



**FLOOD HAZARD ASSESSMENT AND MAPPING OF FLOOD  
INUNDATION AREA OF LOKA-ABAYA WOREDA OF SIDAMA  
ZONE IN S/N/N/P/R/S ETHIOPIA**

**MASTER OF SCIENCE**

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**HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA**

**February, 2019**

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A THESIS SUBMITTED TO THE FACULTY CIVIL AND BUILT  
ENVIRONMENT ENGINEERING, HAWASSA INSTITUTE OF  
TECHNOLOGY, SCHOOL OF GRADUATE STUDIES HAWASSA  
UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE  
OF MASTER OF SCIENCE IN CIVIL ENGINEERING (SPECIALIZATION:  
HYDRAULICS ENGINEERING)

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February, 2018

**SCHOOL OF GRADUATE STUDIES**

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**ADVISORS' APPROVAL SHEET**

This is to certify that the thesis entitled “**Flood Hazard Assessment and Mapping of Flood Inundation Area of Loka-Abaya woreda of Sidama zone in S/N/N/P/R/S Ethiopia**” submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Hydraulic Engineering**, the Graduate Program of the **Faculty Civil and Built Environment Engineering School Civil Engineering**, and has been carried out by **Yehulashet Mulat** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

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## **DEDICATION**

This work is dedicated to my beloved family. It is their love and support that enabled me not only to complete this task but taught me to walk every step of life with confidence and commitment.

## **Acknowledgements**

First and foremost, thanks to the Almighty God for granting me His limitless care, love and blessings all along the way. I would like to express my sincere appreciation to my advisors Dr. Moltot Zewdie and Mr. Nebyiat Fekede for their advice and valuable suggestions, encouragement and guidance from the commencement of the study to the completion my research work, Furthermore, they have devoted their time and energy to advise me during the whole work and recommended valuable comments to improve the thesis.

My sincere gratitude to Hawassa University for awarding me a scholarship to attend my education and Ethiopian Road Authority (ERA) for sponsor me a fund to follow my M.Sc thesis.

I would like gratefully to acknowledge Ethiopian Ministry of Water, Irrigation and Electric (MoWIE), National Metrological Service Agency Hawassa Branch (NMSA), Ethiopian Map Agency (EMA) for providing me invaluable input data for my research work.

Last but not the least; I would like to express my heedful gratitude to my parents and family members for their tremendous support and encouragement in difficult situations that have enabled me to attain this level.

## List of Acronyms

DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Geographical Positioning System
HEC	Hydraulic Engineering Centre
HEC-GeoRAS	Hydraulic Engineering Center Geographical River Analysis System
HEC-RAS	Hydraulic Engineering Center for River Analysis System
MoWR	Ministry of Water Resource
NGO	Non-Governmental Organization
PDF	Probability Density Function
S/N/N/P/R/S	Southern Nation Nationalizes Peoples Regional State
SCS	Soil Conservation Service
TIN	Triangular Irregular Network
USACE	United States Army Corps of Engineers
XML	Extensible Markup Language
XS	Extra Small

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## **Abstract**

Loka-Abaya woreda is found in S/N/N/P/R/S Rift Valley, surrounded by Bilate catchment. The area is dominated by undulating terrain with relatively steep to moderately steep and flatter slopes in the downstream of the catchment. This flood plain has been vulnerable to high flooding from rainfall during rainy season. This study focuses on estimation of flooding of the woreda due to the out-braking of Bilate River. The data used for generating the peak discharge for different return period related to the hydro metrological data of past events, and geometrical characteristics of the river channel and the reach boundary conditions are prepared in SCS method, HEC-RAS and HEC-GeoRAS models and Arc GIS environment. It was found that simulation result for return period of 5, 10, 25, 50 and 100-yearflood discharges of magnitude are 405.38, 551.48, 707.20, 745.37 and 898.12 in m<sup>3</sup>/s respectively. The maximum flood hazard and flow depth for the return periods are found to be 3699.3 and 3.42; 3851.4 and 5.52; 4011.2 and 6.18; 4067.0 and 6.29; and 4224.5 hectare and 6.78 m respectively with a maximum velocity of 5.6m/s. The percentages of area inundated by floods are found increasing from 18.6 (3699.3ha) for 5 years to 21.3 (4224.5 ha) 100-year return period. Billate erisha lemat, Billate chricho, Thinbaho erisha lemat, Billate Eta and Boro shebela Keble of the woreda is found as flood prone area. It is observed that the findings of the research lead to key inputs in the designing of sustainable mitigation measures to minimize the impact of floods and the associated risks; it supports policy and decision makers to decide about how to allocate resources, flood forecasting, ecological studies, and significant land use planning in

*Key Words: Flood inundation mapping, Flood depth, Velocity mapping, Loka-Abaya modeling*

# 1 INTRODUCTION

## 1.1 Back ground of the study

Flooding is the most common natural hazard that can happen any time in wide variety of locations due to high intensity rainfall events. A flood is any relatively high flow that overtops the natural or artificial banks in any reach (Chow 1956).

Floods are the most common occurring natural disasters that affect human and its surrounding environment (Hewitt 1997). Flood is one of the major natural disasters that have been affecting many countries or regions in the world year after year. Arguably, the rate of flooding occurrence in recent times has been unprecedented. With 70 million people globally exposed to flooding every year, and more than 800 million living in flood prone areas.

Flood – one of the major natural hazards in Ethiopia – affects lives and livelihoods in parts of the country. Topographically, Ethiopia is both a highland/mountainous and lowland country. It is composed of some nine major river basins, the drainage systems of which originate from the centrally situated highlands and make their way down to the peripheral or outlying lowlands. Especially during the rainy season (June-September), the major perennial rivers as well as their numerous tributaries forming the country's drainage systems carry their peak discharges. The country experiences two types of floods: flash floods and river floods.

Flash floods are the ones formed from excess rains falling on upstream watersheds and gush downstream with massive Concentration, speed and force. Often, they are sudden and appear unnoticed. Therefore, such floods often result in a considerable toll; and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration. On the other hand, much of the flood disasters in Ethiopia occur as a result of prolonged heavy rainfall causing rivers to overflow or burst their banks and inundate areas along the river banks in lowland plains. Since April 2016, heavy spring/belg rains have caused floods and landslides, resulting in 100 deaths as of 12 May. Up to 120,000 people have been displaced in six regions. The most affected regions are Somali, Oromia, Southern Nations, Nationalities, and Peoples (SNNP), Afar, Amhara, and Harari. Also, Heavy rainfall in the western and central highlands of S/N/N/P/R/S resulted in flooding and landslides which affected 53,170 people and displaced 12,634. Of this 3,130 people are from the study area Loka-Abaya woreda 7

Keble catchment in Sidama Zone is suffering the consequences of flood coming from the Bilate River during the main rainy season (CSA, 2007). The sustainable and effective flood risk measures demand a holistic approach that can integrate the flood risk assessment information in the decision-making process in any proposed developmental activity. Numerous flood risk assessment studies by many researchers throughout the world indicated the significance of technical and scientific approach in developing methodologies. Integration of technologies – HEC-RAS (Hydrologic Engineering Centers River Analysis System) and GIS (Geographic Information System) to obtain scientifically derived information has been specified as efficient in simulating, identifying and analyzing flood events in a geo spatial environment. By generating the peak discharge for different return period related to the hydro metrological data of past events, and geometrical characteristics of the river channel and the reach boundary conditions and using SCS method, HEC-RAS and HEC-GeoRAS models water surface profile and flood mapping has been done for the kbeles catchment.

## **1.2 Statement of Problem**

The rainy season in Ethiopia is concentrated in four months from June to September. Large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands causes flooding of settlements close to any stretch of river courses. The flood from the Bilate River, which is usually formed by out-banking of the river channel, is causing direct damage to property as well as disruption of economic activity and displacement of affected population and the loss of agricultural productivity in the loka-abaya woreda. In 2008 extreme flooding affected 3,130 people in the woreda. The sociological damages caused by inundation are also serious. Community are often isolated during the rainy season due to floods and inundation and there life also completely disrupted.

So that it worth to apply the commonly applied hydrological computational techniques for arriving at estimates of flood flows in Bilate River at 5 kebele of loka-abaya woreda and evolve, flood inundation map of the flood plain which are flood prone in the region. Therefore, it is of paramount importance to simulate the Bilate River flow using GIS software and the HEC-GeoRAS/HEC-RAS model to explore the extent of the flood in the plain in the form of Vulnerability and risk maps and suggest control measures to be under taken for the problem.

## **1.3 Objective**

### **1.3.1 General objective**

To investigate flood risk of Bilate River in Loka- Abaya woreda S/N/N/P/R/S Sidama zone.

### **1.3.2 Specific objective**

- To conduct flood frequency analysis using different year scenarios for the site.
- To simulate flood profiles of the Bilate River at the study site using HEC-RAS model.
- To delineate flood-prone areas and to develop flood inundation map of the site.

## **1.4 Significance of the Study**

It is essential to understand the characteristics of flood inundation for Loka- Abaya woreda of the catchment Bilate River. With this study we can know, how much area will be flooded due to a given discharge. In addition to that, we need to know how fast or at what rate the flood plain areas are flooded due to given discharge, to answer these key questions, this study has been taken. Therefore, the flood inundation map will show the areas will the high risk and help to reduce the risk of direct flood damage to human life and property in the study area. More importantly, it is envisaged that the outputs of the study will be key inputs in the designing of sustainable mitigation measures to minimize the impact of floods and the associated risks; it supports policy and decision makers to decide about how to allocate resources, flood forecasting, ecological studies, and significant land use planning in flood prone areas of the woreda. The outcome of this study will help the planner to prepare river flood warning maps to reduce the sufferings of people, damage of crops and vegetation, and destruction of infrastructures.

## **1.5 Researcher question**

The thesis originated in different questions.

Is the flood differing for different scenarios?

Can HEC-RAS model simulate flood profiles of study area?

How much area is affected by the flood?

## **2. LITERATURE REVIEW**

### **2.1 Flood Definition**

Throughout the long human history, floods are the most frequently occurring natural hydrological phenomena, which consist of the futures such as water depth, flow velocity, and temporal and spatial dynamics. As a result, their significant impacts cause imponderable damage on human society and ecosystems, particularly in terms of life loss and property damage. The frequency, pattern and severity of flooding are expected to increase as a result of climate change. Development can also exacerbate the problems of flooding by accelerating and increasing surface water run-off, altering watercourses and removing floodplain storage. (John G 2009)

The current trend and future scenarios of flood risks therefore demand for accurate spatial and temporal information on the potential hazards and risks of floods. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping, such as in Euro [Dragan and Slobodan (2009) and Panagoulia et al. (2013)], Yongping and Kamal (2011) and Keren et al. (2008)], in Africa [Botes and Smith (2010), Fosu et al. (2010) and Okirya et al. (2012)], in Asia [Menon and Ajin (2014)] and also in Ethiopia [Getahun and Gebre (2015), Brhane (2011), and Tesema (2009)]

### **2.2 Floods in Ethiopia**

Flood – one of the major natural hazards in Ethiopia – affects lives and livelihoods in parts of the country. In most cases floods occur in the country as a result of prolonged heavy rainfall causing rivers to overflow and inundate areas along the river banks in lowland plains. For instance, in the NMA analogue years of 1982/83 and 1997/98, unseasonal rains affected crop harvest in parts of Oromia, Amhara and SNNP regions.

### **Previous studies**

#### **2.2.1 Previous studies on flood mapping**

A number of studies have been carried out in the past, particularly concerning the floodplain inundation mapping, flood hazard mapping, and flood forecasting and others nonstructural measures. Some of these researches have been summarized in order to gain proper conception about flooding problem and mitigation managements and to be able to prepare a good quality flood plain inundation

map. Efforts have been made to collect and review the thesis reports, journals, books, tools user manuals. An outline of some of the reports is given below:

According to Kneblet al. (2005) studied regional scale flood modeling using GIS, HEC-HMS, and HEC-RAS in San Antonio river basin summer 2002 storm event. They developed a framework for regional scale flood modeling that integrates NEXRAD Level III rainfall, GIS, and a hydrological model (HEC-RAS/HMS). Hicks and Peacock (2005) studied the suitability of HEC-RAS for flood forecasting. They found that most river flood forecasts were conducted using a two-step procedure. First, flood routing was conducted, normally using hydrological models. The resulting flood peaks were then converted to water level forecasts using a steady flow hydraulic model, such as HEC-RAS. The HEC-RAS model had been extended to facilitate unsteady flow analysis. Here, the viability of the HEC-RAS unsteady flow routine for flood forecasting was examined through an application to the Peace River in Alberta and it is shown that accuracy comparable to more sophisticated hydraulic models can be achieved. Since many agencies already have HEC-RAS models established for floodplain delineation purposes, it would be simple matter to extend them to the flood forecasting application. They thought an ancillary advantage would be that flood forecasting accuracy could potentially be improved and simplified into a one-step process, without necessitating time-consuming transition to unfamiliar models.

According to Hatipogluet al. (2007) studied on floodplain delineation in Mugla-Dalaman plain using GIS based river analysis system. In his study, an application of HEC-RAS and HEC-GeoRAS model were applied HEC-RAS simulations were performed to generate water surface profiles throughout the system and floodplain zones for the design storms were reproduced in three dimensions with HEC-GeoRAS by overlaying the integrated terrain model for the region with the corresponding water surface TIN. As a result, it was seen that the floodplain extend that was found by GIS based methods gives considerable better results than by traditional methods.

According to Abera (2011) studied flood mapping and modeling on Fogera flood plain. HEC-HMS, HEC-RAS and HEC-GeoRAS were used in river basin flood modeling. He found a flow value of 91.8, 202.4, 273.1, and 308.4 cumec for return periods of 2, 10, 50 and 100 respectively by hydrologic model HEC-HMS. This flow value was used to generate water surface profile for flood inundation mapping by hydraulic model HEC-RAS. The 13 flooded area for the return periods 2, 10,

50 and 100 year was 12.63, 18.63, 21.31 and 22.5 sq.k respectively. He found most of the area flood depth is less than 1.5 m. He also found 88% of agricultural land, 11.6% of agro-pastoral land and 1.36% river inundated by the flood.

### **2.3 Flood Impact Parameters**

(According to Van Der Sande (2001) the most important parameters influencing flood impact are:

Water depth,

Sediment concentration,

Wave or wind action,

Duration of flooding,

Flow velocity,

Sediment size,

Pollution load of flood water,

Rate of water rise during flood onset.

Damage is usually represented in stage-damage curves, where water depth is the major damage variable. The stage-damage curve determines the probable loss for the given event (ICPR, 2002). Consequently, land use, which represents the number of vulnerable assets present, makes a clear difference in damage. Even if the flood intensity parameters mentioned above include many different flood effects, water depth is the most important and also the easiest to observe and quantify and therefore plays the major role in flood loss estimation. Generally, flood depth and extent are most important for direct losses, duration for indirect losses and warning time for intangible losses (Green et al., 1994).

### **2.4 The Flood Hazard**

Flood hazard is defined that those floods generate pop-up threats to the life and properties of human beings at the flood-prone areas where man had encroached into. The hazard level is validated by a combination of physical exposure and human vulnerability to the flood inundation process.

## **2.5 Flood Estimation**

Flood estimation for planning purposes aims to estimate the long-term probability of flood impacts so that appropriate planning decisions can be made to minimize that impact. As a complex set of factors influences whether or not flooding occurs in a catchment, it is difficult to define the causes or the effects of an ‘average’ flood. Put simply, no two floods in the same catchment are ever identical. To overcome this problem, floodplain managers and hydraulic engineers rely on a series of design flood events and historical rainfall and flood level information.

Typically, these analyses are undertaken by hydrologists and specialist engineers skilled in the physical understanding of rainfall patterns and the behavior of floods. The results of such studies are often used to set freeboards for proposed development (such as housing) or public works like roads, bridges and levee systems.

## **2.6 Application of Hydrologic and Hydrodynamic Model Study across the World**

### **2.6.1 Application of HEC-HMS Model**

The model consists of a rainfall–runoff model (HEC-HMS) that converts precipitation excess to overland flow and channel runoff, as well as a hydraulic model (HEC-RAS) that models unsteady state flow through the river channel network based on the HEC-HMS derived hydrographs. With the calibrated discharge, HEC-RAS is capable of producing floodplain polygons with GIS tool named Map to Map. The result of this research provides a tool for hydrological forecasts of flooding on a regional scale.

### **2.6.2 Application of HEC-RAS and HEC-GeoRAS Model**

According to Heimann, et. al., 2015 developed flood inundation map for the Blue River and Selected Tributaries in Kansas City, Missouri. In this study flood inundation map were created in a geographic information system (GIS) by combining simulated water-surface profiles and terrain elevation data. The terrain model data were derived from lidar data and stream channel and bridge surveys at selected locations. Estimated flood-inundation boundaries for each simulated profile in HEC-RAS were developed with HEC–GeoRAS software, which allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS (U.S. Army corps of Engineers, 2010). These maps give detailed information on flood extents and depths for modeled sites.

### **2.6.3 Remote Sensing and GIS Applications**

Remote sensing technology along with geographic information system (GIS) has become the key tool for flood monitoring in recent years. Development in this field has evolved from optical to radar remote sensing which has provided all weather capability compared to the optical sensors for the purpose of flood mapping. The central focus in this field revolves around delineation of flood zones and preparation of flood hazard maps for the vulnerable areas. A GIS could be feeded with relevant information in a standardized form to produce computerized maps and further used for integrated analysis. For instance, the information for flood in GIS could be points (gauge station, structures), line (flood embankments, power lines) and polygon (flooded land, field plots). GIS allows the manipulation of each datum in its entire spatial and temporal context .With this the analysis could be initiated for decision makers (World Bank 1990). Several institute and organization were keen in using GIS.

### **2.9.4 GIS model**

At present, GIS modeling for floods or delimiting some flood prone areas is very advanced, and numerous mathematical methods for calculating the extent of a river (according to its flow rate, the water infiltration rate into the soil, land use etc.) have been developed. These mathematical models have been integrated into GIS software, whose purpose is to create a model that would replicate the shape of the landscape as precise, as possible (Edsel et al. 2011). The flood risk maps have a clear purpose of identifying vulnerable areas and the population that is exposed in a certain region; they represent a useful tool during General Urban Plan creation and intend to be used in the interdiction of constructing houses in the affected areas and creating management plans for emergency situations, as close as possible to the probabilities of certain events of this type (Iosub et al, 2014).

### **2.7 HEC- RAS**

HEC-RAS is software for one-dimension or two-dimension simulations of the evolution of a flood, which could have a stable or an unstable flow rate, sediment transport, change of the river bed etc. The software itself has four main river analysis possibilities: the constant flow rate at the surface of a considered river profile; simulation of an unsteady flow of water; calculations of the sediment transport and modifications of the river bed; and analysis of the water quality (U.S. Corps of Engineers, 2002, Tate et al. 1999). The basic computational equation for computing water surface

profile for HEC RAS is based on one-dimensional energy equation. It is based on the principle of conservation of energy and it states that the sum of the kinetic energy and potential energy at particular cross-section is equal to the sum of the potential and kinetic energy at any other cross section plus or minus energy loss or gains between the sections.

## **2.8 HEC-GeoRAS**

HEC-GeoRAS is a GIS extension with a set of procedures, tools, and utilities for the preparation of river geometry GIS data to import into HEC-RAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC GeoRAS model are Triangular Irregular Network (TIN), DEM, and land use. The river geometry file and stream flow data are the input files for HEC-RAS to generate the water surface level along the River. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping, such as in Europe in the USA in Africa and in Asia.

HEC-GeoRAS is a data management interface between ArcGIS and HEC-RAS. This tool provides or creates the river geometric file to be analyzed in HEC-RAS model. The river stream centerline, bank lines, flow path centerlines, and XS cut lines should be digitized from a previous river file, aerial photographs, or topographical datasets using HEC-GeoRAS interface. The river reach (river segment between junctions), cross-section and other related data are stored in the geo database file of HEC-GeoRAS. The river and cross-section data layers are created with predefined attribute tables that are manually populated in the case of the river and reach names, while all other attributes are automatically calculated by the HEC-GeoRAS. The interface extracts the geometric data in an .xml format that is imported into HEC-RAS. The results of the HEC-RAS model simulation will be entered into a GIS environment and further analyses will be performed using HEC-GeoRAS tool. The GIS data exchanged between HEC-RAS and ArcGIS are in file format. This paper is focused solely on the first possibility, of simulating a constant water flow rate and the total surface occupied by flood water, could be calculated, for different flow rate probabilities. The focus area is the Bilate River, where the villages of the Loka-Abaya Zuriya kebele are located.

