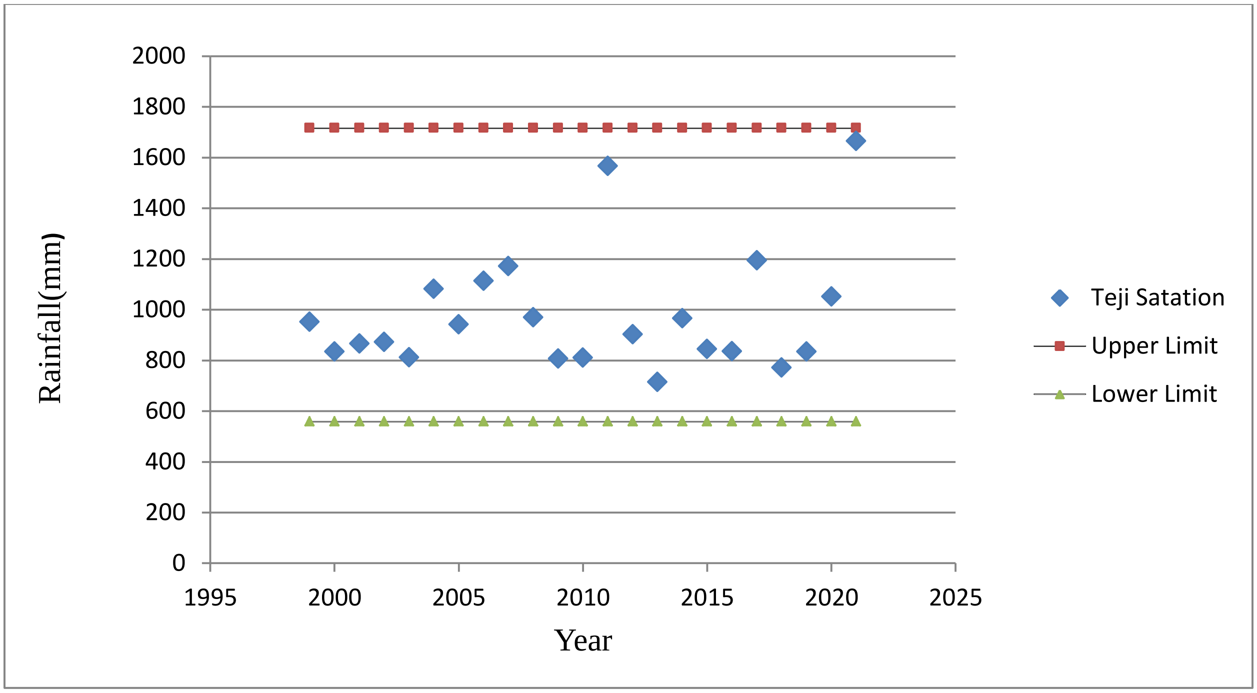
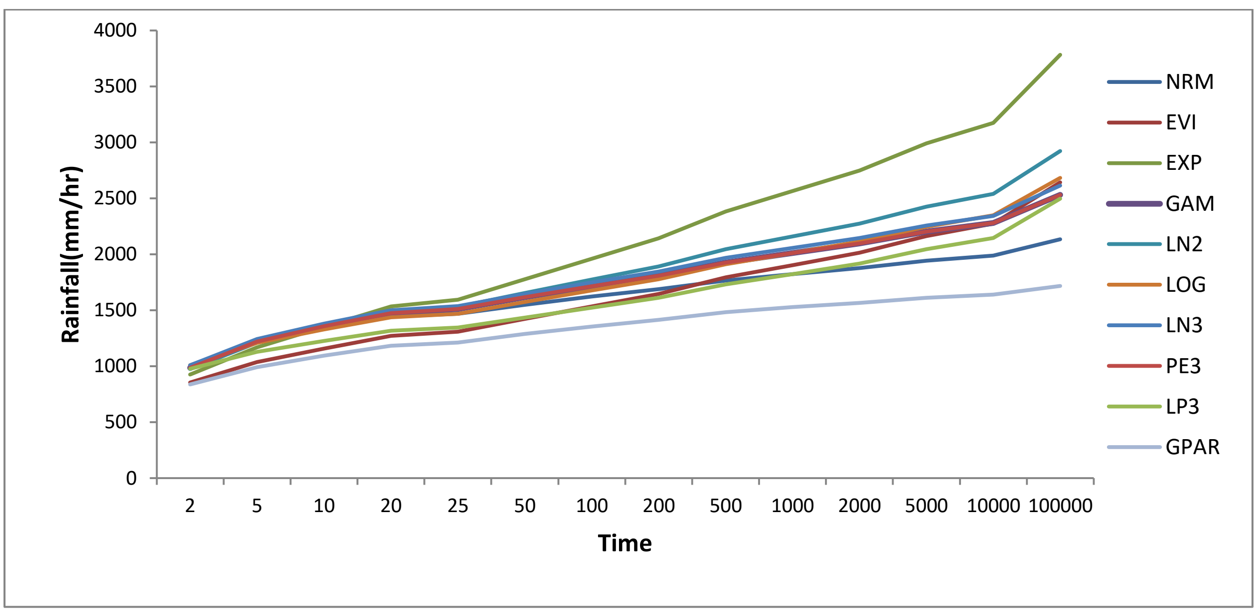
