



FLOOD PLAIN ANALYSIS AND RISK ASSESSMENT
ON ABELA-ABAYA FLOOD PLAIN AREA
IN BILATE RIVER, RIFT VALLEY LAKES BASIN, ETHIOPIA

M.Sc. THESIS

TARIKUA TEKLU TEMA

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ABELA-ABAYA FLOOD PLAIN AREA IN BILATE RIVER,
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Name of major advisor

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Date

Name of Co-advisor

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We, the undersigned, members of the Board of Examiners of the final open defense by TARIKUA TEKLU have read and evaluated his/her thesis entitled “FLOOD PLAIN ANALYSIS AND RISK ASSESSMENT ON ABELA-ABAYA FLOOD PLAIN AREA IN BILATE RIVER RIFT VALLEY LAKES BASIN, ETHIOPIA”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

_____	_____	_____
Name of Major Advisor	Signature	Date
_____	_____	_____
Name of Internal Examiner-I	Signature	Date
_____	_____	_____
Name of Internal Examiner-II	Signature	Date
_____	_____	_____
Name of External examiner	Signature	Date
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Dedicated to

My beloved Father Teklu Tema: You deserve even more

&

To all those people who are facing flood disaster.

LIST OF ABBREVIATIONS

1D	One dimensional
2D	Two dimensional
AM	Annual maximum
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
DTM	Digital Terrain Model
GIS	Geographical Information System
GEV	General Extreme value method
HEC-DSS	Hydrologic Engineers Center - Data storage system
HEC-RAS	Hydrologic Engineers Center - River Analysis system
HEC-SSP	Hydrologic Engineering Center-Statistical Software Package
LN (2P)	Two-Parameter Log-normal Distribution
LN (3P)	Three-Parameter Log-normal Distribution
POT	Peak over Threshold
TIN	Triangular Irregular Network
USACE	United State Army Corps of Engineers
USGS	United State Geological survey
WETSPro.	Water Engineering Time Series Processing tool
WWMEO	Wolayita water, mines and Energy office
XS	Cross-sections

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DECLARATION

I hereby declare that this M.Sc. Thesis is my original work and has not been presented for a Degree in any other university, and all sources of material used for this dissertation have been duly acknowledged.

Name: Tarikua Teklu Tema

Signature _____

Date of submission _____

ABSTRACT

Flood is the most devastating extreme events across the globe. The floods phenomena are common in Abela-Abaya flood plain in Chokare and Guricho Kebele in the course of Bilate River. The main objective of this study is to conduct the flood plain and flood risk assessment in the flood plain Abela-Abaya area. Different input data were gathered and analyzed. Rainfall and air temperature data for a period of 1980 to 2015 were analyzed for characterizing the climate in the area. The streamflow data for a period of 1980 to 2015 was checked by stationarity and independence for input of unsteady process of HEC-RAS. Spatial inputs digital elevation model with a resolution of 12.5*12.5 m and land use map with a resolution of 30m * 30m were used for the HEC-RAS 2D model. Various methodological approaches were employed to achieve the objective. The easy fit software tool was used to identify the parent probability distribution which best fit the stream flow time series. HEC-SSP was used to compute the flood magnitude for various return periods. The HEC-RAS 2D 5.0.7 model was used to model the flood inundation depth, extent and velocity for various return periods in the flood plain area. Flood hazards are estimated based on flood depth, duration and velocity. Vulnerability index analysis was done from Questioners. Flood risks are then computed as product of flood hazard and vulnerability of different location in flood areas. The result of the frequency analysis show that the Extreme-Value Type I (Gumbel) best fitted the time series as evidenced through the goodness of fit statistics. Consequently the estimated quintiles for 2, 5, 10, 25, 50, and 100 years return periods were found to be 104, 156, 195, 252, 292 and 338m³/s respectively. The HEC-RAS 2D model from RAS Mapper showed that the 2, 10, 25, 50 and 100 years return period flood magnitude inundate about 674, 726, 752, 783, 804 and 998 ha of land. The relation between flood velocity and flood depth indicates that 79.2% is in ranges of medium to high hazard level and the other relation between flood duration and flood depth shows that 65% is in long-duration with a higher depth value. The map illustrates that most of the agriculture land and rural settlements area are in moderate risk ranges. The total crop loss for 100years flooding is 233,871.1 quintal and damage cost is 901,584\$. To reduce the impact of risk a structural measures such as levee and drop structure are recommended along the river reach to safely pass the flood into the river.

Keywords: Probability distribution, HEC-RAS 2D model, Flood risk, Abela-Abaya flood plain

1. INTRODUCTION

1.1. Background

Flood disasters are rise in the past decade. World meteorological organization (WMO) in 2005 was reported that average more than 140 plus million people have been affected each year. Much of Africa is vulnerable to flooding with episodes of floods accounting for 26% of total disaster occurrences (Institute for Catastrophic Loss Reduction (ICLR, 2004).

Throughout history, many parts of Ethiopia experience two types of floods: flash floods and river floods. In 2013 DPPC reported that the South region of Ethiopia becomes 106300 Vulnerable and 44000 are affected. There have been floods recorded in the years 1981, 1986, 1996, 1998, 1999, 2000, 2005, and 2014. The main causes of flooding in the area are the intensive rainfall in the uplands area along the Bilate Rivers and Omo River and it affects the downstream areas in the river. One of the downstream areas of Bilate river flood plain is Abela-Abaya which experiences Fluvial type of flooding.

The flood hazard problem in recent times is getting more and more frequent and acute due to growing population size and human interventions/socioeconomic activities in the floodplain at an ever-increasing scale (Alemayehu, 2007; Getahun and Gebre, 2015). Many countries like Ethiopia used structural measures to reduce flood damage. Furthermore, the benefits of structural flood control projects cannot be reached at all levels of society. The experiences with structural flood control interventions gave way to new insights, which are a combination of structural and non-structural flood hazard mitigation measures depending on the specific local or regional needs (Elias, 2015). The preparation of flood risk maps is the basic requirement before non-structural flood hazard mitigation approaches. Most importantly, it helps in identifying and prioritizing the mitigation and response efforts and helps to inform emergency responses (Tran *et al.* 2009).

Overall, the studies of flood hazard and vulnerability are good in number as well as they are updated. However, still, now flood risk as a concept has not been addressed properly in flood studies Since knowledge of flood risk is a must for a planner to plan a disaster resilience society, addressing flood risk properly but it has not done. This study aims to introduce a new approach to assessing flood risk using HEC-RAS 5.0.7 in concert with ArcGIS which Properly addresses the above-mentioned critical issue.

1.2. Statement of the Problem

The major problem of Abela-Abaya flood plain was flood damage. This district lies in lower part of Bilate River. As River emerges from highlands to flood plain, it has flooded a wide area. It displaced many people, damage cultivated land, and loss of life in every year. Due to high flood in every year, many hectares cultivated land harvested by local people currently out of services. According to (UNOCHA, 2018) report, some of these floods were recorded in the years 1996, 1998, 1999, 2000, 2001, 2005, and 2018. In the year 2005, Bilate burst its banks between 24 and 30 April 2005 making a total of 13 settlements with a total population of 24,633 has been affected as well as killed two people. The most affected Kebele is Abaya-Chewcore and Abaya-Guricho where a total of 1,633 and 1,650 households. The main cause of this flood is due to the intensive rainfall in the up lands of the watershed, sparse vegetation cover, steep slopes and low infiltration capacity of the ground surface (Muse, G and Getaneh, B., 2018).

Most researchers Mulugeta (2017), Berhanu (2019) also SWME (2017) have addressed the problem of flood on agricultural land and rural settlements area by considering only flood depth and flood extent parameter and most of them are not considered indicators of vulnerability for the Risk analysis. Therefore, this research analyzes the flood plain area and assesses the flood risk on agricultural and Settlement flood plain area of Bilate watershed in Abela-Abaya district.

1.3. Objective

1.3.1. General Objective

The main objective of this study is to conduct floodplain analysis and risk assessment of the Abela-Abaya flood Plain area in the Bilate River Ethiopia.

1.3.2. Specific Objectives

The specific objectives are:-

- ✓ To estimate peak flood magnitudes for the various return period
- ✓ To estimate Hazard map on different return period
- ✓ To produce the flood risk map of Abela-Abaya floodplain for 100 return period
- ✓ To propose possible mitigation measures

1.4. Research Question

- ✓ What is the magnitude of flood in Bilate River for different return periods?
- ✓ What are the flood risk parameters and how to generate these parameters?
- ✓ What is flood risk map for 100 return periods?
- ✓ What are the possible mitigation measures for the flood-prone area to control flood?

1.5. Significance of the study

This Study gives special emphasis on fluvial types of floods of Bilate River by taking the flood plain of Abela-Abaya district. It fills the research gaps carried out earlier by reducing flooding to cultivated crops in the study area and settlement, improved non-structural and structural flood mitigation measurement options. In addition to this, the study will envisage benefiting the following groups of people: rural communities living in flood-prone areas, disaster managers, policymakers, researchers and scholars, and funding agencies.

1.6. Scope and Limitation of the Study

The study focused only on the flooding of Bilate River particularly at-risk areas Abaya Chewcore and Abaya-Guricho Kebele of Abela-Abaya Woreda. It also encompasses the estimating of the amount of flood and simulates flood mapping, mapping of flood risk maps and gives mitigation measures. The main limitation of the discharge data obtained from the Ministry of Water resources was not complete and poor Quality. Due to the Covid-19 pandemic virus, it is difficult to cover half of the area in Questioners.

1.7. Thesis outline

This paper is organized as follows. The first section provides information about the background information on the flood, problem statement, objectives, Significance of the study, and the scope of the study. The second section discusses the literature review of the study. The third section of this study describes the introduction of the study area and includes both the research methodology and the data collection process to answer the research questions. The fourth section describes the results and findings of this study. The performance of the model was also tested in this chapter. In addition to this, it presents damage analysis on agriculture land and also Suggesting structural measures by using the flood risk map. Our conclusions and recommendation are drawn in the final section of this paper.

2. LITERATURE REVIEW

2.1. River Flood and Flood Plain

Smith and Ward (2013) defined River (fluvial) flood as a high flow that exceeds or over-tops the capacity either the natural or the artificial banks of a stream. This causes a watercourse to overflow its banks onto adjacent lands. Floodplains are, in general, those lands most subject to recurring floods, situated adjacent to rivers and streams (Bates, 2005). Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow, and duration of the rainfall event (Smith, 1994).

2.2. Flood Magnitude Estimation

The first step for flood risk management is the estimation of the flood hazard for the region; this process can be done based on the study of triggering factors causing the flood.

As suggested by the Chow et al (1988) there is two main cause that increases the capacity of runoff which are rainfall characteristics (Rainfall Intensity, Depth of rainfall, spatial distribution over an area and temporal distribution over time) and the other one is Catchment characteristic's (size and shape, Topography, Soil condition, and Land use and management). Many hydrologic methods are available to estimate peak flood. Among the many hydrologic methods, some are explained below.

2.2.1. Rational Method

It estimates the peak runoff at any location in the catchment area as a function of the area, runoff coefficient, and rainfall intensity for the duration equal to the time of concentration.

Wijesinghe and Wijesekera (2011) applied the rational method for the Srilanka region and observed that rational method, in general, are intended for smaller catchment areas less than about 6177.63 acres and stated reason behind this limitation is that only the peak discharge can be calculated using the rational equation and in that equation, the peak discharge is directly proportional to the runoff coefficient, when the other parameters are kept constant.

2.2.2. SCS and other Unit Hydrograph Methods

This technique requires the same basic data as the Rational Method: catchment area, a runoff factor, time of concentration, and rainfall. The main parameter for the rational method is the runoff coefficient (C) and for the SCS method the curve number (CN) (Bhola and Singh, 2010).

Sahu *et al.* (2013) has done appreciable work in this field. They conclude that the SCS approach is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during a storm. Besides them, Stuebe and Johnston (2016); concludes that Runoff estimation with annually consistent curve number values has limited application because watershed response varies from season to season.

2.2.3. Analysis of Stream Gage Data

If a project is located near one of the gauged stations and the gauging record is of sufficient length, flood estimation may be made. The method commonly used for estimating the peak discharges is usually Flood Frequency (ERA Drainage Manual, 2002).

Flood frequencies have many methods and models proposed for their estimation by using observed historical records of peak flows data. The selection of flood frequency distribution would be widely accepted, simple and convenient to apply, consistent, flexible, or robust (low sensibility to outliers) and theoretically well based (Rao and Hamed, 2000). From the methods of frequency analysis based on the distributions, several models are proposed such as estimation of flood frequency by using the Annual Maximum series model, Partial Duration series model (or Peak over Threshold model), Time Series model, and distribution models like based on the theory of extreme values as developed by Todorovic and Zelenhasic (1970). Several authors used AM from this Lang *et al.* (2009); Solomon (2012); and Dawit (2015) for estimate maximum discharge in each year.

Dawit (2015) used flood frequency analysis by using the annual maximum method and found that EV1 (Gumble) is the best fitted distribution for overall flood frequency analysis. He found 39.30, 50.38, 73.86, 80.69 and 96.46 m³/s for 2, 5, 50, 100, and 500 respectively.

A series of recent studies on comparison of AM with POT series has indicated that the POT method gave better results than the AM method For instance, Nejik *et al.* (2012) and Bhunya *et al.* (2012) concluded that using POT series were more effective for estimating discharge.

Frequency analysis was carried out with different probability distributions functions (PDFs) Chow et al (1988). They are commonly used in hydrological applications. These PDFs are: Two-Parameter Log Normal (LN2), Three Parameter Log Normal (LN3), Pearson Type III (P3), Log Pearson Type III (LP3) and Gumbel (EV1). To estimate peak discharge for different return periods, some of these five PDFs perform well in some cases. For example,

Pumchawsaun (2018) found Log Pearson Type III (LP3) distribution fit well in case of estimation of peak discharges for 1-in-100 year flood; on the other hand, Khan and Sabbir (2018) found that Pearson Type III (P3) is the best fitted distribution for overall flood frequency analysis. Haghighat, (2014) demonstrated that, in the absence of information about the distribution of floods and economic losses associated with the design of flood reduction measures, the use of the normal distribution is better than other distributions such as extreme value, log-normal or Weibull.

Results from (Cunnane, 1999) show that distributions with 2 parameters (EV1) have a smaller standard error, but larger bias than 3 or 4 parameter distributions (GEV, LP3), especially in a small sample size. The 3 or 4 parameter distributions often have a negligible bias. He also found EV1 is effective for small sample sizes, however, if the size is greater than 50, GEV shows better overall performance.

According to Abramowitz and Stegun, 1985, the two-parameter gamma distribution (parameters β and u) has a lower bound at zero, which is a disadvantage for application to hydrologic variables that have a lower bound larger than zero.

2.2.4. Software for estimation of flood magnitude

Suitable Computer Programs such as HYDRAIN's HYDRO, HEC-HMS, and others may be used to facilitate tedious hydrologic calculations.

Brhane (2011) used the HEC-HMS method to estimate Peak discharge for 2, 5, 10, 50, and 100 years and the result is found to be 197.7m³/s, 246.8 m³/s, 265.4m³/s, and 306.0m³/s and 319.60m³/s respectively. The most frequently used time parameters are the time of concentration (TC), lag time (TL), and time to peak (TP), However, frequently there is no distinction between these time parameters in the hydrological literature; hence, the question whether they are true hydraulic or hydrograph time parameters while some methods, as a consequence, are presented in a disparate form was the main limitation on using this model.

The catchment response time is influenced by, climatological variables (e.g. meteorology and hydrology), catchment geomorphology, catchment variables (e.g. land cover, soils), and channel geomorphology (Royappen et al. 2002, McCuen 2009).

Overall based on the desired objective, Available data, the importance of the model, the size of the catchment, Flexibility, and simplicity Flood frequency analysis is used for this thesis.

2.3. Application of Flow Duration Curve for flow analysis

The flow duration curve is a plot of flow versus the percent of time particular flow can be expected to be equaled or exceeded. The flow duration curve is done from daily as well as from selected period flows. Flow–duration curves from monthly and annual discharges can also be derived, but their usefulness is much less than those constructed from the daily mean (Elizabeth et.al.2011).

When summarizing the previous study using FDC for flow analysis such as Norman, (2001); Dawit, (2015), etc. describe that the shape of a flow duration curve in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics. According to their analysis for the shape of the curve in a high flow, region indicates the type of flood region the basin is likely to have, whereas, the shape of the low flow region characterizes the ability of the basin to sustain low flows during dry seasons. A very steep curve (high flows for short periods) would be expected for rain caused floods on small watersheds. In low flow region, an intermittent stream would exhibit periods of no flows, whereas, a very flat curve indicates that moderate flows are sustained throughout the year due to natural streamflow regulation, or due to a large groundwater capacity which sustains the base flows to the stream.

2.4. Flood simulation model

Following to estimation of flood magnitude, the next step was the selection of an appropriate model for simulation of the flooding process. Selecting the best and appropriate model is an essential part of any research work. Different flood modeling tools have a distinct model structure and solution procedures.

HEC-RAS was compared with two other models in Horritt and Bates (2002). The two other models in the comparison were LISFLOOD-FP and TELEMAC-2D, which include two-dimensional modeling capabilities. They get HEC-RAS was the overall best modeling system between the three options. When compared to other 2D models, HEC-RAS was able to comparably predict inundation areas (Ghimire, E., 2019). Deal (2017) compared HEC-RAS 2D, SRH-2D, and HEC-RAS 1D. He used HEC-RAS 4.1, 5.0, 5.0.1, 5.0.2, and 5.03 and SRH-2D version 3.0. He also found that HEC-RAS 2D was the fastest model. Similar mesh size and time steps were used, but HEC-RAS performed simulation up against 28 times faster than SRH-2D. SRH-2D requires more excessive pre- and post-processing than HEC-RAS. Their conclusions point out the capabilities, strengths and shortfalls of these models.

As stated earlier, out of the numerous hydraulic models, HEC-RAS 2D was chosen for this research based on among other reasons the fact that it is an open source application and its geometric data input and simulation can be done in GIS environment, easy to navigate even for users with minimal modeling experience, and can run quickly for real-time forecasting.

2.5. Flood Risk mapping

The most common approach to define flood risk is that it is the product of hazard, i.e. the physical and statistical aspects of the actual flooding (e.g. return period of the flood, extent, and depth of inundation, and flow velocity), and the vulnerability, i.e. the exposure of people and assets to floods and the susceptibility of the elements at risk to suffer from flood damage (Sayers *et al.*, 2003; Apel *et al.*, 2009). Kourgialas and Karatzas (2011) prepared a Flood risk map from the flood hazard map and flood vulnerability analysis. Examples of similar studies dealing with the flood risk (Beffa 2000; Dutta *et al.*, 2012; Kubal *et al.*, 2015; Masood and Takeuchi 2017, etc.) suggest that some several problems and tasks need to be undertaken.

Al Baky *et al.*, 2019 Done the most appreciable work on Flood risk by integrating GIS, Hydraulic model, and required field information. They also had done Expected annual damage to Bangladesh.

Flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth, and distribution of flow velocity (Elena, 2002). She used parameters like flood depth and flood velocity and flood duration for Flood Hazard mapping.

Another report by Klijn (2014) and Eleuterio (2013), refer that Vulnerability is a function of three parameters such as Susceptibility, Exposure, and resilience. Susceptibility refers to the propensity of a particular receptor to experience harm. Exposure refers to the value of the element at risk and resilience refers to the resilience of a particular group, people, property, and the environment, and their ability to respond to a hazardous condition. For example, elderly people may be less able to evacuate in the event of a rapid flood than young people. With similar to this definition the other study Kang and Chang (2005) describes Exposure analysis, therefore, aims to examine the economic assets and activities covered by the flood. Combining all the definitions above, the following vulnerability equation is developed.

Flood vulnerability is measured through the development and use of flood loss functions. The relation between flood and damage depends on the flood depth. The functions of inundation timing are used to estimate crop damage (Reith, 2012).

The procedures for Vulnerability indicator selection follow two general approaches. These are deductive and inductive approaches (Adger *et al.*, 2004) in the deductive approach, indicators are selected based on relationships established from theories and conceptual frameworks, whilst inductive approach involves statistical procedures to relate a large number of variables to vulnerability to identify the statistically significant factors.

Dawit (2015) studied flood risk analysis in Illu floodplain. An inundation area for this district is 2354.06ha for 500 years. It was simulated based on DEM and observed flood data for 50 years (1960-2010). The inundation simulation has been conducted using 1D dimensional model such as HEC-GEORAS and HEC-RAS software. After the simulation, he calculates the total loss of crop about 52,966.25quantal of the crop. This raises many questions about the depth of flooding Duration and velocity for analysis of risk and calculates the loss of crop. The main limitation was using a dimensional model it doesn't answer the above question.

2.6. Flood Hazard Index (FHI) and the Vulnerability Index (FVI)

2.6.1. Flood Hazard index

There is a broad consensus that the degree of flood Hazard is a function of velocity and depth from Tao *et al.*, 2017 the risk index calculation methods. The empirical method of calculating the flood risk recommended by Defra/Environment Agency of the United Kingdom is used. The main limitation of this report is the use of Velocity and depth for risk analysis. Velocity and depth are some of the parameters of Hazard. As mentioned in the above literature hazard by itself not a risk, so this parameter not appropriate for risk analysis it is better to use in Hazard Index calculation, not for risk.

The hazard index has to be assigned according to inundation depth. But other factors such as frequency of flood, duration of the flood, etc. should be considered (Islam and Sado, 2000).

2.6.2. Flood Vulnerability Index

In literature, a quantitative assessment of vulnerability is usually done by constructing a vulnerability index. This index is based on several sets of indicators that result in the the vulnerability of a region. In literature, a quantitative assessment of vulnerability is usually

done by constructing a vulnerability index. This index is based on several sets of indicators that result in the vulnerability of a region.

Kissi (2014) uses thirty indicators of vulnerability for exposure, Susceptibility, and Resilience Yoto District of Mono River. His result gives more verifications of the Vulnerability assessment. He concludes that FVI offers an easy comparison of communities' vulnerability to flood disasters.

2.7. Software's used for the study

2.7.1. Water Engineering Time Series Processing tool (WETSPRO.)

The WETSPRO tool is available in two versions: a zip file with MATLAB p-files to run the tool in MATLAB (Willems, 2008) and an executable file that can be run on computers without the MATLAB software. Users without a MATLAB license can use the executable file to run the WETSPRO – tool. It is used to select POT values (Division, 2014) and (Willems, 2004).

The main drawbacks of the partial duration series are the threshold selection and assuring independence criteria. Begueria (2005) investigated the influence of threshold selection on partial duration series model assumptions, stating that a unique optimum truncation level cannot be found.

2.7.2. HEC-SSP software

As stated in the manual Bartles and Gary (2019) it is an integrated system of software, designed for interactive use in environment domain: General frequency analysis that allows the user to adjust parameters and Volume-duration frequency analysis. The HEC-SSP software is one of the required hydrologic models to estimate the return period (i.e., the 100-year floods), to explain the exceedance probability and its relationship to return period and to apply them for our flood frequency analysis for the river.

2.7.3. Easy-fit software

As cited on Hossein and Alireza (2014) the software uses well-known goodness of fit test statistics. These are the chi-square test and the Kolmogorov Smirnov test. The chi-square test is used to determine if a sample comes from a population with a specific distribution. Easy fit computes the test statistics and compares to the critical value with the chosen significance

level, the test is rejected if and only if the test statistics is greater than or equal to the critical value at the chosen significance level.

Birhanu (2019) and Nebyiat, (2016) uses Easy fit soft ware for selecting best fit distribution.

2.7.4. Geographic Information System

A Geographic Information System is a rapidly developing tool with a range of applications. GIS is defined as computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information (U.S.G.S, 1998).

According to Sorayya (2015), GIS is a system for capturing, storing, checking, identifying, manipulating analysis, and displaying data, which are spatially referenced to the earth.

Modeling tools incorporated in Geographic information systems (GIS) are also powerful (Zerger, 2002; Kourgialas & Karatzas 2011). They provide an effective way of assembling information from different maps and digital elevation. It helps in visualizing flood simulation in an interactive setting, where the spatial impact of various scenarios can be viewed along with the location of critical facilities and thus to assess the vulnerability of the region towards a flood event efficiently.

2.7.5. HEC-RAS 2D

It is free software with a user-friendly and graphical user interface that is successfully used for many flood studies for example (Quiroga *et al.*, 2016) etc.

Recently, several studies have compared the performance of 1D and 2D hydraulic models for river flood simulations (e.g., Horritt and Bates, 2002; Papaioannou *et al.*, 2016).

Gharbi *et al.*, (2016) recommend using 1D modeling for longer rivers, or for rapid studies that do not require too much precision.

Abdulaziz (2017) answer the key question of 2D HEC-RAS in his thesis. Paper such as Tolera *et al.* (2019) uses only 1D HEC-RAS and Birhanu (2019) uses only 2D HEC-RAS. using only 1D had there own limitation on flood risk assessment because the result does not include parameters like velocity and duration Behind from this using only 2D model had raised the question of using fewer terrain data. For both limitations, Abdulaziz briefly cited in his thesis. Using a modification of Terrain was done by the channel terrain model it is created by right-clicking on the geometry layer and selecting Export Layer, then Create Terrain GeoTiff from XS's (Channel Only).

In the same manner, the models have been applied in Ethiopia basins at a different time and space for flood modeling and mapping study Such as (Birhanu *et al*, 2016), (Erena *et al.*, 2018), (Nigusse *et al.*, 2019), etc. but most of them are used 1D HEC-RAS. It has limitation to visualize the flood plain as well as the river in two dimensions.

2.8. Uses of HEC-RAS in Floodplain Inundation Modeling

Several studies such as Kalra and Ahmad (2012), Betsholt and Rouf (2015), and Nordlof (2017), and from Ethiopia, Berhane (2011), Mulugeta (2017) and Berhanu (2019), etc. performed on HEC-RAS for flood plain mapping.

Brhane (2011) worked on Flood mapping of Fogera flood Plain. He used the HEC-RAS 1D inundation area concerning depth for 2 and 100 return periods is 22.27km² with 7.36m and 31.36km² with 7.94m respectively. The big question that arises in this paper is there is a big difference between 2 and 100years peak discharge and the depth of two return periods is almost within the range of 7-8m. He does not discuss the reason behind this result.