## 2.9 HEC-RAS, HEC-GeoRAS and GIS integration

To facilitate the creation of geometric files for use by and the viewing of output from HECRAS the software package HEC-GeoRAS was created to manage the passage of geographic information between the GIS environment and HEC-RAS. HEC-GeoRAS facilitates the development of geographic features to be stored in GIS layers. Users edit the layers by digitizing or loading pre-existing data into these layers in preparation to developing a geometric file for use by HEC-RAS.

The basic data HEC-GeoRAS utilizes in developing geometry files include a DTM, in the form of a GRID or TIN, and geographic features located in GIS layers. HEC-GeoRAS handles these layers and by utilizing the digital terrain model creates an input file, which HEC-RAS accepts as an input for the creation of a geometry file. Upon completion of hydraulic computations HEC-RAS allows for the export of water surface profile data into an output file. With the output file HEC-GeoRAS creates new GIS layers representing water surface extents, velocity grids, and depth grids which can be viewed and analyzed within GIS (USACE, 2010). Brunner (2010a) indicates that the descriptions of HEC-RAS, HEC-GeoRAS and Arc-GIS as a whole indicated in Figure 2.1 constitutes therefore a coherent computation tool that allows primarily to prepare the geometric data (preprocessing) then, to make the necessary calculations (simulation) and finally, to exploit the results (post-processing).



2.1 Schematic representation of HEC-RAS, HEC-GeoRAS and GIS environment

### 3. MATERIALS AND METHODS

#### 3.1 Description of the study area

##### 3.1.1 Location of the study area

Loka- Abaya is one of the woredas in the Southern Nations, Nationalities, and Peoples' Region of Ethiopia. Part of the Sidama Zone located in the Great Rift Valley is found 57kms from Zonal capital (Hawassa), The Woreda is bordered in the North by Boricha Woreda; in the South by Abaya woreda of Borena Zone; in the West by Humbo and Damotwoyde Woredas of Wolita zone; and in the East by Dale and Chuko Woredas of Sidama Zone. Geographically, Lokabaya Woreda is situated between 38° 00' 33.56'' to 38° 21' 08.48'' East Longitude and 6° 25' 32.36'' to 6° 49'28.03'' North Latitudes.

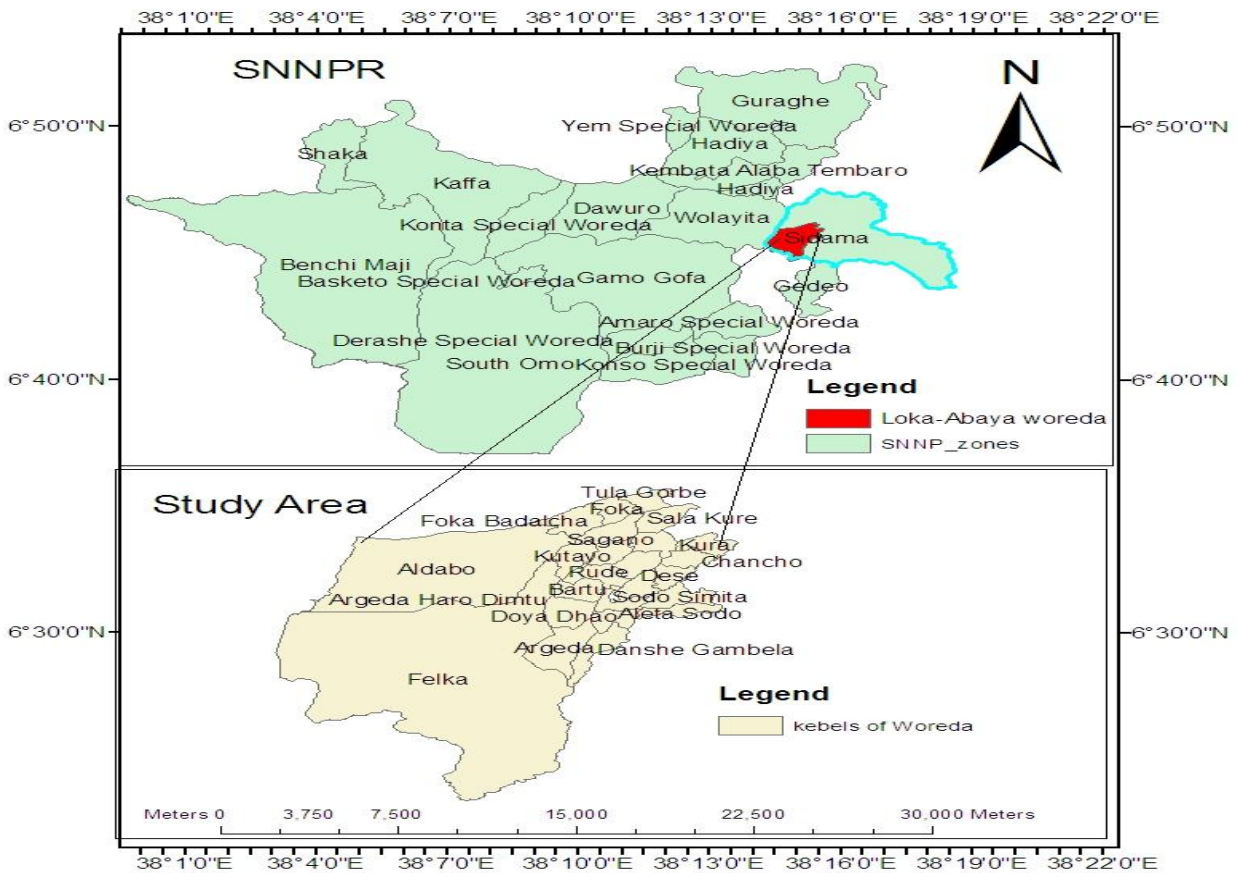


Figure 3.1 : location map of the study area

### **3.1.2 Topographic feature of the Area**

According to the GIS spatial analysis slope gradient computation results of Woreda area, around 25.82% area have almost flat topography, about 33.7% areas have gently undulating topography nearly 18.58% areas have Sloping feature and the remaining 21.9% area have rolling topography or Steep sloping.

### **3.1.3 Climate**

According to the climatic variables analysis results, the study area can be characterized as moist-warm climate with about 7 warm and dry months which can be used as an irrigation cropping season for the proposed project. Moreover, annual rate of evapo-transpiration is 2.28 times larger than the annual effective rainfall amounts of the study area.

### **3.1.4 Existing Farming system**

The farming system of the project area is dominantly Chat-Inset based low land cereals mixed farming system. The farming system is highly integrated with livestock production system. The farming system has two distinct farm areas where diversified types of crops are cultivated in two cropping seasons. These farm areas are: farm plots around the homesteads and the other is field plots which may be located bit far from their home.

The farm around the homesteads have more diversified crops than the field plots, where ensets, maize, sweet potato and shade trees are growing in mixed cropping system. In some areas cereal crops like maize (for green cob) and pulses are included as backyard activity to meet special purpose. Animal dung, wood ash and house disposal are the major source of soil improving nutrients to restore the soils and conserve the soil moisture. Moreover, the crop residues mainly the Inset leaf and other parts are reliable feed source for livestock mainly during dry season. The major crops growing on the main household landholding are haricot bean, maize, teff, and others.

### **3.1.5 Population**

Based on the 2007 Census conducted by the CSA, this woreda has a total population of 99,233, of whom 50,603 are men and 48,630 women; 1,059 or 1.07% of its population are urban dwellers. The majority of the inhabitants were Protestants, with 87.7% of the population reporting that belief, 3.88% were Catholic, 2.85% observed traditional religions, and 1.93% were Muslim.(CSA, 2007)

## **3.2 Material Used**

Generally, to process the overall required parameters, the following materials and GIS packages were used:

- ARCMAP 10.1 was used for GIS Analysis.
- Arc-Hydro module ArcGIS 10.1 extension was used for catchment delineation and drainage extraction; used for creating, managing and generation of different layer and maps;
- DEM or map of the study area from MoWIE and used for generation of Land use / land cover map in GIS;
- HEC-RAS 4.1 was used for flood inundation mapping;
- HEC-GeoRAS 10.1 was used for integration of GIS and HEC-RAS;
- Hec-RAS; Hec-GeoRAS and Arc GIS.

## **3.3 Data collection and Analysis**

### **3.3.1 Topography**

The Bilate River catchment in Loka- Abaya woreda indicated in Figure 3 is divided in to two major zones Sidama and Wolaiyta: low land areas with an altitude less than 1695 m.a.s.l which mostly covers large part of the lower to central part of the catchment; middle land areas with an altitude of ranging from 1695 to 2285 m.a.s.l which mostly covers the central part of the catchment; and the high land areas having altitude above 2285 m.a.s.l which covers the from eastern to northern and from western to middle eastern edges of the study area. In addition, in this study area the minimum altitude is 1460 m.a.s.l which is the outlet of the catchment and a maximum altitude of 2873.7 m.a.s.l as shown in the figure3 below. The Bilate River catchment topography is highly exposed to soil erosion by high flood due to very steep land features. It is characterized by undulating terrain and steep slopes, erratic rainfall and sparse vegetation coverage which in turn facilitate soil erosion by flood. According to FAO (2006) guideline for soil description, the general shape of slope in both horizontal and vertical directions of this catchment ranged from 0 up to > 60 % which is from flat area to very steep slope. The slope of the study area is ranging from 0 to 66 % and based on the FAO classification the catchment is more dominated by moderately sloping to very steep slope as shown in Figure 3.2 below.

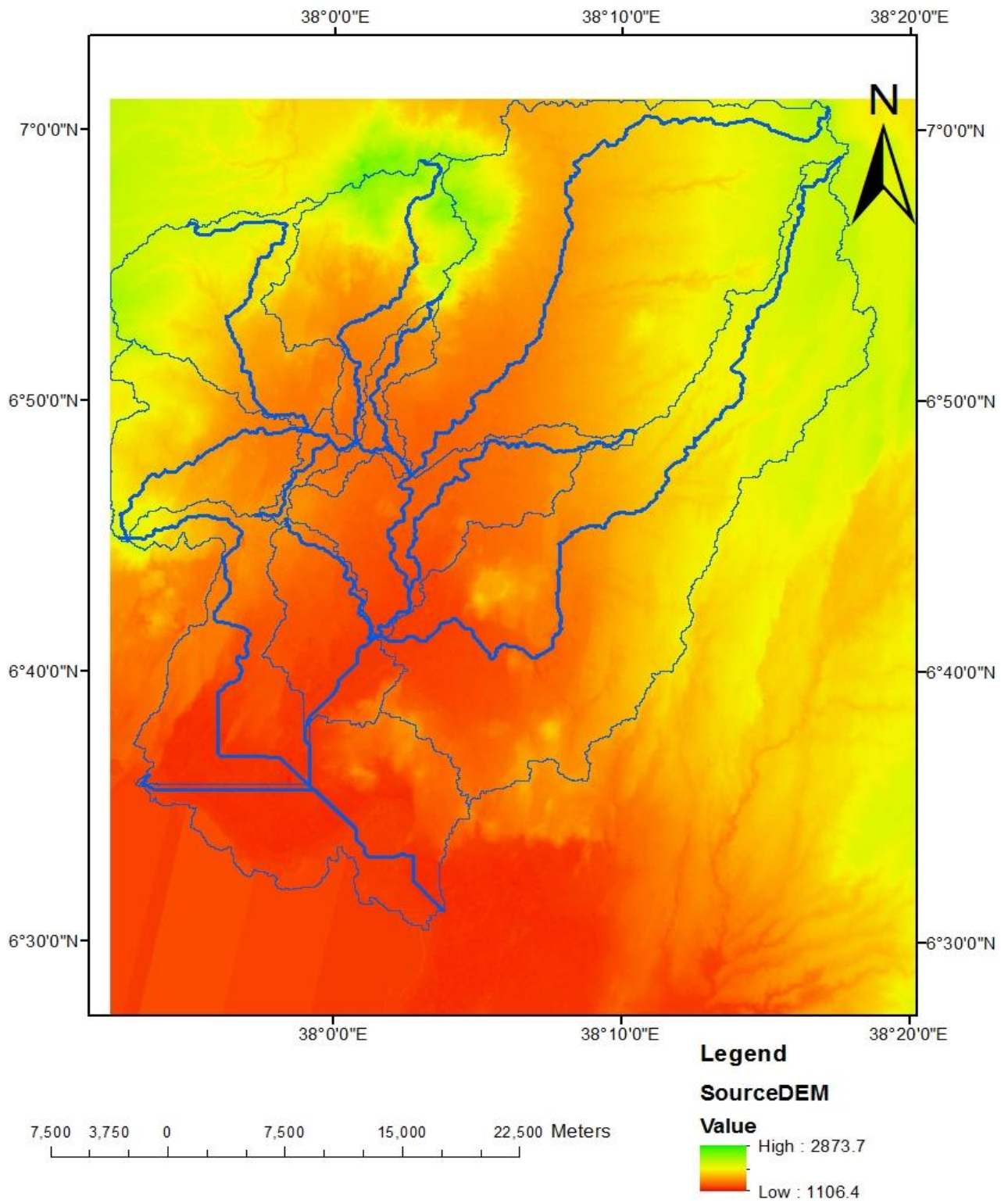


Figure 3.2 : Topographic/Elevation map of the study area in m.a.s.l

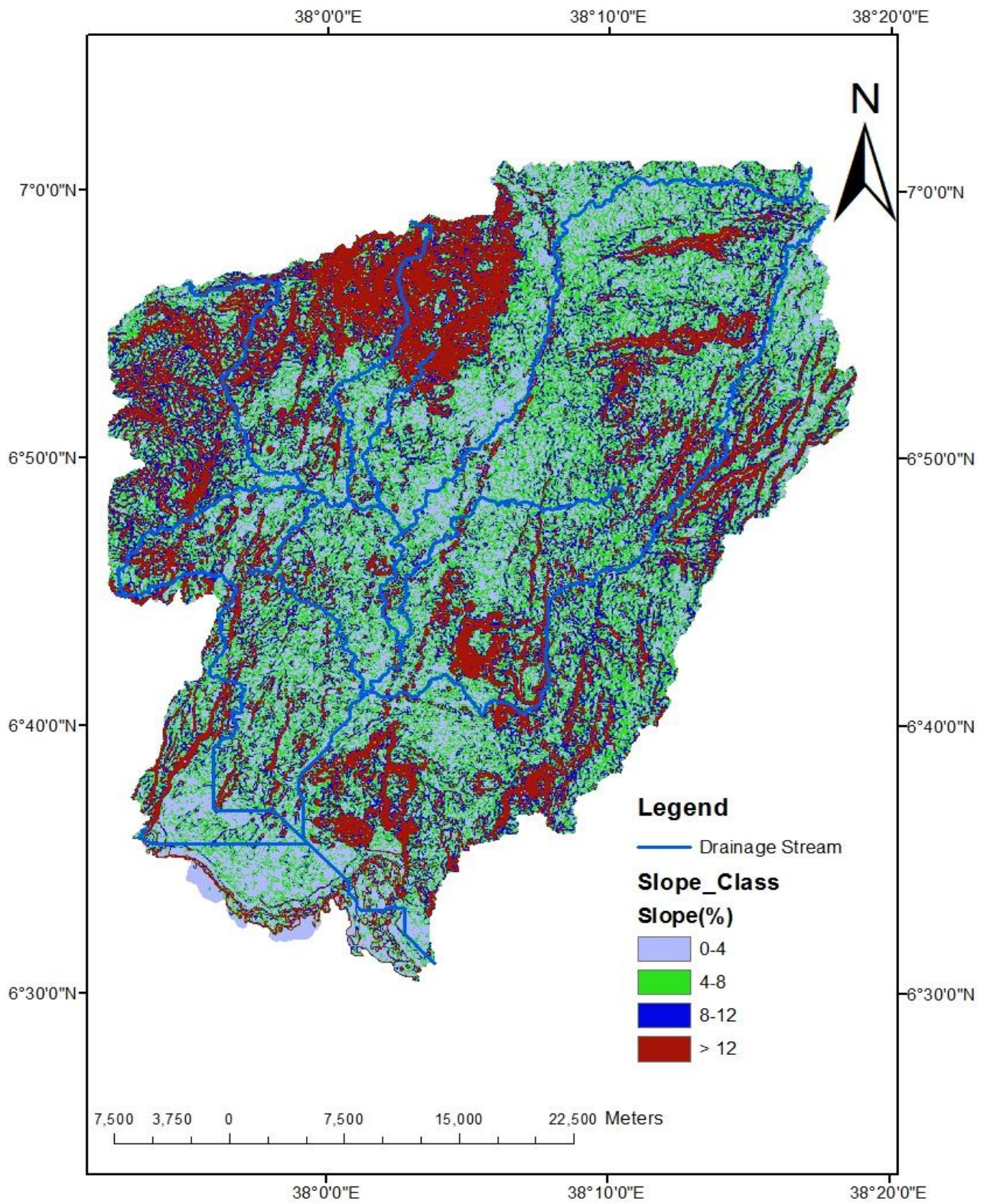


Figure 3.3 : Slope map of the study area (%)

Table 3.1 : Slope range and area coverage of the study area

Slope Class	Description	Area (ha)	% Area
0-4	Very gently sloping (flat)	46715.71	25.82
4-8	Gently sloping	60960.12	33.7
8-12	Sloping	33609.32	18.58
> 12	Steep sloping	39615.99	21.9

According to FAO (2006) guideline for slope description as shown in table 1 and as the above Figure4 indicated that the topography of the catchment is from steep sloping in the upper (comparatively very red color) to the flat in the lower part (yellow to green color) which the river has carved through the surrounding plateau. The river is located in an undulating terrain, begins from the upper Catchment Mountain to the lower part of the agricultural villages and water marshy lands. In addition to the map indicates us the upper catchment is very Steep Mountain which is high flood intensity; whereas the lower catchment is very flat area and comparatively almost similar slope which is exposed to soil erosion and degradation due to high intensity of flooding.