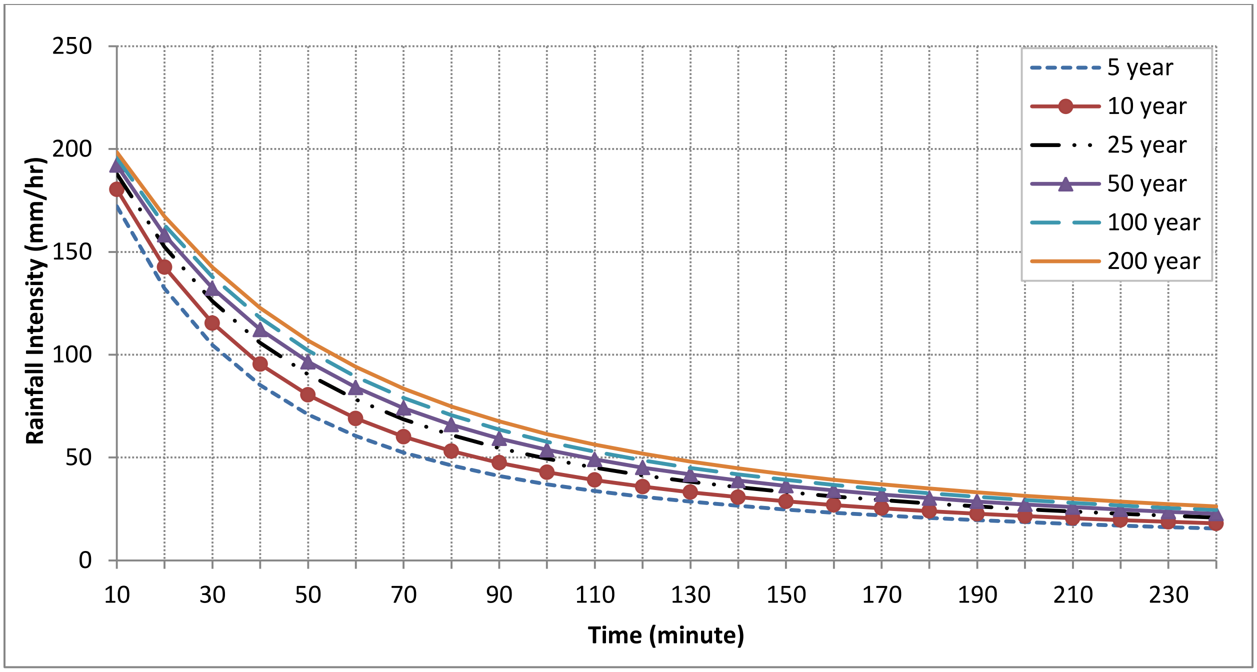
7 ANNEXES