Mulugeta (2017), Studied on flood mapping on Horosha River in Tigray using HEC-RAS 4.1. He used 30*30m DEM and SCS method to estimate Peak discharge for 5, 10, 25, 50, and 100 years is 347.4, 383.7, 420.8, 443.6, and 463.1m³/s respectively. The maximum flood hazard and flow depth maps for return periods of 5, 10, 25, 50, and 100 years are 84.6 and 3.36; 86.1 and 3.84; 86.9 and 4.35; 87.1 and 4.91; and 87.7 hectares and 5.89 m respectively with a maximum velocity of 4.6 m/s. He suggested an innovative approach to 1D HEC-RAS when compare to a recent study in Ethiopia in this topic by using depth and velocity. These studies show that for lower resolution DEMs, the predicted area and width of inundation is higher than for models generated using a higher resolution DEM (Berhanu, 2019).

The other most recent study in flood mapping is done by Berhanu (2019) in Akaki catchment using HEC-RAS 505. He used 12.5*12.5m DEM and flood frequency for estimate discharge for 210.29, 333.04, 453.16, 626.19, 769.75, and 925.41m³/s respectively. Flood inundation concerning depth is 86ha with 5.4m, 123ha with 7.23m, 156ha with 10m, 228ha with 11.21m, and 350ha with 13.98m respectively. The maximum velocity for 100 returns period 4.54m/s. He was also done the flood risk map based on hazard and some vulnerability indicators. The result seems to be reliable by considering the peak discharge and the result and it provides further evidence in using 2D HEC-RAS. A key problem with this study in consideration of

Risk map it must consider further indicators for vulnerability and it considers Duration for Flood Hazard.

2.9. Flood Protection Measures

Flooding regimes could increase crop damage and rural settlements in some areas. Therefore different methods of structural measures are needed to maintain agricultural crop production and settlements under flooding effects. Therefore, flood mitigation is one of the primary concepts to prevent flood damages in agricultural fields as well as for Settlements (Tsamalashvili, 2010). Flood mitigation includes structural flood control measures such as the construction of the canal, levee or dikes, drop structures and non-structural measures such as flood forecasting and warning, flood hazard, and risk management (Klijn, 2009).

Webshet (2019) used flood protection structures such as Canal and Dyke to reduce flood damage analysis in the case of upper Awash Sebeta-Awas woreda.

In conclusion, flood mitigation techniques decrease agricultural losses by adapts new management practices in agricultural land.

2.10 Previous Studies on a study area

In the study area, there are different studies performed under different topics. Some of these concentrated on, Local Adaptation Practices in Response to Climate Change in the Bilate River Basin, Groundwater Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, In Bilate River Catchment etc. There are few studies concerning to flood analysis in whole Bilate river as well as Bilate in Abela-Abaya flood plain some of this are:-

Muse *et al.*, (2018) conducted on mapping flood prone areas of Bilate watershed by using Multi-criteria Analysis and GIS Techniques. Five parameters were selected as criterion namely Rainfall, Slope, drainage density, Land use / Landover and soil of the watershed. The final result produced using Weighted overlay function of the five criterions developed identified three flood prone areas in the watershed as high, moderate and low flood prone areas covering 28.5% (1603.16 Km²), 61.4% (3453.82 Km²) and 10.1% (568.14 Km²) area respectively. After mapping flood prone areas the map indicates they classify the downstream part of Bilate was Low flood prone area. But not accurate because most of flood prone area was in downstream of Bilate as reported on Joint Government and Humanitarian Partners (2006).

In 2017 the South Water, Mines and Energy office (SWME) office and Hawassa University Studied a co-operative work on carried out Flood Risk Assessment and Management in Bilate

River Basin. The main aim of this study was identifying those areas which have frequently been attacked by floods. For identification of flood hazard areas: Normalized Difference Vegetation Index (NDVI) using indicators, Accordingly to their analysis three critical areas were identified Bilate-Humbo areas at the very entry of Bilate River to Lake Abaya, Shashego area at Boyo Lake resulting from Guder River, Shashego area at Boyo Lake resulting from Metenchiso River. After selecting floodplain area estimating peak discharge at Bilate-Humbo by using SCS unit hydrograph was $634\text{m}^3/\text{s}$ for 50 years return period. Using one dimensional HEC-RAS model the maximum and minimum Bilate river bank depth at Humbo-Abaya from the base of river vary from 0.9 to 5.5m and 0.4 to 4.5m respectively. Finally they propose construction levees as best solution for flood risk management with appropriated depth at left and right banks in which the river bank depths. It raises the question that how much flood affected the area? How to conjugate HEC-RAS result with flood risk assessment? Because it is the major points that are not clear in the report

Even though the Bilate river in Abela-Abaya (formerly on Humbo Woreda) flood area is characterized as high flood prone area, still there is no studies in Flood risk conducted on Bilate River based on two dimensional model by including depth, duration and velocity. The current flood problem and lack of studies in the areas show as the importance of study to analysis the flood risk in 2D HEC-RAS. This study concentrates flood mapping for different return periods using the HEC-RAS new version of 2D unsteady flow analysis and it mainly focus on crop loss and loss of life.

3. MATERIALS AND METHODS

3.1. Discription of Study area

3.1.1. Location and Topography

The study was conducted in the downstream area of the Bilate River basin in Abela-Abaya woreda (new woreda first it placed on Humbo woreda) in Abaya-Chokare and Abaya-Guricho Kebele. It is geographically bound by latitude 6°32'and 6°39'N, longitude 37°55'and 38°1'E. The study area covers 72km² and 13.7km from the whole 255km of Bilate river length (Figure 3.1).

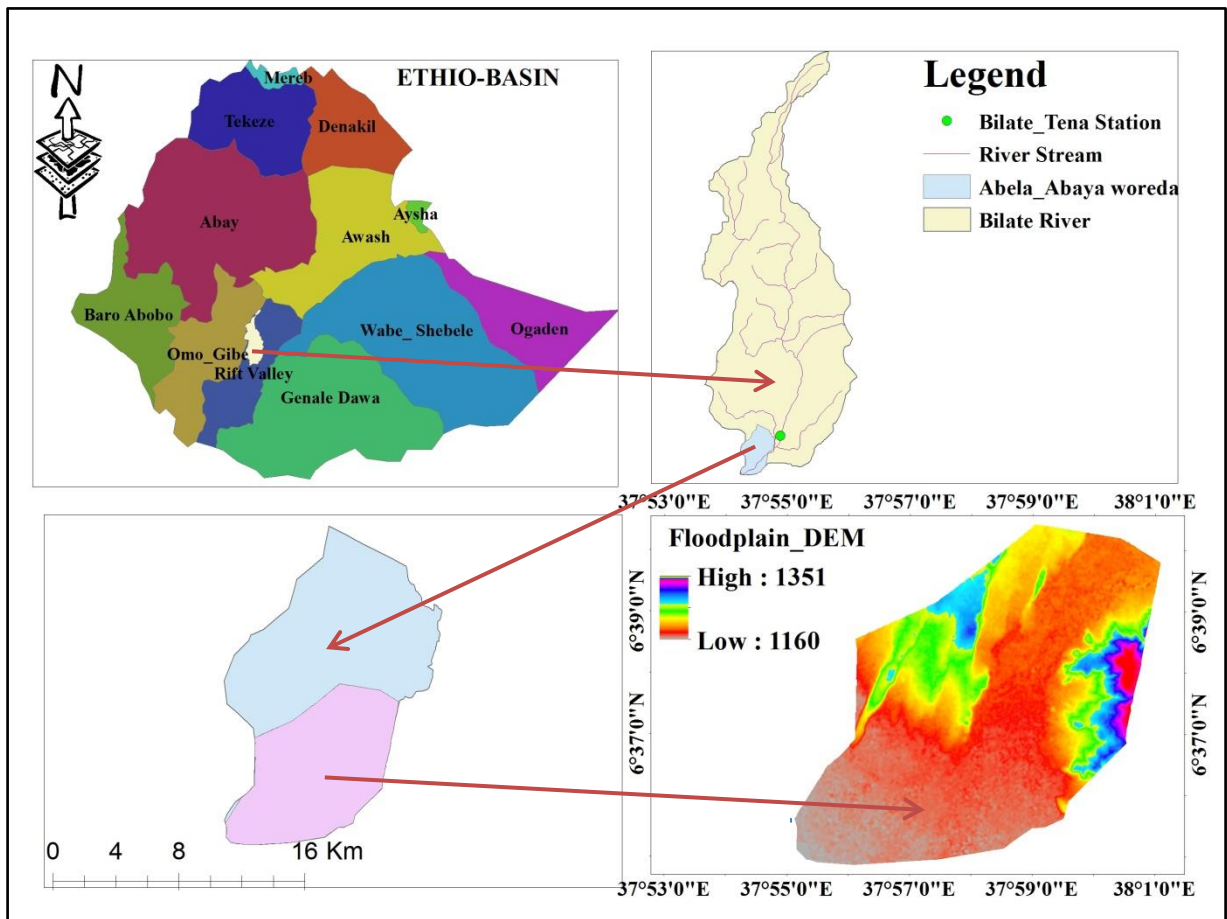


Figure 3.1: Location of Study Area

The elevation of the catchment ranges from 1160-1351m above sea level. According to FAO (2006) guideline for slope Classification, the slope of the study area was mainly dominated by highly flat (0-3) and flat (3-8) which cover 48.82km²(67.82%) and 2.35km² (3.26%) respectively. Followed to these Moderate (8-15), Steep (15-30), Very steep (30-50) cover 14.25km²(19.8%),0.057km² (0.079%), and 6.44km²(8.94%) respectively (Figure

3.2) out of a total Area 72km². The relationship between slope and flood vulnerability is inverse in such a way that steeper slope results high runoff and low flood vulnerability level in that area. Whereas in flat areas low runoff and high vulnerability.

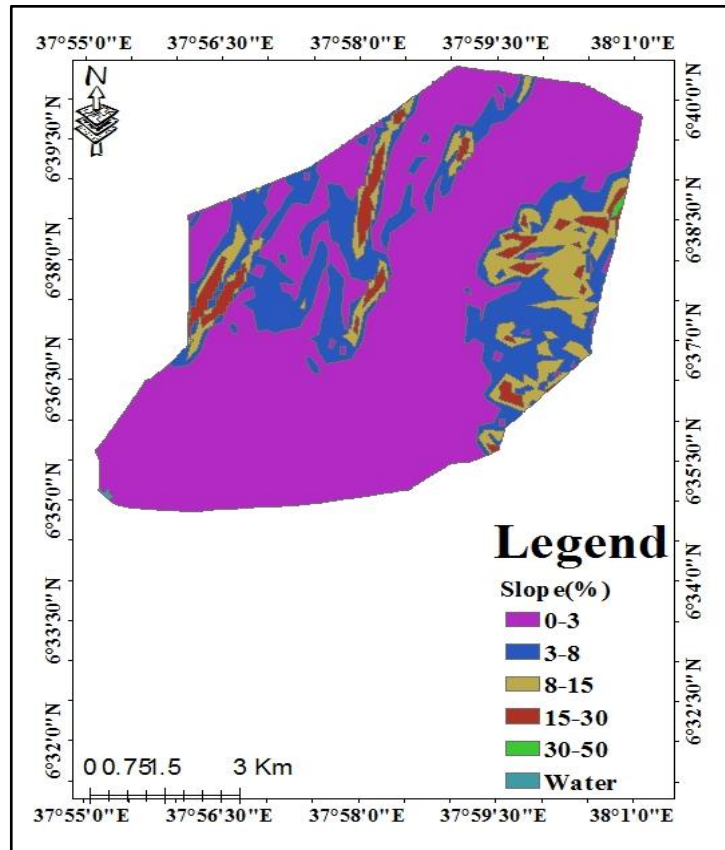


Figure 3.2: Slope of the Study Area

3.1.2. Climate and Hydrology

The climate varies concerning its high extent of altitude and topographical features. The amount of rainfall increases with a rise in altitude (WRB – FAO, 1998). For characterizing the Climate of the study area in the station of Bilate Farm (near site) from 1980-2015 is used. The rainfall of the study area is also a bi-modal type the heights of rainfall season Starts from March and end in October in general (eight months) while the dry season starts from November and Continues up to February (Figure 3.3). The rainy Season further has two peaks in April and July.

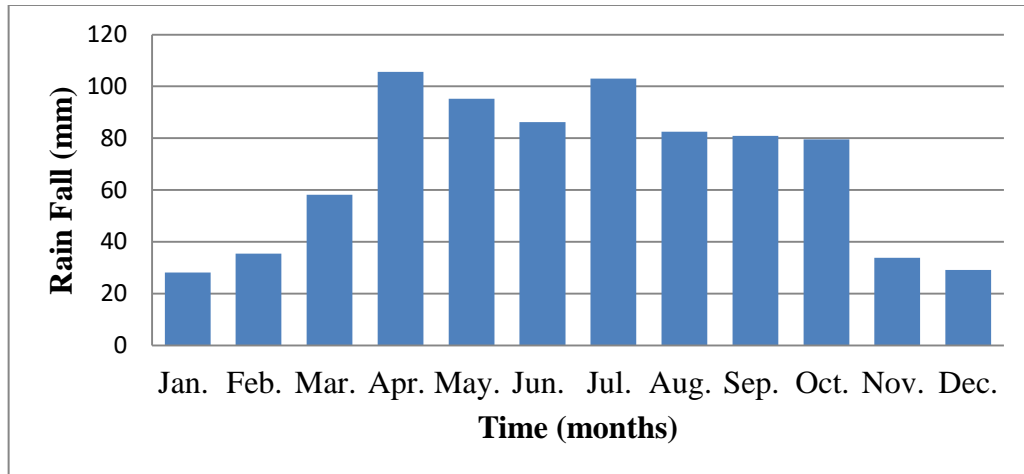


Figure 3.3: Monthly Mean Rainfall (1980-2015)

Mean Monthly Temperature in Bilate state farm station ranges between 24.4°C- 28.4°C (Figure 3.4). The diurnal variation of temperature in the study area is more visible than its seasonal variation.

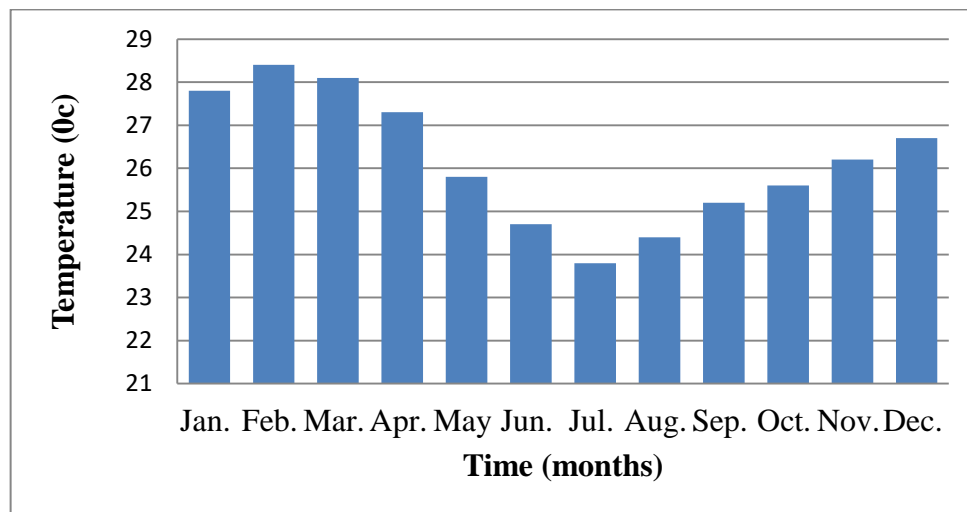


Figure 3.4: Monthly Mean Temperature

Daily runoff is gauged on the big Bilate-Tena station with a catchment area of 3476 km². This gaging station is located about 24 km upstream from the boundary of the study area. The maximum peak of runoff at this station is 283.54m³/s and the Average runoff is 17.562m³/s. Bilate River has two main sources are Guder and weira river are main sources of Bilate river

3.1.3. Soil and Land use/Land cover

As indicated in figure 3.5 below the soil of the study area classified as FAO soil classification is classified into three, namely Chernic Vertisols (Vc), Nitisol (NTu), Ferric Vertisol (VRe.FI). The most widely dominated soil of the study area is Ferric Vertisol (44km²), Chernic Vertisols

(20.91km²) and the less dominant soil type of the study area is Nitisol (6.092km²) and water bodies (0.49km²). As seen on Figure 3.5 that the study area was dominant by Vertisol. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. These soils are dominated by clay soil. This indicates that does not allow very much infiltration and leading to the highest scale in the flood hazard rating.

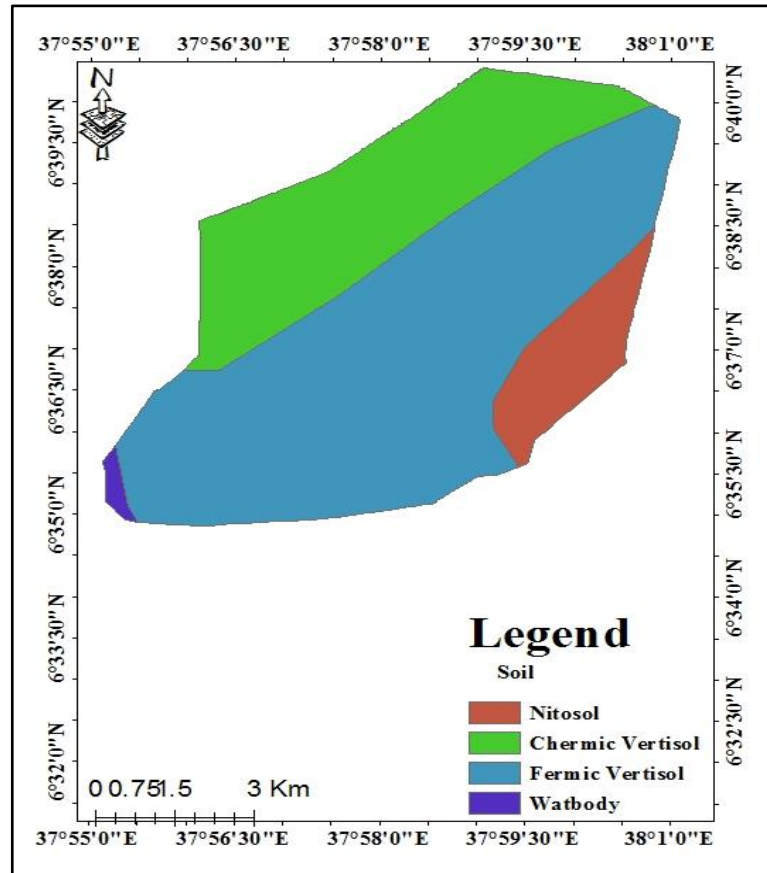


Figure 3.5: Soil type of the Study Area

Since the use of accurate LULC maps can improve the results of flood risk management. In this study, satellite images of Sentinel 2 A with a spatial resolution of 30 m for different bands were used to generate the LULC map used by considering the frequency of flooding is in August and May. A total of eight classes were selected upon prior field investigations. The image was taken through four stages to generate land cover classes in the study area. These include image pre-processing; feature extraction; selection of training data (signatures); and selection of suitable classification approaches. The following eight land cover and use classes were obtained; are water, natural channel, scattered trees, settlement, Cultivation land, dense trees, medium Grassland, and bare lands. After the classification, 100 sample points were

obtained from the field for accuracy assessment. The image classification was guided by reconnaissance information gathered from the field of the study area and classification accuracy of 77.8% was obtained from the error matrix. Figure 3.6 and Table 3.1 shows the classified image with eight classes.

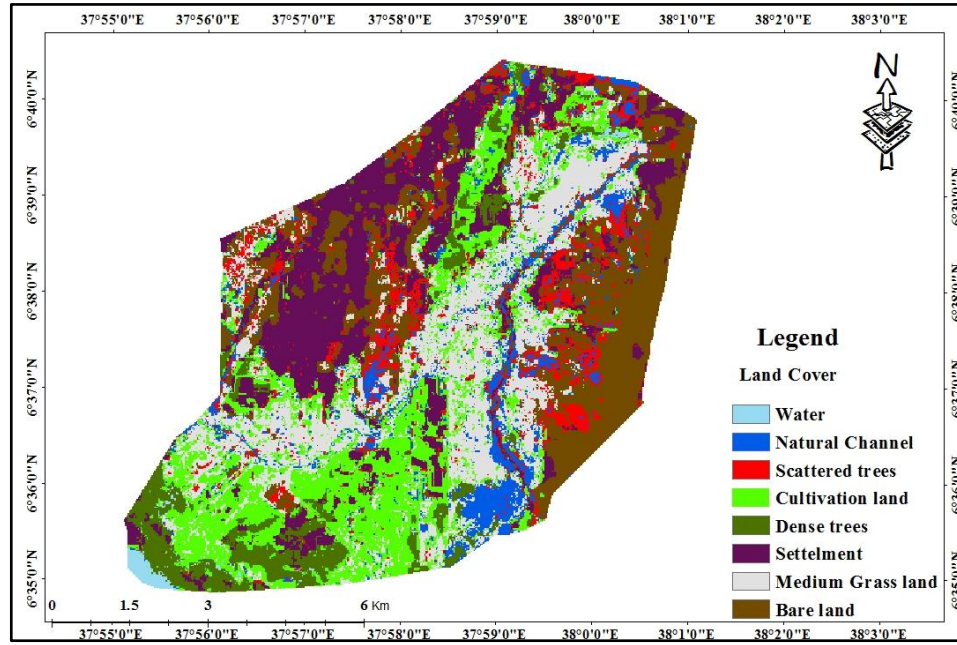


Figure 3.6: Land Cover of the study area

Table 3.1: Land Cover of the study area

Land cover	Area(km ²)	Percent (%)
Water	0.48	0.68
Natural channel	4.66	6.48
Scattered trees	4.6	6.4
Cultivation land	14.84	20.64
Dense trees	5.1	7.09
Settlement	13.92	19.36
Medium Grassland	15.13	21.04
Bare land	13.18	18.33
Total	71.9	100

3.1.4. Population and Economic activity

Based on the Questionary from local Woreda and Kebele authority the total population around two Keble Abaya-Chewcore and Abaya-Guricho were a total of 9200 and 4029 respectively.

Agriculture is the most important activity being carried out in the area with a majority of the people living practicing subsistence farming. The main crops grown in the area include Sorghum, Corn, Cassava, and Teff (Abela-Abaya woreda Agriculture and natural resource office, 2018). Livestock (e.g. cattle, sheep, goat, poultry, and donkey) has also an important place next to crop production in the economy of the inhabitants of the Woreda. Furthermore, other economic activities like the handicraft industry, trade, and others also play important role in the life of the inhabitants of the Woreda.

3.2. Data collection and analysis

This part describes data collection processes as well as data analysis methods.

3.2.1. Primary Data Collection

Fieldwork plays a very important role in collecting primary data. By applying simple random sampling technique, information was collected through questionnaire-based interviews at household levels and personal observation. The questionnaires are designed based on selected indicators developed under (Turner *et al.*, 2003) in Appendix G. They were obtained by directly talking to the interviewees at the household level to get very reliable and accurate information because they were the ones directly affected by the flood disasters and whose livelihood was being disrupted. The households were interviewed by their homes. Firstly, the questionnaires were written in the English language but for communication to the householders, it converts to the local language (Wolayitegna) by fluent speaker and listener of Woreda agriculture and natural resource development office.

For calculating the number of houses and population for each return period by overlying the inundation area into Google earth and select each number of Houses.

To take the number of Sample for Interview from two Kebele (Abaya-Chokare and Abaya-Guricho)

$$n = \frac{Z^2 pqN}{e^2(N-1) + Z^2 pq} \dots \dots \dots \text{Equation 1}$$

Where: n= the minimum number of sample sizes within the range of acceptable error margin.
 N= the total number of households in the two selected Kebele (70hhs for a 100years return period)

z= confidence level (95%) and which is 1.96

e= acceptable error margin (0.05)

p= proportion of sampled population (0.11)

q = estimate of the proportion of the population to be sampled (0.89)

Based on the above equation, the numbers of sample households selected were 48. Therefore, 48 sample households were selected using systematic random sampling techniques.

3.2.2. Secondary Data collection

To reach goals listed in the introduction part of this research the different type of dataset is used: streamflow data, DEM, land use/land cover data and field Measure Data. The streamflow data were collected from the Ministry of Water Resources, Ethiopia. The digital elevation model (DEM) and land use/land cover data were also downloaded from the Alaska Satellite Facility (<https://vertex-retired.daac.asf.alaska.edu/>) and the United States Geological Survey (USGS) (<https://earthexplorer.usgs.gov/>) respectively. Manning's roughness coefficient was collected relevant literature (Chow, 1959). The other useful data were used other than my questionnaire was done by VSO consulting and field survey data in the Bilate river along 13km in December 2019 about 534 points along 39 stations which were done in Abaya-Chokare and Abaya-Guricho (VSO, 2019).

3.2.3. Hydrological Data

The streamflow data were available for Bilate-Tena gauging stations for Thirty-six years (1980-2015) with enormous data gaps as shown in Table 3.2. The flow data was used to know the magnitude of the flood with perspective to its return Period and areas inundated because of this flood.

Table 3.2: Bilate river Gaging record at Bilate-Tena station

Station Name	Easting	Northing	Discharge Record Period	Area (sq. km)	Missing data (%)
Bilate-Tena	403995	765960	1980-2015	5518	21.0%

3.2.4. Digital Elevation Model (DEM)

Topography was defined by a DEM which describes the elevation at any point in a given catchment area at a specific spatial resolution. This high resolution of DEM 12.5mx12.5m was downloaded from the website of <https://www.asf.alaska.edu/> and projected properly as shown

on figure 3.1. It is used to create the terrain model in Ras-Mapper which was then used for establishing the geometry and hydraulic properties of the 2D flow area. It represents the floodplain terrain in the flood model.

3.2.5 Satellite image data

The satellite image of the study area was obtained from Google earth imagery as shown in Figure 3.7. It is used for projected all maps on Google earth imagery to have better view and understanding the nature of flood water.