### 3.3.2 Drainage Networks

The study area is consisting of separate drainage units emerging from the western highlands to eastern lowlands of the catchment, which have a sub-parallel flow path in east-west directions. The southern, western and northern margin of the catchment is a source of the rivers in the study area and the south west of the study area is the most source of the main river line or stream line of the catchment. Most of the streams that originate in the catchment highlands flow following the dip direction at the middle of the catchment and join the major river system of the Lake Abaya as shown in Figure5

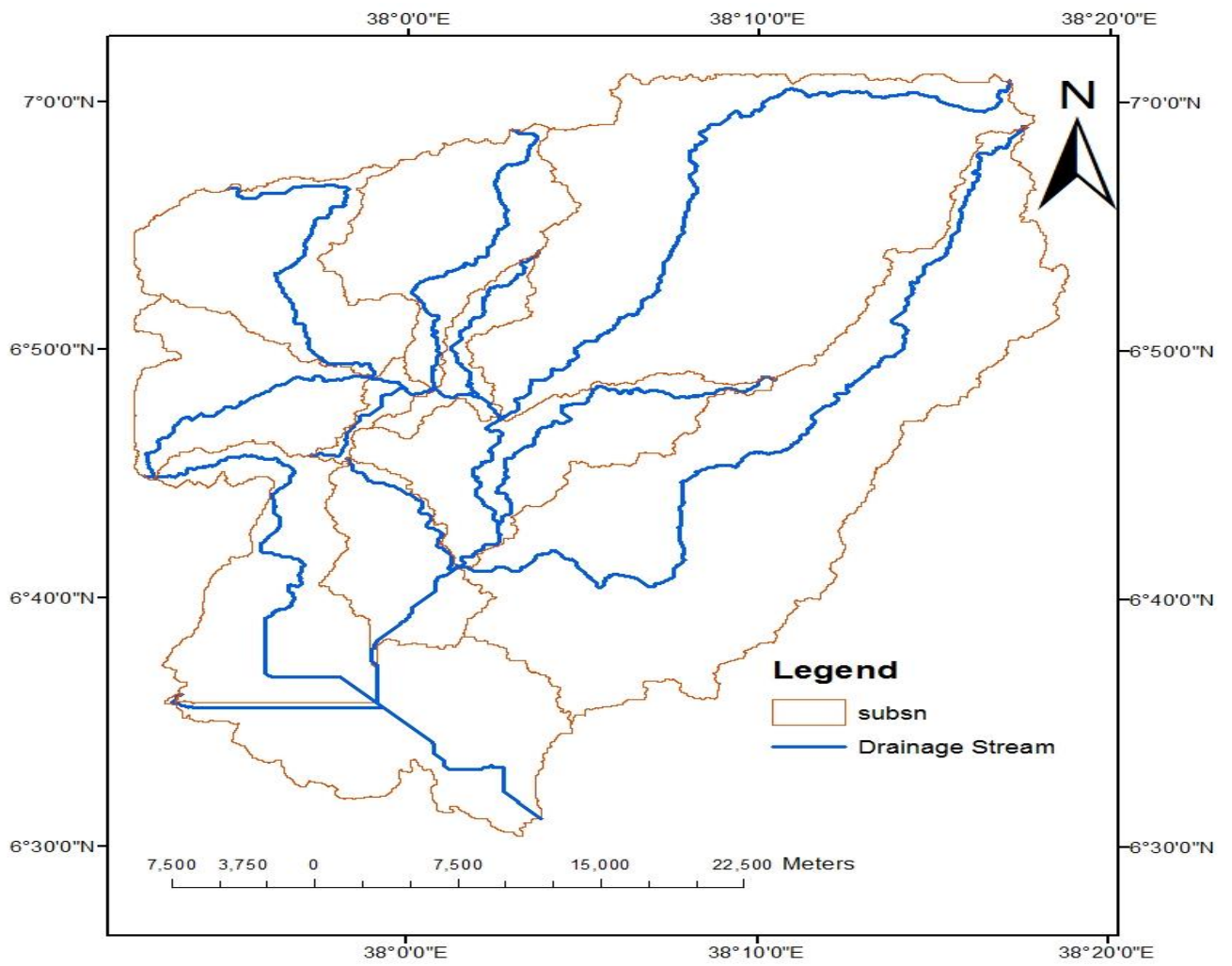


Figure 3.4 : Map of Catchment Boundary and Drainage Network of the study area

### 3.3.3 Soil Type

As indicated in Figure 6 and table 2 below the soil of the study area classified as FAO soil classification is classified into eight and the major soil in the watershed are namely Chromic Luvisols, Chromic Vertisols, Eutric Nitosols and Lithosols. The most widely covered soil of the study area is Chromic Vertisols (29.75%) followed by Lithosols (29.12%), Eutric Nitosols (23.83%), Chromic Luvisols (11.38%) and the less dominant soil type of the study area is Vitric Andosols (2.49%) which is found in the study area fig 6 and table 2

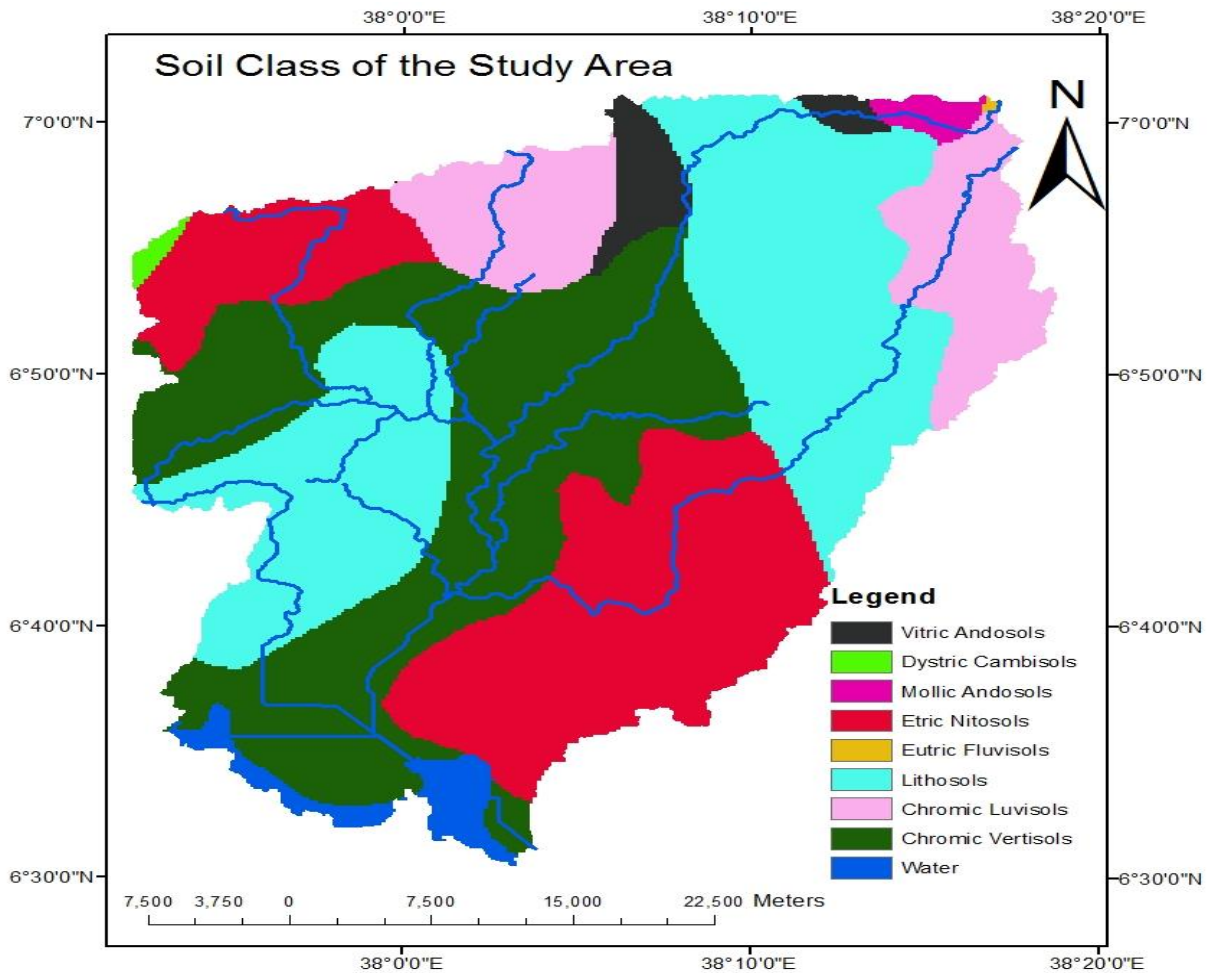


Figure 3.5 : Soil Map and Drainage Network of the study area

Table 3.2 : Soil Type and Coverage of the study area

Soil Types	Area Coverage (ha)	Percentage (%)
Chromic Luvisols	20589.48	11.38
Chromic Vertisols	53820.49	29.75
Dystric Cambisols	532.934	0.29
EutricNitosols	43107.27	23.83
EutricFluvisols	77.45	0.04
Lithosols	52681.95	29.12
Mollic Andosols	1362.59	0.75
Vitric Andosols	4507.78	2.49
Water	4221.18	2.33

### 3.3.4 Land use and cover

Land use and land cover is one of the most important factors that affect runoff in a watershed (ERADDM, 2002). Using GIS and Google Earth the reclassifications of the land use were done to represent the land use according to the specific land cover types. In addition, the map indicated in Figure7 and table 3 below is the LU/LC of the study area updated in the year of 2013.

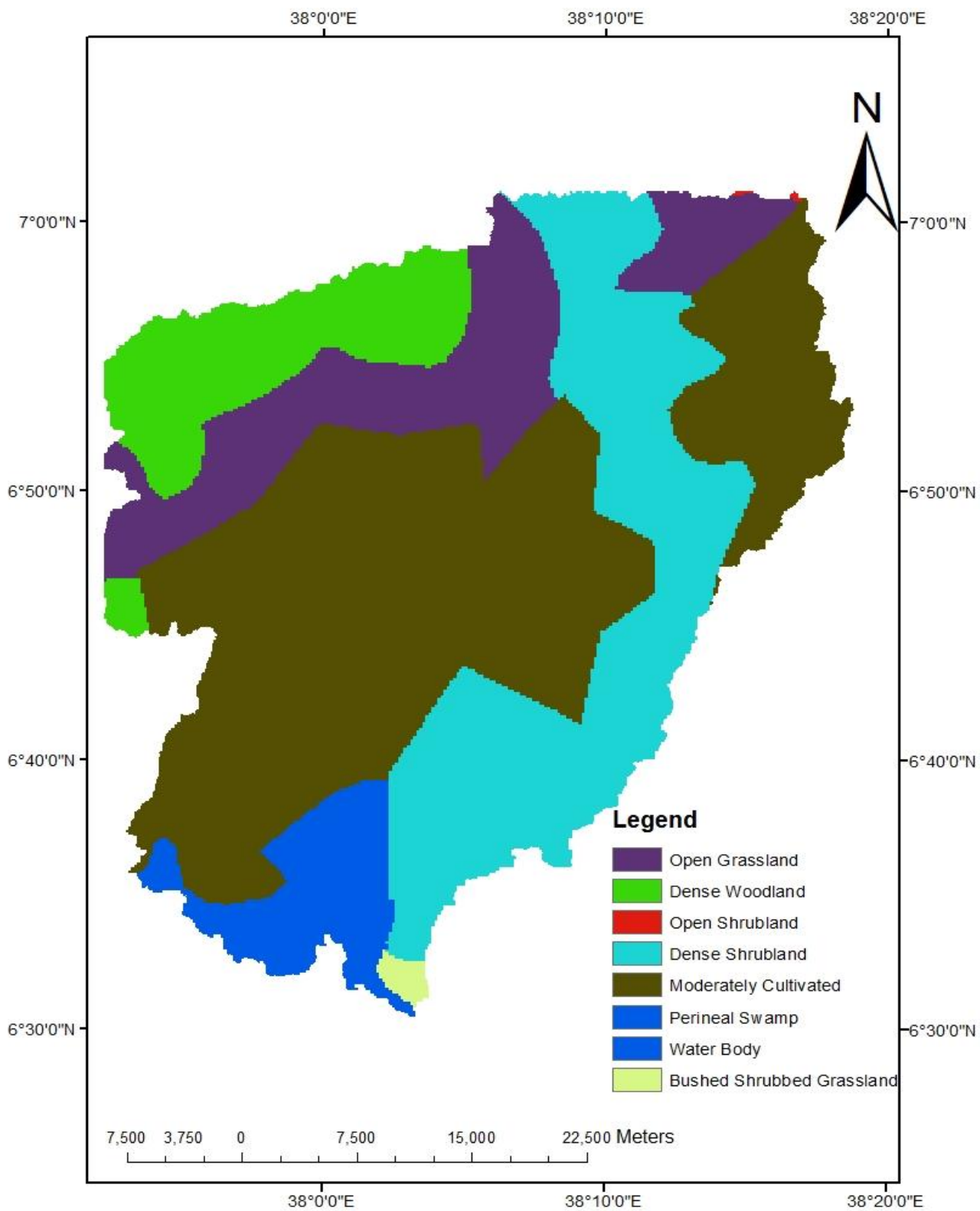


Figure 3.6 : Land use/land cover of study area

Table 3.3 : Land Use Type and Coverage of the study area

Land Use Class	Abbreviation symbol	Area Coverage (ha)	Area Coverage (%)
Open Grassland	PAST	26259.28	14.52
Dense Woodland	FRSE	18517.67	10.24
Open Shrubland	RNGE	64.00	0.04
Dense Shrubland	FRST	43682.82	24.15
Moderately and State Farm Cultivated	AGRR	79950.87	44.2
Perineal Swamp	WETN	7370.35	4.07
Water Body	WATR	4243.21	2.35
Bushed Shrubbed Grassland	RNGB	812.95	0.45

There are eight LU/LC types recognized from the land use map of Bilate River catchment or watershed as indicating Figure 6 above. The crop land which is used for Agriculture purpose, Dense Shrub land and Open Grassland which are the most dominant land use types while in smaller coverage land use are found.

### 3.3.5 Data Input Preparation for HEC-RAS

#### Pre-field work

This stage included collection of necessary information about the area, collecting available secondary data from different sources, preparing base map and preparation for field work including acquisition of field equipment's. Among the activities are reviewing the Rift Valley River Basin feasibility study and S/N/N/P/R/S Bureau of Agriculture and Natural Resource Development Disaster Risk Management and Food Security Coordination Office to have good understanding about the problem and to define the approach to the research and flood peak discharge estimation using SCS method for generating flood inundation and flood hazard mapping.

## **Field work and Post field work**

A field trip was made to collect primary data from the study area and secondary data from different sources. The primary data collection included, taking readings of outlet location and elevation of the study area using inspection site, collection of soil samples based on soil type and land cover of the study area for runoff curve number analysis and different part of the study area damaged by flood for flood inundation mapping and to see the effect of flood hazard on different land use. The ground truth field observations were focused on the description of the location, topography, main drainage networks, land use and location of damaged land uses areas by flood.

Data processing was the main activity of this stage. The data collected during pre-fieldwork and during fieldwork were processed and analyzed. The main activities here are organizing the collected data, preparing the database for the recharge calculation, and peak flood estimation for different return periods and flood inundation and flood mapping using SCS method and HEC-RAS software.

### **3.3.6 Rainfall Data**

The rainfall data from three rain gauge stations as indicated in table 7 which have been considered to describe the rainfall regime using Thiessen polygon areal ratio were collected and analyzed. The available data for twenty-eight years (1990 to 2017) have relatively consistent data, by using adequacy completeness and homogeneity methods; that can be used for the purpose of this study are listed in table 7. In this case the annual daily maximum rainfall data was taken for analyses. Since there is no stream flow data the peak flood was estimated from the recorded rainfall data using SCS rainfall – runoff model. Data was analyzed for Adequacy Completeness and Homogeneity by:

1. Extracting the daily annual extreme series.
2. Identifying and estimating the missed year's data.

A criterion for extraction of daily annual maximum series was the years of 1990 and 2016 for Aposto, Bilate, Bilate Tena and Morocho Station. The missed data was calculated using normal ratio method as indicated in equation 3.1 this is due to the annual maximum rainfall at each of the index station is outside 10% of that for the stations with a missing record; and also, the daily maximum rainfall (P) was calculated using equation [(ERADDM, 2002) and (FDREMWR, 2002)].

$$P_A = \frac{1}{n} \left[ \frac{N_A}{N_B} P_B + \frac{N_A}{N_C} P_C + \dots + \frac{N_A}{N_N} P_N \right] \dots \dots \dots (3.1)$$

Where;  $P_A = P_{max}$  = an estimated value for missing record at station A;

$n$  = number of stations;

$P_B, P_C \dots P_N$  = rainfall records at index stations at a time of missing records,

$N_A, N_B, N_C,$  and  $N_N$  = Normal annual maximum rainfall values at stations A, B, C ...N. To use the stations climatic data to the watershed area coverage ratio modeling process a Thiessen polygon method was developed and used accordingly. This method was used in the ArcGIS to determine how much part of the watershed is covered by each of the meteorological stations as shown in Figure 8. Thiessen polygon method was applied to estimate the mean annual rainfall for the entire watershed. In the Thiessen polygon method, the study area is divided into three polygons with the rain gauge in the middle of each polygon assumed to be representative for the rainfall on the area of land included in its polygon. These polygons are made by drawing lines between gauges, and then making perpendicular bisectors of those lines form the polygons (ERADDM, 2002). The weighted mean of the precipitation was calculated using equation 3.2 which resulted in 77.68 mm/day of mean annual daily maximum rainfall for the entire Bilate River catchment for Bilate meteorological station which is the class I station.

$$P = \frac{A_1 P_1 + A_2 P_2 + A_3 P_3 + \dots + A_i P_i \dots A_n P_n}{A_t} \dots \dots \dots (3.2)$$

Where:  $P$  = Mean annual maximum rainfall on the entire catchment whose area is  $A_t$  [mm],

$A_1, A_2, A_3 \dots A_n$  = Area of enclosed polygons [ $km^2$ ]

$P_1, P_2, P_3 \dots P_n$  = daily annual maximum rainfall of each stations [mm]  $A_t$  = Total area of the catchment [ $km^2$ ]. The geographical coordinates of each meteorological stations and the delineated watershed boundary through use of the application of Thiessen polygon in ArcGIS (Table 4) helps to capture the grids for annual maximum daily precipitation for use for ungauging stream flow using SCS method for peak flood estimation.

Table 3.4 : Location of Metrological stations for Thiessen polygon application

Station Name	Longitude (E)	Latitude (N)	Altitude (m)
Aposto	38 <sup>0</sup> 22' 19.9"	6 <sup>0</sup> 44' 09.0"	1762
Bedesa	37 <sup>0</sup> 56' 17.6"	6 <sup>0</sup> 52' 13.0"	1609
Billate	38 <sup>0</sup> 05' 16.1"	6 <sup>0</sup> 49' 20.3"	1361
Billatetena	38 <sup>0</sup> 07' 32.1"	6 <sup>0</sup> 55' 50.1"	1496
Morocho	38 <sup>0</sup> 24' 32.9"	6 <sup>0</sup> 52' 20.3"	1831
Belela	038 <sup>0</sup> 25' 07.4" E	06 <sup>0</sup> 56' 30.8" N	1866

(Source: Ethiopian Meteorological Agency Hawassa Branch)

As indicated in Figure8 the locations of Belela, Moroch and Aposto Metrological stations are do not share boundary with study area but they are used for preparation of Thiessen polygon given for better representation.

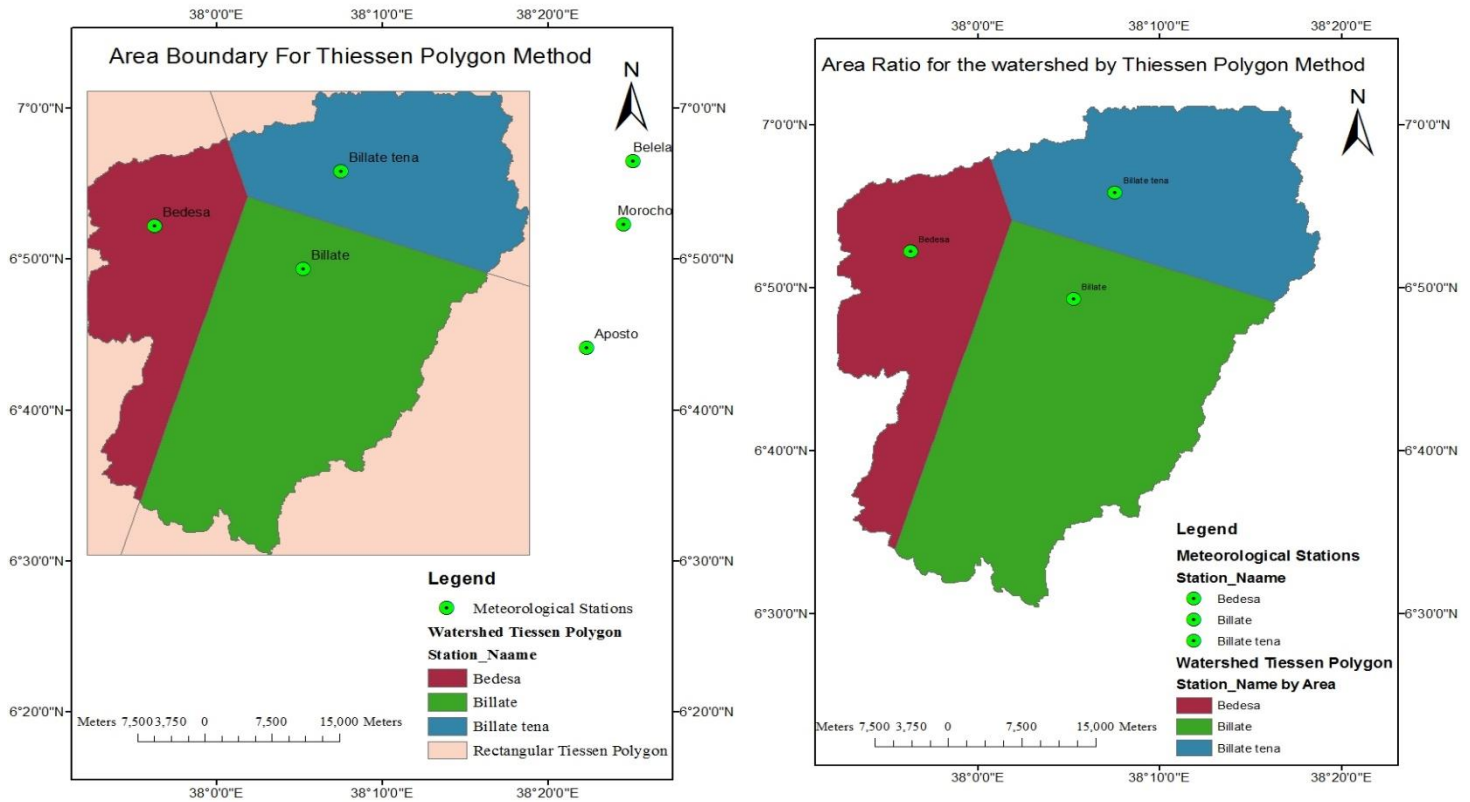


Figure 3.7: Spatial distribution of rainfall stations for generating Thiessen polygon map

The Thiessen polygon generated grid clearly identifies areal weight of each meteorological station, and accordingly, the percentage of areal coverage of Bedesa 23.65%, Billate tena 27.42% and Billate 48.93% has covered the watershed area (Table 5).