7.1 Figures

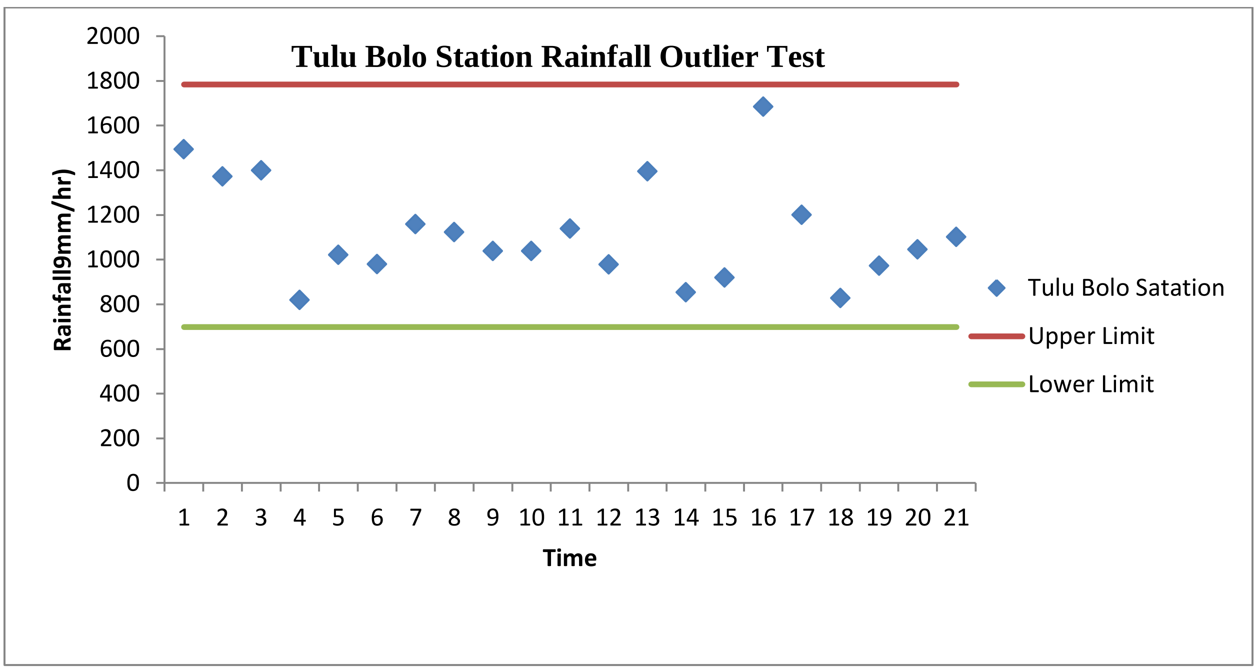
Quantile test for Teji station

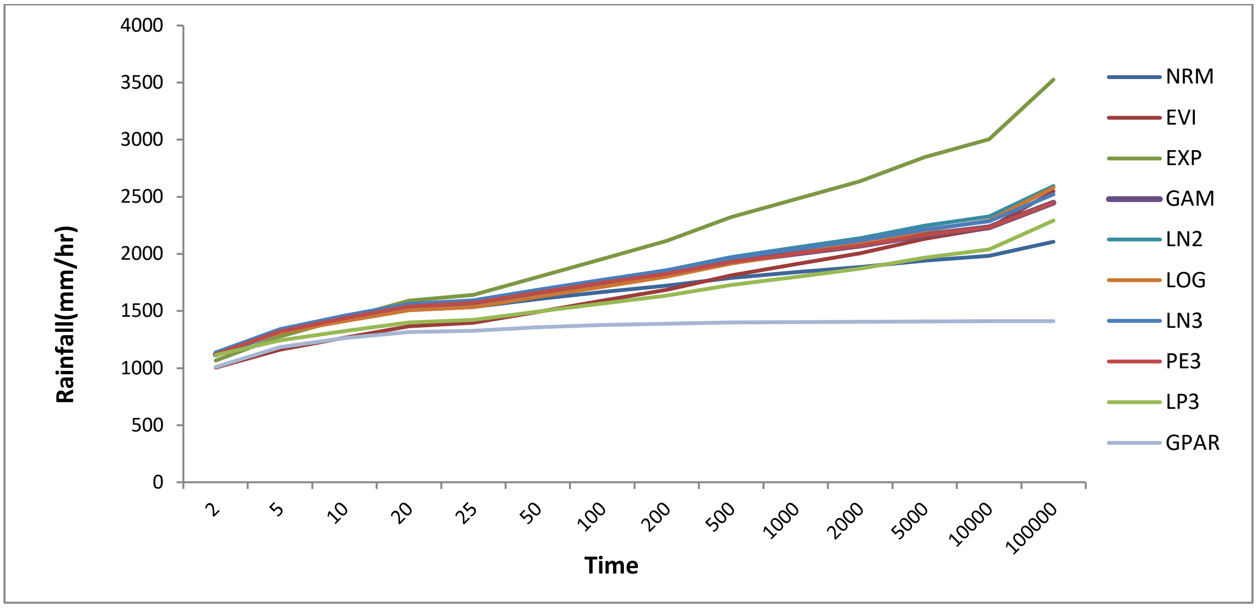