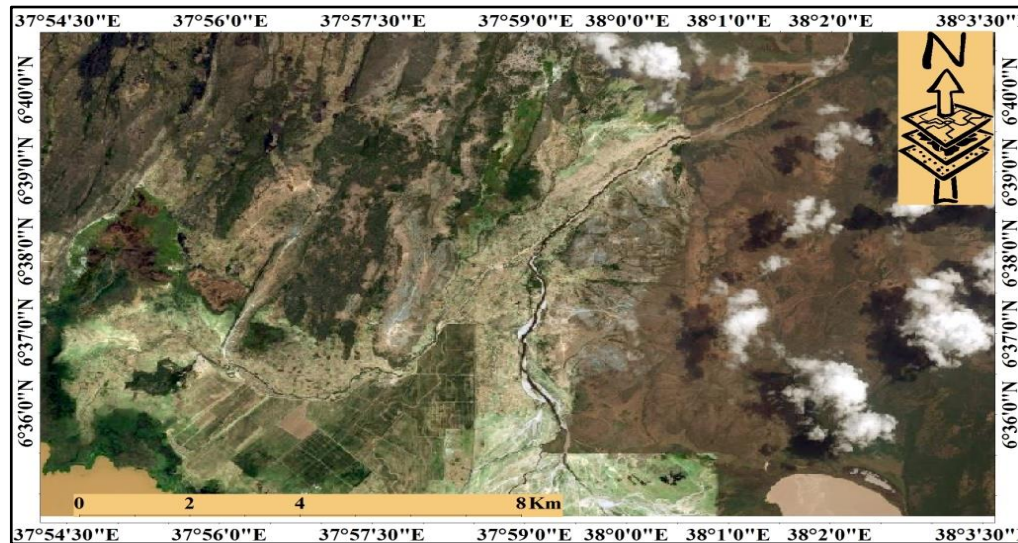


Figure 3.7: Google earth image of study Area

3.2.6. Production data

The productive data of crops in the study area were collected from Woreda Agricultural and Development Office (2019). The reason to know the productive data is to determine the risk of flooding of different year return period flood on the local crops because the overlaying flood or inundation area may lie on the produced crops. From those crops, annual crop such as Sorghum is the most dominant crop product that has almost 50 % of the total crop coverage. The other crop is Corn it is the predominant type of crop product next to Sorghum it has 35% of crop coverage the other type of crop is Teff has 15% of the crop coverage. The data obtained from the woreda also shows the average crop yield per hectare in terms of Quintal of Sorghum, Corn and Teff crops are 32, 56, 275, respectively and root crop such as cassava is 19quintal respectively. Cost of each crop in 2019 Ethiopia price collected from Ethiopia monthly market watch report. Perennial fruit crops including Cassava, mango, avocado and Banana. But the area coverage is insignificant compared with annual crops discussed above.

3.3. Data analysis

3.3.1. Data filling and consistency

The Flow data play a central role in determining the quintile estimation of a flood. Measured flow data are important to many problems in hydrological analysis and design. When missing data appear inflow data, it might come from a different reason. The main is the failure of the observer, distraction or damage of the recording station, and instrumental failure because mechanical or electrical malfunctioning can result in missing data. Any such case reduces the length and information content of the flow data. Several methods are available for estimating missing river flow data. There are station average method, normal ratio method, regression methods, and inverse-distance weighting method, and quadrant method. Consistency and extension of flow data are analyzed by the regression technique. For this study, XLSTAT 2016 tool (<http://www.xlstat.com>) is used for linear regression. There is only one gauging station (Alaba- kulture) nearby station that has a long record period. The two flow variables, of these stations, were correlated using the linear regression method by using XLSTAT Software. The correlation equations used for the Bilate-Tena gauging station in terms of Alaba-kulture gauging station, which shows good correlation is expressed in table 3.3.

Furthermore, more of these missing gaps lay in the dry seasons of the year means that small contribution in increasing runoff.

Table 3.3: Correlation Matrix

	Alaba-Kulture	Bilate-Tena
Alaba-Kulture	1	0.854
Bilate-Tena	0.854	1

Equation of the model (Bilate-Tena)

$$\text{Bilate-Tena} = 5.304 + 0.92 * \text{Alaba-Kulture} \dots \dots \dots \text{Equation 4}$$

3.3.2. Tests on hydrologic data

Two basic assumptions in statistical flood frequency analysis are the independence and stationarity of the data series. Besides, the assumption that the data come from the same distribution (homogeneity) is made.

3.3.3. Test of independence and stationarity

The Wald-Wolfowitz (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 x_1, x_2, x_n the statistic R is calculated from Eq. 8.

$$R = \sum_{i=1}^{N-1} X_i X_{i+1} + X_i X_n \dots\dots\dots \text{Equation 5}$$

Where:- X_i – Magnitude of flow at i period

X_{i+1} – Magnitude of flow next to i period

X_1 – Magnitude of flow at first period

X_n – Magnitude of flow at last period

N– Total number of flows

When the elements of the sample are independent, R follows a normal distribution with Mean and variance given.

$$\bar{R} = \frac{S_1^2 - S_2}{N - 1} \dots\dots\dots \text{Equation 6}$$

$$(R) = \frac{S_2^2 - S_4}{N - 1} - \bar{R}^2 + \frac{S_1^4 - 4S_1^2 S_2 + 4S_1 S_3 + S_2^2 + 2S_4}{(N - 1) - (N - 2)} \dots\dots\dots \text{Equation 7}$$

Where; $Sr = Nm_r'$ and m_r' is the rth moment of the sample about the origins.

The statistic U is approximately normally distributed with mean zero and variance unity. In this thesis, the test of independence was at a 5 % significance level, by comparing the statistic u with the standard normal variate $ua/2$ corresponding to a probability of exceedance.

$$U = \frac{R - \bar{R}}{\sqrt{\text{Var}(R)}} \dots\dots\dots \text{Equation 8}$$

3.3.4. Tests of homogeneity and stationary

The Mann- Whitney, (1947) test considers the quantities V and W by testing two samples of size p and q, where p is less than or equal to q are compared. The combined data set of size N = p + q was ranked in increasing order.

$$V = R - \frac{(P(P + 1))}{2} \dots\dots\dots \text{Equation 9}$$

$$W = pq - V \dots\dots\dots \text{Equation 10}$$

R is the sum of the ranks of the elements of the first sample (size p) in the combined series (size N), V and W are calculated from R, p, and q. V represents the number of times an item in sample 1 follows an item in sample 2 in the ranking. Similarly, W can be computed for sample 2 following sample 1. The M-W statistic U was defined by the smaller of V and W. When $N >$

20 and $p, q > 3$, and under the null hypothesis that the two samples came from the same population, U is approximately normally distributed with mean and variance $\text{Var}(U)$.

$$\bar{U} = \frac{pq}{2} \dots \dots \dots \text{Equation 11}$$

$$(U) = \left[\frac{pq}{N(N-1)} \right] \left[\frac{N^3 - N}{12} \sum T \right] \dots \dots \dots \text{Equation 12}$$

$$T = \frac{J^3 - J}{12} \dots \dots \dots \text{Equation 13}$$

Where T and J is the number of observations tied at a given rank. T is summed overall groups of tied observations in both samples of size p and q . Therefore, in this thesis the statistic u were used to testing the hypothesis of homogeneity at 5 % significance level a by comparing it with the standard normal variate for that significance level.

$$u = \frac{U - \bar{U}}{\sqrt{\text{Var}(U)}} \dots \dots \dots \text{Equation 14}$$

3.3.5. Testing of outliers

Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of this outlier can significantly affect the magnitude of statistical parameters computed from the data; especially for small samples procedures for trending outliers require judgment involving both mathematical and hydrological considerations. According to Jekel and Baumgarten (2014) water resources management if the station skew is greater than +0.4 tests for high outliers are considered first; if the station skew is less than -0.4, the test for a low outlier is considered first. Where the station skew is between -0.4 and +0.4, tests for both high and low outliers should be applied before eliminating any outliers from the data set. The following frequency equation can be used to detect high outliers.

$$Y_h = \bar{Y} + K_n S_y \dots \dots \dots \text{Equation 15}$$

Where: $-Y_h$ = High outlier threshold in log units;

K_n = Value read from the table for sample size N

S_y = Standard deviation

$$QH = 10^{Y_h}$$

A similar equation can be used to detect low outliers

$$YL = \bar{Y} - K_n S_y \dots \dots \dots \text{Equation 16}$$

If the logarithms of the values in a sample are greater than Y_h in the above equation, then it is considered a high outlier. Flood peaks considered high outliers should be compared with

historic flood data and flood information at nearby sites. Historic flood data comprise information on unusually extreme events outside of the systematic record. According to Jekel *et al.*, (2014) if the information is available that indicates a high outlier is a maximum over an extended period, the outlier is treated as historic flood data and excluded from the analysis. If useful historic information is not available to compare to high outliers, then the outliers should be retained as part of the systematic record.

3.4. Estimation of Discharge on Study area

After filling missing data and checking consistency of data in Bilate-Tena Station. As mentioned in section 3.1.2 the study area is far from Bilate-Tena station about 24km. When flow values are requested at an ungauged site, traditional streamflow transfer techniques can be applied. Mainly, four types of flow transfer techniques are named as standardizing flows by drainage area, standardizing flows by mean flows, standardizing with the maintenance of variance extension (MOVE), and the use of the FDC. The use of drainage area ratio (DAR) is the most common and is appealing as it requires no additional information other than the stream flows at an index site and the drainage areas of the index and ungauged sites, making it the easiest possible method that one could consider (Fatih and Hasan, 2019). That is, for any given month for two sites

$$\frac{A_G}{Q_G} = \frac{A_U}{Q_U} \dots \dots \dots \text{Equation 17}$$

Where: - A_G =Total drainage area below Gauging Station

A_U = Total drainage area of the study area (ungauged area)

Q_G = Total Streamflow in m³/s of the gauged station

Q_U = Discharge in m³/s in the study area

The estimation is made on considering the following conditions: similarity in topography, climate patterns, soil characteristics, land-use, and land cover.

The drainage area was calculated in ARC-GIS. The total drainage area below Gauging Station is 72km² so; this is equal to the total drainage area of the study area. Therefore, the Total Streamflow in m³/s of the gauged station is the same in the study area.

3.5. Flood Frequency analysis

Based on the desired objective, Available data, the importance of the model, the size of the catchment, Flexibility, and simplicity Flood frequency analysis is used for this thesis. The

distributions are selected based goodness of fit. As recommended by ERA Drainage Design Manual (2002) for the 100Return period minimum record length is 25 years. Accordingly to this the flood estimates for 2, 5, 10, 25, 50 and 100 return period.

3.5.1. Annual Maximum Series Model

For this study, single annual maximum values were selected from observed flow data Starting 1980 to 2015 from the Bilate-Tena flow gauge station for comparing the best result of AM discharge with POT discharge.

3.5.2. Partial Duration series model or Peak over Threshold model

The selection of the peaks from the time series can be done using different methods. In this study, WETSPRO version 2.1 was used to select POT. The objection noted under annual floods is resolved by listing all floods that are greater than a selected base without regard to number within any given time period. The base is generally selected as equal to the lowest annual flood so that at least one flood in each year is included, however, in a long record, the base is generally raised so that on the average only 3 or 4 floods a year are included. (Willems, 2008).

3.6. Selected the best fit of statistical distribution

The goodness of fit tests was executed in the downloadable software Easy-Fit, available at <http://www.mathwave.com/easyfit-distribution-fitting.html>. All test values and statistics were produced from this program. The POT values and Annual maximum series of flow data supplied to the software through a file or clipboard using copy/paste commands and then by selecting the well-known probability distribution from the distribution fitting option of the software then after the software automatically fit the distribution based on Kolmogorov Smirnov, Anderson Darling, and Chi-square statistical test. The Easy Fit software was rank according to the quality level of fitting with data based on goodness of fit statics. Lastly, the distribution graphs and goodness of fit results were used to compare the fitted distribution and the software also estimates the parameters by using the method of moments. Based on the data the selected distributions were Log-Pearson type III and Extreme-Value Type I for AM and POT maximum data series respectively.

3.6.1. Log-Pearson type III distribution

It has been adopted to reduce skewness; it is the application of Pearson Type III but transforming variable in logarithm form. The rearranged annual maximum flow data are first transformed to logarithms discharges of base 10.

The Log Person Type III probability distribution function is given by

$$F(x) = \frac{\lambda^\beta (y-\epsilon)^{\beta-1} e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)} \dots\dots\dots \text{Equation 18}$$

Where, Γ =gamma function, $y=\log x$ $\log x \geq \epsilon$; $\lambda = \frac{s_y}{\sqrt{\beta}}$, $\beta = \left(\frac{2}{c_{s_y}}\right)^2$, $\epsilon = \bar{y} - s_y \sqrt{\beta}$ assume $c_s \geq 0$.

The magnitude Y_T (quantile estimate) of a hydrologic event is therefore represented as;
 $\text{Log } x = \overline{\log X} + K\sigma \log x \dots\dots\dots \text{Equation 19}$

3.6.2. Extreme Value Type-I distribution

The Extreme Value I distribution is also called the Gumbel I distribution in recognition of Gumbel’s work on the statistical theory of extreme values (Gumbel 1958). It is mostly used for analyzing positively skewed data flood data and predicting hydrological events such as flood.

$$F(x) = \frac{1}{\alpha} e^{-\left(\frac{x-\mu}{\alpha}\right)} \dots\dots\dots \text{Equation 20}$$

For $-\infty \leq \mu \leq \infty$

$$\alpha = \frac{\sqrt{6.S_x}}{\pi}; \quad \mu = \bar{x} - 0.5772.\alpha \dots\dots\dots \text{Equation 21}$$

$$Q_T = b_0 + b_1 Y_T \dots\dots\dots \text{Equation 22}$$

$$Y_T = - \ln [\ln (T_T - 1)] \dots\dots \text{Equation 23}$$

Where Q_T is the flow corresponding to the return period T ; and Y_T is the reduced variable

3.7. Comparison Flood magnitude b/n AM and POT Value with different return period

The present study confirmed the findings of comparison b/n AM and POT value. Below Table 3.4 illustrates that POT results became even better and also more efficient than the AM series results. This result has further strengthened our confidence in using POT value.

Table 3.4: Comparison of flood magnitude b/n AM and POT value with different return period

Return Period	AM	POT
2	103.5	104.2
5	144.2	156.3
10	191.3	195
25	242.6	251.5
50	273.4	291.9
100	306	338.1

3.8. Flow Duration Curve Analysis

The flow duration curve is done by using software FDC 2.1 by using daily discharge from 1980-2015. The software was done FDC from Long term (daily), Months, and annual as well as from the selected period. For this study, FDC did from the long term as described in the literature part it gives satisfactory results when compared to others.

3.9. Hydraulic Model (2D-HEC RAS)

The full unsteady flow equations can simulate the widest range of flow situations and channel characteristics. The basic data requirements for hydraulic routing techniques include flow data, channel geometry, roughness coefficients, and internal boundary conditions. Hydraulic modeling is further subdivided into steady flow analysis and unsteady flow analysis. In unsteady flow, time-dependent changes in flow rate are analyzed explicitly as a variable, while steady flow analysis models neglect time altogether (Manahari and Narayan, 2017). Unsteady flow analysis can be used to evaluate the downstream attenuation of the flood wave, providing a more accurate estimate of flood magnitude and velocity at critical locations.

3.9.1. Geometric data

The accuracy of the HEC RAS result is dependent on the terrain of the study area. Most of DEM (Terrain) resolution use lasers that are incapable of penetrating water. A two-laser system must be used to penetrate the water and hence obtain channel bathymetry information. Adjustments to the terrain model must be made if the terrain data does not contain the actual main channel bathymetry. Fortunately, this can be accomplished within HEC-RAS. From RAS Mapper, by creating a geometry layer using field measurement cross-section for the geometry data by VSO consultant in 2019 for use in creating the channel terrain model. After finishing

creating geometry data with cross-section for main channel bathymetry the channel terrain model is created by right-clicking on the geometry layer and selecting Export Layer, then Create Terrain GeoTiff From XS's (Channel Only) by using the same cell size of the base terrain. HEC-RAS combined between these two-terrain layers and the newly created terrain will have a channel data and floodplain by creating new terrain layer data and will choose these two layers and HEC-RAS will combine two layers automatically. The other is 2D flow areas (Figure 3.8) for flood plain channel are drawn in the geometric data. Indeed, very accurate grids require powerful engines 2D Mesh of size 10*10m generated for the study area that contains 349,672 cells based on my requirements and capabilities of my computer machine.

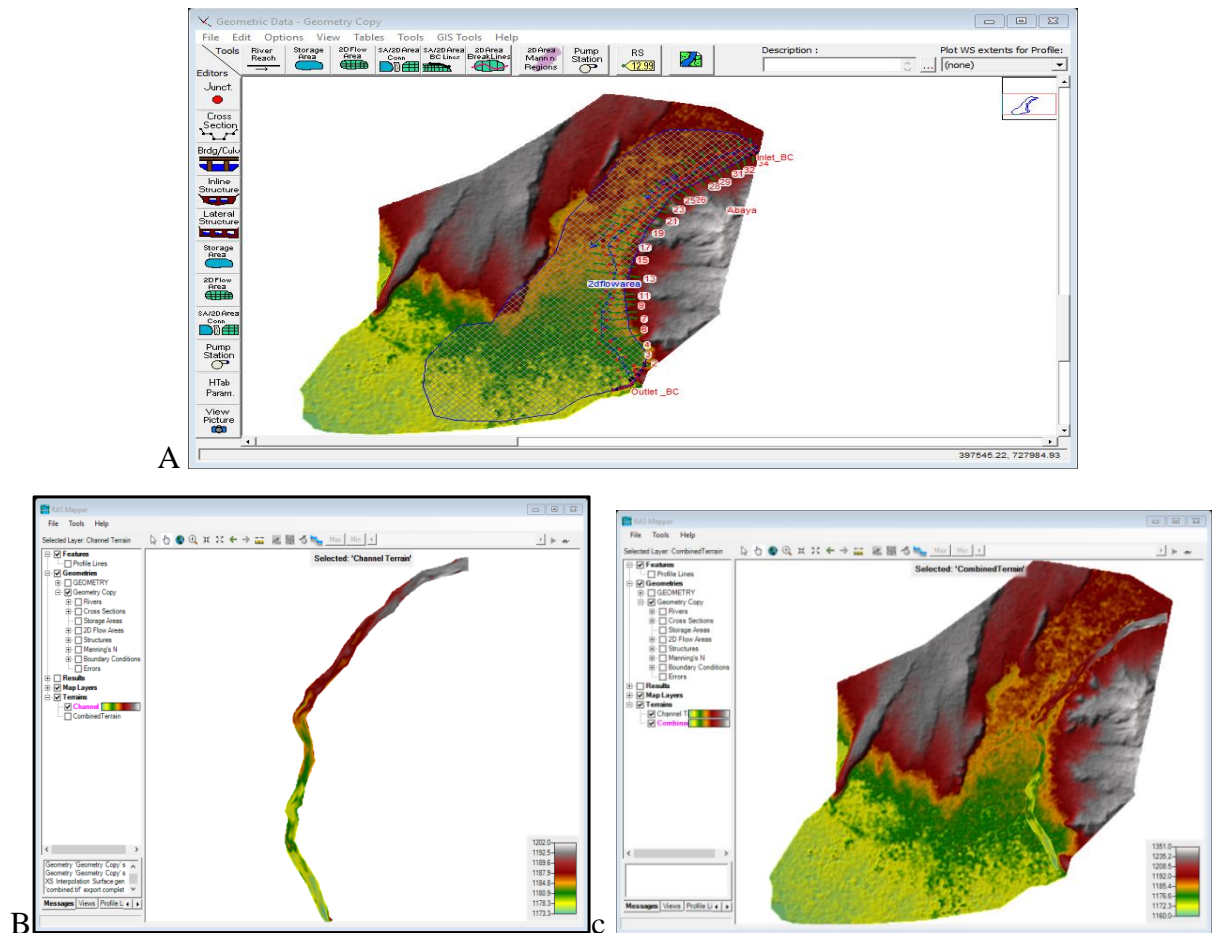


Figure 3.8: (A) Original Terrain with cross-section. (B) New Terrain with Channel Data. (C) Combination of Original Terrain and New Terrain with Channel Data

3.9.2. Boundary conditions

HEC-RAS requires the setting of boundary conditions, both at the upstream and the downstream. Boundary conditions included at the upstream are the stage hydrograph, flow hydrograph, and coupled stage/hydrograph. Additionally, the downstream boundary conditions incorporate the normal depth and the rating curve. At the downstream boundary, the normal depth option commonly is used. This option is simple and the users must have an estimate of the friction slope in Manning's equation to compute the stage based on the flows obtained from the unsteady flow analysis. The average normal depth should be calculated between the upstream and downstream end profile of the study area is 0.0003. Aside from the boundary conditions necessary to perform the calculations; flow hydrographs can be entered laterally along a reach. For this study inflow hydrograph of POT, values were considered as an upstream boundary. The flow data are required to perform a water surface profile calculation. For carrying out the analysis here, the peak flood having 2, 5, 10, 25, 50, and 100 years return period of flows were used.

Based on the Generalized Extreme Value distribution results, flood frequency distributions were derived for N the rainfall-runoff discharges in a range of aggregation-levels which varies from 1 day to 15 days. They were summarized in the form of 'composite hydro-graphs'. These composite hydrographs are synthetic hydrographs constructed in such a way that the average discharge equals a specific return period for all durations that are considered centrally in the hydrograph. When the composite hydrographs are constructed, they are considered as the upstream boundary conditions. The use of composite hydrographs can thus be considered as an accurate and easy method to simulate specific safety levels along the river, based on the two-dimensional flood modeling approach.

3.9.3. Manning's roughness coefficient regions

The Manning's roughness coefficient used to reflect the resistance to flow from the bed material. For overland flow, increased roughness delays the runoff and increases the potential for infiltration. Reduced velocities associated with increased roughness should also decrease the amount of erosion (Gilley and Wieman, 2009). All hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel. Common methods of estimating Manning's roughness coefficients for stream channels include the use of published n - value data, comparison with photographs of channels for which n

values have been computed, and n - value equations (Coon, 1997). A Manning n was assigned following a simple land cover classification that was manually created from parcel outline, using (Chow, 1959) tabular n values for similar land characteristics in Appendix C. Therefore, the selection of the n values was assigned based on the observation of Bilate river channel and flood plain area and taking them with engineering judgment is as follows. Table 3.5 indicates the Manning roughness coefficient for different land use it is selected after several iterations in HEC-RAS. Also, it gives good agreement between observed and simulated values.

Table 3.5: Manning Roughness Coefficient Values for Different Land Use

Features	n values	Features	n values
Water	0.015	Settlement	0.05
Natural channel	0.04	Medium Grass land	0.03
Scattered Trees	0.07	Bare land	0.04
Cultivation land	0.03	Dense trees	0.07

3.10. Theoretical Basis for Two Dimensional Hydrodynamic Calculations

There are two equations that HEC-RAS 5.0.7 used such as the Diffusion Wave equation and the Saint Venant equation (Full Momentum). In this study, the Full momentum equation has been used because it requires much smaller time steps, more accurate and slower run times when compared to the diffusive wave equation (Gary, 2016).

2-D St. Venant Equations (full momentum) equation

(Horizontal distance in X-direction)

$$\frac{\partial u}{\partial t} + u \left(\frac{\partial u}{\partial x} \right) + v \left(\frac{\partial u}{\partial y} \right) = -g \left(\frac{\partial H}{\partial X} \right) + v_t \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \dots \dots \dots \text{Equation 22}$$

(Horizontal distance in Y-direction)

$$\frac{\partial v}{\partial t} + u \left(\frac{\partial v}{\partial x} \right) + v \left(\frac{\partial v}{\partial y} \right) = -g \left(\frac{\partial H}{\partial X} \right) + v_t \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - c_f u + f_v \dots \dots \dots \text{Equation 23}$$

Where

$\frac{\partial u}{\partial t}$ = Local Acceleration Term;

$u \left(\frac{\partial u}{\partial x} \right) + v \left(\frac{\partial u}{\partial y} \right)$ = Advective Acceleration Term;

$g \left(\frac{\partial H}{\partial X} \right)$ = Hydrostatic pressure gradient term

$$v_t \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) = \text{velocity (Turbulence term)}$$

$c_f u = \text{Bed friction Term}$ and $f_v = \text{Coriolis' term}$

3.11. Unsteady simulation

It is unusual for natural channel flow to be steady or constant. Rather natural channel flow is unsteady, meaning that the flow rate in the channel varies with time. Unsteady flow routing is the process of determining depths and flows at various locations along within a channel at various times. This means that velocity, discharge, and depth are functions of location (distance along the stream channel) and time.

3.11.1. Post Processor

The post-processor is used to compute detailed hydraulic information for a set of user-specified timelines during the unsteady flow simulation period. The computation setting area of the unsteady flow analysis window contains the computation interval, hydrograph output interval, mapping output interval, and detailed output interval (Eichert, 1999). In this study it is taken with Based on Courant number and stability of the model Twenty (20) seconds for computation interval, 30 minutes for hydrograph output interval it defines the spacing of point of the hydrograph. One hour is used for a detailed output interval because it requires a lot of computer engine. 30 minutes is used for mapping output interval. Based on selecting the equation used (Full momentum equation) the courant numbers have been used based on the following formula:-

This option can improve model stability, as well as reduce computational time.

Fully saint Venant equation

$$C = \frac{V * \Delta t}{\Delta x} \leq 1 \text{ with max } c = 3 \dots \dots \dots \text{Equation 24}$$

C= Courant Number

$\Delta T = \text{Computational time step [s]}$

$\Delta X = \text{Average cell size [m]}$

3.12. Flood characteristics affecting crop damage

Flood characteristics such as depth, velocity, and duration of the flood were computed from 2D HEC-RAS of Ras mapper for the analysis of Flood risk as well as crop damage.

3.12.1. Water depth (unit in m)

This flood characteristic map indicated the depth of water that occurred during an event. This map is very important for identifying potential areas that were affected by the highest depth of water and influence the elements at risk in the area. It denoted the amount of potential damage for a given area for a particular return period.