Table 3.5 : Metrological stations-based area coverage of the study area

S.No	Shape type	Station name	Shape Area (Km <sup>2</sup> )	Area Coverage (%)
1	Polygon	Bedesa	561.4910932	23.65
2	Polygon	Billate	1163.712991	49.01
3	Polygon	Billatetena	649.1901248	27.34
Total			2374.394209	100

**3.3.7 Data adequacy, Goodness of fit and consistency checking**

As per ERADDM (2002) and FDREMWR (2002) the following different equations for the purpose of testing the consistency of record and finally reconstructing the data for any gaps and inconsistency of records are used:

**A. Data adequacy:** The adequacy of rainfall data in research will be made by using outlier which is given as “higher outlier” and “lower outlier” and can be expressed by the following formulas.

$$\text{Higher outlier} = \hat{Y} + Kn\sigma \dots\dots\dots (3.3)$$

$$\text{Lower outlier} = \hat{Y} - Kn\sigma \dots\dots\dots (3.4)$$

$$\text{Standard error} = \frac{\sigma^2}{\sqrt{N*100}} \dots\dots\dots (3.5)$$

Where; n = total number of rainfall data,  $\hat{Y}$  = mean rain falls of the given data,  $\sigma$  = standard deviation of the given data, and  $\sigma^2$  = variance of the given data. In addition to this test for adequacy will be made and if the standard error is < 10%, the data is adequate but if it precedes 10% the data could not be adequate.

**B. Goodness of fit:** The goodness of fit can be checked by after the frequency distribution analysis is done using the methods described in the topic of flood frequency distribution analysis and observed which distribution fits the given data. After observing and choosing which method can fit the data given, we can conclude that distribution analysis fits the data and the goodness of fit is good and better as that frequency distribution analysis method.

**C. Data consistency:** The consistency (K) is given by the following equation:

$$K = \frac{\sigma}{\hat{Y}_m * N^{0.5}} \dots\dots\dots (3.6)$$

Where: N = total number of rainfall data,  $\sigma$  = standard variation of the given data, and

$\hat{Y}_m$  = mean rainfall of the given data.

### 3.3.8 Methods of Flood Frequency Analysis

The flood frequency analysis is one of the important studies of river hydrology. It is essential to interpret the past record of flood events in order to evaluate future possibilities of such occurrences. The estimation of the frequencies of flood is essential for the quantitative assessment of the flood problem.

Frequency of a hydrologic event, such as the annual peak flow is the probability that a value will be equaled or exceeded in any year. The length of record should be sufficient to justify extrapolating the frequency relationship. For example, it might be reasonable to estimate a 50-year flood on the basis of a 30-year record, but to estimate a 100-year flood on the basis of a 10-year record would normally be absurd (BWDB 2010). Frequency analysis is cautioned when working with shorter records and estimating frequencies of hydrologic events greater than twice the record length (Viessman and Lewis 1996). The flood frequency analysis is one of the important studies of river hydrology which was conducted based on maximum instantaneous flow (Yadav 2002)

As per Chow et al. (1988), ERADDM (2002) and FDREMWR (2002) the following different equations for different flood frequency analysis methods are used for determination of peak flood. When there is stream flow data arranged in the descending order of magnitude, they constitute statically array whose distribution can be expected in terms of frequency of occurrence.

The probability “p” of each event being equal to or exceeded (plotting position) formula using Weibull.

$$P = \frac{m}{N+1} \dots\dots\dots (3.7)$$

Where; m = order number of the events and N = Total number of events in the data. The recurrence interval (T) return interval is calculated as:

$$T = \frac{1}{P} \dots\dots\dots (3.8)$$

But in our case, there is no measured flow data instead it is possible to determine the probability of occurrence of daily maximum rainfall (rain fall frequency analysis). The general equation for flood frequency analysis is:

$$X_T = \mu + K \times \sigma \dots\dots\dots (3.9)$$

Where;  $X_T$  = Value of variant (X) of random hydrologic series with return period (T),

$\mu$  = Mean value of variant,  $K$  = frequency factor which depends up on the return period (t)

And assumed frequency distribution, and  $\sigma$  = standard deviation of variate.

The most frequency-distribution functions in the hydrologic studies can be expressed by the

General equation of hydrologic frequency analysis:

$$X_T = X_m + K_T \sigma \dots\dots\dots (3.10)$$

Where;  $X_T$  = value of the variation X of a random hydrologic series with a return period T,  $X_m$  = mean of the variate,  $\sigma$  = standard deviation, and  $K_T$  = frequency factor which depends up on the return period T and the assumed frequency distribution.

Frequency analysis can be conducted in two ways: one is the analytical approach and the other is the graphical technique in which flood magnitudes are usually plotted against probability of exceedance. Different frequency analysis method is described the following section.

**A. Normal distribution Method of Analysis:** if the distributions of the rain fall data is normally distributed.

$$K_T = \frac{X_T - X_m}{\sigma} \dots\dots\dots (3.11)$$

Where;  $K_T$  = frequency factor,  $X_T$  = value of the variate  $X_m$  = mean of the variate, and  $\sigma$  = standard deviation of sample data.

**B. Log Normal Distribution Method of Analysis:** if the distributions of the rain fall data is log-normal and the following formula can be used for determining the frequency factor ( $K_T$ ).

$$U = w - \frac{c_0 + c_1 w + c_2 w^2}{1 + d_1 w^2 + d_2 w^3 + d_3 w^3} \cdot + \varepsilon(p) \dots\dots\dots (3.12)$$

Where;  $C_0 = 2.515517$ ,  $C_1 = 0.802853$ ,  $C_2 = 0.010328$ ,

$d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308, \varepsilon(p) = \text{error, it is less than } 4.5 \times 10^{-4} \text{ or } K_T =$

$$Z = W - \left[ \frac{(2.516 + 0.802W + 0.0103W^2)}{1 + 1.4328W + 0.1893W^2 + 0.0013W^2} \right] \dots \dots \dots (3.13)$$

Where; W is intermediate variable calculating from the formula of:

$$W = \left[ \ln \frac{1}{p} \right]^{\frac{1}{2}} \dots \dots \dots (3.14)$$

Where; p is the probability of exceedance. When  $p > 0.5$ ,  $1 - p$  is substituted for p and the value of Z which is computed is given a negative sign.

**C. Log Pearson Type III Distribution Method of Analysis:** if of the rain fall data is fitted by this distribution. The frequency factor of this distribution depends on return period T and coefficient of skewness ( $C_s$ ). when  $C_s$  was zero then  $K_T = Z$ , if not  $K_T$  would be approximated by:

$$K_T = Z + (Z^2 - 1)K + \frac{1}{3}(Z^3 - 6Z)K^2 + ZK^4 + \frac{1}{3}K^5 \text{ Where; } K = \frac{C_s}{6} \dots \dots \dots (3.15)$$

**D. Gumbel (EVI) distribution Method of Analysis:** Gumbel distribution is a member of family of Extreme Value distributions with the value of parameter  $k = 0$ . It is a two-parameter distribution and is widely used in hydrology. The frequency factor of this distribution is given by:

$$K_T = \frac{Y_T - Y_n}{S_n} \dots \dots \dots (3.16)$$

Where;  $Y_T$  is the reduced variation which is given by:

$$Y_T = - \left[ \ln \left( \frac{T}{T-1} \right) \right] \dots \dots \dots (3.17)$$

### 3.3.9 The SCS method of Runoff Estimation

Runoff was estimated with the aid of hydrological model using USDA (1985) for estimation of surface runoff using SCS-CN model. According to USDA (1985) Figure 3.9 below shows the methodology followed to estimate runoff using SCS-CN model to achieve the first objective of the research.

#### 1. Curve number model

The CN values documented for the case of AMC-II (USDA, 1985) and to adjust the CN for the cases of AMC-III, the following equations are used:

$$CN(III) = \frac{23 \times CN(II)}{10 + (0.13 \times CN(II))} \dots\dots\dots (3.18)$$

Where, CN (II) is the curve number for normal condition, and CN (III) is the curve number for wet condition.

#### 2. Runoff estimation

Surface runoff is mainly controlled by the amount of rainfall, initial abstraction and moisture retention of the soil. The SCS curve number method is based on the water balance equation and two fundamental hypotheses which are stated as, ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration and the amount of initial abstraction is some fraction of the potential infiltration.

$$\frac{Q}{P - I_a} = \frac{F}{S} \dots\dots\dots (3.19)$$

$$F = (P - I_a) - Q \dots\dots\dots (3.20)$$

Substituting equation (3.4) in to equation (3.5) and solving results:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \dots\dots\dots (3.21)$$

Where, Q is the actual direct runoff (mm), P is the total rainfall (mm), I<sub>a</sub> is initial abstraction which represents all the losses before the runoff begins and is given by the empirical equations:

$$I_a = 0.2S \dots\dots\dots (3.22)$$

Substituting equation (3.22) in equation (3.21) and it becomes:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{For } (p>0.2s) \dots\dots\dots (3.23)$$

Where, S is the watershed storage or the potential infiltration after the runoff begins (mm); S is related to CN and given by the following equation:

$$S = \frac{25400}{CN} - 254 \dots\dots\dots (3.24)$$

Where, CN is a dimensionless parameter and its value range from 1 (minimum runoff) to 100 (maximum runoff). It is determined based on hydrologic soil group, land use, land treatment, and hydrologic conditions depending on the study area criteria. Land Use / Land Cover of study area has been classified in five classes which are crop land, forest, bushes and shrubs, built-up area and bare land. Area under each class has been calculated from the attribute table and given in Table 3. The Land Use/ Land Cover thematic map and soil map are interpreted. Once the data has been gathered, the typical process for results and discussion of estimating the curve number for the catchment is summarized as follows (ERADDM, 2002):

Define and map the boundaries of the drainage basin for which curve number to be calculated. Determine the area of the catchment or drainage basin. b. Map the soil types and land use for the Bilate River catchment of interest; c. Converts the soil types to hydrologic soil groups based on their FAO Soil map descriptions; d. Overlay the land use and hydrologic soil group maps, identify each unique land use soil group polygon, and determine the area of each polygon; e. Overlay the catchment map on the land use soil group polygons; f. Assign a curve number to each land use classes, based on standard SCS curve number tables; and finally g. Calculate the curve number for drainage basin by area-weighting the land use-soil group polygons within the catchment boundary. According to FDREMWR (2002) the following equations of 3.25 to 3.31 below are recommended to be used in our country for determination of Peak rate of discharge created by 1mm run off depth (excess rain fall). Weighted CN for each sub area is worked out using the following equation:

$$\text{Weighted CN(II)} = \frac{\sum(CN_i \times A_i)}{A_i} \dots\dots\dots (3.25)$$

Where, CN<sub>i</sub>= Curve number for watershed uniform land use and soil types, A<sub>i</sub>= sub area with curve number CN<sub>i</sub>, and A<sub>t</sub>= Total area of the catchment. Slope of the main water course:

$$S = \frac{H_1 - H_2}{L} \dots\dots\dots (3.26)$$

Where;  $H_1$  = maximum elevation of the catchment (topographic map), m

$H_2$  = lower elevation of the catchment (topographic map), m

$L$  = length of water course (the longest flow path of the stream), m

Time to concentration:  $T_C = \frac{1}{3000} \left[ \frac{L}{S^{0.5}} \right]^{0.77} \dots\dots\dots$   
 (3.27)

Where;  $T_c$  = time to concentration (hr) and  $S$  = slope of the main water course (m/m)

Rainfall excess duration is given as:

$$D = 1 \text{ hr if } T_c > 3 \text{ hrs; } D = \frac{T_c}{6} \text{ if } T_c < 3 \text{ hrs} \dots\dots\dots$$

(3.28)

Where,  $D$  = rainfall excess duration (hr) and  $T_c$  = time to concentration (hr) Time to peak is given as:

$$T_p = 0.5\Delta + 0.6T_x \dots\dots\dots$$

(3.29)

Where;  $T_p$  = time to peak (hr),  $D$  = rainfall excess duration (hr)

$T_c$  = time to concentration (hr)

Time to base of hydrograph is given as:  $T_b = 2.67 \times T_p \dots\dots\dots$  (3.30)

Where;  $T_p$  = time to peak (hr),  $T_b$  = time to base of hydrograph (hr).

Peak rate of discharge created by 1mm run off depth on whole of the catchment (excess rain fall) ( $q_p$ ) is given as follows:

$$q_p = \frac{0.208 \times A}{T_p} \dots\dots\dots (3.31)$$

Where:  $q_p$  = is peak rate of discharge ( $m^3/s$ ),  $A$  = area of catchment ( $km^2$ ), and

$T_p$  = time to peak (hr)

## Hydrologic Soil Group Classification

According to the ERADDM (2002) HSG for Ethiopia, as indicated in table 3.6 below the two HSG types of the study area are hydrologic soil groups of B and D. HSG - B are soils which have soils primarily consist moderate infiltration rates when thoroughly wetted and these soils have a moderate rate of water transmission. They are Silt loam, or loam, due to moderately infiltration rates Soils having a moderately low runoff potential. HSG - D are soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential. These soils have a very slow rate of water transmission which are clay loam, silt clay loam, sandy clay, silt clay or clay; Soils having a high runoff potential due to very slow infiltration rates (ERADDM, 2002)

Table 3.6 : Types of Hydrologic Soil Group for Bilate River Catchment

SNo.	Soil Type	Hydrologic soil group	Area(ha)	Area(acres)	Area Ratio (%)
1	Vitric Andosols	B	4507.781	11138.9523	2.49
2	Dystric Cambisols	D/B	532.9396	1316.9205	0.29
3	Mollic Andosols	B	1362.5887	3367.0248	0.75
4	EtricNitosols	B	43107.2696	106520.2186	23.83
5	EutricFluvisols	A	77.4496	191.3817	0.04
6	Lithosols	C	52681.9489	130179.7299	29.12
7	Chromic Luvisols	D/B	20589.4871	50877.6521	11.38
8	Chromic Vertisols	D	53820.4935	132993.1306	29.75
9	Water	D	4221.1816	10430.7507	2.33

### **3.4 General HEC-GeoRAS and HEC-RAS Model Description**

HEC-RAS is an integrated system of software, designed for interactive use in a multitasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for:

- 1) steady flow water surface profile computations;
- 2) unsteady flow simulation; and
- 3) Movable boundary sediment transport computations.

A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computations routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed (HEC-RAS 2010).

HEC-GeoRAS or HEC-RAS has been developed by USACE Hydrologic Engineering Center and it is a free downloadable with other supportive documents about how to use the model for flooded area mapping. The HEC-GeoRAS is a GIS extension with a set of procedures, tools and utilities for the preparation of river geometry GIS data to import into HEC-RAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC-GeoRAS model are TIN, DEM, and land use. The river geometry file and stream flow data are the input files for HEC-RAS to generate the water surface level along the River (USACE, 2002). HEC-GeoRAS is a data management interface between ArcGIS and HEC-RAS. This tool provides or creates the river geometric file to be analyzed in HEC-RAS model. The river stream centerline, bank lines, flow path centerlines, and XS cut lines should be digitized from a previous river file, aerial photographs, or topographical data sets using HEC-GeoRAS interface. The river reach (river segment between junctions), cross-section and other related data like flow paths and banks are stored in the geo data base file of HEC-GeoRAS. The river and cross-section data layers are created with predefined attribute tables that are manually populated in the case of the river and reach names, while all other attributes such as flood inundation are automatically calculated by the HEC-GeoRAS (Botes ZA and Smith, 2010). It is possible to edit the exported GIS geometric data in the HEC-RAS model using the

HECRAS editor tools. The HEC-RAS consists of a number of editor's tools to deal with different functions in the modeling process. For this study only the geometric, steady flow data, cross-section, and steady flow simulation editors are used. The .xml file exported from the HEC- GeoRAS is imported into the Geometric Editor, which is a Graphical User Interface (GUI) that is used to manage the geographic data. In this editor, the Manning friction values of left and right overbanks and channel were entered for the cross sections in each reach. The stream flow data is entered into the steady flow data editor. This editor extracts the river and data for the reaches from the geometric editor. To compute the water surface level, the model needs to know the starting water level at the start and end of reaches that are not connected and at junctions to other reaches (boundary conditions). For a steady flow analysis, four types of boundary conditions are available, namely known water surface level, critical depth, normal depth, and rating curve [(Brunner, 2013) and (Botes and Smith, 2010)].

### **3.5 Hydrological and hydraulic Model application for flood mapping**

Flood mapping models using GIS for hydrologic/hydraulic modeling usually involves three steps: 1) preprocessing of data, 2) model execution, and 3) post-processing/visualization of results. Pre-RAS, post RAS and GeoRAS menus of HEC-GeoRAS extension in ArcGIS were used for creating required data sets, making import file for model simulation in HECRAS.

**Pre GeoRAS-application:** The Pre-RAS menu option was used for creating required data sets for creating import file to HEC-RAS such as Stream centerline, main channel banks (left and right), flow paths, and cross sections were created. Also, 3D layer of stream centerline and cross section were also created for RAS GIS import file.

**HEC RAS application:** This is the major part of the model where simulation is done. The import files created by HEC-GeoRAS will import in Geometric Data Editor interface within HEC-RAS. All the required modification and editing were done at this stage. The flood discharge for different return periods were entered as steady flow data. Reach boundary conditions were also entered in this window. Then, the water surface profiles were calculated in steady flow analysis window. After finishing the simulation, the RAS GIS export files were created.

### 3.6 Flood Inundation and Flood Hazard data analysis

According to USACE (2002), the general method adopted for hydraulic modeling and flood hazard and flood inundation basically consists of different steps as indicated in the Figure9.