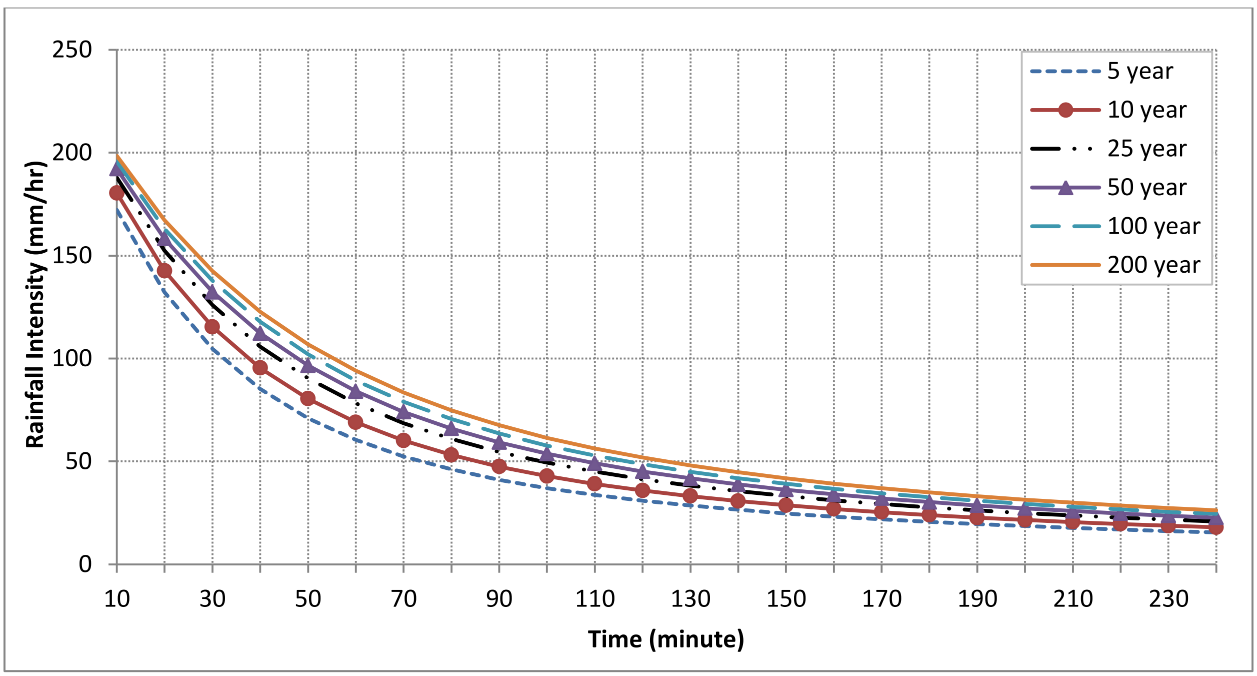




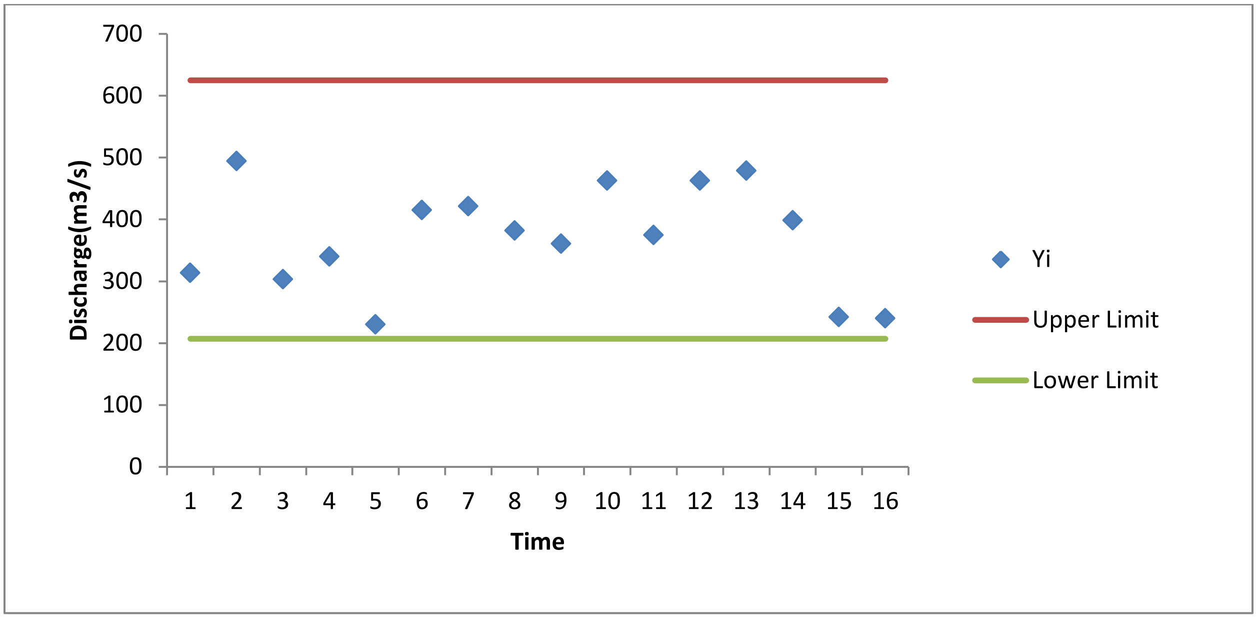
Quantile test for Tulu Bolo station.