3.12.2. Velocity maps (unit m/sec)

These parameter maps indicated the velocity of the flood water per unit of time. This component of flood characteristics is essential for hazard identification since it is an essential parameter for identifying the degree of damage. It is interesting to note that sometimes a large amount of water with lower velocity causes much less damage than a smaller amount of water with higher velocity.

3.12.3. Duration (Day)

Besides the water depth, also another factor that determines the resulting floods damages. This factor is often not taken into account in flood damage models. One of these influences is the flood duration. The longer the flooding lasts, the larger material damages and especially damage in agriculture land.

3.13. Computation of Flood Hazard Index (FHI) and Vulnerability Index (FVI)

3.13.1. Computation of Flood Hazard Index (FHI)

To obtain a comprehensive view of the influence of the Flood depth on the flood damage, not only the impact of flow velocity and water depth on the damage was investigated, but also combinations of these two factors. The computation of Flood Hazard is calculated by connecting Flood depth with Flood Velocity this formula. It is prepared by exporting the Depth-Velocity Geo-tiff file (raster) from RAS Mapper to ArcGIS and copies the attribute to Excel and calculate with debris value. Finally, export to excel value to ARC-GIS Attribute.

$$HI = D \times (U + 0.5) + DF \dots\dots\dots\text{Equation 25}$$

Where HI is the Hazard index value; D is water depth (m); U is the velocity of floodwater (m/s); DF is the debris factor (=0, 0.5 or 1 depending on the probability that debris will lead to a significantly greater hazard (Tao Cheng *et al.*, 2017) as shown in Table 3.6. According to his classification of hazard index; 0-0.75(low), 0.75-1.25 (medium), 1.25-2.5 (high), >2.5(very high).

Table 3.6: Debris Factor for Different Flood Depths, Velocities and Dominant Land Uses

Depth (m) & velocity (m/s)	Pasture/arable	Woodland	Urban
$0 < h \leq 0.25$	0	0	0
$0.25 < h \leq 0.75$	0	0.5	0
$h > 0.75$ or $V > 2$	0.5	0.5	1

The relative scale of each Hazard index category is determined by trial and error. Karim and Chowdhury (1995) made a sensitivity analysis for three alternative scales, namely (i) HI increases linearly, (ii) the rate of increase in HI is linear, and (iii) HI increases geometrically. They found that the linear scale was the best option. Islam and Sado (2000) used a similar type of linear scale in calculating weighted hazard rank. The linear scale is therefore used in the present study. To devise a scale for HI three critical values for flood depth are selected namely 0.5, 1.5 and 3m. Minimum HI is assigned 1 and the maximum is 4. The hazard index values for different categories of flood depth are given in Table 3.7. So far, there is no standard time limit to define the hazard category for duration of flooding. However, it is natural to divide the total flood period into several intervals as the magnitude of damage increases with time. In the present study, four categories of duration of flooding were used. A linear scale of HI for flooding duration similar to the scale of depth of flooding was used. Minimum HI is set 0. The reason is that short duration flooding represents that was identified as non-flooding zone. The hazard index values for different categories of duration of flooding are given in Table 3.8.

Table 3.7: Hazard index for Flooding depth

Depth(m)	Category	Hazard Index	
		Alternative1	Alteranative2
$0 < D \leq 0.5$	1	1	1.5
$0.5 < D \leq 1.5$	2	2	2
$1.5 < D \leq 3.0$	3	3	2.5
$3.0 < D$	4	4	3

Table 3.8: Hazard Index for Flooding Duration

Duration(days)	Category	Hazard Index	
		Alternative1	Alteranative2
short($t \leq 2$)	1	1	0
medium($2 < t \leq 3$)	2	2	1
Long($3 < t \leq 4$)	3	3	2
very long($t > 4$)	4	4	3

The HF was calculated as a summation of WHI for depth and duration. The MHI is given by the following equation

$$HF = aWHI_D + bWHI_T \dots \dots \dots \text{Equation 26}$$

Where WHI_D is weighted area average hazard index for flooding depth and WHI_T is a weighted area average hazard index for flooding duration. a and b are weighted factors for flooding depth and flooding duration. The sensitivity analysis of weighting factors for depth and duration was performed for three sets of factors, (0.5, 0.5), (0.3, 0.7) and (0.7, 0.3).

Table 3.9: Four Combination Cases of Hazard Index

Case study	Hazard index	
	Depth of flooding	Duration of flooding
Case 1	Alternative1	Alternative1
Case 2	Alteranative2	Alternative1
Case 3	Alternative1	Alteranative2
Case 4	Alteranative2	Alteranative2

All three sets are nearly the same result for simplicity the weighing factor taken as 0.5 for both depth and duration of flooding. The hazard factor is normalized by dividing the hazard factor by the maximum hazard factor HF_{max} . i.e $HF_n = HF / HF_{max} * 100$.

Tingsanchali, T and Karim, M.F., (2005) Suggested four levels of Hazard zone to represent hazard magnitude. These level are categorized Very low ($0\% < HF \leq 25\%$), Low ($25\% < HF \leq 50\%$), Medium ($50\% < HF \leq 75\%$), and high ($80\% < HF \leq 100\%$).

3.13.2. Computation of Flood Vulnerability Index (FVI)

In this study, only the deductive approaches were used to select indicators to serve as proxies of human-environment vulnerability to flood disasters. The field survey and interviews that were carried out in the scope of this research showed whether the selected indicators (Appendix E) are most relevant for flood vulnerability analysis in the study area taking into account the local knowledge and perception of the affected people. Those indicators are based on the Vulnerability factor. To compute the Flood Vulnerability Index (FVI) normalization equation method has been used for each indicator.

Normalization of indicators using Functional Relationship

Two types of functional relationships are possible: vulnerability increases with increase (decrease) in the value of the indicator (KISSI, 2014).

$$Y_{ij} = \frac{X_{ij} - \text{Min}(X_{ij})}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})} \dots \dots \dots \text{Equation 26}$$

X_{ij} denotes the value of j indicator ($j=1, 2, \dots, 30$) in i village ($i=1, 2, \dots, 8$). Y_{ij} is the matrix corresponding to the normalized score. The scaled value of Y_{ij} lies between 0 and 1. The value 1 corresponds to that village with maximum value and 0 corresponds to the village with minimum value.

This equation is used in the present study to compute Flood Vulnerability Index (FVI)

$$\text{FVI} = \text{Exposure Index} + \text{Susceptibility Index} - \text{Resilience Index}$$

Any flood vulnerability analysis requires information regarding indicators, which can be specified in terms of exposure indicators (X_i), Susceptibility indicators (X_i), and Resilience.

3.14. Assessment of Flood Damage Functions

The quantification of vulnerability depends on the susceptibility of ‘elements at risk’. It can be termed as the degree of loss to a given element at a given severity level. It is usually expressed on a scale 0 (no damage) to 1 (total loss) unit. The present study considers ‘depth of inundation’ as the main parameter for assessing flood damage functions for croplands and rural settlements. The study further considers the direct economic damages of floods. Considering depth as the flood damage parameter, depth–damage relationships were developed for different elements at risk: crops and settlements. Depth–damage relationship presents information on the relationship of flood damage of a certain element to a certain depth of flooding (or stage) (Smith 1994). In this study, for developing depth–damage relationships for crop, the flood damage data were collected from different, and extensive

interviews with the local people were conducted as part of the questionnaire survey. Based on this flood depth–damage information from the questionnaire survey, a depth–damage curve was developed. For developing the depth–damage relationship for settlement, a valuation survey was conducted for the settlement vulnerability assessment. This included information on the height above the floor of each item or the height taken as standard from house to house. The information for all samples of each element class was then averaged and stage–damage curves were constructed.

The most damage reported every year Agricultural loss. Amount of land inundated in hectare estimated by ArcMap from water surface profile

Crop Loss = Average Crop Grown per hectare * % of Crop Coverage *Flood Inundated Area for the different return periods.

$$C_T (\$) = Y \times X \times (\% \text{cultivated}) \times A_T \dots\dots\dots \text{Equation 27}$$

Where: $C_T (\$)$ is the damage cost of cultivated land at a given elevation

A_T is land inundated due to the rise of water in the River (in Hectare).

Y is yield in Quintal or 100 kg yield per Hectare

X is the cost (\$)/ quintal Cost of one quintal (100kg cultivated land yield) in Dollar

% cultivated is the percent of different cereal sown

3.15. Computation of Flood Risk

Flood risk is a combination of flood hazards and vulnerabilities at a particular location. So, it needs systematic assessment, collection, and analysis of variables. Based on the objective of this research risk analysis consider mainly on agriculture damage (crop loss and livestock) and Rural settlement area. The flood inundation map of 100 years returns period (Figure 4.9) was overlying on high resolution rectified Google image. So that some number of vulnerable houses already at risk could easily be counted. The interview was taken from houses that were affected by flood to know several people per and number cattle per house (cow, ox, goat, sheep, hen). According to the interview, the number of vulnerable people per house was six on average. Farmland area, Swamp area, Population settlement area in hectares, No. vulnerable houses, and No. of the vulnerable population for different return periods are presented in table 4.11.

Also, the Flood risk map was done by using the Hazard index (depth, duration, and velocity) and vulnerability index (24 indicators). By importing the flood hazard maps with its

magnitudes in ArcGIS and the result of the vulnerability index in the attribute table, the flood risk map was prepared.

3.16. Flood Inundation Mapping

Flood Inundation mapping was done on RasMapper on the HEC RAS environment to identify the potential risk, safe settlement areas, and alignment of preliminary protection works. The outputs of the model were exported to the GIS environment for further analysis and reporting purposes.

3.17. Establishing HEC-RAS Model Credibility

3.17.1. Sensitivity Analysis of HEC-RAS Model

It should be noted that sensitivity analysis is a very critical stage in the implementation of the hydraulic model. The Model stability with the 2D approach was significantly higher. The Major sensitivity tests are the Roughness coefficient. Different tests are undertaken, decreased To Minimum Value, and as well as increased to Maximum value in the whole domain For Roughness Sensitivity. The main objective of the roughness sensitivity test is to probe the stability of the model and the sensibility of the results. The other most sensitive parameter in 2D HEC-RAS is grid size wider cross-section spacing causes the simulation to have damping of the flood wave. The test was undertaken with a cell size of 20m*20m, 15*15m, and 10m*10m (Table 3.10) based on computer Performance. Also incorrect time step selection can cause diffusion and instability in this study Time step sensitivity check by one minute, 20second, and 15 seconds.

Table 3.6: Grid Detail

Grid №	Grid size(m ²)	No of cells
1	20	87210
2	15	155233
3	10	349672

3.17.2. Model Calibration

Observed data such as Recorded discharges, stages, and velocities are valuable for calibration purposes; however, it is rare that sufficient gage data are available for comprehensive calibration. The preponderance of calibration data usually comes from local observations during and after an event. The best data often come from people who have lived near the stream for many years. They can supply information concerning flood elevations. For this

study the observed data was done on field survey after 2 days flooding occurs in 2005. The survey was done by WWME office by natural resource department. One of the most important variables for predicting the impact of a flood event is the water depth. For these reasons, the calibration of the river hydrodynamic model focused on predicting water depth and correctly representing the propagation of flood through the main river system. For these reasons, the calibration of the river hydrodynamic model focused on predicting water depth and correctly representing the propagation of flood through the main river system. Calibration of the hydrodynamic model was performed in two steps. Initially a calibration was made through a direct comparison between simulated and observed water surface elevation. By changing Manning's roughness coefficient, the model was re-run to optimize the adjustment between the results. Hence surface roughness coefficients of river and floodplain were adjusted iteratively until the best agreement between simulated and observed water levels on the river were obtained.

3.17.3. Validation of HEC-RAS Model

To validate the inundation map, a field survey by hand GPS to locate the area in ARC-GIS was conducted for several points where flood usually occurs also by using interviews of the affected community. The information is compared with the simulation by using the same return period of the flood. Then compare and contrast hand GPS point data with google satellite if there is a point error, correct it using a photo taken from the area, and Google satellite.

3.18. Model Performance Evaluation

In this study, three model evaluation methods were used, which were Nash Sutcliffe efficiency (NSE), the coefficient of determination (R2) and RMS to check calibration model.

3.18.1. Nash-Sutcliffe Efficiency

Nash-Sutcliffe indicates how well the plot of observed versus simulated data fits the 1:1 line.

NSE is computed as shown below

$$NSE = \left[1 - \frac{\sum_{i=1}^n (D_s - D_o)^2}{\sum_{i=1}^n (D_o - \bar{D}_o)^2} \right] \dots\dots\dots \text{Equation 28}$$

Where: -

D_o = observed depth

D_s = simulated depth

\bar{D} = average observed depth

3.18.2 Coefficient of Determination

The R_2 value is an indicator of the strength of the relationship between the observed and simulated values. R_2 ranges from zero to one with higher values indicating better agreement.

$$R^2 = \left(\frac{\sum_{i=1}^n (D_o - \bar{D}_o)(D_s - \bar{D}_s)}{\sqrt{\sum_{i=1}^n (D_o - \bar{D}_o)^2} \sqrt{\sum_{i=1}^n (D_s - \bar{D}_s)^2}} \right) \dots\dots\dots \text{Equation 29}$$

3.18.3. RMSE-observations standard deviation ratio –RSR

Based on the recommendation by Singh et al (2004) a model evaluation statistic, named the RMSE observation, was developed. RSR standardizes RMSE using the standard deviation ratio-RSR observations standard deviation, and it combines both an error-index and the additional information recommended by Legates and McCabe (1999). RSR is calculated as the RMSE and standard deviation of measured data, as shown in the equation below

$$\text{RMSE} = \frac{\sqrt{\sum_{i=1}^n (y_{\text{obs}} - y_s)^2}}{\sqrt{\sum_{i=1}^n (y_{\text{obs}} - y_{\text{obm}})^2}} \dots\dots\dots \text{Equation 30}$$

$$\text{RMS} = \frac{\text{RMSE}}{\text{STD}_{\text{obs}}} \dots\dots\dots \text{Equation 31}$$

Where Y_{obs} and Y_s are observed and simulated water surface elevation respectively. Y_{obm} is the Mean observed water surface elevation.

3.19. Flood Protection Structure

There are various river engineering works that are used either individually or in combination to provide flood protection and reduce flood damage along the river reaches. Most popular flood protection structure is Canal (River improvement), Dyke (levee), Dam, and Floodwall Retarding basin. Existing Flood protection structure such as dyke structure constructed at flat area of Guricho Kebele with 1m height and 500m wide as shown in figure 3.9 to safe flood inundated area. This structure was not enough to resist coming flood. In this study, based on the topography of the study area and condition of the river carrying capacity Levee was selected as well as for minimizing high velocity of the river in upstream drop structure was selected. Drop structures provide protection for high velocity hydraulic conditions that allow a drop in channel grade over a relatively short distance. Drop structure include a hydraulic jump dissipater basin length is 1m and Flatter longitudinal face slopes (i.e., flatter than 8(H):1(V), help to mitigate overly retentive hydraulics at higher tail water depths that can cause

submerged hydraulic jump formation. The length of drop structure is about 1.7 km (Figure 4.18(A)). The topography of the study area is characterized by a very small river bank and gentle slope (approximately flat), which requires river improvement to increase the flow capacity of the existing river channel. Simulation of drop structure in HEC-RAS was in geometric editor as inline structure as shown in figure 3.10. The levee has been used and to compare the depth before and after using structural measure it must have simulated the data in HEC-RAS.



Figure 3.9: Flood Protection Structure on Guricho Kebele (Source Author)

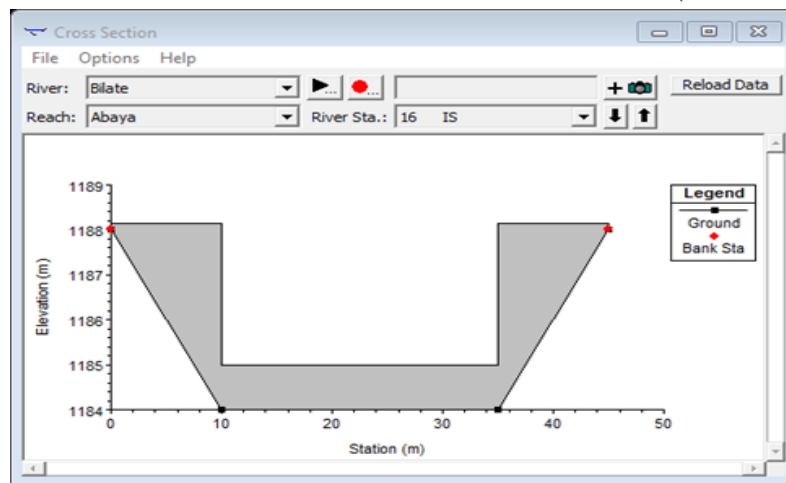


Figure 3.10: Alignment Drop Structure in HECRAS

Levee Height from Jia and Wang (1999).

The height of a dike is based on the design flood level with a required freeboard added to it.

$$\text{Levee height} = \text{Design flood level} + \text{Freeboard}$$

Levee Freeboard from Jia and Wang (1999).

The freeboard of a dike is an allowance in height and it is the function of design flood discharge shown in Table 3.11

Table 3.7: Minimum Required Freeboard for Levee Source

Design Flood Discharges (Cumecs)	Free Boards (m)
< 200	0.6
200-500	0.8
500-2000	1.0
2000-5000	1.2
5000-10,000	1.5
>10,000	2.0

Levee Crest (Jia, & Wang, 1999).

The crest width of a Levee shall be following the design flood discharge, and shall not be less than the value given in the table 3.12.

Table 3.8: Recommended Crest Width for Levee Source

Design Flood Discharges (Cumecs)	Crest width (m)
<500	3
500-2000	4
2000-5000	5
5000-10,000	6
>10,000	7

Levee Slope (Jia, & Wang, 1999).

The slope of a dike shall have a gentle gradient of 2:1 (Horizontal to Vertical) or less. The the slope is decided based on the dike's body. A gradient steeper than 2:1 is generally not preferable because of the stability conditions of the slope face.

To insert the Levee structure to HEC-RAS first define break lines along levee direction in Geometry editor in 2D Area Break lines then create a river reach and bank lines along the break line (from upstream to downstream) in RasMapper and Then add two cross-sections representing the levees in the river reach and interpolated between the two cross-sections with a spacing of 3m. Then, export the levee as a terrain. To do this, in RAS Mapper, select the

geometry you are using, right-click on Geometry and select Export Layer and then Create terrain GeoTiff from XS's (channel only) shown in Figure 3.11. The height of the Levee is computed by adding a 100-years flood level to a required freeboard (Jia, & Wang, 1999). The recommend freeboard for discharge between 200-500m³/s is 0.8. The recommend crest width for less than 500m³/s about 3m and the slope has a gentle gradient of 2:1 (Horizontal to Vertical). The average level of a 100-year flood is 1174.32m above sea level at that point that the Levee was constructed. Recommended freeboard for 338.1 Cumecs was 0.8m (Table 3.11) Top dyke height was 1175.12m above sea level. The average ground level is about 1173.14 above sea level The height of dyke above average ground level is 2m.. The length of the levee is 1.5km.

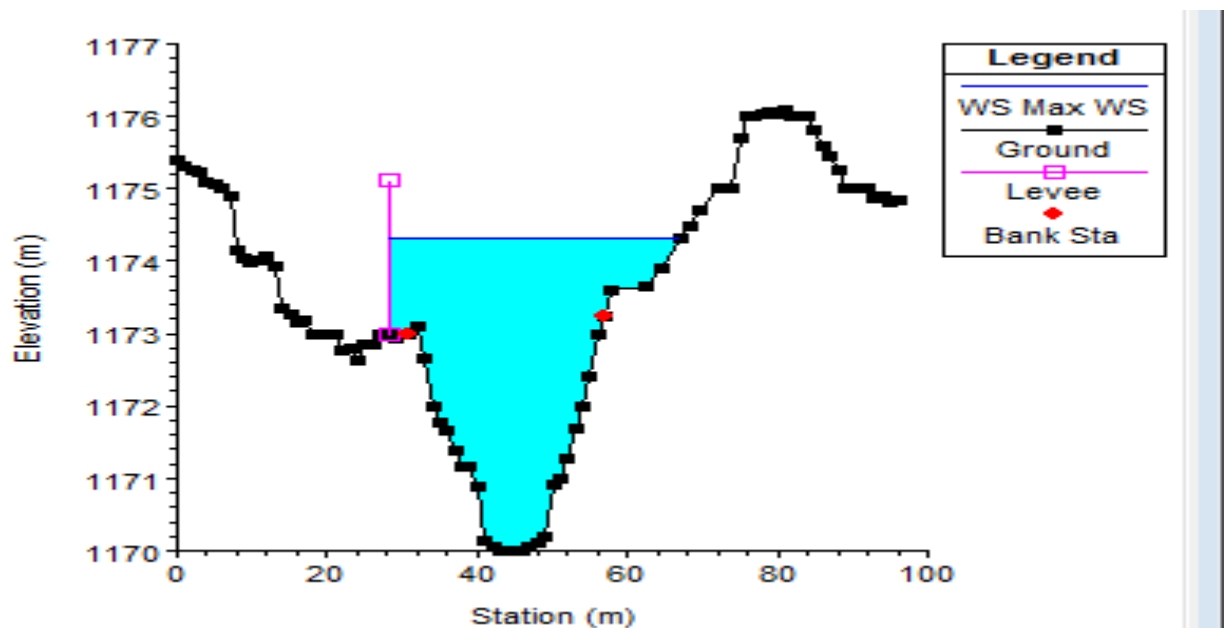


Figure 3.11: Levee Alignment in HEC-RAS

3.20. Overall Schematic Representation of River Flood Modeling

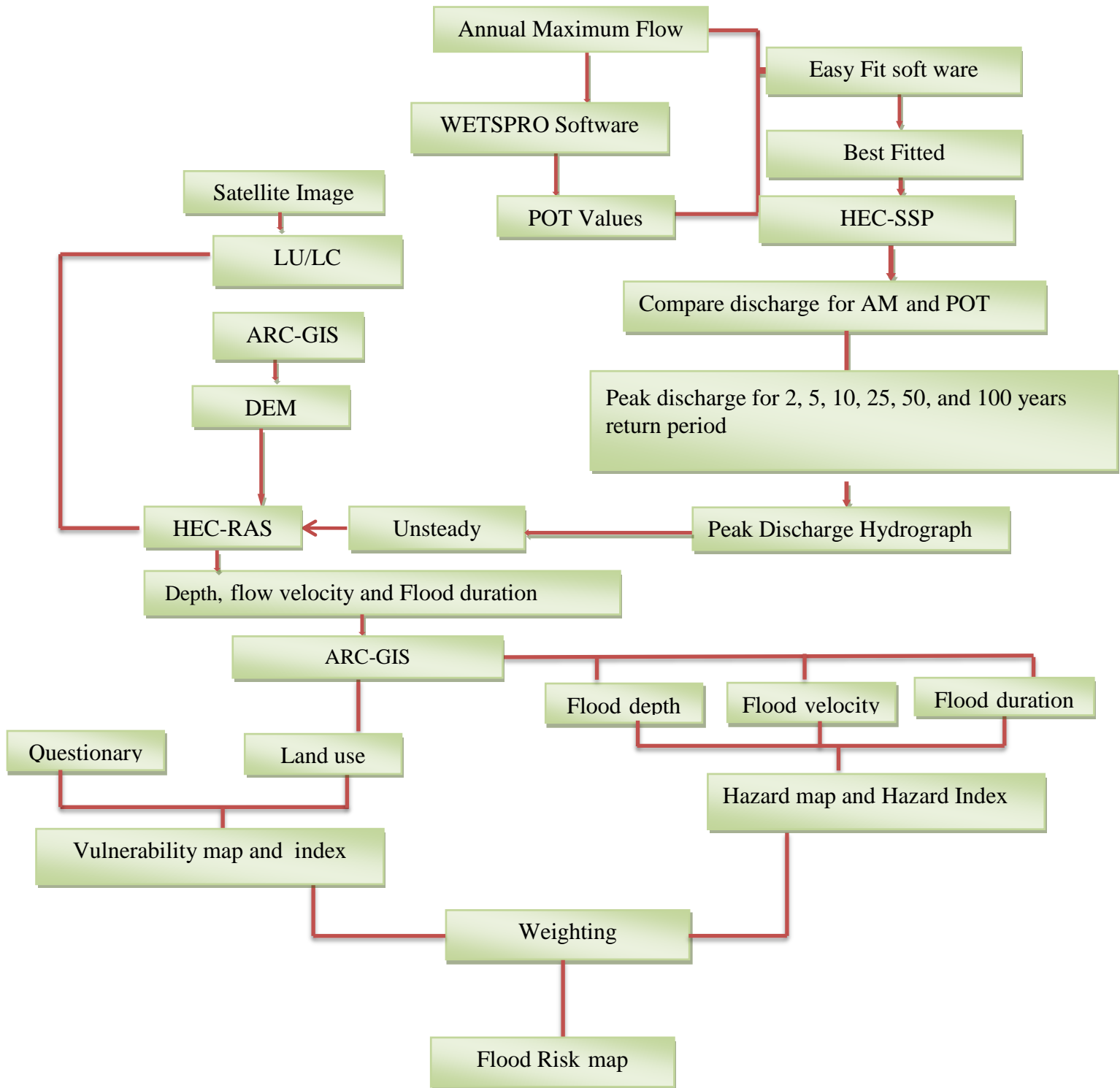


Figure 3.12: Over all view of Methodology

4. RESULTS AND DISCUSSION

4.1. Test results on hydrologic data

Before conducting flood frequency analysis, test on the hydrological data must be done in order to know the quality of the data that is used for quantile estimation. This includes homogeneity and stationery, and independency, and outlier test.

4.1.1. Homogeneity and Stationary (M-W) test

The results of the Homogeneity and Stationary (M-W) test indicated that the test value $u = 0.329$ is less than the critical value at 5% significance level, $u_{0.025} = 1.96$. Thus, we can accept the hypothesis of homogeneity and stationary of Bilate_Tena River flow data at 5% significance level.