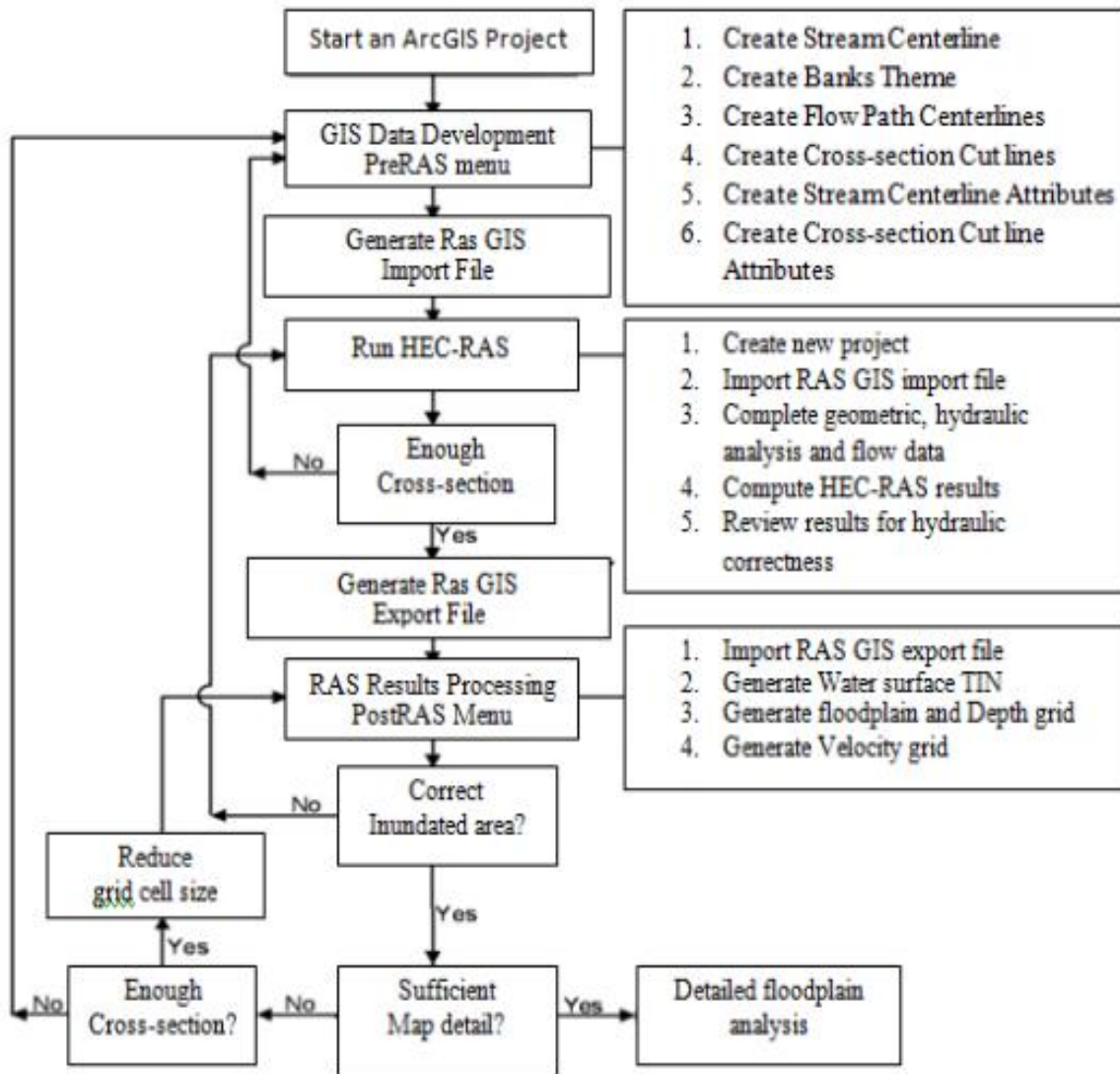


Figure 3.8 : The scheme showing data assimilation for flooding mapping

### **3.6.1. Pre-processing of Geometric Data**

#### **A. Generating DTM from DEM**

The beginning step in the pre-processing stage was to create a Digital Terrain Model (DTM) of the river system in a TIN format. The TIN must be constructed with a special care in order to provide for accurate analyses. Elevation data for each cross section is extracted from the TIN. The objective of this part is to form the spatial data required to generate a HEC-RAS import file with a 3-D stream network and 3-D cross sections defined. Watershed and stream delineation developed in this step is preliminary and they are used for stream delineation (USACE, 2002)

#### **B. Creating RAS Layers**

According to USACE (2002) this is the main objective of the pre-processing HEC-GeoRAS for creating physical attributes in Arc-GIS and then exporting them to the HEC-RAS geometry file. The geometry file for HEC-RAS contains information on cross-sections, hydraulic structures, river banks and other physical attributes of river channels. In HEC-GeoRAS, each attribute is stored in a separate feature class called as RAS Layer. The RAS layers were created in one step and stored collectively in a Geo-Database. By default, this Geo Database is saved under the same name and at the same location as the ArcMap project. The RAS layers are created by selecting from the HEC-GeoRAS toolbar and individual RAS layer created (digitized) after the creation and digitizing layers was done for the first four parts as in Figure 10 which are river, flow paths, banks and XsCutLines. Based on this, the next step to populate the remaining attributes of the river layer. After creating RAS layers, these are added to the map document with pre-assigned symbols. Since these layers are empty, the task is to populate some of these layers depending on the project needs, and then create a HEC-RAS geometry file.

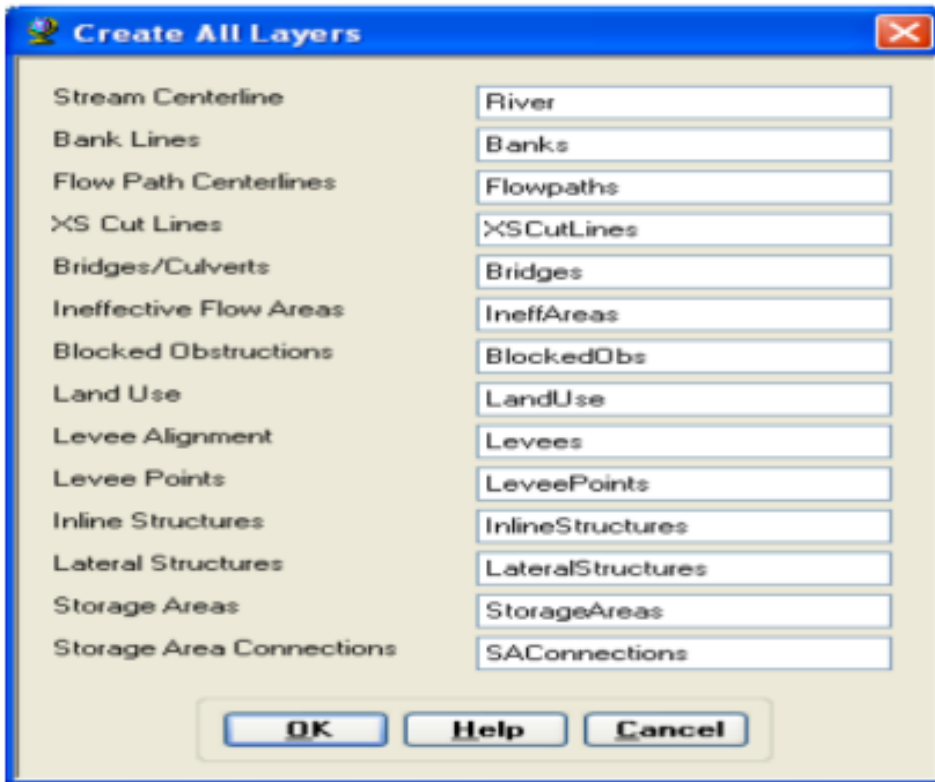


Figure 3.9 : Window for Creating Ras layer

### C. HEC-GeoRAS pre-processing to generate HEC-RAS import data file

According to USACE (2002) HEC-GeoRAS is an extension specifically designed to process geospatial data for use with the HEC-RAS. This extension allows us to create an HEC-RAS import file containing geometric attribute data from an existing DTM and complementary data sets, and also to process results exported from HEC-RAS. It creates an import file, referred as the RAS GIS Import File, containing river, flow paths, banks and XsCutLines. Prior to performing hydraulic computations in HEC-RAS, the geometric data must be imported and completed and flow data must be entered. Once the hydraulic computations are performed, exported results from HEC-RAS can be imported back to the GIS using HEC-GeoRAS for spatial analysis.

### D. Exporting GIS Data to HEC-RAS

The last step is to create a GIS import file for HEC-RAS so that it could export the GIS data to create the geometry file. First, it is necessary to define which layers would be exported to HEC-RAS. The Required Layers option is used for entering the River Layer, XS Cut Lines Layer and XS

Cut Lines 3D Layer. The Optional Layers option is used for entering other RAS layers. Figure 11 below shows a typical RAS Layers definition at Optional Layers tab. Export of GIS Data is performed in this way.

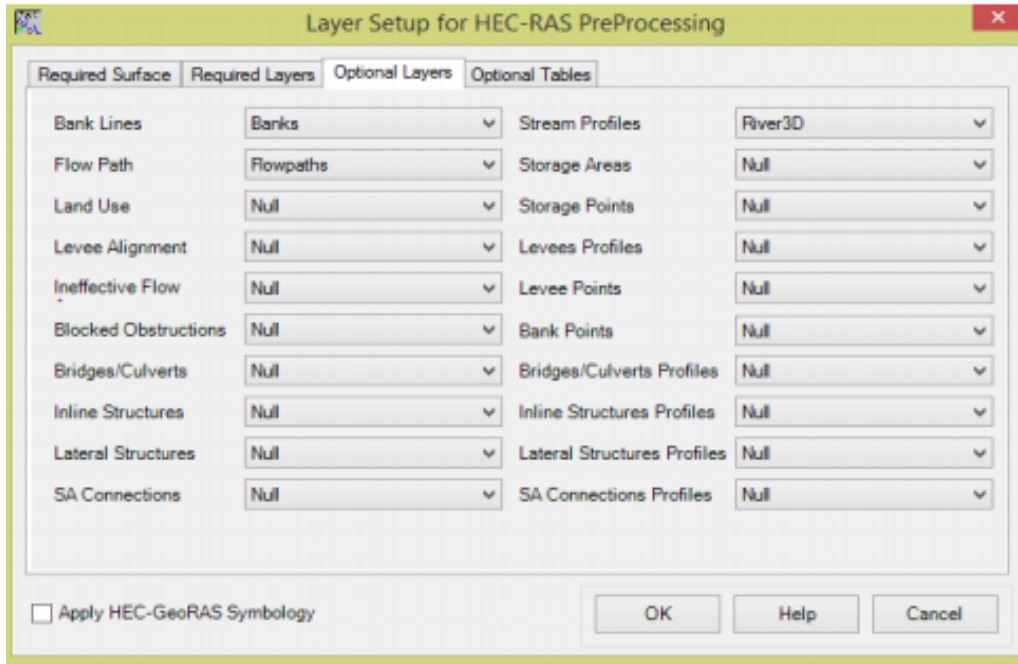


Figure 3.10 : Optional layer setup Definition window

### E. Creating Cross-sections in the Imported Geometric data

Cross-sections are one of the key inputs to HEC-RAS. Cross-section Cutlines are used to extract the elevation data from the terrain to create a ground profile across channel flow as indicated in Figure 3.13 below. The intersection of Cutlines with other RAS layers such as centerline and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), downstream reach lengths (distance between cross-sections) and Manning's n. Therefore, creating adequate number of cross-sections to produce a good representation of channel bed and floodplain is critical. Certain guidelines must be followed in creating cross-section Cutlines: (1) they are digitized perpendicular to the direction of flow; (2) must span over the entire flood extent to be modeled; and (3) always digitized from left to right (looking downstream) (USACE, 2010).

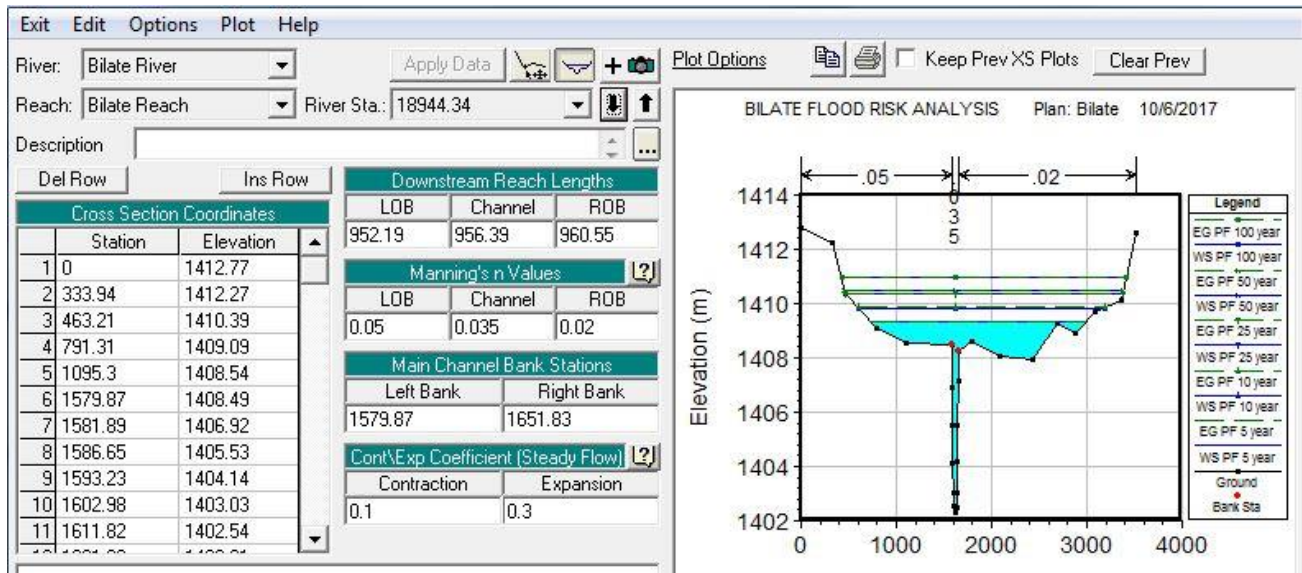


Figure 3.11 : Output of River Cross-section window profile

### Manning's Roughness Coefficient for flow data:

Manning's n values were used in the model to define roughness for each cross section. The "n" values were assigned in two steps: The first step involved defining land-use characteristics for common areas throughout the watershed and flood plain. Each land-use characteristic was given n-value based on published values for similar conditions (Chow, 1959) and on engineering judgment and experience. Once the land-use was defined for the entire watershed, the representative n-values were assigned to the portion of each cross section that intersects the respective use area. These n-values were then exported to the HEC-RAS model using HEC-GeoRAS.

For the study area the typical manning's coefficient is determined by using field visit or survey and compared it with the standard "n" values of different land use depending on the ERDDM (2002) shown in table 3 of appendix A.

### Flow Data to GIS Export

After the geometric data is completed and the steady flow data and new boundary conditions are entered, the HEC-RAS system is executed for the subcritical flow profile. The output results are checked for hydraulic correctness. The next or final step involves export of the computation results (water surface elevation) back to GIS. In the GIS export window, all five profile results (for the five

flow scenarios) are selected and exported using the default format “RASexport.sdf”. The Figure13 below shows the GIS Export window and the selected profiles used for export. Then, now return to ArcMap to create a flood inundation map.

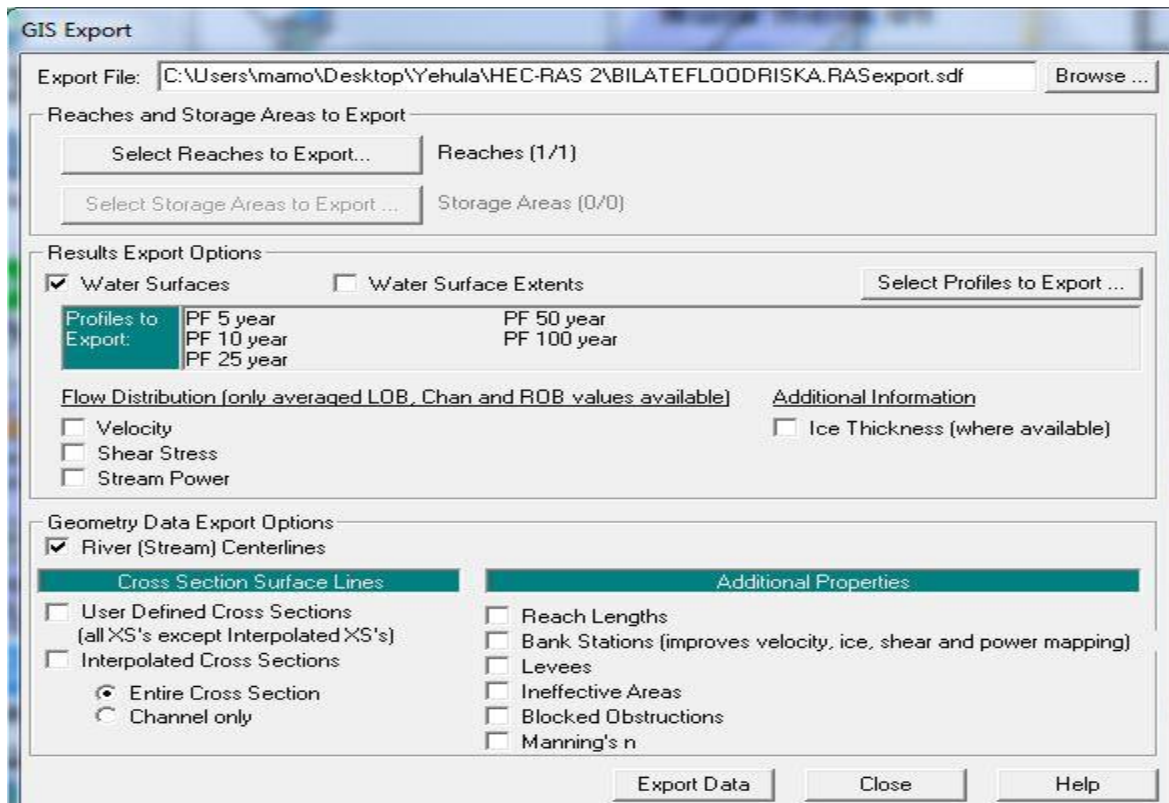


Figure 3.12 : GIS export window in HEC-RAS

### 3.6.2 Post processing of HEC-RAS results for floodplain mapping

With the development of a GIS Import File from HEC-RAS, we can begin the last portion of the model application. Post-processing using GeoRAS incorporates the water surface profiles derived from the HEC-RAS model into the spatial environment of GIS. The water surface profile data is used to develop a water surface TIN, and the intersection of the water surface TIN with the terrain model TIN provides flood visualization (USACE, 2002). The post-processing of computation results is performed using the same maps which were used for the pre- processing of geometry data. The only additions to these maps are new map layers. Detailed explanation of the data post-processing as follows:

The process starts with opening a desired ArcMap for post-processing. Since the HEC GeoRAS cannot read the proprietary spatial data format (.RASExport.sdf) file created in the HEC-RAS, It is necessary to convert into the XML file format, supported by HEC GeoRAS. This is achieved by selecting the “Import RAS SDF File” option from the HEC-Geo RAS Toolbar. Creating the Layer Setup is a necessary step for processing the HEC-RAS results. In the Layer Setup window, the type of analysis and the input and output data are identified. Now click on RAS Mapping → Layer Setup to open the post processing layer menu as Figure14 below shows a typical Layer Setup window from the data post-processing

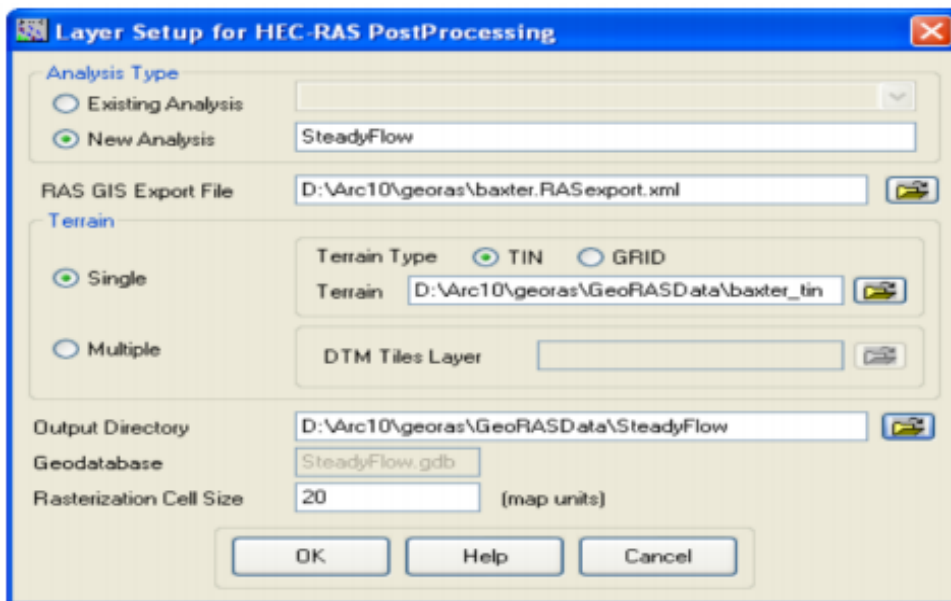


Figure 3.13 : Layer setup for HEC-RAS Post processing

### A. Hydraulic analysis Water Surface Profiles Using HEC-RAS

The HEC-RAS program, like the HEC-GeoRAS software, it can be downloaded free of charge from the Hydrologic Engineering Center's. The model is used for determination of water surface profiles for different flow scenarios. The peak discharge generated by the SCS method is used to determine the flow profiles and flood plain profiles for the selected return periods. The key data used in this model are field observation, cross sectional survey works using DEM and the peak flow resulted from simulation of the SCS method.