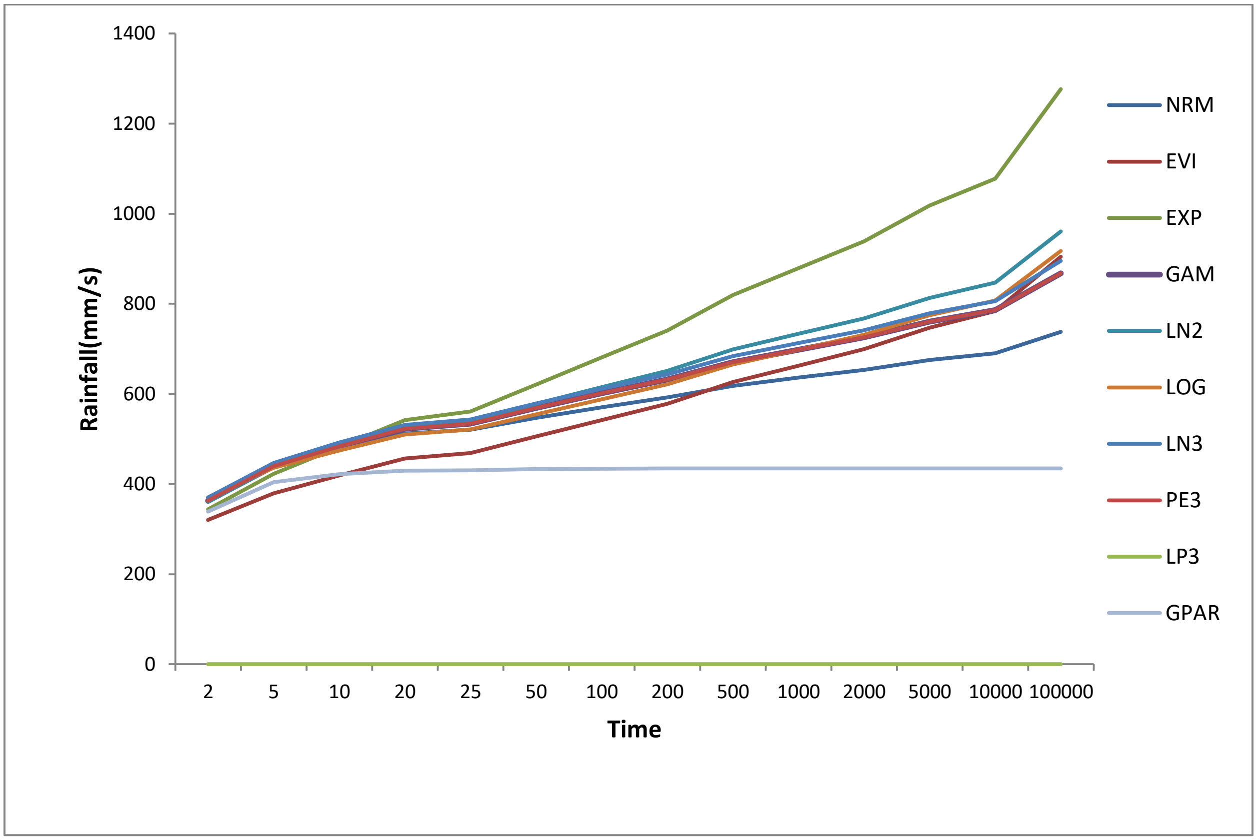



4000
3500
3000
2500
2000
1500
1000
500
0
Rainfall(mm/hr)
2
5
10
20
25
50
100
200
500
1000
2000
5000
10000
100000
Time
NRM
EVI
EXP
GAM
LN2
LOG
LN3
PE3
LP3
GPAR


250
200
150
100
50
0
Rainfall Intensity (mm/hr)
10
30
50
70
90
110
130
150
170
190
210
230
Time (minute)
5 year
10 year
25 year
50 year
100 year
200 year

Quantile test for Hombole station.





7.2 Photos

Photo showed when the Awash River over topped on cultivated land and residential area since, July, 2023




This photo indicated field survey and FDG March,2023.


Maximum monthly stream flow data of Awash River at study area (Source: ministry of water, and Energy, Hydrology Department).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Max Flow
1999	0.43	0.26	0.45	0.35	1.57	8.84	30.42	37.87	27.72	23.06	3.18	0.51	37.87
2000	0.35	0.23	0.19	0.81	1.84	4.74	25.48	37.47	29.39	30.08	6.6	1.72	37.47
2001	0.41	0.37	1.8	2.01	4.74	39.66	32.69	28.18	29.05	12.59	2.33	0.49	39.66