4.1.2. Stationary and independence (W-W) test

The results of the stationary and W-W tests indicated that the test value $u=0.217$ is less than the critical value at 5% significance level, $u_{0.025} = 1.96$. Hence, we can accept the the hypothesis of independence and stationarity of Bilate_Tena River flow data at 5% significance level.

4.1.3. Outliers test

The result of the outliers test indicates that The higher and lower threshold value is $365.3\text{m}^3/\text{s}$ and $30.68\text{m}^3/\text{s}$ respectively range reported by the HEC-SSP software version 2.0. The maximum and the minimum annual maximum flow data are $283.54\text{m}^3/\text{s}$ and $40.397\text{m}^3/\text{s}$ respectively. So that there are no high and low outliers at a 10% significant level in the annual maximum flow data from 1980 to 2015 of the Bilate River at Bilate Tena streamflow gauging station.

4.2. POT model

The Pot model results indicate that Nighty five (95) POT values were found. The retained time series are in Appendix B. The present findings confirm that three or four peak flow values were extracted from each year as shown in figure 4.1. This is very important to show the normal trend of the river system. Our Result provides further evidence for Nejc *et al.* that the POT result gives a better result.

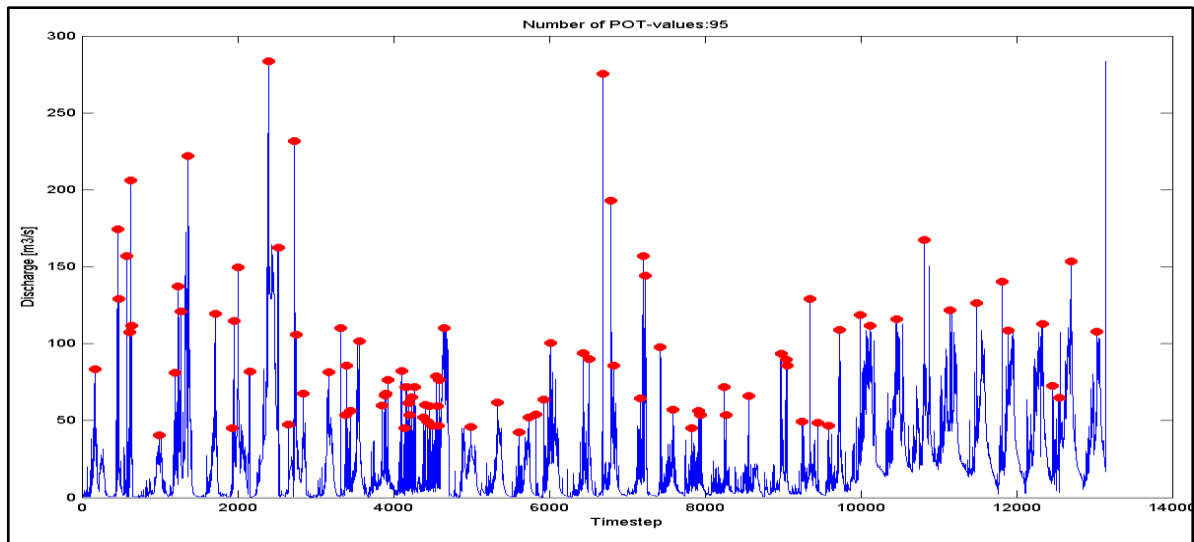


Figure 4.1: POT Values of WETSPRO. Software

4.3. Goodness of Fit Test

The results of the East-fit model show that the Extreme Value Type-I distribution is a more acceptable fit for the total of 95 POT data used shown in the Table 4.1.

Table 4.1: Rank of Probability distribution For POT values

№	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Extreme Value Type-I	0.05266	1	0.33674	1	2.8227	1
5	Log-Pearson 3	0.0569	2	0.34414	2	3.0278	2
6	Lognormal	0.05794	3	0.45852	3	7.1148	5
7	Lognormal (3P)	0.06297	4	0.49511	4	3.1217	3
4	Gumbel Max	0.0881	5	0.95936	5	5.6985	4
2	Exponential (2P)	0.11181	6	1.4542	6	37.7344	6
8	Normal	0.15084	7	3.2377	7	11.47	7
1	Exponential	0.3436	8	12.447	8	60.103	8

4.4. Extreme Value Type-I distribution

The quintile estimation in Extreme Value Type-I distribution which corresponds to different return periods was summarized in table 4.2. The retained Monthly peak discharges are in Appendix A. It shows that the peak flows are changing over time, either due to land use, stream channel deformation, or some other reasons. However, peak flows are highly variable and changed unevenly from year-to-year. On the other hand, even if flows are decreased the frequency of the flood events increases. The reason might be highly likely due to deforestation, poor agricultural practices, change of the river morphology, and population growth. This all are the causes for climate change. This scenario agree to the study of Tekle A. 2015 study of climate change in water availability of Bilate River. He concludes that the trend of water availability of Bilate River is decrease due to climate change. These problems would be managed by taking into account many controlling measures such as improved land-use policies.

Table 4.2: Quantile Estimates for Different Return Periods Based On Extreme Value Type-I Distribution

Return Periods	X _T , 1day	X _T , 3day	X _T , 5day	X _T , 7day	X _T , 9day	X _T , 11day	X _T , 13day	X _T , 15day
2	104.2	74.1	70.4	70.3	69.4	68.7	68.4	68.2
5	156.3	105.6	99.7	96.7	95.9	94.6	93.6	92.5
10	195.0	129.6	121.6	117.2	115.5	113.5	113.3	110.8
25	251.5	168.8	153.6	147.0	143.7	140.3	139.0	135.2
50	291.9	192.7	176.7	168.0	163.6	159	156.9	152.6
100	338.1	250.5	203.3	192.0	186.1	180.2	177.1	171.6

By comparing the results from Mulugeta, 2012 it is much lower than his peak discharge finding this is because of low rainfall distributions on each catchment owing to high infiltration capacity of the soil then a lower surface runoff generated. In contrary to Dawit, 2015 study it is higher peak discharge by comparing rainfall distribution and infiltration capacity of the soil of his study area.

4.5. Composite Hydrograph

Figure 4.2 shows the composite hydrographs for various return periods. The observed peak discharge in 1986, 1998, and 2005 years are $283.5\text{m}^3/\text{s}$, $275.3\text{m}^3/\text{s}$, and $167.5\text{m}^3/\text{s}$ was approximately that of the 50years, 25years, and 10years of flooding respectively. Such a variable discharge of the Bilate River indicates that future floods could occur at any time.

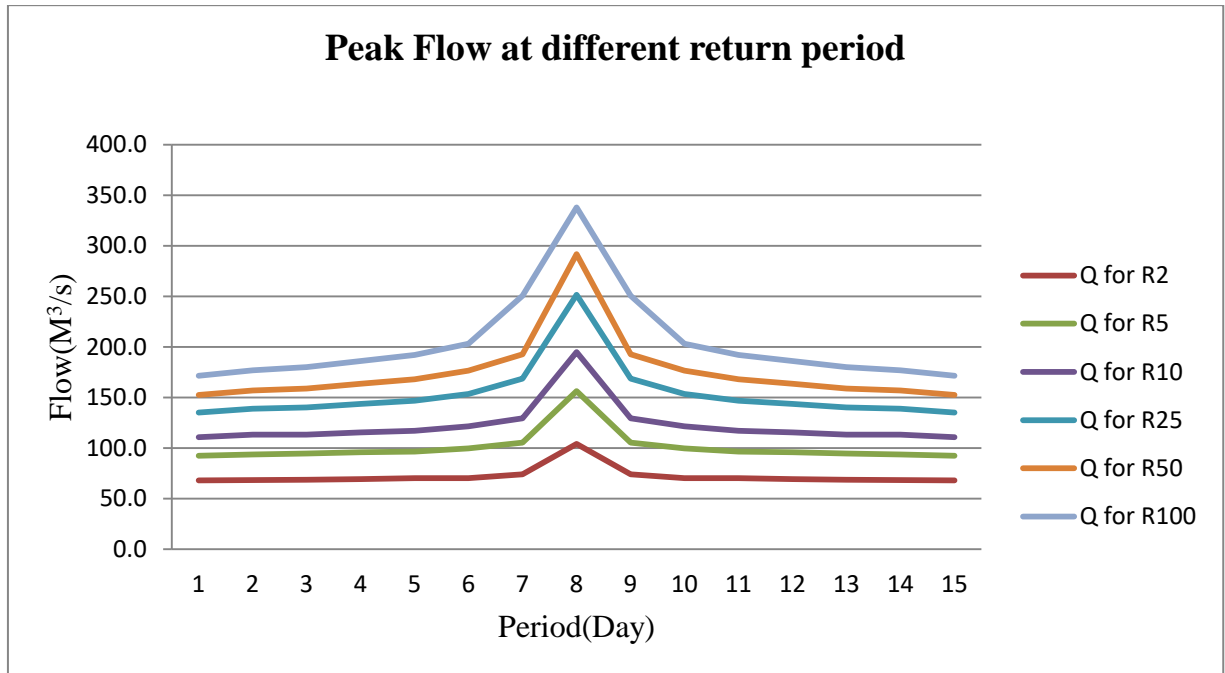


Figure 4.2: Composite Hydrograph for Return period of 2, 5, 10, 25, 50 and 100 year

When comparing these results to those of older studies that done the SWME office the peak discharge for the 50return period by SCS method is $634\text{m}^3/\text{s}$. This discharge is much higher than from my study. This is because of the SCS limitation as mentioned by the ERA drainage design manual. However, from my paper, the study area covers about 72km^2 . This area is greater than for limitation of the SCS method hence it is not an appropriate method to use in this area. Generally by considering the limitation estimation of peak discharge with flood frequency is the best method for this study area.

4.6. Flow Duration Curve

The result of FDC2.1 software indicates that the Bilate River at Bilate-Tena station was very steep as shown in Figure 4.3. which indicates a highly variable stream whose flows is largely due to the quick runoff of rainfall to the stream similarly it shows that high flows for short periods. Besides this, it indicates the low dominance of groundwater discharging to the stream

via spring or diffuse inflow along the length of the stream. A related pattern of results was similarly obtained by Norman, (2001); Dawit, (2015); Nebyiat, (2016).

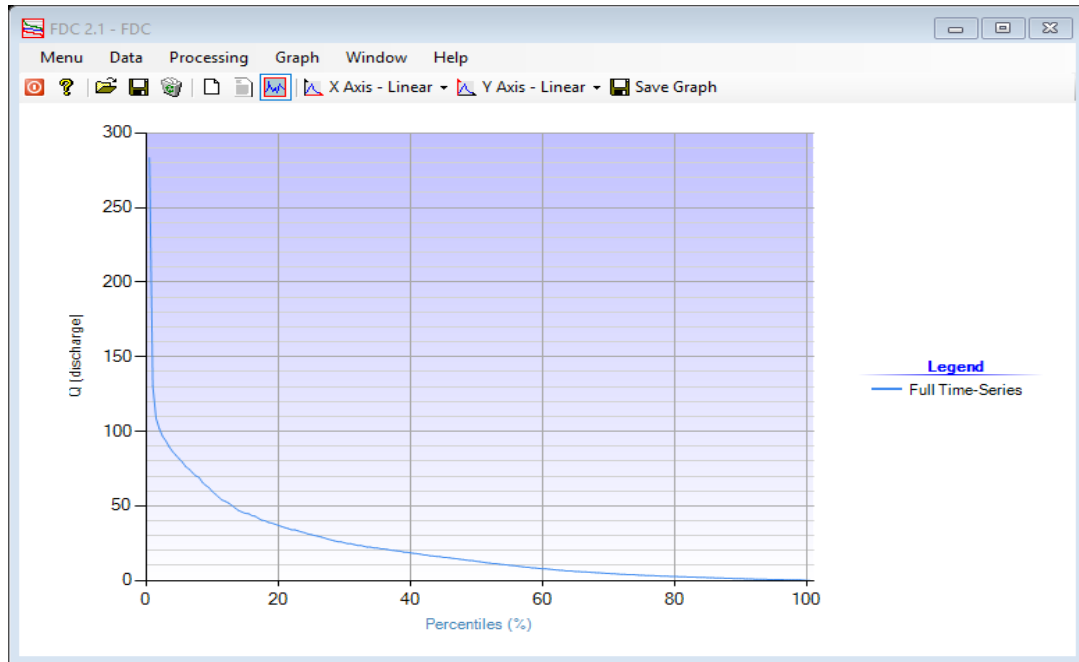


Figure 4.3: Flow Duration Curve of Bilate River at the Station

4.7. Graphical overview of Sensitivity Parameter comparisons

Figure 4.4 Shown that the sensitivity parameter of Roughness. It illustrates that Decrease in roughness parameter gives the best result on a decrease in water depths for the scenario where the Roughness coefficient has been decreased to minimum Value.

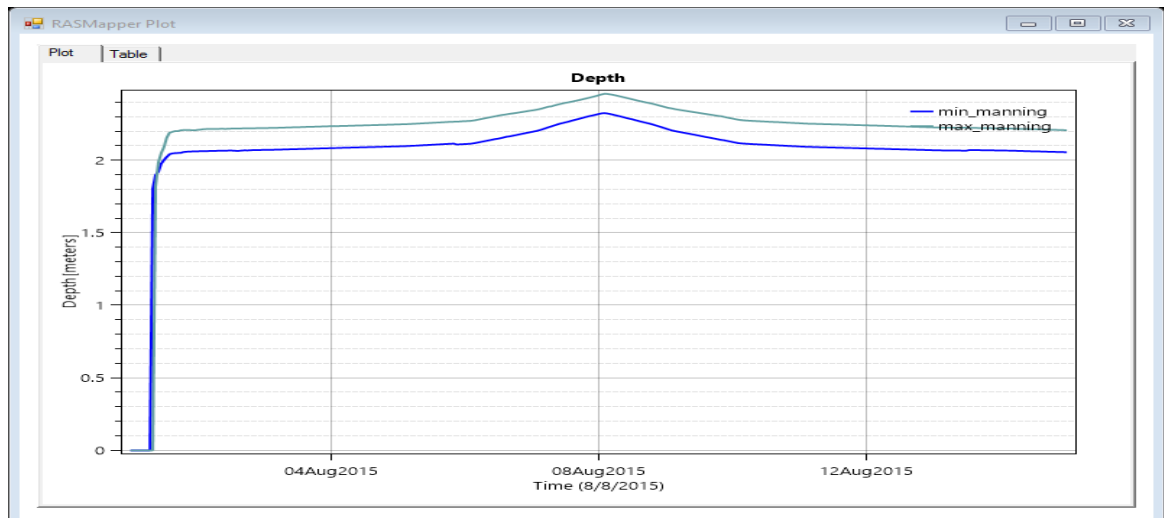


Figure 4.4: Roughness Sensitivity Test for 10years Return Period

From Figure 4.5 show that 10m*10m cell size gives a good result on the reduction of Flood depth

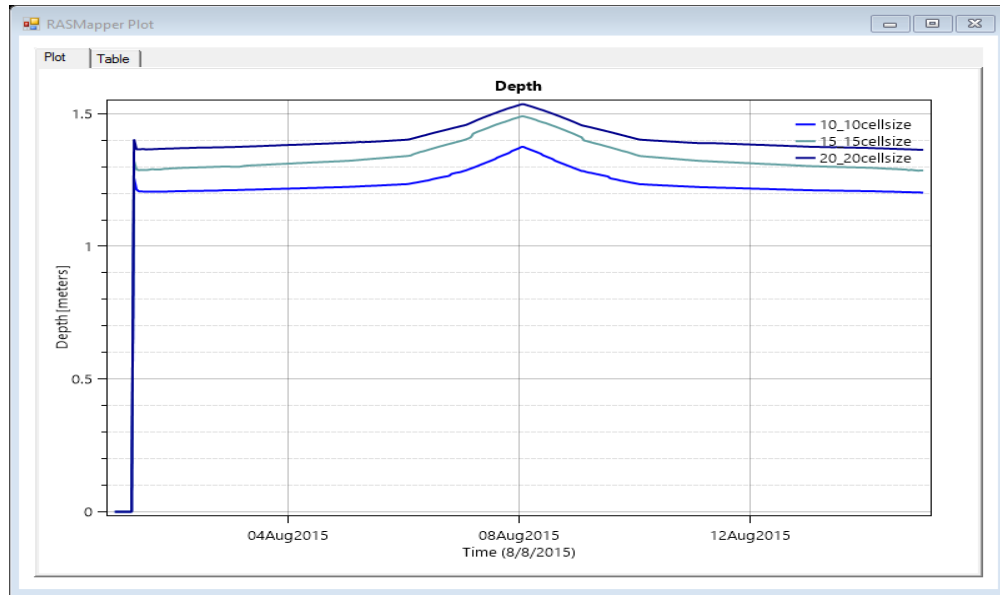


Figure 4.5: Cell Size Sensitivity Test for 10years Return Period

Moreover, Figure 4.6 illustrates that a decrease on Time step based on the courant number gives the best result.

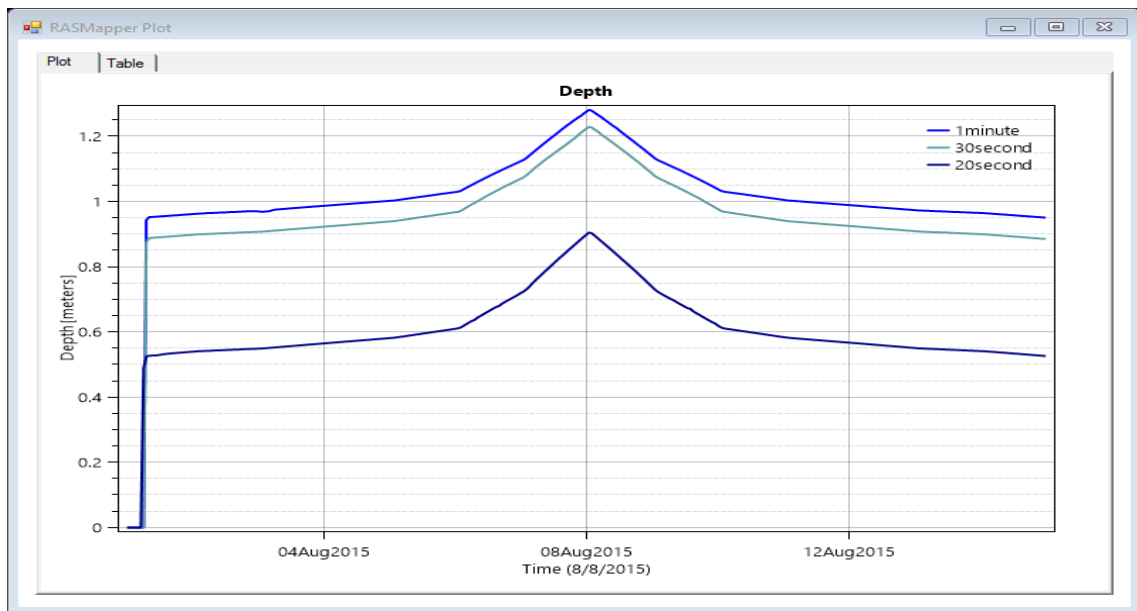


Figure 4.6: Time Step Sensitivity Test for 10years Return Period

Over all, the greater flow discharge the more sensitive to water depth changes to roughness coefficient. The most sensitivity parameter is Manning roughness due to great variation between maximum and minimum roughness when the depth is increase. Beside to this time

step and cell size have little variation on higher depth but it is not saying that time step and cell size have no impact on model result.

Furthermore, Based on the Performance of Computer and courant number 10m* 10m cell size and 20 second time step is more appropriate respectively as well as using Minimum Number of Manning Roughness for best simulation Result.

4.8. Calibration of the Model

Figure 4.7 Indicate that the observed and simulated value of water level data to check the performance of the model. It can be noticed that water surface elevation between simulation and observation is small.

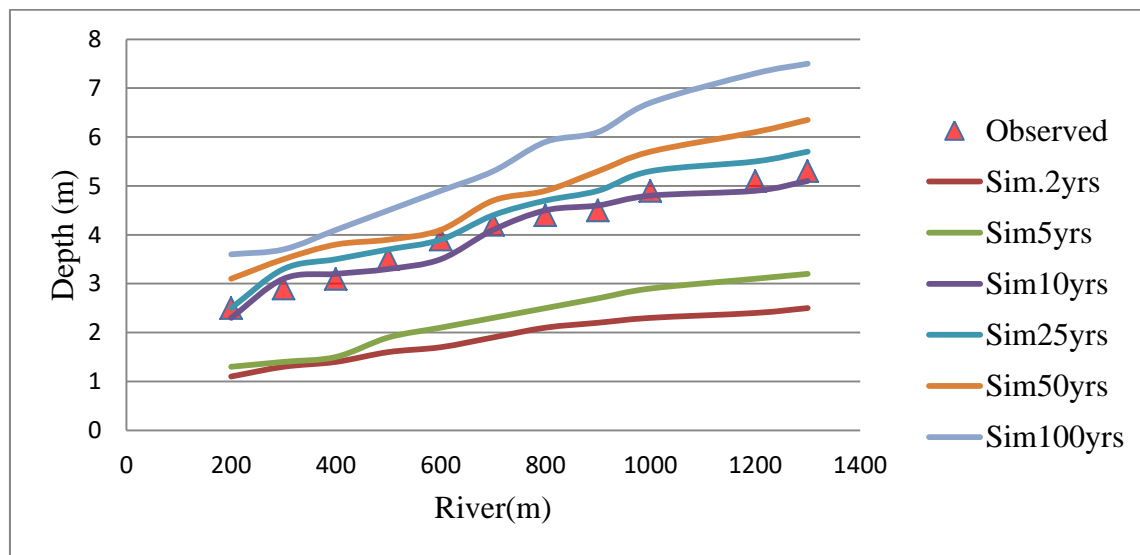


Figure 4.7: Comparison of Simulated and Observed Surface Water Level

The performances the models are shown in table 4.3.

Table 4.3: Performance of the model

Return period	NSE	RMS	Correlation Coefficient (R2)
2	-5.18	0.98	0
5	-3.1	0.76	0
10	0.95	0.07	0.92
25	0.86	0.23	0.87
50	0.74	0.34	0.78
100	0.54	0.44	0.67

As indicated on figure 4.7 and table 4.3 the best fitted simulated flooding year was 10years with acceptable value of $NSE=0.95$, $R^2= 0.92$ and RMS value approximately to 0. It indicated that good agreement between simulated 10years flood and observed depth for 2005 year. The NSE value of less than 0 indicates that the mean value is a better predictor than the simulated value which indicates unacceptable performance.

Generally, the result indicates the simulated result of 10 return year flooding agree with 2005 flood. As mentioned on section 4.5 the observed peak discharge in 2005years was approximately to that of 10 years flooding respectively. This result agree with observed with observed depth in 2005 to simulated depth in 10 years flooding.

Similar to the study by Solomon (2012) land-use types were the basis for estimating the roughness coefficients for rivers and surface in this present study found good agreement with the observed value.

The main limitation of the model is that its simulated extent covers about 7% less area than the flood from the observed field data. This difference may be caused by: the model does not consider some hydrological processes like infiltration or evaporation that could reduce the flood volume, those processes may be assumed as negligible for the purpose of the present study. Due to the low permeability of the soil (section 3.1.3.) more ever infiltration rate for dominant Vertisol (clay soil) is between 1-5mm/hr. (FAO, 2015). It is reasonable to assume that infiltration during this period is negligible. Gintamo (2014) shows that the potential evaporation is 94.2 mm/month. Correspondingly the evaporation may be assumed as negligible compared to the mean flood depth 3.8m. The total evaporation during accounts was 2.7% of the mean flood depth. Thus, it is reasonable to assume that hydrological processes of infiltration and evaporation may be assumed as negligible.

4.9. Validation of the Model Result

From the validation of 100 years simulation data with survey data where the flood usually occur in several locations as can be seen in Table 4.4 and Figure 4.8, it is showed almost the same and still included in the high range of survey results of flood depth although there are slightly different due to the level of human memory and the influence of the lack of accuracy in the measurement.

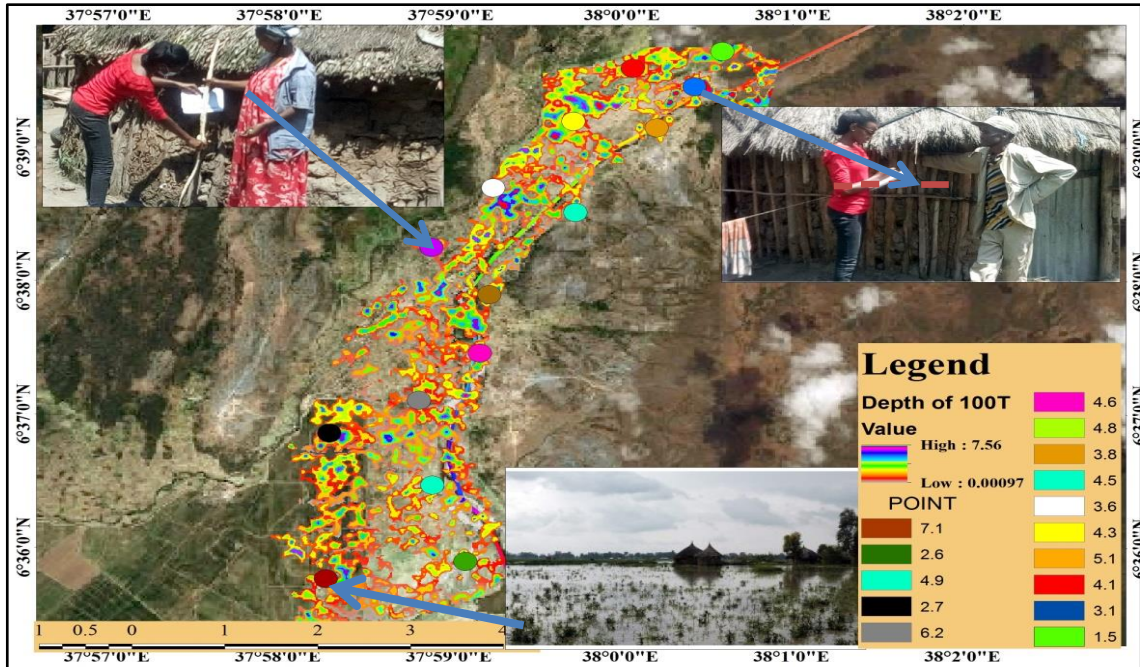


Figure 4.8: Flood Simulation for 100 Years Return Period

Table 4.4: Comparison for 100 years Return period of flood depth

No	Location		Survey Data(m)	Simulation Data(m)
	Latitude	Longitude		
1	386780.8665	729009.4	7-8	7.1
2	387892.8684	729569.1	2-3	2.6
3	387624.6307	730470.4	4-5	4.9
4	386472.3176	731511.3	2-3	2.7
5	387042.361	731703.7	6-7	6.2
6	387944.7268	732229.1	4-5	4.6
7	387404.0294	733785.6	4-5	4.8
8	388150.8174	733234.2	3-4	3.8
9	388979.6466	734426.6	4-5	4.5
10	388310.7786	734883.8	3-4	3.6
11	388753.1258	735344.9	4-5	4.3
12	389709.1237	735389.7	4-5	5.1
13	389761.1145	736397.8	3-4	4.1
14	390406.4345	735936.9	2-3	3.1
15	390584.086	736433.1	1-2	1.5

Through calibration and validation, it is concluded that the model has well represented the observed value with reasonable accuracy and confidence

4.10. Questioner's

Based on the questioner in Appendix G are reported based on three factors as Exposure, Susceptibility, and Resilience.