## **B. Flood Inundation mapping**

Flood hazard maps for the 5, 10, 25, 50, and 100-year floods were generated. Floodplain mapping is performed using the water surface elevations on the XS cut lines, within the limits of the bounding polygon. Flood plain mapping was completed in two steps, which are explained as water surface TIN and flood plain delineation.

### **I. Water surface TIN**

The first step is to create a water surface TIN from the cross-section water surface elevations. After the analysis extent is defined, we are ready to map the inundation extent. This can create a surface with water surface elevation for the selected profile which is all five-flow data. Water surface profiles are selected from the window. The TIN that is created in this step were defining a zone that was connect the outer points of the bounding polygon, which means the TIN can include area outside the possible inundation. At this point we have a water surface and we have an underlying terrain.

Now we can subtract the terrain from the water surface which is included in the water surface TIN. These areas are removed in the process of delineation with the bounding polygon was created that represents the flooded area.

### **II. Flood inundation mapping**

We select Ras mapping in order to do inundation map with select the profiles with highest flow data. The area with positive results (meaning water surface is higher than the terrain) is flood area, and the area with negative results is dry. All the cells in water surface grid that result in positive values after subtraction are converted to a polygon, which is the final flood inundation polygon (USACE, 2002). After the inundation map is created, we must check the inundation polygon for its quality. We had to look at the inundation map and the underlying terrain to correct errors in the flood inundation polygon. This is an iterative process requiring several iterations between GIS and HEC-RAS. The ability to judge the quality of terrain and flood inundation polygon comes with the knowledge of the study area and experience

## 4. RESULTS AND DISCUSSION

### 4.1 Estimation of peak flood

#### 4.1.1 Rainfall Data

The 28 years annual daily maximum rainfalls in mm are tabulated in the table7 and Figure 15 below from three meteorological stations that are Bilate, Bedesa and Bilate Tena. The daily rainfall data for entire basin collected and the weighted curve number of the watershed has been used for the estimation of direct runoff.

The major portion of this watershed is under agricultural land. Curve number table of the Soil Conservation Service was used to determine the curve number of the watershed. By intersecting the land use map and soil map the curve number was assigned to each combination of land use and soil type. Weighted value of CN was found out to be 84 for AMC II conditions. Then, the potential maximum retention can be easily calculated from the CN value, also missed rainfall was calculated using equation of 3.1, and the actual rainfall of the catchment (P) is determined by equation 3.2. Therefore, the runoff depth value can be used to estimate the peak runoff in cumec. After calculation the value is 898.1248 m<sup>3</sup>/s (Table 10)

Table 4.1: Annual maximum daily Rainfall (mm/day)

Year	Bil Tena	Bilate	Bedesa	RF Thiessen polygon
1990	59.6	44	29	44.7
1991	57.9	60	22.5	50.6
1992	75.9	38.6	61.2	54.1
1993	34.6	72.6	40.7	54.7
1994	70.5	22.4	64.4	45.5
1995	69.6	35.4	31.6	43.9
1996	84.3	54.8	55.8	63.1
1997	48.3	75.6	66.2	65.9
1998	48.2	50	38.7	46.8
1999	41	58.9	37	48.8
2000	54	49.2	44.6	49.4
2001	37	54.5	53.4	49.5
2002	34	52.2	36.6	43.5

2003	35.8	41.8	49.3	41.9
2004	58.4	65	39.9	57.3
2005	65.5	40.5	46.7	48.8
2006	62.7	48.2	62.1	55.5
2007	85	45.6	73.5	63.0
2008	48.2	58.5	62.3	56.6
2009	68.5	67.1	70.5	68.3
2010	43	69.7	59.5	60.0
2011	66	48	81.9	60.9
2012	51.1	50.5	57.2	52.2
2013	43	40.2	56.8	44.9
2014	84.8	42.6	57.7	57.7
2015	55	61.5	49.4	56.9
2016	27.7	77.7	69.9	62.2
2017	65.1	68	61.5	65.7

#### 4.1.2 Land Use and Land Cover

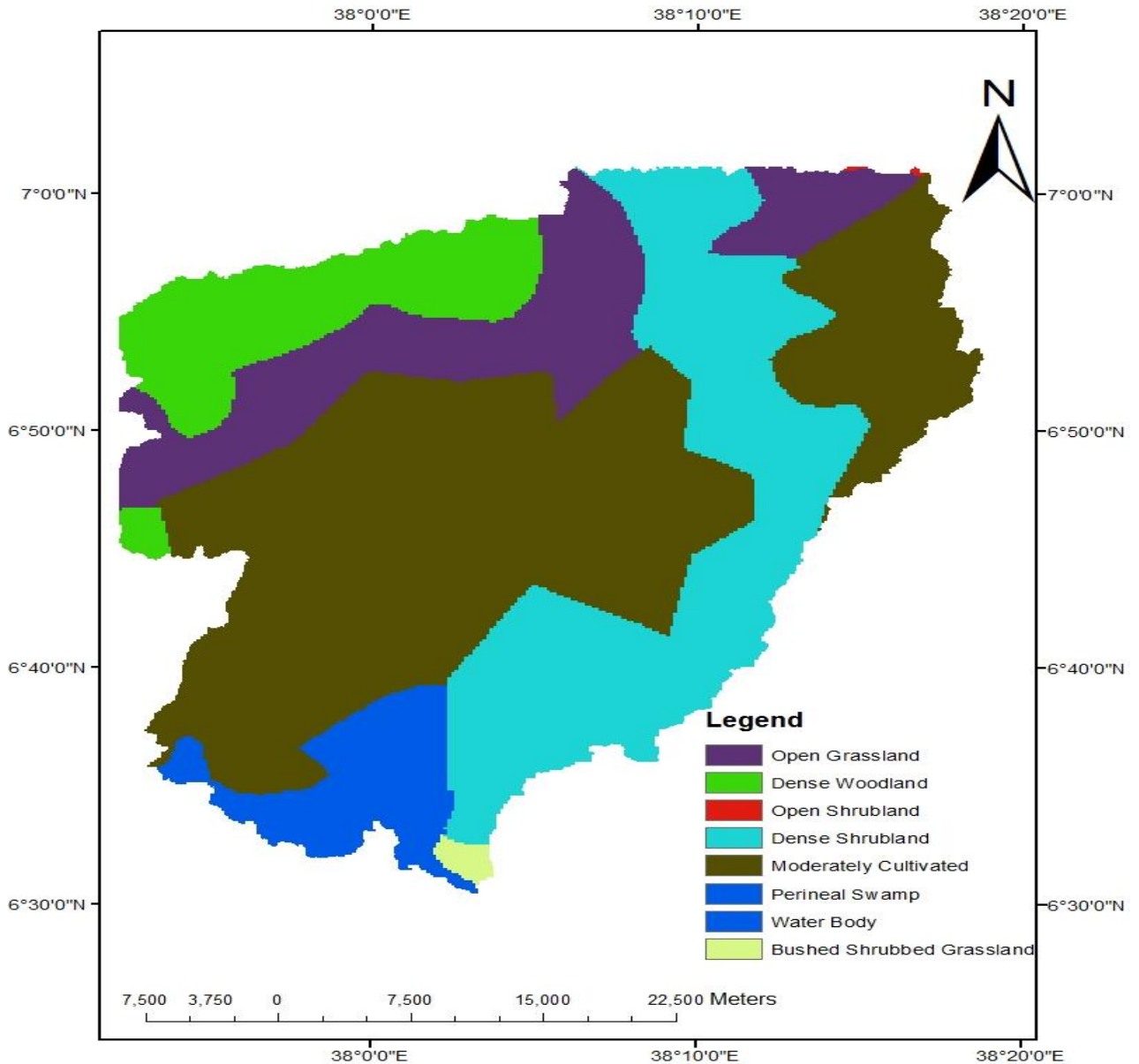


Figure 4.1: Land use/land cover of the study area

As indicated in Figure 16 above the land use and land cover classes were categorized in the watershed as given in table 3 above. The crop types of the study area are namely where enset, maize, sweet potato and shade trees are growing in the study area.

### 4.1.3 Hydrologic Soil Group (HSG) Classification

According to the ERADDM (2002) hydrological Soil Groups for Ethiopia are Groups of A, B, C, and D. According to soil map of the study area result, the soil of Bilate river catchment can be classified into three types; chromic Vitric Andosols, Dystric Cambisols, MollicAndosols, EtricNitosols, EutricFluvisols, Lithosols, Chromic Luvisols, Chromic Vertisols, Water. Table 8 Land Class based Hydrologic Soil Group coverage.

Table 4.2: CN Values for Bilate River Catchment

Land Use Class	Area Coverage (ha)	Area Coverage (%)	Hydrologic condition	Curve No	Ia	S	CN(II)	CN(III)
Open Grassland	26259.28	14.52	Fair,B	69	22.8	114.12	10.02	84
Dense Woodland	18517.67	10.22	Good,B	55	41.6	207.82	5.63	
Open Shrubland	64	0.04	Poor,D	83	10.4	52.02	0.03	
Dense Shrubland	43682.82	24.15	Poor,B	73	18.8	93.95	17.63	
Moderately and State Farm Cultivated	79950.87	44.2	Good,D	85	9	44.82	37.57	
Bushed Shrubbed Grassland	812.95	0.45	Poor,B	67	25	125.10	0.30	
Perineal Swamp	7370.35	4.07	Good,B	69	22.8	114.12	2.81	
Water Body	4243.21	2.35						
Total	180901.15	100						

The catchment area is dominated by the weighted CN value of cultivated land 37.6 and followed by Dense Shrub land 17.63 and Open Grassland 10.02 and the less dominant soil type of the study area Dense Woodland, Perineal Swamp, Bushed Shrubbed Grassland area and Open Shrub land come to be 5.63, 2.81 and 0.03 respectively.

Table 4.3: Table of Distribution Value and D-Index

Distribution	Distribution value	D-Index
<i>Normal distribution</i>	79.49642 mm	0.941004964
<i>Log normal distribution</i>	92.755mm	0.259597765
<i>Extreme value- I distribution</i>	84.951mm	1.116299215
<i>Pearson type III</i>	78.594mm	2.6768
<i>Log pearson type III distribution</i>	82.94mm	0.7221

D-index is minimum in case of log normal distribution hence on the bases of this test log normal distribution best fits the data, as result  $X_{50} = 92.755\text{mm}$  is taken as design point rainfall. The calculations are steted on appendix A below.

#### 4.1.4 Peak Flood for different Recurrence Periods

Time of concentration and the slope has been determined using equation 3.27 and 3.26 and respectively. The flood frequency analysis for 5, 10, 25, 50 and 100 years return period was determined using different methods and some of them are Normal distribution, Log normal distribution, Log Pearson type III distribution and Gumbel EVI distribution. The Log normal distribution, method was selected as a best fit due to the least value as compared to other methods. The results of flood frequency analysis for 24-hour rainfall depth for the different recurrence period are listed in the table of 10 below. To determine the peak discharge (Runoff estimation) it has been used the SCS method developed by the U.S soil conservation service (1972) because of the catchment area is greater than 50 hectares, applicable for areas which do not have stream flow records, it is also approved by the ERADDM and FDREMWR in 2002 for maximum flood estimation.

Peak runoff potential has been estimated using SCS method using equations of 3.18, 3.23, 3.31, and using the detail procedure equations of hydrograph. Maps and SCS method for various parameters have been generated and finally a map and SCS method showing the runoff potential has been prepared. Using SCS method calibration was performed for a period of twenty-six years (1990 to 2017) Loka-Abaya Watershed using Thiessen polygon method of annual daily maximum rainfall. The mean daily annual rainfall of the study area for the period between 1990 and 2017 is 54.14 mm with annual daily maximum rainfall of 85 mm in 2007 and annual daily minimum of 22.5 mm in 1991. The weighted curve number for AMC II and III for the catchment is estimated as per the SCS methodology and results are 69.7 and 84.4. The Rainfall data and the result of the calibrations for the five different return periods in the study area were obtained, and the result of the 24 hrs rainfall, runoff depth and maximum peak flow is presented in table 10 as shown below. The maximum peak discharge was determined using ordinate hydrograph for 1-hour time duration.

Table 4.4: Peak Discharge for Different Return Periods.

Return Period	24 hours rainfall Depth	Direct surface Runoff Depth	Maximum peak discharge
Years	P (mm)	Q (mm)	Qp (m <sup>3</sup> /s)
5	21.90	76.70	405.38
10	29.80	104.35	551.48
25	38.21	133.83	707.20
50	43.65	152.87	745.37
100	48.53	169.97	898.12

from the result of discharge for different return periods we can understand that as the return period increases the maximum peak discharge is increasing this is mainly due to land use land cover change and population growth of the study area.

## 4.2 Hydraulic analysis and Flood Mapping

### 4.2.1 Pre-processing of Geometric Data

Hydraulic modeling in this pre-processing research was conducted for the main Bilate River line downstream from the total of 23.54 km. 20 cross sections at different suitable intervals are created the extent average of 1.17km. The cross sections distance restriction is do not have rule due to differences in direction, size, and depth of the river. It was done by taking many sections in the curve and downstream part for reduction of errors, using assumptions of cross sections Cutline rules such as the crossing always from left to write, no cross each other, the crossed line should be perpendicular to the river line and should extent to the flood plain. Based on this the results of preprocessing developed map including DTM, river lines, banks,flow paths and cross-section Cutline with 3-Dimensions are shown in the Figure17 below.

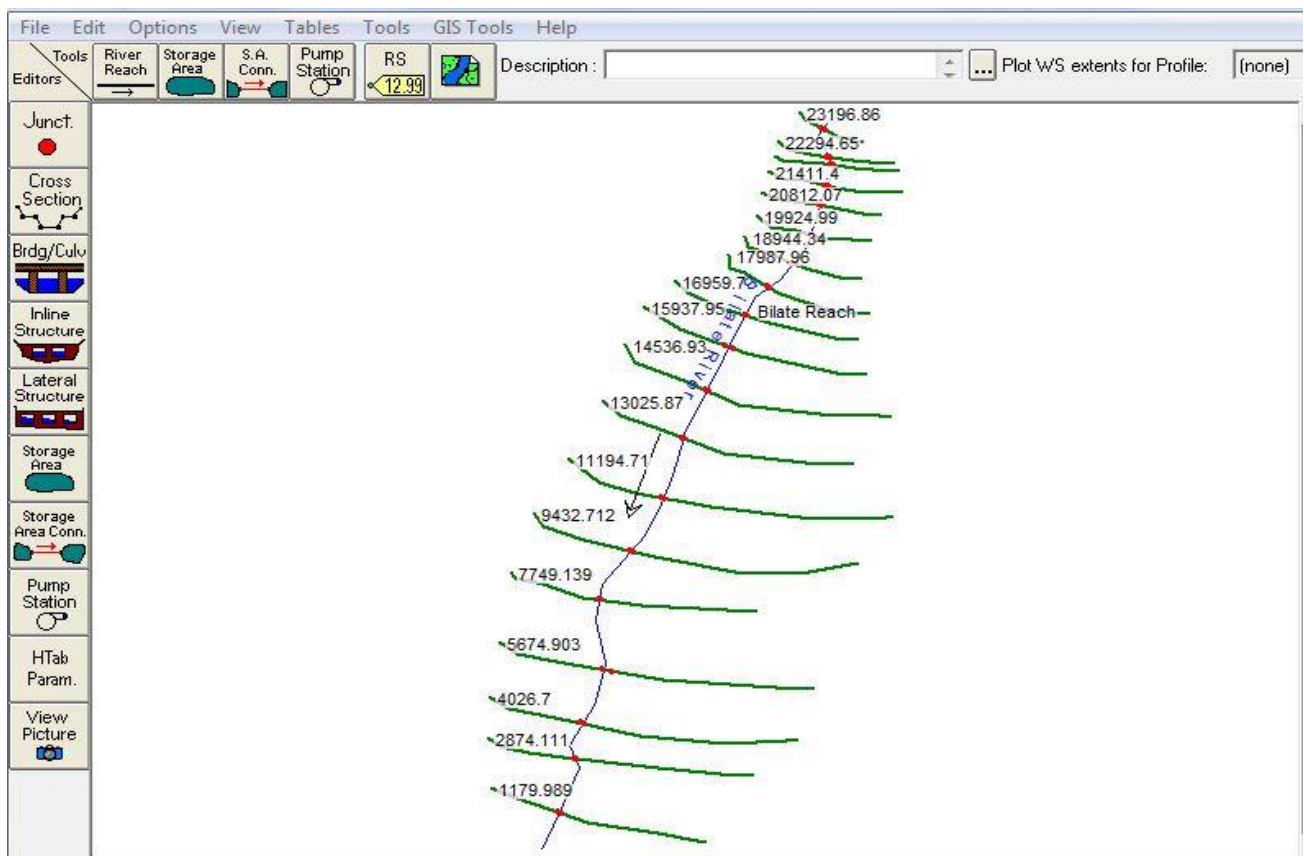


Figure 4.2 : Pre-processing and Cross-section cut lines Map of the study area

#### **4.2.2 Hydraulic Results in HEC-RAS**

After finishing the cross sections of Bilate River and importing the pre-processed Geometric data shown in Figure11 below, the maximum flood discharge with different return periods, and other information such as the coefficient of roughness of the main channel and normal depth, modeling was performed. Therefore, the roughness value was determined by comparing the manning's value for different land uses recommended for our country approved by ERADDM with that of Bilate River catchment and found to be 0.035 and 0.05 for main channel and overbanks respectively. The flow regime was considered as steady one and boundary conditions for downstream river flow a downstream normal depth 0.035 slope of Bilate River using downstream reach elevation difference and length were introduced. After stimulating the flow in HEC-RAS Model, its many characteristics such as cross-sectional profile as shown in Figure18 below can be observed and based on their result of river and flood control option can be provided and also these areas show the level and depth of flooding

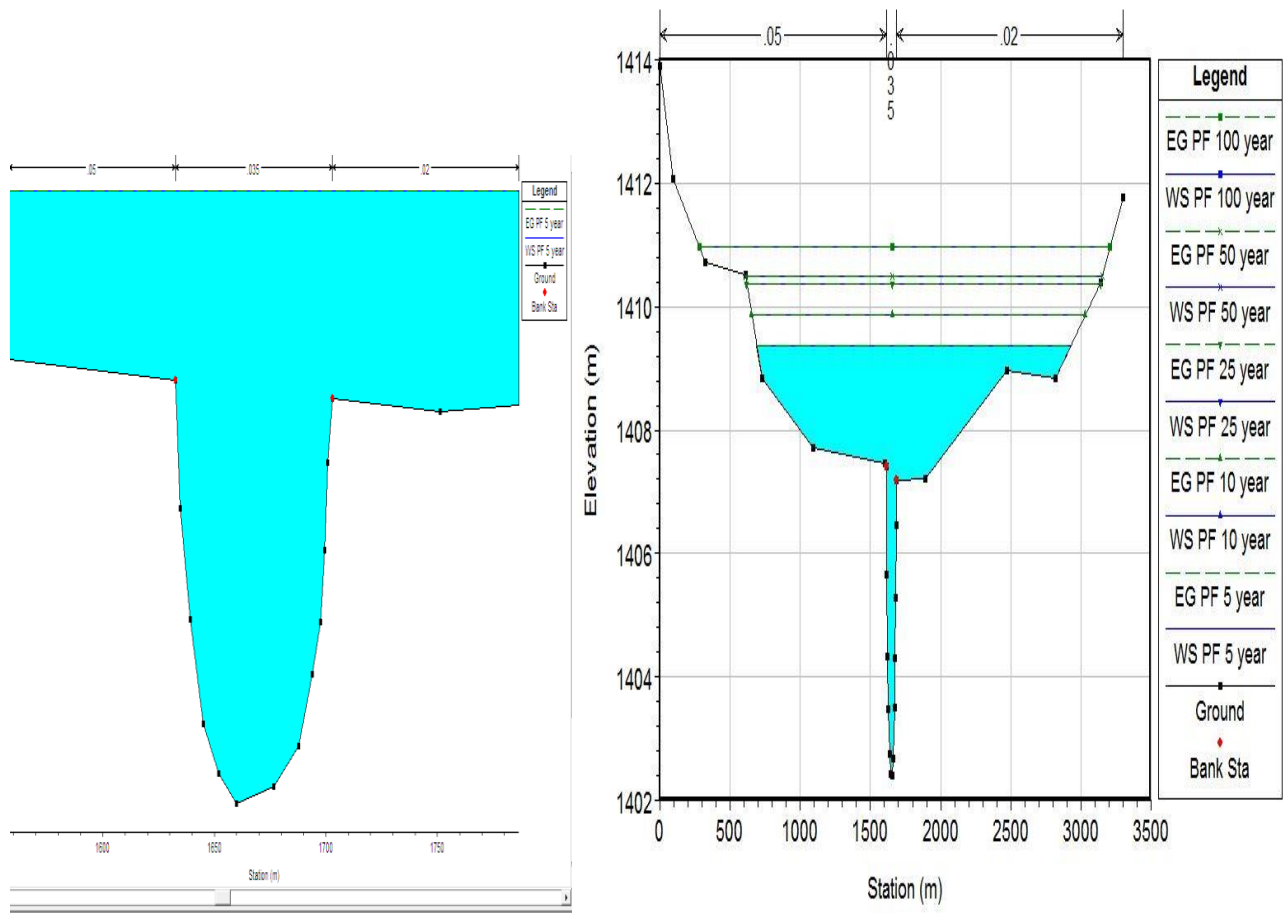


Figure 4.3 : Locations of cross sections on the Bilate River

The simulation results were shown the flood levels in different cross sections, as a result Profile plot views of flood levels and X-Y-Z Perspective views of flood plain in a part of the study reaches as shown in Figure19.