2002	0.56	0.3	0.58	0.68	0.47	10.05	32.37	25.66	22.51	4.25	0.47	0.63	32.37
2003	0.41	0.58	0.75	0.89	0.33	2.42	25.66	35.25	30.53	18.23	0.6	0.49	35.25
2004	0.75	0.35	0.45	1.08	0.6	3.97	18.68	34.6	29.94	23.27	1.05	0.84	34.6
2005	0.81	0.39	0.45	0.93	1.97	15.02	36.67	41.3	30.28	17.1	1.51	1	41.3
2006	0.83	0.4	0.45	0.86	2.65	26.07	54.66	48.01	30.62	10.93	1.98	1.16	54.66
2007	0.86	0.42	0.45	0.79	3.33	19.89	32.14	43.64	34.77	21.92	0.83	0.38	43.64
2008	0.28	0.22	0.16	0.36	4.37	20.09	41.24	37.51	38.63	8.67	19.5	0.9	41.24
2009	0.47	0.36	0.42	6.06	0.86	2.15	25.39	43.94	33.44	20.89	1.38	1.21	43.94
2010	0.67	0.39	0.44	3.42	2.1	11.02	28.76	43.79	34.1	21.41	1.1	0.79	43.79
2011	0.5	0.44	0.54	1.62	4.44	7.83	31.42	40.1	37.51	23.12	2.01	0.14	40.1
2012	0.48	0.48	0.48	0.48	0.48	0.48	26.08	13.91	37.99	15.15	1.2	0.64	37.99
2013	0.44	0.41	0.56	0.35	0.86	2.87	16.09	36.81	18.1	5.01	0.52	0.52	36.81
2014	0.69	1.02	0.56	1.33	2.04	11	24.13	38.75	25.43	10.71	1.66	0.56	38.75
2015	0.3	1.09	0.46	3.24	6.52	23.12	25.16	40.69	23.31	7.69	6.83	0.73	40.69