4.10.1. Exposure factor response

The number of sample respondents handled during the survey was 70hhs. In the survey, the total population from the surveyed sample is about 420 composed of children, young, elderly, and adult. 42.74% of the total populations are children, 4.61% are elderly and 17.14% are women. Most of the respondents were aged between 40 and 59 years (52.1%). Based on information collected it was found that those surveyed households were having agriculture croplands of about 456 ha of which the majority is very closer to the river body (less or equal to 200m). As observed during the field survey, most of the settlements (87.9%) are located near the river as the river is the main source of water in the study area approximately by averaging about 200m.

The interviewed household could recall the peak duration of flooding during the latest more severe flood was about 2-8days. Flood water levels were measured inside the house as revealed by marks on building walls concerning the ground floor during the interviews.it was a maximum of about seven-meter.

4.10.2. Susceptibility factor response

This factor indicates that before and during flood disasters. The majority of the respondents were male-headed (75.6 %) while females headed Households constituted 24.4 %. The majority of the respondents 68.9% having no schooling at all, 21.1 % attained only primary education as their highest level with. 10% had secondary level education Most of the households that is 72.90% had more than 5 members.

A total sample comprised of 420 respondents was household heads. The majority of the households interviewed (85.8 %) lived in a building made up of thatched walls with a thatched roof. Of the households, 4.2% lived in clay walls with iron/tiles sheet roof's building. The majority of households therefore lived in the type of houses that make them susceptible to floods.

The interview reveals that the main source of income for the assessed households is agriculture activities (crop production) 90% and 7.2 % of respondents who do not have agriculture as main activities have it as secondary activities.

According to the key informants (NGOs and Public institutions) that were interviewed in the field, the occurrence of flood in the area does not take the residents by surprise because even though it is a natural phenomenon, the residents know when the river may overflow and they received warning on radio and through the signposts implanted to indicate the water level. Equally, they are aware of flood-related risks in the area. The analysis shows that the majority, 94.1% is aware of the flood risks, while only 4.5% said they are not aware. A majority of the households (84.6%) said they had warnings about the threat of flood and how to handle its effects, while 13.6% said they did not have any prior warning about the impending threat of flood. During and after flood disasters, most of the households do not have any assistance from government and there is no policy to help the communities out. Each household, then, relies on itself and on their families and relatives in the non-flooded area to cope with the flood. Despite the existing anticipatory information in the study area, there is no adequate strategy to increase the population's resilience to flooding disasters. This calls to think of alternative solutions to increase the adaptive capacities of the population. According to the key informant interview, the population in vulnerable areas should firstly change their mentality to accept their relocation to a safe area; they should build strong houses and adopt appropriate agricultural practices adapted to their area and the use of short-cycle seeds to increase their resilience.

The majority of respondents (36.2%) said it takes a long time for them to recover from flood disasters, while 24.9% reported they recover quickly from flood disasters. 75.11% of respondents of the total sample said the flood had no positive effects on their household while 24.9% reported flood had some positive effects on them. Of all those who reported having the experienced positive effect of flood, 11.31% said their farmlands become more fertile after flood, 7.2 % said they experienced an increase of crop yield after the flood, 4.07% said they were able to practice garden activity after the flood because the soil becomes suitable for such activity.

4.10.3. Resilience factor response

This factor indicates that during and after flood disasters. According to the interview carried out in the scope of this study, the increase of flood hazards in the area is not only due to change in precipitation patterns causing an overflow of the river but besides to man-made actions such as: deforestation in the upstream part of the basin. Flood hazard in the study area is a natural phenomenon that was exacerbated by anthropogenic factors. Correspondingly, the area is made up of heavy soil which can decrease the floodwater infiltration capacity and increase the duration of floodwater in the area.

The majority of the respondents of the total sample (58.4%) reported they employed preparedness measures to reduce flood impact and (48%) have used reactive measures to cope during. They employed pro-active measures such as the use of short-cycle seeds (6.3%), early harvest (13.1%), preparation of evacuation place (9%), protection of food supply (5%), putting of important assets in a safe place (12.2%).

4.11. Flood inundation boundary

Flood inundation boundary map of the area for 100 years return periods are shown in Figure 4.9. The total inundated area in 100 years of flooding was found to be 988 hectares. Wholly the inundation area for 2, 5, 10, 25, 50 and 100 return period was 674, 726, 751, 783, 845.68, and 998 ha respectively.

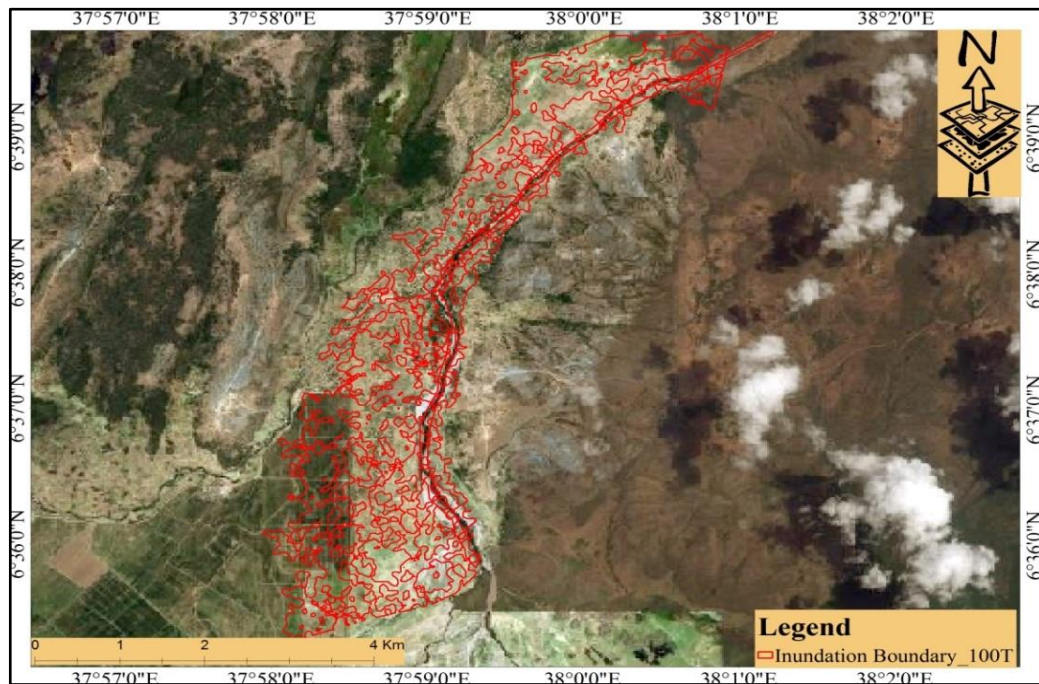


Figure 4.9: Flood Inundation Boundary of 100T

When the simulated result is studied critically, it can be found that the flood polygon shows some discontinuity in some areas. This is because these areas have steep river beds which cause water to move quickly downstream preventing inundation. Furthermore, some of the areas have high banks which serve as an impedance to overflow.

Here, comparing the results of the Flood inundation boundary with those of the previous study done by Mulugeta in 2015 in Horosha River. The inundation area for the Horosha river in Fogera Flood Plain mapped by Mulugeta in 2017 (The area of flooding for 5, 10, 25, 50, and 100 years was reported as 84.6ha, 86.1ha, 86.9ha, 87.1ha, 87.7ha) it is much lower than Bilate river in Abela-Abaya flood plain this is because of the infiltration capacity of the soil is high as compared to Abela-Abaya flood plain. The other cause for this result the surface condition of Abela-Abaya flood plain was impervious and most of the precipitation changed to surface runoff.

4.12. Flood Hazard Analysis

For each scenario, the water depth, flow velocity, and Duration have to be represented on the maps. Each Hazard map was prepared for 100years flood and Flood depths for each return period were illustrated in Appendix D for other flood scenarios (2, 5, 10, 25, 50, and 100 years).

4.12.1. Flood Hazard map using Flood depth

Based on the guidelines in the flood-plain development manual (NSWG, 1986) these three critical values of flood depth (D) of hazards were classified as low ($D < 0.5$ m), medium ($0.5 \text{ m} < D < 1.5$ m), high ($1.5 \text{ m} < D < 3.0$ m) and very high ($3.0 \text{ m} < D$) shown on figure 4.10.

The maximum flood inundation depth for 2, 5, 10, 25, 50, and 100 years return periods are 2.49m, 3.21m, 5.15m, 5.78m, 6.35m, and 7.56m respectively. The inundation depth map for 100years flood (Figure 4.10) The Percentage of flooding area 10.2%, 14.7%, 68% and 7.1% for depth categories under or equal to 0.5m, 0.5m-1.5m, 1.5m-2.5m and above 2.5m respectively.

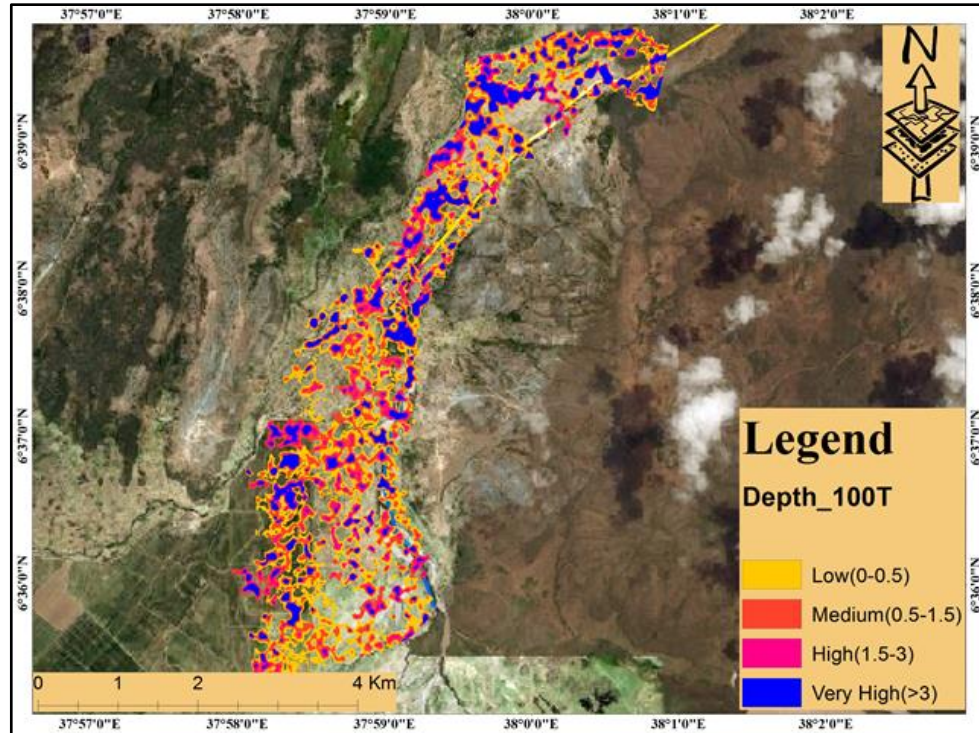


Figure 4.10: 100years Flood Depth

In General, the flooding depth under 0.5m, the level of flooding impact will be not much for rural buildings as well as for humans. Most of the rural buildings are slightly affected by in range from 0.5m-1.5m of depth, while some of the other areas have a higher impact for 1.5m-3.0m similarly it affects some crop types that have a short height. The area which has flooding above 3.0m is agricultural land. Generally, high water depth occurred along the main channel and spreads gradually to the floodplains. The river flows in between slightly hilly terrain and, as such, rainwater uphill flows rapidly into the river channel. Moreover, higher flood depths generally cause more fatalities and pose serious threats to the settlement and agriculture along the river.

4.12.2. Flood Hazard map using Depth and velocity

To identify the potential danger or hazard associated with the flood, flood hazard maps were derived taking into account the depth and velocity of the floodwaters Shown in figure 4.11.

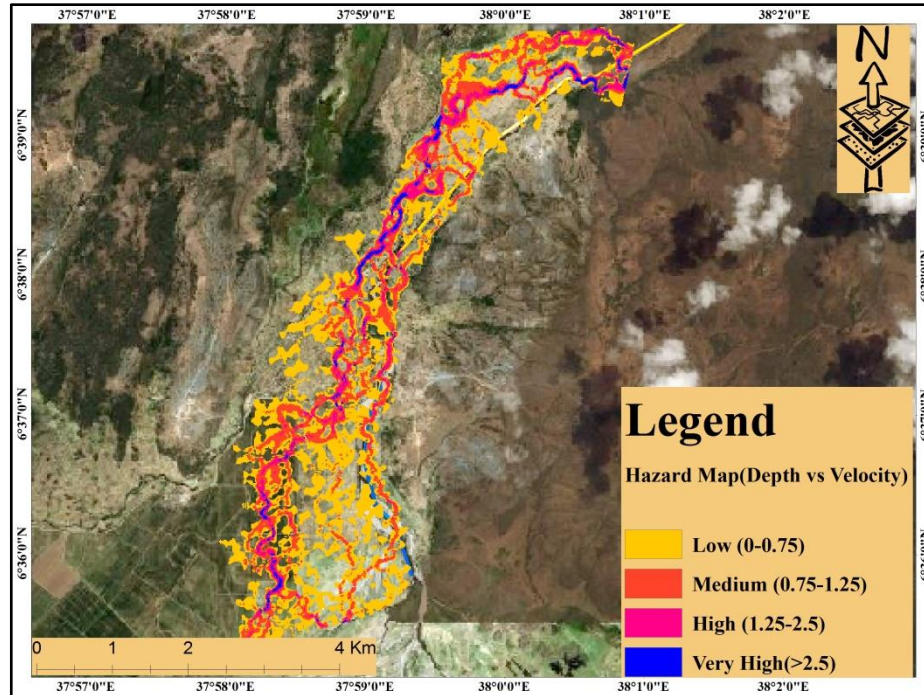


Figure 4.11: Flood Hazard map (Depth and Velocity)

The maximum flood velocity for of 2, 5, 10, 25, 50 and 100 years return period's are 1.01, 1.10, 1.21, 1.42, 1.54 and 2.25 m/s respectively (Appendix D). The velocity of flood is very strong. There is no measurement to check velocity accuracy consequently according to interview the velocity of flood is fast when it can wash away goats, chicken and peoples could not swim.

The simulation produced variable flow velocities in the main channel and the inundated floodplain. Generally, high velocities were recorded in the main channel than the floodplains. Furthermore, due to high variability in the velocity of the river from upper to lower, greater overflow of the river occurs along the lower reach than along the upper reach, causing an extensive inundation of the region around the lower (Figure 4.11).

As compared this result to Berhanu's finding in 2019 on Akaki catchment his result in Depth and velocity is much higher than my study this is because of the high values at the upstream can be accredited to the steep slope of the terrain whiles the low velocities at the downstream is attributed to the flatness of the terrain. This indicates that the Akaki catchment is steeper in upstream and more flat in the downstream area than Abela- Abaya flood plain.

Generally, The Hazard map indicates that has a higher velocity concerning depth although it lies between high and very High Scenarios.

4.12.3. Flood Hazard map using Depth and Duration

The results of all case studies were examined carefully to determine the best combination of the hazard index value for depth and duration of flooding. The results of each case study were checked for consistency in different hazard zones and with other case studies. As described in the methodology part the four case results are Case 1 has the area under medium to high hazard level equal to 65% (Figure 4.12) which is very close to the actual flooding depth area of medium to high flooding area.

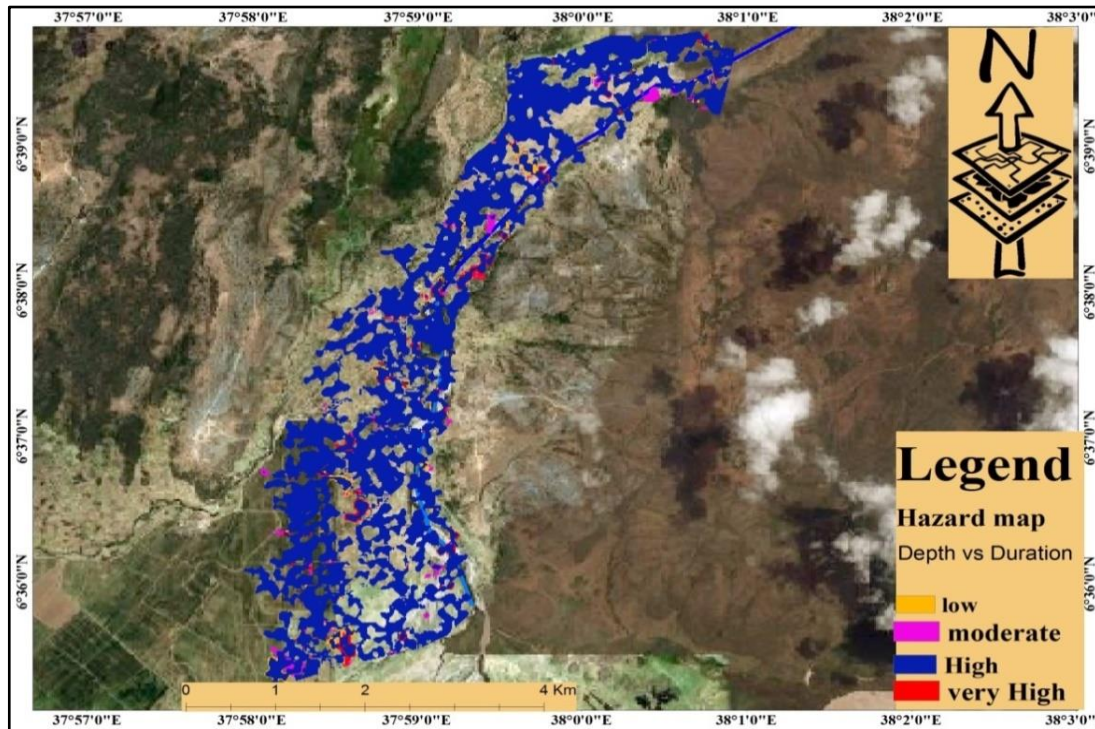


Figure 4.12: Flood Hazard Map (Depth and Duration)

In the case of 2, 3, and 4 the area under medium to high hazard level is 45.7%, 40.2%, and 16.8% respectively.

The output of HECRAS indicates for the maximum Duration is 1.5, 2, 3.3, 5, 5.8, 6.5 days in 2, 5, 10, 25, 50, and 100 years of the return period.

Figure 4.12 shows the hazard map of the study area, which was classified into five hazard zones based on Case-1. The figure shows that the about 61% of area are under high ranges it means that longer duration with higher depth which have lower elevation. This mainly damages the agriculture area when the duration days are long.

The present findings confirm (Figure 4.12) that most of them are in long-range greater than 5 days about 65% concerning depth. This mainly damages the agriculture area when the duration days are long.

Generally, the prediction of flood Hazard in the floodplain gives a good indication and significant information ahead. This helps considerably to prepare and to take action before the actual flood occurred to reduce the consequences due to flooding.

4.13. Flood Vulnerability Analysis

Using the inundation depth (Figure 4.10), the stage-damage curve (Figure 4.13) and Below the three factors from Questioner report crops vulnerability maps and rural Settlement for 100 return periods of the flood were constructed, as shown in Figure 4.14 and Figure 4.15 respectively.

4.13.1. Exposure factor

Based on Six (6) indicators of Exposure factor of the most exposed area has the highest scores for most of the considered indicators under the elements at risk compared to the other villages: high population and farmland in the flooded area, high percentage of women, and children and elderly in the flooded area shown in Appendix E. By considering the composite index of exposure factor classify the normalized exposure factor in three scenarios. This are (0-0.2221) Low, (0.2221-0.342) medium and (0.342-1) High.

4.13.2. Susceptibility Factor

As shown on Appendix E the Six (6) indicators of Susceptibility Factor indicates that The most susceptible area have the highest scores for most of the considered indicators: high female-headed household, low education level, limited livelihood strategies, high household size, low coping capability, and low access to emergency service. By considering the composite index of the susceptibility factor classifies the normalized Susceptibility factor in three scenarios. These are (0-0.2154) low, (0.2154-0.458) medium and (0.458-1) high.

4.13.3. Resilience Factor

The Six (6) indicators of Resilience Factor shown on Appendix E illustrates that The least resilient villages have the lowest scores for most of the considered indicators: Low knowledge on warning system, low evacuation capability, low recovery capacity Appendix F. By considering the composite index of resilience factor classify the normalized Susceptibility

factor in three scenarios. These are (0-0.2154) Low, (0.2154-0.5636) Medium and (0.5636-1) High.

Over the entire Vulnerability, the index was done for the Crop and Settlement area based on this study aim. Using the factor value above and inundation boundary map (figure 4.9) the crop vulnerability maps for 100 return periods of the flood were constructed as shown in Figure 4.13.

In the crop vulnerability mapping, the flood depths were divided into four scales low ($D < 0.5$ m), medium ($0.5 \text{ m} < D < 1.5$ m), high ($1.5 \text{ m} < D < 3.0$ m) and very high ($3.0 \text{ m} < D$) and their respective vulnerability is: (0-0.2153) in low range of vulnerability, (0.2153-0.4457) moderate, (0.4457-0.619) High, (0.619-1) Very high.

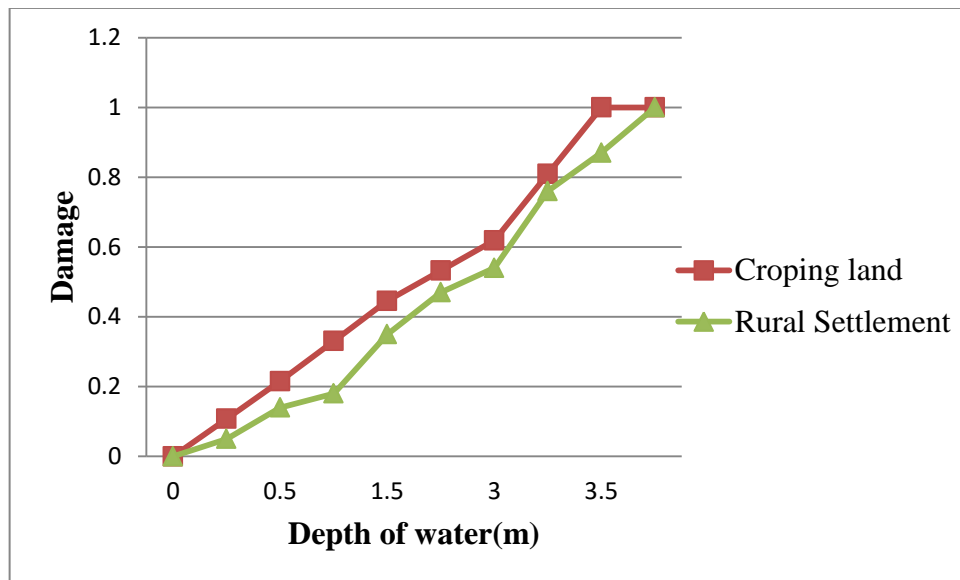


Figure 4.12: Flood damage vulnerability (depth–damage function) of cropping land and rural settlement

From Figure 4.14, it is found that crop vulnerability in Abaya-Guricho about 61% is in range of medium, high, and very high Vulnerability. These areas are close to the rivers (Figure 4.14), and further generally laying at low elevations. On the other hand 39% of the total cropping land area (in Abaya-Chokare) is “low” to “medium-high” vulnerable to a 100-year flood. Most of these areas tended to be further away from the high drainage density areas. Significantly, the results in Figure 4.14 depict the fact that the cropping land in Guricho study site is much more vulnerable to flood than any other area of the study site. This is due to the fact that the Abaya-Guricho is very close to the Bilate River (Figure 4.14). However, one

might argue with different varieties of the crop as crop vulnerability can differ from one variety to another variety (Cutter 1996). This is probably a scope of further study in the future.