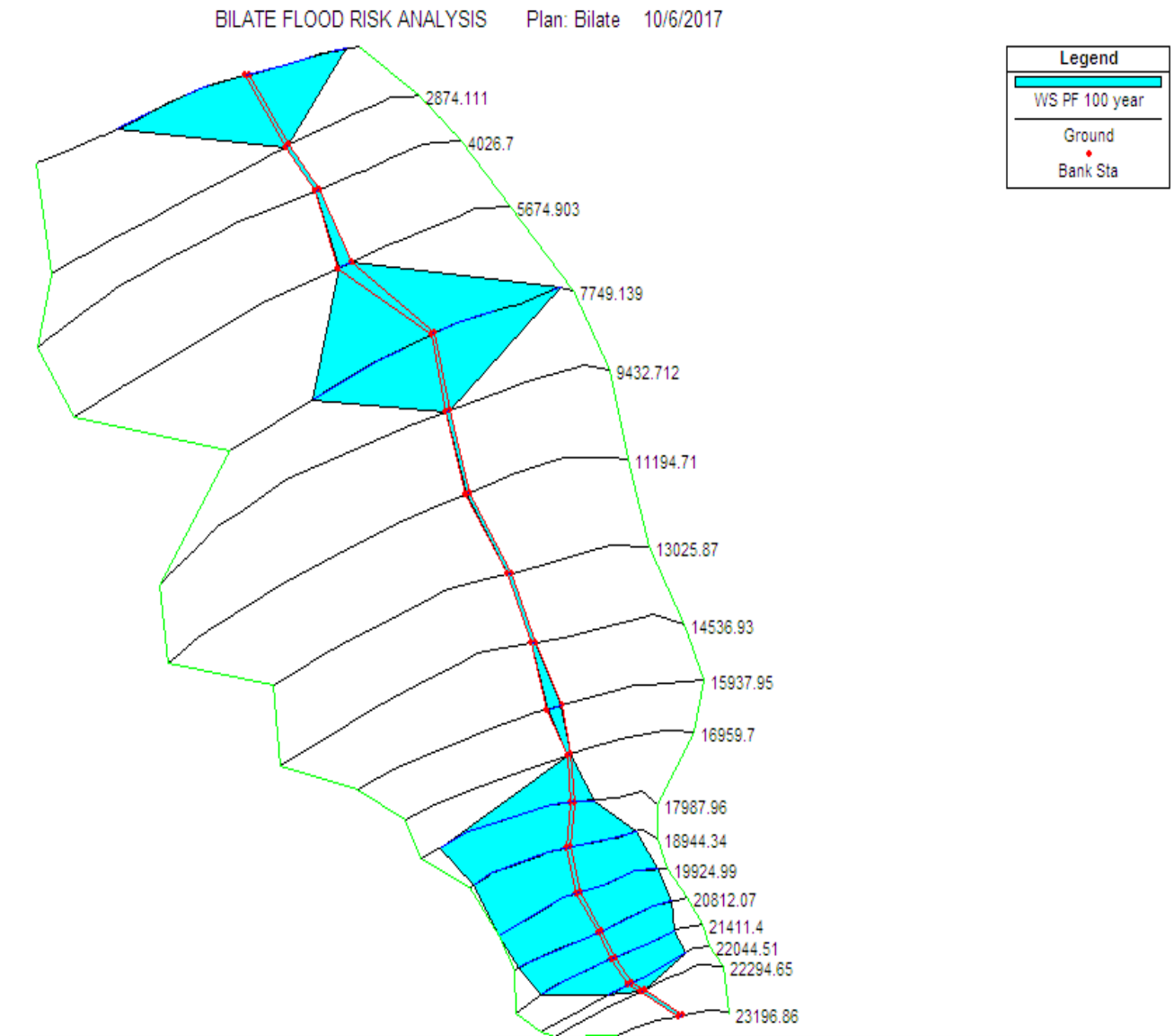


Figure 4.4 : for 5 years return period

After preparing the flooding map areas in GIS with different return periods, it shows the flood plan area. Flood inundation area are showed in figure 19 for return periods of 100 year and in Appendix B figures for the return periods of 5, 10, 25 and 50 years. The flood maps showed that increasing the discharge of longer return periods, flood covers more surface area. Expansion of flood zoning affected by topographical features of the Bilate River, human intervention in river channel and river banks such as agriculture and irrigation structures.

### 4.2.3 Post-processing of Hydraulic Results and Flood Plain Mapping

After running HEC-RAS for water flows of 5, 10, 25, 50 and 100-year return periods, water surface profiles, and other hydraulic parameters such as flows, minimal and maximum channel profiles, channel velocity, flow area, and critical water surface are available for each cross section from HEC-RAS outputs.

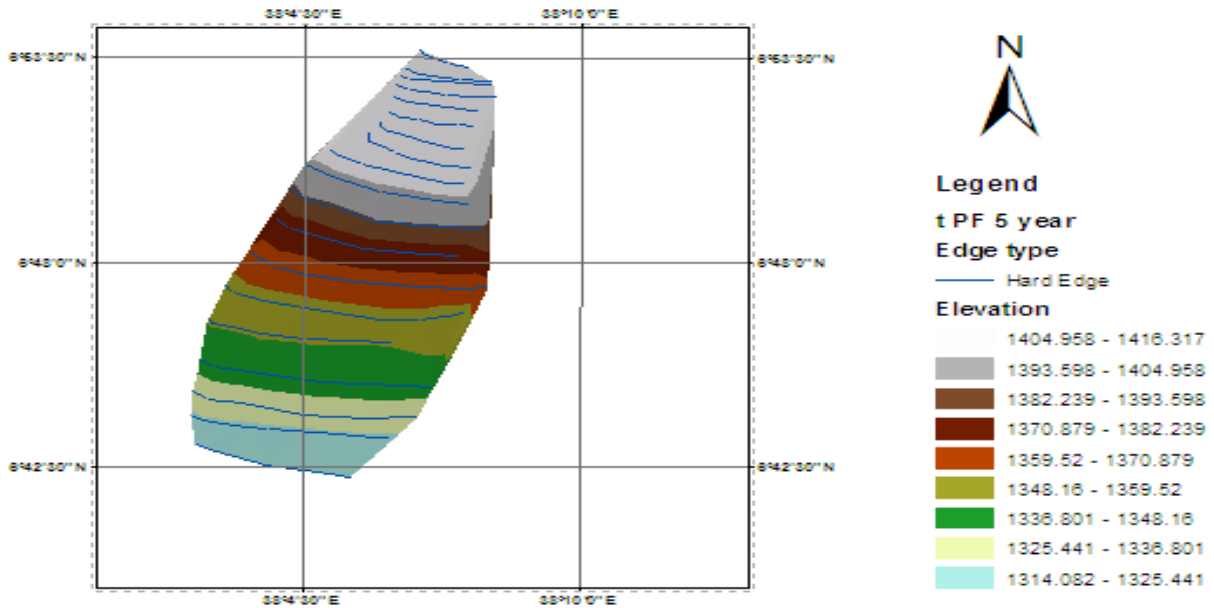


Figure 4.5: Water surface TIN of the study area for return periods of 5

After simulation the hydraulic analysis in HEC-RAS the water surface TIN result as shown in figure 20 is delineated by ArcGIS with combination of HEC-GeoRAS from bounding polygon for flood plain inundation boundaries calibration. After preparing the flooding map areas in GIS with different return periods, it shows the level and depth of flood areas. Flood inundation area figure 21 for return periods of 5 and in Appendix C Figures for the return periods of 10, 25, 50, and 100 years flood maps below shows that by increasing the discharge of longer return periods, flood covers more surface flooding. Expansion of flood zoning affected by topographical features of the Bilate River, human intervention in river channel and river banks such as agriculture and irrigation structures. Anywhere in the valley the widths of channel have increased, the width of the flood area has increased and flood water has expanded. The most flood prone area in the Bilate River catchment is

at the middle and lower reach. Also, the flood plain would be affected more especially with the 25, 50 and 100-year floods. The effect of flood on the river flood hazard maps is the factor that can be assessed based on the generated flood map for the Bilate River basin. The results show that an increase of the runoff or flood magnitude leads to an increase in the extent of the flood hazard as indicated in table 11. for example, in existing river basin development condition, the area of high hazard class changes from 3699.3 to 4224.5 for 5 years to 100 years. This means that, increases of high hazard class can be observed by increase of flood event magnitude from 5 years to 100 years.

Table 4.5: Table of Flow Data and Floodplain Inundation Coverage.

Profile	Return Period	Flow data	Flood inundation area	
	Year	(m <sup>3</sup> /s)	Km <sup>2</sup>	hectare
Pf1	5	405.38	36.9934435	3699.3
Pf2	10	551.48	38.5141484	3851.4
Pf3	25	707.2	40.1119888	4011.2
Pf4	50	745.37	40.6699346	4067.0
Pf5	100	898.12	42.2452644	4224.5

Flood inundation the study area shows large increment in both area coverage and discharge of flooding us the return period increases

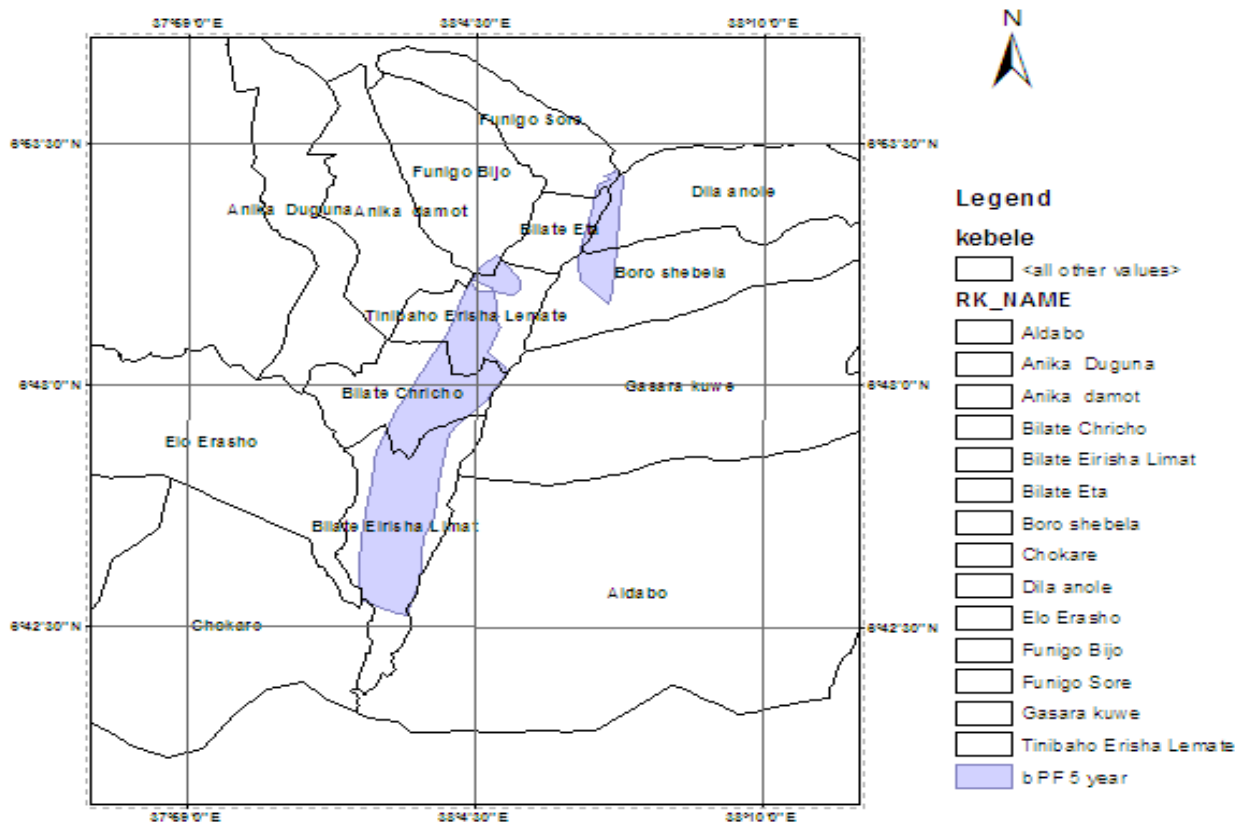


Figure 4.6: Flood Inundation Kebele of the study area for return periods of 5

### Depth of Flood inundation and Flow Velocity

The HEC-RAS simulation produced and depths flow velocities in the main channel and flood inundated areas. The maximum depth of flood inundations is 1.25 m, 1.72 m, 2.44 m, 2.83 m and 3.03 m, for simulated of 5, 10, 25, 50 and 100 recurrence years respectively. All of the depths flood inundations for recurrence period are done and for return periods of 5 depth of flood inundations map are considered for mapping can be seen in the Figures of 22 below and the rest depth of flood inundation map for 10, 25, 50 and 100-year return periods are considered in the Figures of appendix D. The Figures indicate the maximum depth of flood inundation occurs at the middle of the reaches. In addition to this the return period of 100-year maximum depth is greater than return period of 5-year maximum depth of flood inundations map. This indicates as recurrence period increases the depth of flood inundation also increase.

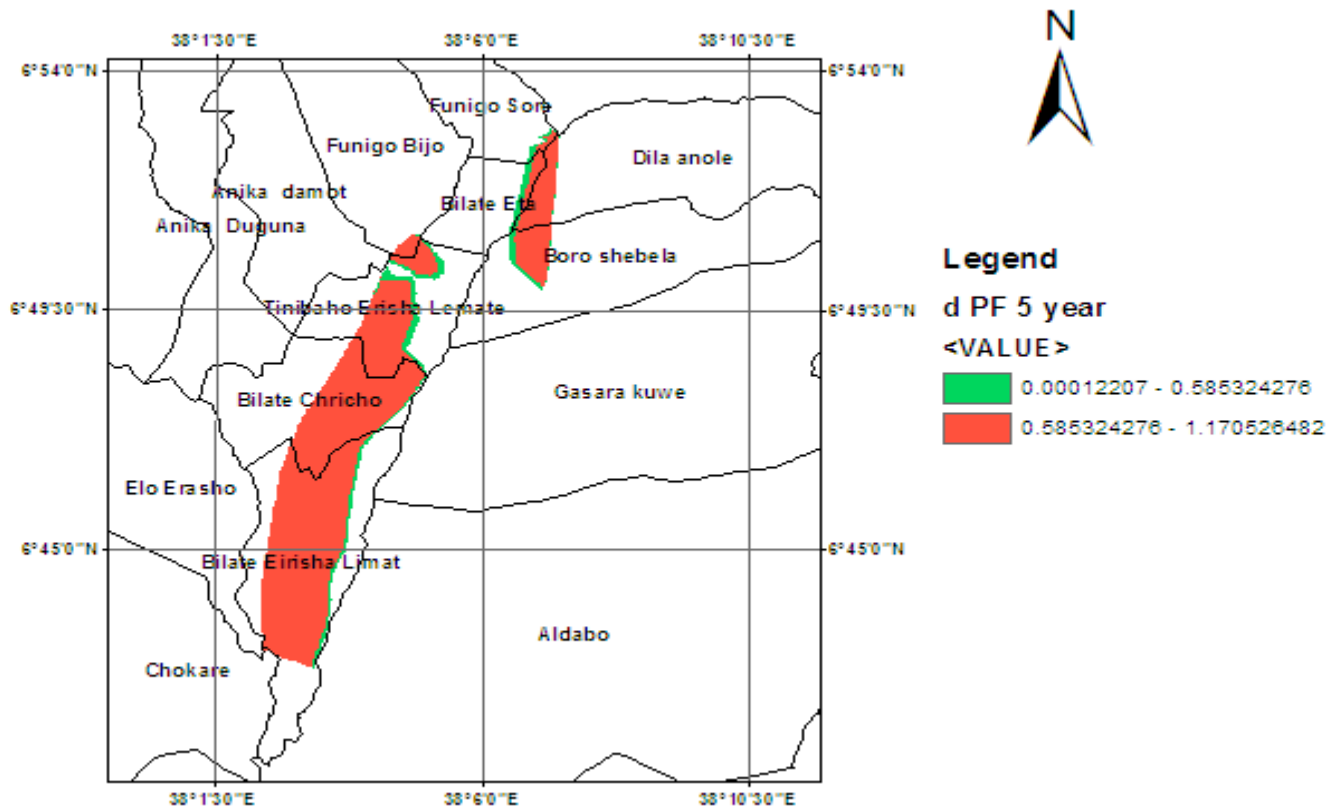


Figure 4.7 : Depth of flood plain map for 5-year return period

The high velocity is occurring mostly in the main channel. The maximum velocity of the catchment is 6.8 m/s. The spatial distribution of inundation flow velocity of the catchment shows a correlation with the spatial distribution of the elevation as high values flow velocities are observed at upstream and low values at downstream. The high values at the upstream can be accepted to the steep slope of the terrain whilst the low velocity at the downstream is attributed to the flatness of the terrain. Generally, high velocities were recorded in the main channel than the floodplains and also at the upstream than downstream due to weak soil and water conservation activity, poor land use activity and topography of the area as shown in Fig 23 for year return period and Appendix E Figures.