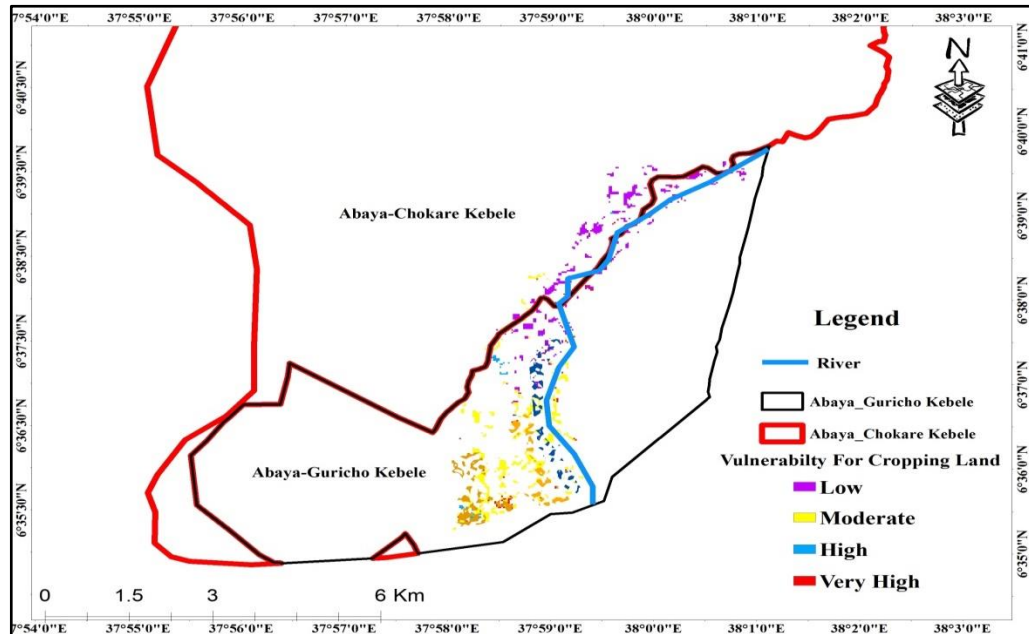


Figure 4.13: Vulnerability for Crop Land

Rural settlement vulnerability maps for different return periods of the flood were constructed, as shown in Figure 4.15. The rural settlement vulnerability map, the flood depths were divided into four scales low ($D < 0.5$ m), medium ($0.5 \text{ m} < D < 1.5$ m), high ($1.5 \text{ m} < D < 3.0$ m) and very high ($3.0 \text{ m} < D$) and their respective vulnerability is: (0-0.2153) in low range of vulnerability, (0.2153-0.4457) moderate, (0.4457-0.619) High, (0.619-1) Very high.

The result of the vulnerability map for rural settlement showing in Figure 4.15 depicts that rural settlement vulnerability increases in Abaya-Guricho. This indicates that more settlements near to the river are in Abaya-Guricho than Abaya-Chokare flood plain.

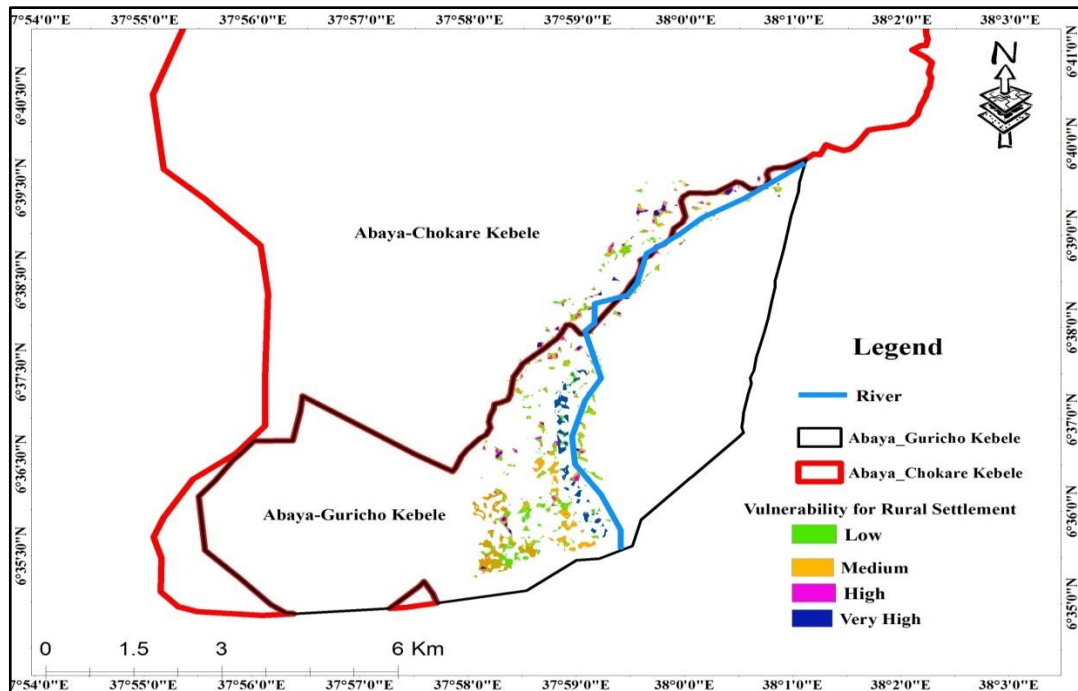


Figure 4.14: Vulnerability for Rural Settlement

The number of vulnerable and population number are increased when the return period is increased as shown in table 4.5. As shown in figure 4.9 (Section4.10), Most of the settlements are near to river channel. This causes a high vulnerability of the human settlement and agricultural land which must be properly managed to minimize loss.

This is because of flatness of the study area this leads the inundation to take several weeks and to have a farmer’s uncomfortable life during inundation time

Table 4.5: Number of Vulnerable houses and exposed population number

Return Period	2	5	10	25	50	100
No. vulnerable houses	15	17	21	30	39	70
No. of vulnerable population (6 per house)	60	102	126	180	234	420

4.14. Flood Risk Analysis

Based on the objective of this thesis the risk analysis mainly focuses on Agricultural land and rural settlement areas as described in table 4.6. It indicates that flood in 100return period depth and LULC.

Table 4.6: Flood Risk Classifications

Depth of flood(m)	Cultivation land(ha)	Settlement area(ha)
<0.5	56.8	11.7
0.5-1.5	156.8	31.5
1.5-3.0	279.8	78.9
>3.0	37.4	11.9
Total	530.8	134

Most of the settlement areas are in the range of 1.5-3.0m. According to the interview the foundation level above the mean sea level was 1-1.5 above ground surface for the reason that most risky for rural settlements areas are near to river channel. Besides this 279.8ha of agricultural land are in the range of 1.5-3m depth. This mainly affects annual crop type because of the growing height in average about a maximum of 2m.

Table 4.7 presents Agriculture Area Affected By Inundation Level for each return period.

It demonstrates that for depth 1.5m-2.5m Annual crop gets more damage to about 56.67ha and 98.67ha for 2years and 100years flooding respectively as well as more than 2.5m depth about 26.67ha fully damage the above crop type.

Table 4.7: Agriculture Area Affected By Inundation Level

Flood year	Crop Type	Area affected by inundation level				Total area(ha)
		<0.5m	0.5m-1.5m	1.5m-3.0m	>3.0m	
2	Annual crop	15.89	36.1	112.82	9.89	174.7
	Perennial crop	2.88	3.2	21.84	0.58	28.5
5	Annual crop	14.67	40.6	148.43	11.1	214.8
	Perennial crop	2.99	0.9	38.01	0.2	42.1
10	Annual crop	15.67	42.67	240.98	12.38	311.7
	Perennial crop	0.56	0.93	31.34	0.17	33
25	Annual crop	9.67	45.98	321.41	12.14	389.2
	Perennial crop	0.2	0.76	18.46	1.78	21.2
50	Annual crop	5.78	47.87	353.19	15.86	422.7
	Perennial crop	0.45	0.59	25.78	1.28	28.1
100	Annual crop	52.7	152.4	257.4	28.9	491.4
	Perennial crop	4.1	4.4	22.4	8.5	39.4

The major damage was in annual crop due to height of crop before harvesting. When considering Annual crop such as Corn its Height is 1.5m-3.0m in average and maximum duration can survive being underwater up to 36hour-48hour. From the results, it is clear that the corn plant gets fully damage in 100 return periods because its height and ability to survive underwater is much less than of 100years of flooding depth and duration. Furthermore Sorghum grows 60-120cm this crop type easily damaged in 2years flooding.

More ever, for perennial crop such as Cassava the damage due to depth is not much but duration of flood high depth affect the root because it cannot hold up very long against water up to 5 days (Tan, 1984).

Consequently, the extent of flood damage would be higher in the left portion than any other portion of the study site. Note that, this proposition is true for the same flood, in terms of intensity and exceedance probability. However, one might argue with different varieties of the crop as crop damage can differ from one variety to another variety (Dawit, 2015). This is probably a scope of further study in the future.

The estimated crop loss due to flooding for different return periods is indicated in Table 4.8

Table 4.8: Estimated Crop Loss Due To Flooding

№	Crop	Aver.	%of coverage	Return Period					
				2yrs	5yrs	10yrs	25yrs	50yrs	100yrs
				Flood inundated area(ha)					
				674.37	726.45	751.62	782.57	803.68	998
1	Sorghum	32	50	10789.92	11623.2	12025.9	12521.1	12858.9	12858.9
2	Corn	56	20	7552.944	8136.24	8418.14	8764.78	9001.22	9001.22
4	Teff	19	10	1281.303	2760.51	1428.08	1486.88	1526.99	1526.99
Total crop loss(Quintal)				19624.167	22520	21872.1	22772.8	23387.1	23387.1

Our results demonstrated that the total crop loss for 100years flooding is 23387.1 quintal. These indicate that the cause of flood in crop goes to Scarcity as well as it financial crises. Flood events with long return periods have a small probability of occurrence but their magnitude and adverse effects on the crop are very high. Flood with a short return period occurs frequently and may result in repeated damage to the crop. Consequently, this flood lead lost the crop due to on wet season from June to November.

This study found much higher values for crop loss with respect to those reported by Dawit (2015). He found that the total crop loss for 100years was 52,966.25 quintal. This is much higher than this study since, soil type of the study area. It is mainly chromic cambisoils and Pellic Vertisols. According to According to FAO (1988) this soil is less content of clay than

Abela Abaya flood plain soil. It is dominant with Ferric and chermic Vertisol. moreover, they are characterized by their high clay content and saturated soon also have water holding capacity but poor in permeability this means that it have low infiltration capacity. Vertisols have great agricultural potential, but special management practices are required.

Table 4.9 shows the damage cost for 2 and 100return periods (for 2019yield and 2019 prices).

Table 4.9: Damage Cost for 2 and 100return Period

Flood	Crop	Crop Loss\ (Quintal)	Cost per Quintal(\$)	Damage cost(\$)
2	Sorghum	10789.92	30.77	332005.8384
	Corn	7552.944	36.9	278703.6336
	Teff	1281.303	113.8	145812.2814
	Total Damage cost			756521.7534
100	Sorghum	12858.88	30.77	395667.7376
	Corn	9001.216	36.9	332144.8704
	Teff	1526.992	113.8	173771.6896
	Total Damage cost			901584.2976

As expected the 100year flood caused the greater total damage loss to Sorghum production to 395667.7\$ as shown in table 4.9 due to inundated the greatest area and it impacted the larger yielding.

The lack of detailed DEMs can be considered as one but not the only key factor of the limited flood risk analysis. Apart from the lack of DEMs for flood hazard analysis, the poor quality or limited availability of flow data must be kept in mind. Furthermore, the analysis of the risk exposure and vulnerability components, which are closely linked to the availability of social data, is also highly compromised by the absence of systematic and quality social data.

4.15. Flood Risk map

In Figure 4.16 The result of the risk map, as shown above, the most flooded risky areas are found in near river channel represented by yellow colors and some on the red color and further generally laying at low elevations (Elevation map-Fig3.1). These areas similarly the most victims of flood hazards and are characterized by cultivation land and population area

compared to adjacent flooded areas. Based on flood hazard and vulnerability indicators the risk levels were identified is shown in Appendix F. Risk level identified as risk values from 0-0.0952 as very low, 0.0952-0.232 as low, 0.232 -0.5080 as moderate, 0.5080 -0.740 as high, and 0.740 -1 as very high

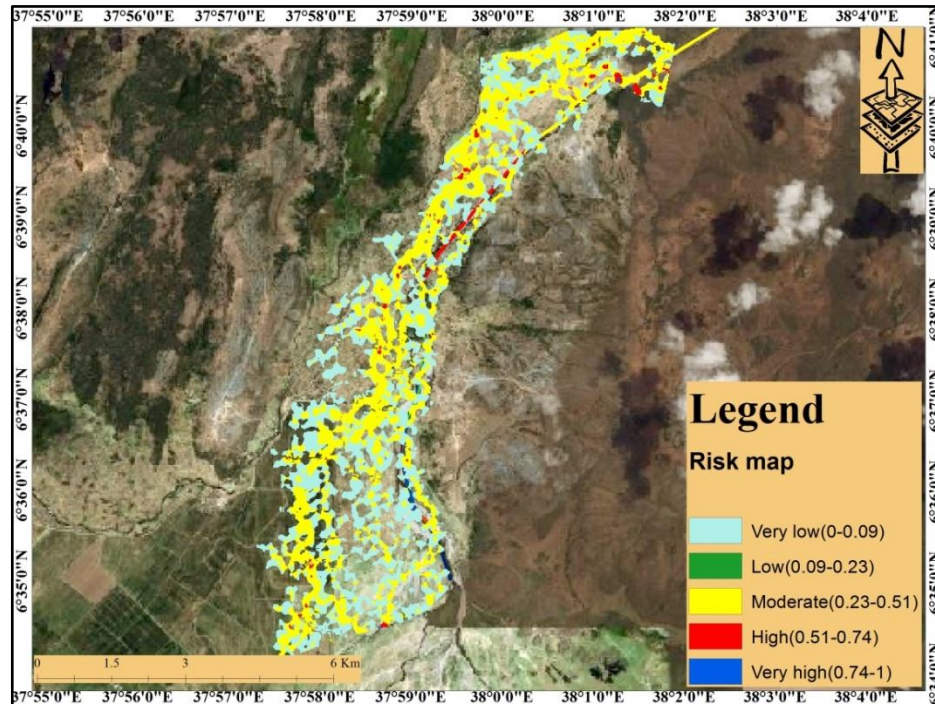


Figure 4.15: Flood Risk Map of 100 Years Return Period

The Left portion of the study area has depression (Elevation map-Fig. 3.1), and this is probably the main reason for which the area is under flood risk at all levels of floods. Furthermore, the Bilate River at the left is responsible for the area to be flooded at all level of floods. The drainage density in the upper portion of the study area is relatively higher (Fig. 3.1), thus increasing the flood risk level for getting high risk in the respective area.

According to Ayele *et al.*, (2020) sediments deposited in in Bilate rivers have changed the rivers gradient, cross sectional area, average velocity of water flow and discharge of rivers. Hence overflow of rivers occurred and flooded the local communities. The cross sectional area of Bilate rivers is decreasing from time to time as a result of sediment deposition.

Over all the river channels depth and width decreased and the water discharging capacity of the Bilate River and their tributaries minimized in which it leads to overflow of water and flooding consecutively. All this indicates that the rate of erosion and soil loss in the upstream is high due to lack of abstraction flood water abstraction.

4.16. Flood Protection Structures

The potential risks could be reduced by devising flood protection works such as Levee. The levee is constructed to prevent encroachment of floodwaters for 50 and 100return period. Figure 4.17 Shows the results of HEC-RAS by including the Levee structure.

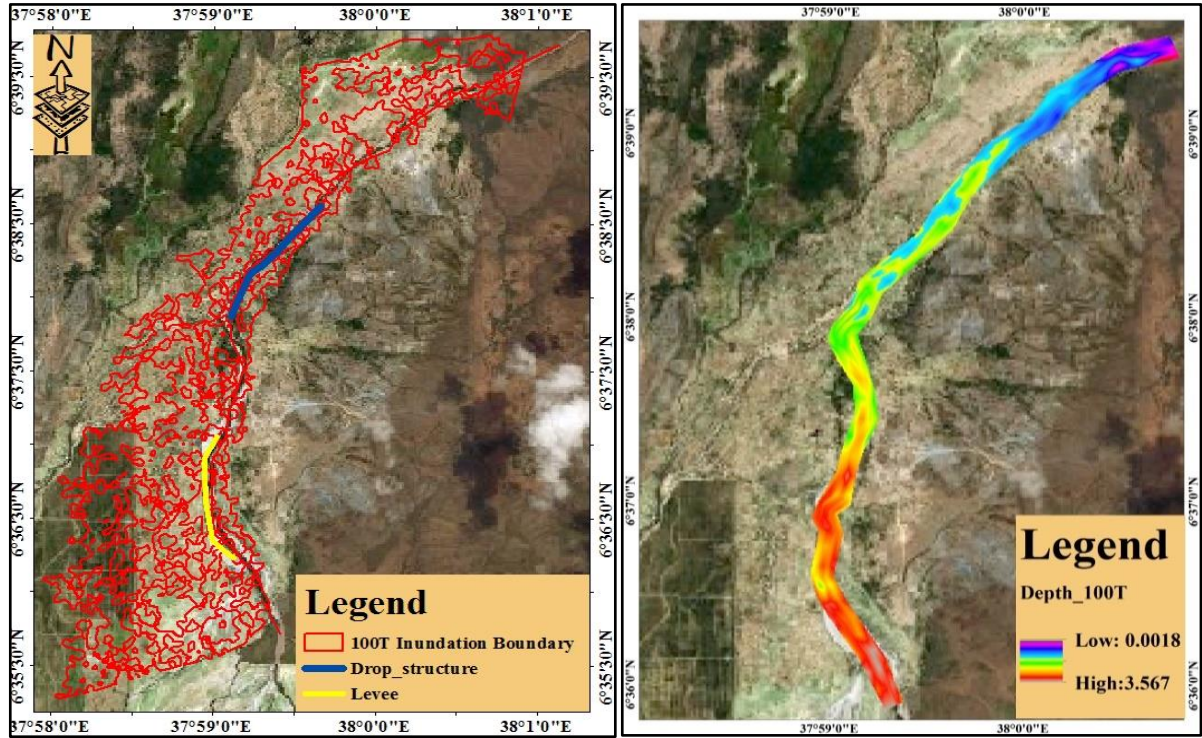


Figure 4.16: (A) Alignment of structure and (B) Depth of 100T after using structural measure. The map illustrates that using structural measures is the best method in the reduction of the impact of the flood. Figure 4.18(B) shows that the maximum depth of 100years flooding is decreased to 3.567m as compared to the depth of 100years flooding without structural measure (section 4.8). The inundation area for 100years flooding with the structural measure is about 256ha when compare this to the inundation area without using structural measure it prevents 742ha from impact.

Besides this structural measure to reduce the impact of flooding on agricultural land by Improving the soil conditions, Land treatment measures modify floods by increasing infiltration and decreasing the amount and rate of runoff. These measures may also be viewed as modifying susceptibility to flooding damage. They include vegetative cover, terraces, and cropping management practices.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study was conducted in the district of Abela-Abaya. This study covered the villages of Abaya-Chokore and Abaya-Gurichu. The main objective of the study was to analyse the effect of flood risk of the Bilate River in the Abela-Abaya district mainly on the agricultural area and rural settlements. The major tools/models used in this study are two-dimensional numerical models of HEC-RAS with the application of unsteady flow models and ArcGIS. The implications of these findings could help Area officials, emergency managers, policymakers and residents for planning an emergency response and to identify flood zones.

The peak flow for the computed inflow hydrograph by using HEC-SSP software after the analysis of Extreme Value Type-I distribution was 104.2, 156.3, 195, 251.5, 291.9, and 338 m³/s for 2, 5, 10, 25, 50, and 100-years return periods respectively.

The study also assessed flood hazards by using parameters like flood depth and flood velocity with relation to the return period of floods as well as flood duration for knowing the risk on cultivation land. The areal extent of the flood due to river flooding for 100 years return period was found 998 hectares with maximum flood depth of 7.56m and with a maximum velocity of 2m/s. The examination of the floodwater depth shows that most of the areas under flooding have water depth between 1.7m and 2.7m.

The bases for determining flood risk maps are the vulnerability index using different indicators and Hazard index. Most of the area of flood plain indicates that under medium and high-risk ranges. The estimated crop loss for 100Years flooding is 23387 quintals which have 901584.2976\$ damage cost. This goes to economic crises. Generally, the relationship between the flood area and flood magnitude indicates that there is a relative rate of increase in the flood area with the increase in the flood.

Finally, it cannot possible to avoid flood Hazard because it is part of nature, but it can be reducing the risk and minimize the harm caused by flooding. Based on the inundation area and risk map was levee and drop structure were proposed as a structural measure with its preliminary alignment which would reduce the flood risk and flood areal extent additional to this Land management practice is most appropriate.

5.2. Recommendations

In order to minimize the amount of flood damage, the following recommendations were forwarded:

- ✓ Flow measuring stations must be measured accurately in flood events.
- ✓ Government, Researchers and Experts must work together with the local community on flood management agenda that reflect the need of all society it means that it converts the Top-down approach.
- ✓ Appropriate land use planning and soil conservation practice should be carried out in the upper catchment in order to reduce the magnitude of flood, sediment transport, and siltation plus for regulated discharge of water at downstream area.
- ✓ Area officials and emergency managers should take mitigation measures by constructing suitable structures across river at left side,
- ✓ Researchers also should give special attention to flood risk analysis on the Bilate River in the Abela-Abaya district by using different damage assessing models.

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APPENDICES

Appendix A: Maximum Monthly Stream Flow Data at Bilate River

Year	Jan	Feb	Mar	April	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual max(m3/s)
1980	2.3	4.9	19.9	45.1	83.4	38.2	42.0	31.4	23.5	28.2	4.4	1.1	83.4
1981	0.7	1.7	12.5	23.9	32.7	128.9	156.9	206.0	81.0	33.9	0.5	1.6	206.0
1982	1.4	4.2	5.1	12.3	4.9	11.1	13.1	40.4	29.4	39.7	12.8	8.1	40.4
1983	2.3	7.9	15.2	36.9	120.9	81.0	55.5	222.1	67.9	36.5	8.2	3.0	222.1
1984	1.2	1.0	1.2	27.2	15.2	1.6	42.0	119.4	100.3	33.4	3.5	2.9	119.4
1985	2.6	0.7	8.4	45.8	149.6	76.3	76.5	32.7	47.6	27.2	6.8	0.3	149.6
1986	1.3	11.9	25.0	83.4	149.6	27.8	283.5	164.5	39.2	47.3	4.6	3.9	283.5
1987	4.5	3.3	5.2	26.6	231.7	47.6	105.9	34.7	30.8	67.5	5.8	4.3	231.7
1988	2.4	1.2	1.8	12.5	19.6	11.0	22.4	81.6	70.2	52.1	4.6	4.8	81.6
1989	1.3	10.9	19.9	42.7	56.5	85.9	22.8	101.7	41.2	56.9	7.3	3.7	101.7
1990	2.5	20.7	30.5	15.2	12.5	37.0	59.8	67.5	66.4	76.3	10.1	8.4	76.3
1991	4.5	22.8	27.2	71.8	71.8	34.7	53.7	71.8	65.4	11.9	13.3	2.9	71.8
1992	4.6	17.1	23.9	37.5	78.6	46.7	76.3	110.3	89.7	23.0	12.9	3.5	110.3
1993	4.8	17.1	2.2	45.0	45.0	11.7	27.2	45.9	38.5	34.0	10.2	4.8	45.9
1994	9.5	5.0	22.4	16.6	24.7	14.3	40.9	45.0	61.8	31.2	7.5	2.4	61.8
1995	1.2	10.2	6.9	42.5	21.2	33.3	26.6	52.1	39.3	16.1	3.7	2.7	52.1
1996	9.5	1.3	4.8	64.9	100.5	34.0	81.6	45.0	76.9	38.5	12.5	2.2	100.5
1997	18.6	1.0	3.9	5.3	16.1	15.6	36.2	43.3	94.0	49.9	2.6	4.0	94.0
1998	10.3	1.2	3.7	21.8	22.8	275.3	22.8	85.9	88.9	61.3	4.9	3.8	275.3
1999	2.3	1.5	6.5	8.7	14.8	3.5	46.7	156.9	64.3	59.0	16.8	3.5	156.9
2000	2.2	1.3	1.2	97.6	15.6	36.1	23.9	34.7	47.3	56.8	11.8	8.4	97.6
2001	3.5	3.5	37.5	27.2	45.1	21.8	35.4	56.5	30.2	53.7	8.4	3.5	56.5
2002	6.9	14.8	13.3	19.0	19.9	12.6	71.8	53.7	19.9	9.5	4.5	19.9	71.8
2003	16.4	11.9	16.0	19.9	19.9	65.9	21.3	21.8	21.8	20.9	4.9	0.6	65.9
2004	16.4	6.2	10.7	20.9	11.0	21.3	93.6	89.7	51.0	29.2	5.6	7.4	93.6
2005	8.1	7.1	17.2	167.5	19.0	46.7	128.9	34.7	74.0	37.5	5.6	3.8	128.9
2006	2.5	10.4	37.5	41.2	20.9	46.7	40.4	63.3	108.8	29.6	13.0	9.8	108.8
2007	21.2	5.7	25.8	29.9	84.0	45.9	108.7	107.5	104.6	36.9	9.9	2.7	108.5
2008	20.7	18.6	17.1	68.1	57.8	48.5	69.1	107.4	115.9	67.0	10.9	3.7	115.9
2009	16.7	22.9	47.0	72.6	55.0	45.8	65.9	84.0	100.5	56.4	9.0	3.9	100.5
2010	12.7	12.7	34.2	96.6	55.9	72.4	121.7	99.2	85.2	45.8	13.6	2.6	121.7
2011	21.8	24.7	21.3	81.6	126.2	32.6	68.1	99.2	108.7	65.9	18.9	1.9	126.2

2012	21.8	24.7	31.9	81.6	105.7	32.6	68.1	99.2	108.7	65.9	12.8	3.9	108.7
2013	17.1	16.1	34.7	54.0	85.2	40.9	90.2	105.0	107.4	45.9	10.8	2.8	107.4
2014	19.6	15.6	38.5	56.9	49.4	51.2	88.9	110.7	108.7	45.9	11.8	1.6	110.7
2015	20.1	15.2	50.1	46.3	70.5	29.8	80.2	107.7	55.7	45.9	7.8	2.8	107.7

Appendix B: WETS Pro. Software Results (POT value)

No.	Time at POT value	POT value	Time at pervious Minimum	No.	Time at POT value	POT value	Time at pervious Minimum
1	173	83.402	1	48	4561	59.336	4556
2	456	174.28	386	49	4578	46.748	4563
3	476	128.924	467	50	4593	76.291	4591
4	576	156.893	533	51	4655	110.293	4598
5	610	107.374	581	52	4995	45.88	4828
6	623	206.048	617	53	5339	61.793	5123
7	639	111.771	626	54	5611	42.521	5538
8	988	40.397	732	55	5741	52.109	5625
9	1198	80.985	1114	56	5831	53.972	5823
10	1240	137.271	1237	57	5930	63.842	5908
11	1273	120.924	1272	58	6014	100.543	5941
12	1366	222.114	1287	59	6443	93.984	6292
13	1716	119.365	1532	60	6512	90.169	6500
14	1928	45.111	1879	61	6691	275.307	6633
15	1960	114.769	1932	62	6795	192.913	6741
16	2007	149.554	1973	63	6824	85.868	6823
17	2157	81.9105	2130	64	7166	64.33	6992
18	2402	283.54	2176	65	7203	156.893	7179
19	2521	162.553	2519	66	7233	144.204	7210
20	2655	47.582	2547	67	7430	97.569	7372
21	2729	231.661	2717	68	7590	56.98	7442
22	2748	105.935	2732	69	7834	45.111	7735
23	2845	67.457	2809	70	7922	56.468	7886
24	3170	81.612	3016	71	7947	53.695	7946
25	3326	110.293	3306	72	8246	71.783	8060
26	3386	53.695	3362	73	8271	53.695	8248
27	3403	85.868	3398	74	8557	65.89	8383
28	3448	56.468	3439	75	8977	93.557	8766
29	3561	101.694	3463	76	9038	89.657	9028
30	3854	59.781	3686	77	9053	85.868	9046

31	3888	66.403	3881	78	9253	49.278	9145
32	3904	67.457	3903	79	9344	128.924	9295
33	3931	76.291	3923	80	9453	48.425	9449
34	4103	82.187	4043	81	9592	46.748	9542
35	4141	45.111	4140	82	9722	108.827	9604
36	4159	71.783	4145	83	9997	118.775	9826
37	4174	71.783	4169	84	10114	111.559	10005
38	4195	61.301	4182	85	10460	115.858	10312
39	4210	53.695	4196	86	10819	167.528	10659
40	4236	65.361	4229	87	11144	121.733	10992
41	4272	71.783	4243	88	11487	126.247	11383
42	4384	51.898	4309	89	11816	140.35	11771
43	4411	60.313	4391	90	11891	108.744	11842
44	4439	49.278	4429	91	12337	112.982	12114
45	4467	59.336	4445	92	12468	72.419	12450
46	4495	46.748	4480	93	12548	64.881	12515
47	4548	78.614	4511	94	12697	153.6	12550
				95	13030	107.6597	12853

Appendix c: Manning’s roughness coefficient value (Chow, 1959)

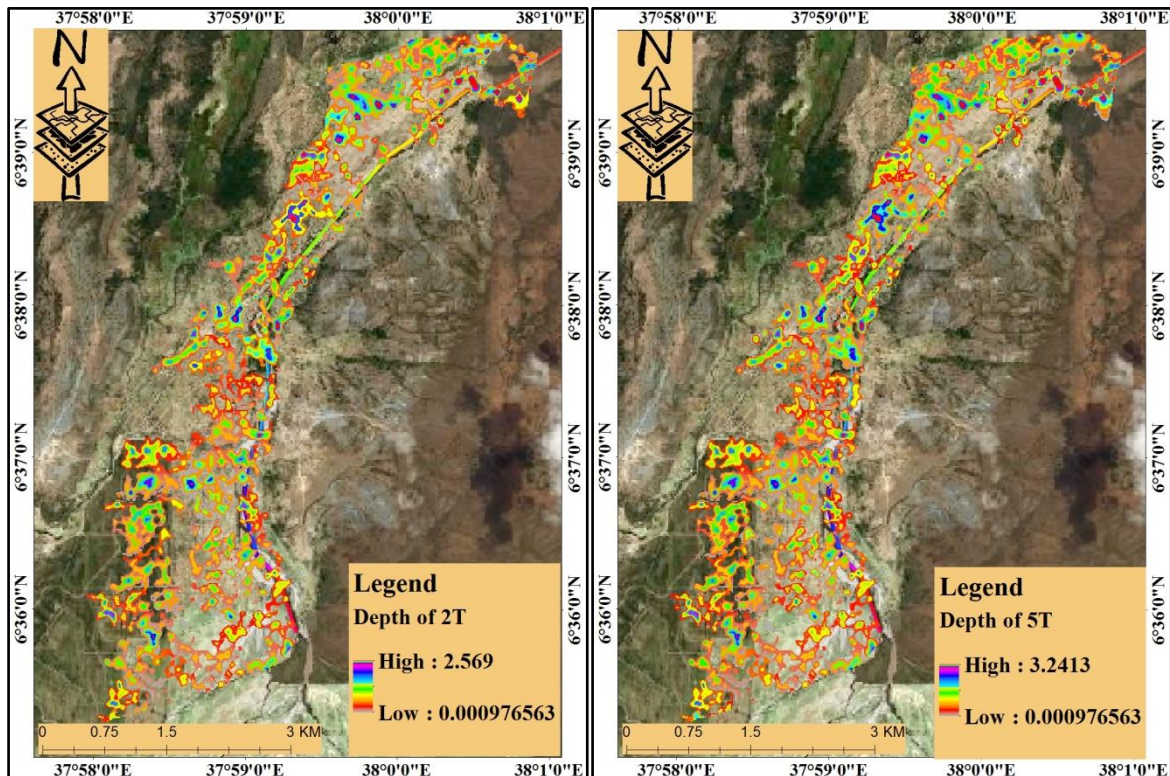
Table A 1: -Recommended design values of manning roughness coefficient

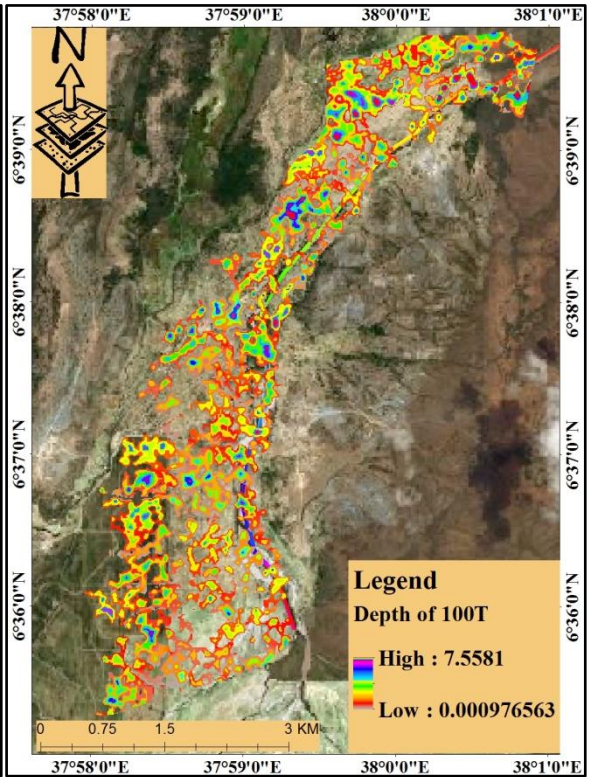
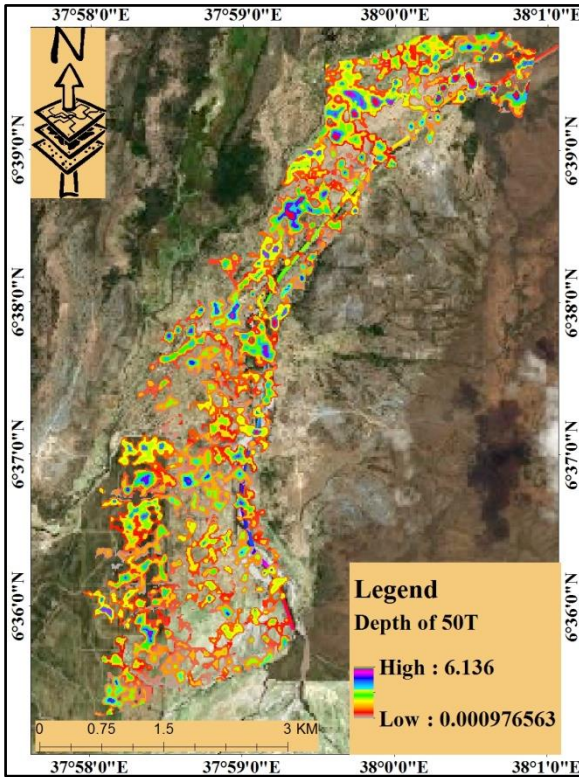
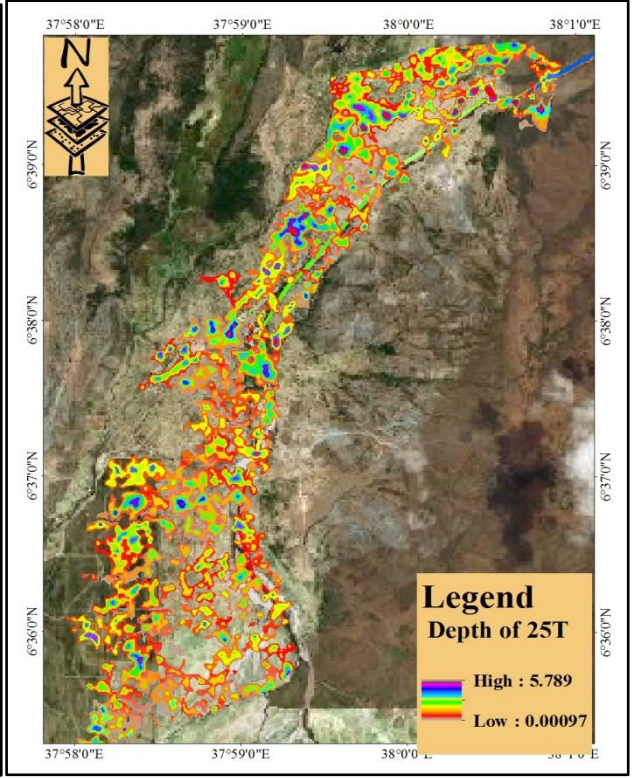
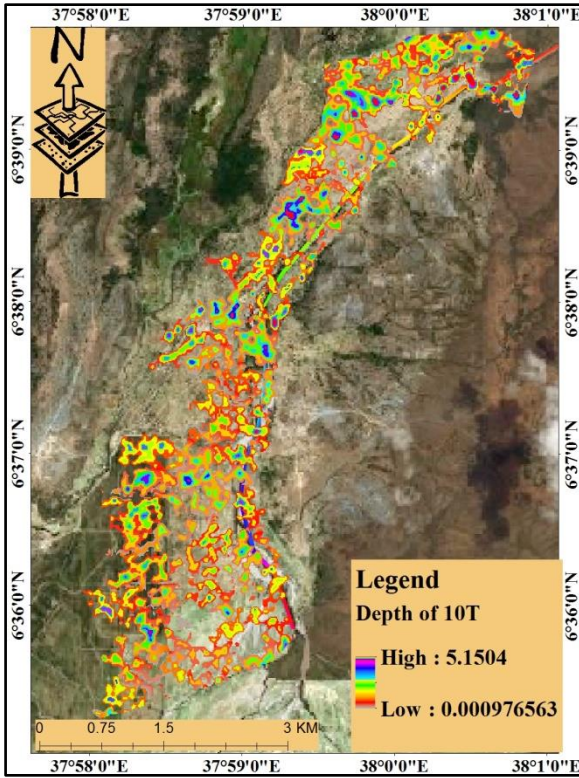
	Manning <i>n</i> Range ^b
I. Unlined open channels^c	
A. Earth, uniform section	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In graveled soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides, clean gravel bottom	0.025–0.030
5. Sides, clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock	
1. Based on design section	0.035
2. Based on actual mean section	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high-stage	0.10–0.14
II. Roadside channels and swales with maintained vegetation^{d,e} (values shown are for velocities of 2 and 6 ft/sec):	
A. Depth of flow up to 0.7 ft	
1. Bermuda grass, Kentucky bluegrass, buffalo grass	
a. Mowed to 2 in.	0.07–0.045
b. Length 4 to 6 in.	0.09–0.05
2. Good stand, any grass	
a. Length about 12 in.	0.18–0.09
b. Length about 24 in.	0.30–0.15
3. Fair stand, any grass	
a. Length about 12 in.	0.14–0.08
b. Length about 24 in.	0.25–0.13

	Manning <i>n</i> Range ^b
B. Depth of flow 0.7–1.5 ft	
1. Bermuda grass, Kentucky bluegrass, buffalo grass	
a. Mowed to 2 in.	0.05–0.035
b. Length 4 to 6 in.	0.06–0.04
2. Good stand, any grass	
a. Length about 12 in.	0.12–0.07
b. Length about 24 in.	0.20–0.10
3. Fair stand, any grass	
a. Length about 12 in.	0.10–0.06
b. Length about 24 in.	0.17–0.09
III. Natural stream channels^f	
A. Minor streams ^e (surface width at flood stage less than 100 ft)	
1. Fairly regular section	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.04–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01–0.10
2. Irregular sections, with pools, slight channel meander; increase value in la-e by	0.01–0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom of cobbles, with large boulders	0.05–0.07
B. Floodplains (adjacent to natural streams)	
1. Pasture, no brush	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees ^b	
a. Winter	0.05–0.06
b. Summer	0.06–0.08

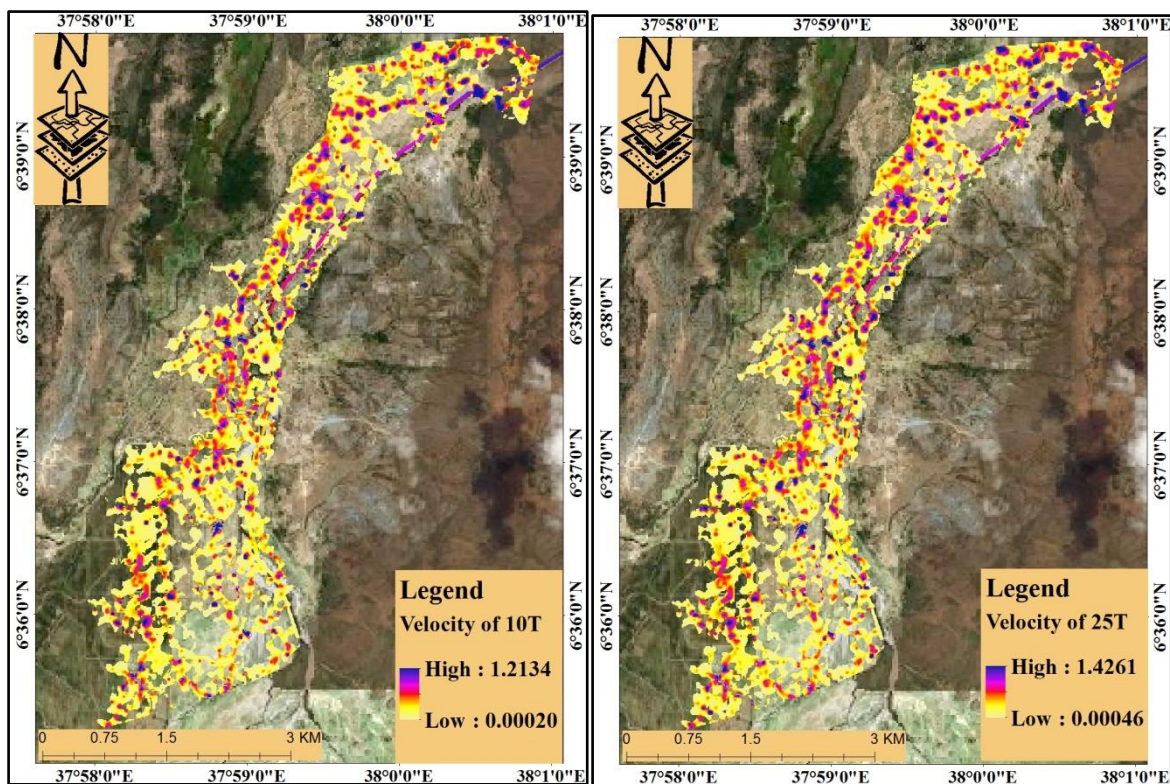
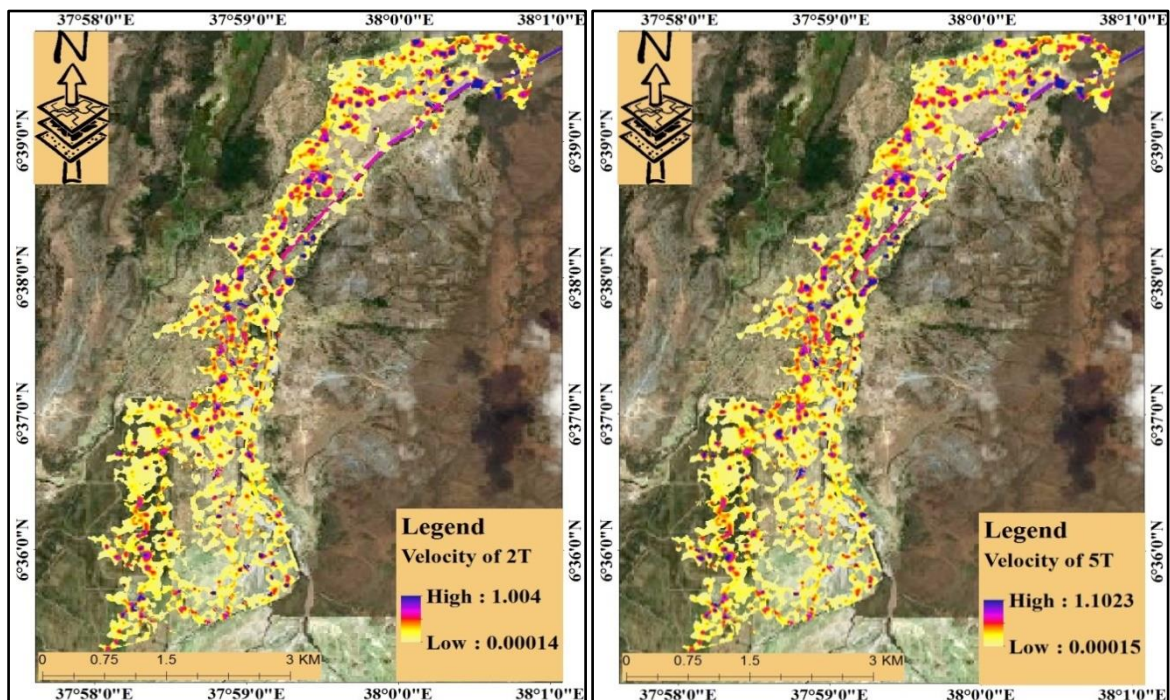
Appendix D: HEC-RAS outputs

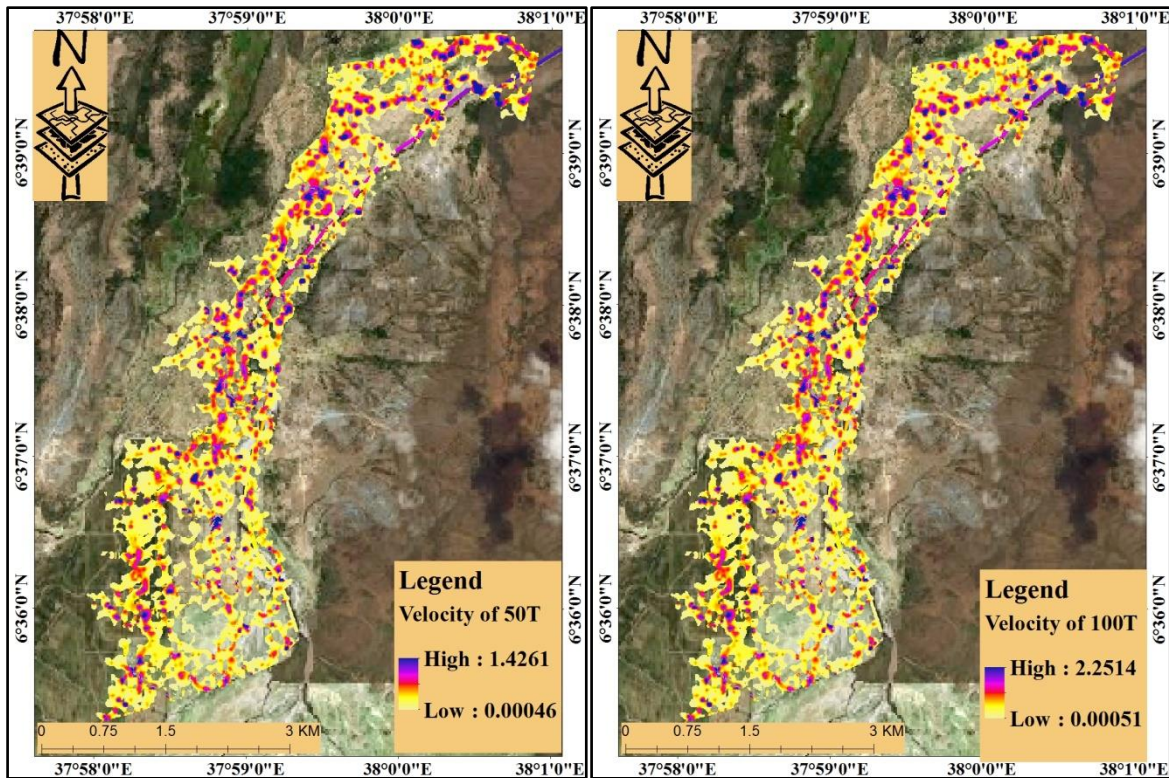
1. Flood Inundation Depth Maps for different return period





2. Flood Flow Velocity Maps for different return period





Appendix E: Indicator for Vulnerability Index

Indicator	Symbol	normalized value
Proximity of the village (m)	E1	0.345
population in the flood area	E2	0.231
Farmland in flood area (ha)	E3	0.567
Women	E4	0.121
Elderly	E5	0.024
Children under 15	E6	0.342
Flood magnitude (m ³ /s)	E7	0.2221
Return period (year)	E8	1
Education : no schooling (%)	S1	0.564
Household size	S2	0.458
Poor building material (%)	S3	0.679
Female headed (%)	S4	0.1732
Farmers (Solely) (%)	S5	1
Household with affected land (%)	S6	0.3421
Community Awareness (%)	S7	0.562
Household Past experience (%)	S8	0.2154
Household Evacuation capability (%)	R1	0.1211
Household flood Training (%)	R2	0.1112
Household perception on flood risk(%)	R3	0.345
Recovery capacity (%)	R4	0.1211
Environmental recovery	R5	0.234
Recovery Time (%)	R6	0.2333
Warning system (%)	R7	0.287
Long term resident 10 years + (%)	R8	0.543

Appendix F: Risk level Analysis

Dep	Nor.de p	Dur	nor. Dur.	Velo .	Nor.Vel o	T.Hazar d Index	T.Vul. index	Risk	Risk level
0	0	0	0	0	0.000	0.000	0	0	very low
1	0.125	0.98	0.14	0.12	0.048	0.104	0.086	0.0952	low
2	0.25	2.47	0.353	0.36	0.144	0.249	0.2153	0.232	low
3	0.375	3.45	0.493	0.76	0.304	0.391	0.4431	0.417	moderate
4	0.5	4.63	0.66	1.30	0.520	0.560	0.4557	0.508	moderate
5	0.625	5.85	0.8357	1.9	0.760	0.740	0.5636	0.6519	high
6	0.75	6.68	0.954	2.20	0.880	0.861	0.619	0.7402	high
7	0.875	6.89	0.9843	2.34	0.936	0.932	0.8093	0.8705	very high
8	1	7	1	2.50	1.000	1.000	1.000	1	very high

Appendix G: Questionnaire for Household Interview

Date: ___ __ / ___ __ / 2020
Keble: _____

INTRODUCTION

I am a student at the University of Hawassa University, I am collecting data for a research study in Abela-Abaya district specially Chokare and Guricho Keble. The study focuses on assessing Flood risk in the area. I would like to ask you some questions about your family. The data that you provide is for academic purpose and it will be kept strictly confidential. This is voluntary, you can refuse to answer to some of the questions but I hope you will accept as your views are very important.

Section 1: Exposure

1. What are the main climate hazards that have affected your community during the last ten years?

1. Flooding 2. Drought

2. What are the causes of flood in your locality?

1. Heavy rainfall ; 2. Overflow of Bilate river ; 3. Other, specify.....

3. Number of flood event during the past ten years

.....
4. Was your household affected by the recently flood?

1. Yes ; 2. No

5. Flood duration (the number of flood days during the flood)

.....
6. What is the height of the flood in your household? (Recently Flood depth)

.....
7. The size of household's agricultural land

.....
8. Does your household's farmlands often affected by floods?

1. Yes ; 2. No

9. Proximity of the farmland to the water body

1. <1km 2. 1-2km 3. >2km

10. Number of women in your household

.....
11. Number of children under 15 years in your household

.....
12. Number of elderly in your household

.....
Section 2: Susceptibility

13. Sex of household head

1. Male; 2. Female

14. Age of head of household

1. <20 ; 2. 20-39 ; 3. 40-59 ; 4. 60+

15. Marital Status of household head

1. Single ; 2. Married ; 3. Widowed

16. Education status: highest level of education attained

1. No schooling ; 2. Functional literacy ; 3. Primary schooling ; 4. Secondary schooling ; 5. Tertiary schooling ; 6. University

17. Household size

.....
18. Type of dwelling for the household

1. Brick walls with iron/tiles sheet roof ; 2. Mud walls with iron/tiles sheet roof ;

3. Mud walls with thatched roof

19. What are the main sources of income for the household?

1. None ; 2. Agriculture ; 3. Breeding ; 4. Fishing ; 5. Handcraft

Section 3: Resilience

20. Did you attend any training on flood management?

1. Yes ; 2. No

21.If yes, what information did you receive during the training?

.....

22.Which structures provide the information/warning/training?

1. Croix rouge; 2. NGOs; 3. Locale government

23.Was the information you received useful during and after flood disaster?

1. Yes ; 2. No

24. Is there a committee of flood management in your community?

1. Yes; 2. No

25. If yes, are you member?

1. Yes; 2. No

26. is your household able to evacuate, in case of a flood?

1. Yes ; 2. No

27. Does the government or others institutions provide prevention and protection measures?

1. Yes ; 2. No

Appendix G: Field Survey photo