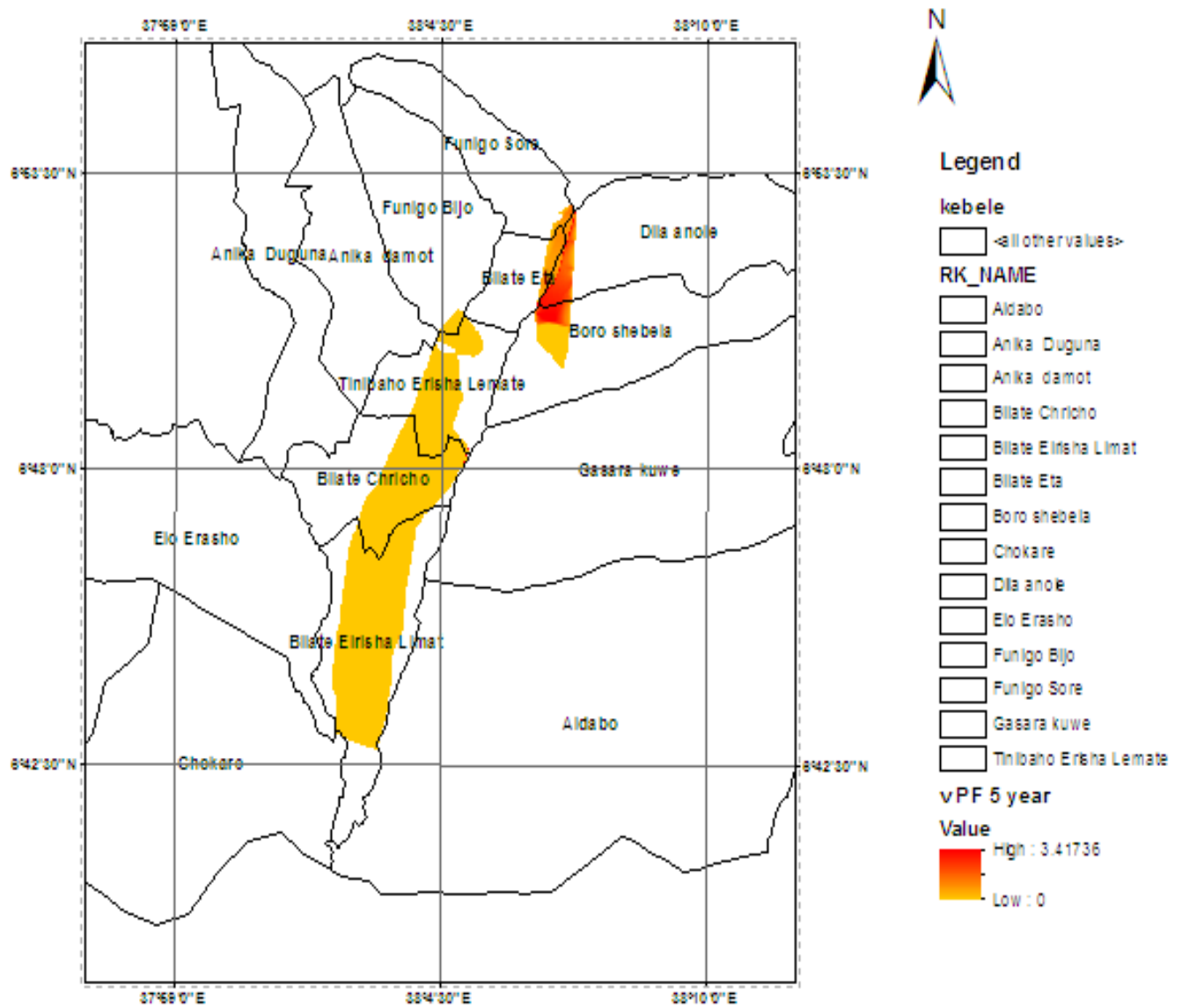


Figure 4.8 : Velocity of flood plain map for 5 year.

## **5. CONCLUSION AND RECOMMENDATIONS**

### **5.1 Conclusion**

This study presents a systematic approach in the preparation of flood inundation and flood hazard maps with the application of hydrodynamic models and GIS. The change of flooding with time also shows in this study by performing unsteady flow analysis and flood mapping.

Different methodologies have been applied to fulfill the objective of this study. These methodologies of this research comprise data and models used. The data used are 28 years of annual daily maximum rain fall, DEM 30 m resolution, land use land cover map, and soil map. In addition to this the modeling used for the success of this research objective are consists of river flood model i.e. SCS rainfall - runoff method model, HEC-RAS 4.1, and HEC-GeoRAS 10.1 and ArcGIS 10.1 environment. Hydrological modeling (rainfall – runoff analysis) was successfully performed using SCS method. The model output results were the quantified runoff floods that resulted from input rainfall data. Together with a detailed analysis of the hydrological characteristics of the study area, the hydraulic modeling results were incorporated into a representative flood hazard map of the study area. Bilate RAS hydraulic model was calibrated and then used to simulate the 5, 10, 25, 50 and 100-year floods of 405.38, 551.48, 707.20, 745.37 and 898.12 m<sup>3</sup>/s magnitude respectively. The flood hazard maps for the 5, 10, 25, 50 and 100-year maximum floods were generated and the total area affected by flood inundation is 3699.3, 3851 .4, 4011.2, 4067.0 and 4224.5 hectare respectively and gave the maximum flood depth of 1.25 m, 1.72 m, 2.44 m, 2.83 m and 3.03 m respectively and also the maximum velocity for Bilate River catchment is 6.78 m/s. The study area especially at the middle and downstream is more unusable due to more flooding especially the agricultural lands, downstream of settlements and irrigation projects such as diversion head works and spate irrigations. The area of flood hazard maps developed indicated that the most flood prone area is located around and below the flood plain this is true especially for flood with return periods of 25, 50 and 100 year.

## 5.2 Recommendation

Based on the aforementioned result and the experience gained during the study, the following recommendations are made.

- ☞ Based on this result encroaching agricultural practices and settlement in and around the reach of flood plain should be avoided or stopped in order to avert the risk especially for flood with return period of 100 year.
- ☞ Terrain data with good resolution is needed to properly and accurately to determine the flood hazard.
- ☞ A simple study about flood hazard assessment impact on flood inundation is done in this study. However, for more accurate prediction, future discharge from a hydrologic model can be used in future studies.
- ☞ Current HEC-RAS uses 1D model with flood plain. However, it does not have 1D/2D coupled model. For future studies, a 1D/2D (such as SOBEK, HEC RAS (1D/2D)) coupled model can be used to see the differences between these two models.

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## Appendix

### A. Peak rainfall estimation

Frequency method may be used for drainage basin of any size. The reliability of the frequency estimates depends on the lengths of the observed record rather than the method of probability analysis. The return period or recurrence interval (T) is the average number of year during which a flood of given magnitude will be equaled or exceeded once and computed by; Wilbur method (1939) as;

$T = n+1/m$  , where n=number of event ,m=order or rank of the event , T=recurrence interval (year)

For determining extreme events, the following techniques are carried out for analysis

#### 1. Normal distribution

$X_T = X_m + K_T * S_x$  where, For T = 50 years,  $p = 1/50 = 0.02$

$W = (\ln(1/p^2))^{0.5} = (\ln (1/0.02^2))^{0.5} = 2.7971$

$$K_t = w - \frac{2.51557 + 0.608486 * w + 0.01033 * w^2}{1 + 1.143279 * w + 0.1992 * w^2 + 0.00131 * w^3}$$

$K_T = 2.054$

From the above table we have,  $X_m = 52.24643$  and  $S_x = 13.26679$

By substituting these values on the formula,  $X_T = X_m + K_T * S_x$

$X_{50} = 52.24643 + 2.054 * 13.26679$

$X_{50} = 79.49642$  mm

#### 2. Log normal distribution

$X_T = 10^{(Y_m + K_T * S_y)}$ , where  $Y_m = 1.718$  ,  $S_y = 0.121392$  and  $K_T = 2.054$  since it is the same as the calculated value on normal distribution.

$X_T = 10^{(1.718 + 2.054 * 0.12392)} = 92.755$ mm

#### 3. Extreme value- I distribution

$$X_T = U + \alpha * Y_T, U = X_m - 0.5772 \alpha, \alpha = (\sqrt{6/\Gamma}) * S_x, K_T = (Y_T - Y_n)/S_n$$

$$Y_T = -\ln(-\ln(1-1/T)) = -\ln(-\ln(1-1/50)) = 3.902$$

$$K_T = (3.902 - 0.5485)/1.1607 = 2.59$$

$$U = 52.24643 - 0.5772 * 13.26679 = 44.5888, \quad \alpha = (\sqrt{6/\Gamma}) * 13.26679 = 10.344$$

$$X_{50} = U + \alpha * Y_T = 44.5888 + 10.344 * 3.902 = 84.951 \text{mm}$$

#### 4. Pearson type III

$$X_T = X_m + K_T * S_x, \text{ where } X_m = 52.24643, S_x = 13.26679$$

$K_T = z + (z^2 - 1)k + 1/3(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + 1/3k^5$ , where  $k = C_{sx}/6 = -0.1473/6 = -0.02455$  and  $z$  is obtained from the table values of  $C_s$  and return period. But  $C_{sx} = 0.09026251$  and a return period of 50 years then we obtain  $z$  value through interpolation.

$$0 \rightarrow 2.054$$

$$-0.02455 \rightarrow z$$

$$-0.1 \rightarrow 2.0 \text{ from this we get } z = 2.067$$

$$K_T = z + (z^2 - 1)k + 1/3(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + 1/3k^5, \text{ by substituting } z = 2.067 \text{ and } k = -0.02455$$

$$K_T = 1.986 \quad X_T = X_m + K_T * S_x$$

$$X_{50} = 52.24643 + 1.986 * 13.26679 = 78.594 \text{mm}$$

#### 5. Log pearson type III distribution

$$X_T = 10^{(Y_m + K_T * S_y)}, \text{ where } Y_m = 1.718, \text{ and } S_y = 0.121392$$

$K_T = z + (z^2 - 1)k + 1/3(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + 1/3k^5$ , where  $k = C_{sy}/6 = -0.11922789/6 = -0.01987132$  and  $z$  is obtained from the table values of  $C_{sy}$  and return period. But  $C_{sy} = -0.11922789$  and a return period of 50 years then we obtain  $z$  value through interpolation.

$$0 \rightarrow 2.054$$

$$-0.11922789 \rightarrow z$$

$$-0.2 \rightarrow 21.945 \text{ from this we get } z = 1.701195$$

$$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5, \text{ , by substituting } z = 2.067 \text{ and } k = -0.02455$$

$$K_T = 1.654$$

$$X_T = 10^{(Y_m + K_T * S_y)}$$

$$X_{50} = 10^{(1.718 + 1.654 * 0.121392)} = 82.94 \text{ mm}$$

<i>Normal distribution</i>	79.49642 mm
<i>Log normal distribution</i>	92.755mm
<i>Extreme value- I distribution</i>	84.951mm
<i>Pearson type III</i>	78.594mm
<i>Log pearson type III distributio</i>	82.94mm

Therefore, from the above calculation Log normal distribution (type II) gives the highest value of point rainfall depth.

Testing the goodness of fit

The D-index tests for the comparison of the fit of various distributions in the upper tail are given by:

$$D\text{-index} = (1/X_m) * \sum \text{Abs} (X_i - X_{ical})$$

Where  $x_i$  and  $X_{ical}$  are the  $i^{\text{th}}$  highest observed and computed values for the distribution respectively.

The distribution giving the least D-index is considered to be the best fit distribution.

Statistical parameter	Normal flow data	Log transformed data
Mean	52.24643	1.725756
Standard deviation	13.26679	0.120348707
Skwness. coefficient	-0.1473	-1.73065942
Variation coefficient	0.2539	0.0697368

### 1 Normal distribution

$$X_{ical} = X_i + K_t * \sigma_x$$

$$K_t = w - \frac{2.51557 + 0.608486 * w + 0.01033 * w^2}{1 + 1.143279 * w + 0.1992 * w^2 + 0.00131 * w^3}$$

The answer is found in the table 3.2 below.

$$W = (\ln(1/p_r))^2 \wedge 0.5$$

Table 3.2 Normal distribution

Xi	Rank	P=m/n+1	KT	Xi cal	Abs(Xi – X ical)
75.6	1	0.142857	1.043192	89.43980919	13.83980919
72.6	2	0.285714	0.525359	79.56982753	6.969827528
69.7	3	0.428571	0.126265	71.37513124	1.675131239
68	4	0.571429	-0.24479	64.75242248	3.247577524
67.1	5	0.714286	-0.63756	58.64162537	8.458374632
65.5	6	0.857143	-1.12864	50.52657013	14.97342987
SUM					49.16414998

$$D\text{-index} = \frac{1}{n} * \sum (x_i - X_{ical})$$

$$= 49.16414998 / 52.24643 = 0.941004964$$

2. Log normal distribution

$$Y_{ical} = Y_i + K_t * \sigma_y$$

Table 3.3 Log normal distribution

Y <sub>i</sub>	Rank	P=m/n+1	K <sub>t</sub>	Y <sub>i cal</sub>	Abs(Y <sub>i</sub> -Y <sub>i cal</sub> )
1.975432	1	0.142857	1.043192	2.10097881	0.125546808
1.91803	2	0.285714	0.525359	1.98125628	0.063226276
1.880814	3	0.428571	0.126265	1.89600983	0.015195829
1.873902	4	0.571429	-0.24479	1.84444184	0.02946016
1.854913	5	0.714286	-0.63756	1.77818348	0.076729522
1.847573	6	0.857143	-1.12864	1.71174264	0.135830365
SUM					0.44598896

$$D\text{-index} = \frac{I}{\sum \square \square \square} * \sum \square \square \square (Y_i - Y_{ical})$$

$$= 0.44598896 / 1.718 = 0.259597765$$

3 Pearson Type III Distribution Method

$$K_t = Z + (Z^2 - 1) * k + 1/3 * (z^3 - 6 * Z) * K^2 - (Z - 1) * k^3 + Z * K^4 + 1/3 * K^5$$

Where  $K = C_s / 6 = 0.0529$

$$Z = w - \frac{2.51557 + 0.608486 * w + 0.01033 * w^2}{1 + 1.143279 * w + 0.1992 * w^2 + 0.00131 * w^3}$$

Where  $W = (\ln(1/pr)^2)^{0.5}$

Table 3.4 Pearson Type III Distribution Method

X <sub>i</sub>	rank	P=m/n+1	KT	X <sub>i cal</sub>	Abs(X <sub>i</sub> - X <sub>ical</sub> )
75.6	1	0.142857	1.043192	89.40691735	13.80691735
72.6	2	0.285714	0.525359	89.75327	17.15327

69.7	3	0.428571	0.126265	77.67115	7.97115
68	4	0.571429	-0.24479	71.5601	3.5601
67.1	5	0.714286	-0.63756	63.16177	3.93823
65.5	6	0.857143	-1.12864	50.56215615	14.93784385
SUM					61.3675112

$$D\text{-index} = \frac{1}{n} * \sum (x_i - X_{ical})$$

$$61.3675112/52.24643 = 1.16299215$$

Gambel EVI Distribution method

Table 3.6 Gambel EVI Distribution method

xi	Rank	P=m/n+1	kt	Xi cal	Abs(Xi-Xical)
94.5	1	0.142857	1.138387	68.27997	26.22003
82.8	2	0.285714	0.465875	60.22472	22.57528
76	3	0.428571	0.027575	54.97483	21.02517
74.8	4	0.571429	-0.3298	50.69426	24.10574
71.6	5	0.714286	-0.66671	46.65878	24.94122
70.4	6	0.857143	-1.04612	42.1143	28.2857
SUM					147.1531

$$X_T = U + \alpha * Y_T, U = X_m - 0.5772 \alpha, \alpha = (\sqrt{6/\pi}) * S_x,$$

$$K_T = (Y_T - Y_n)/S_n$$

$$Y_T = -\ln(-\ln(1-1/T))$$

$$U = 54.9407 - 0.5772 * 10.3195 = 48.9843, \quad \alpha = (\sqrt{6/\pi}) * 13.23526 = 10.3195$$

$$X_{i cal} = U + \alpha * Y_T$$

$$D\text{-index} = \frac{I}{\square\square} * \sum \square\square\square (x_i - X_{ical})$$

$$= 147.1531/54.97407 = 2.6768$$

Log Pearson Type III Distribution Method

$$K_t = Z + (Z^2 - 1) * k + 1/3 * (z^3 - 6 * Z) * K^2 - (Z - 1) * k^3 + Z * K^4 + 1/3 * K^5$$

Where  $K = C_s/6 = 0.0529$

$$Z = w - \frac{2.51557 + 0.608486 * w + 0.01033 * w^2}{1 + 1.143279 * w + 0.1992 * w^2 + 0.00131 * w^3}$$

Where  $W = (\ln(1/p_r)^2)^{0.5}$

Y <sub>i</sub>	Rank	P=m/n+1	K <sub>t</sub>	Y <sub>i cal</sub>	Abs(Y <sub>i</sub> - Y <sub>ical</sub> )
1.975432	1	0.142857	1.044133	2.83125	0.20769
1.91803	2	0.285714	0.514245	2.125723	0.20769
1.880814	3	0.428571	0.111411	2.088507	0.20769
1.873902	4	0.571429	-0.25881	2.081595	0.20769
1.854913	5	0.714286	-0.64621	2.062606	0.20769
1.847573	6	0.857143	-1.12411	2.055266	0.20769
SUM					1.24617

$$D\text{-index} = \frac{I}{\square\square} * \sum \square\square\square (Y_i - Y_{ical})$$

$$= 1.24617/1.725756 = 0.7221$$

D-index is minimum in case of log normal distribution hence on the bases of this test log normal distribution best fits the data, as result  $X_{50} = 92.755\text{mm}$  mm is taken as design point rainfall. Therefore, the average depth over the catchment area should be adjusted for the whole size of the watershed.

Areal Rainfall

A point rainfall  $X=92.755\text{mm}$  is taken as a point design rain fall and it has to be distributed over the area using area reduction factors (ARF) given as;

The area reduction factor (ARF) is introduced to account for the spatial variability of point rainfall over the catchment. This is not significant for small catchments but becomes so as catchment size increases.

$$\text{ARF} = 1 - 0.044(A)^{0.275}, \text{ where ARF= areal reduction factor, } A = \text{catchment area (km}^2\text{)}$$
$$= 1 - 0.044(1808.93)^{0.275} = 0.653866478$$

As it is known for catchment greater than 25 square km, the point rain fall has to be multiplied with areal reduction factor.

Then the areal rainfall  $=0.653866478 * 92.755\text{mm} = 60.65\text{mm}$ , therefore areal rainfall value of 60.65mm is used to determine the peak discharge.

Area Factor	0.654
5	43.222
10	48.878
25	55.725
50	60.650
100	65.441

Table 1: hydrologic soil Group classification

Soil Group	Description	Minimum Infiltration rate (mm/hr)
A	Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well drained sands or gravels. These soils have a high rate of water transmissions.	7.62 - 11.43
B	Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	3.81 - 7.62
C	Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.	1.27 - 3.81
D	Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission	0 - 1.27

(Source: ERADDM, 2002 and Chow et al., 2002)

Table 2: Runoff curve numbers (AMC-II) for hydrologic soil cover complex

S.NO	Land Use	Hydrologic Soil Group			
		A	B	C	D
1	Bare crop residue soil cover of agricultural lands	77	86	91	94
2	Contoured & Terraced soil cover of agricultural lands	70	79	84	88
3	Brush -weed – Grass mixture with brush the major element covers of agricultural lands	48	67	77	83
4	Farms-buildings, lanes, drive ways and surrounding lots	59	74	82	86
5	Mountain brushes with mixture of small trees and brushes	-	66	74	79
6	Desert shrubs and brushes	63	77	85	88
7	Mixture of grass, weeds, and low growing brush, with brush the minor element	-	80	87	93
8	Forest (degraded)	45	66	77	83
9	Forest (plantation)	25	55	70	77

(Source: ERADDM, 2002 and Chow et al., 2002)

Table 3: manning’s value for different land uses

S.No	Type of Channel and Description	Manning’s Roughness (n) Values		
		Minimum	Normal	Maximum
	Natural streams			
A	Minor channels or streams (top width at flood stage < 30 m)			
A.1	Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
A.2	Same as above, but more stones and weeds	0.030	0.035	0.040
A.3	Clean, winding, some pools and shoals	0.033	0.040	0.045
A.4	Same as above, but some weeds and stones	0.035	0.045	0.050
A.5	Same as above, lower stage, more ineffective	0.040	0.048	0.055

	slopes and sections			
A.6	Same as “4” but more stones	0.045	0.050	0.060
A.7	Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
A.8	Very weedy reaches, deep pools or floodways with heavy stands of timber and brush	0.070	0.100	0.150
B	Mountain streams, no vegetation in channel banks usually steep, with trees and brush on banks submerged			
B.1	Bottom:gravels, cobbles, and few boulders	0.030	0.040	0.050
B.2	Bottom: cobbles with large boulders	0.040	0.050	0.070
C	Flood plains			
C.1	Pasture no brush			
C.1.1	Short grass	0.025	0.030	0.035
C.1.2	High grass	0.030	0.035	0.050
C.2	Cultivated areas			
C.2.1	No crop	0.020	0.030	0.040
C.2.2	Mature row crops	0.025	0.035	0.045
C.2.3	Mature field crops	0.030	0.040	0.050
C.3	Brush			
C.3.1	Scattered brush, heavy weeds	0.035	0.050	0.070
C.3.2	Light brush and trees, in winter	0.035	0.050	0.060
C.3.3	Light brush and trees, in summer	0.040	0.060	0.080
C.3.4	Medium to dense brush, in winter	0.045	0.070	0.110
C.3.5	Medium to dense brush, in summer	0.070	0.100	0.160

C.4	Trees			
C.4.1	Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
C.4.2	Same as above, but heavy sprouts	0.050	0.060	0.080
C.4.3	Heavy stands of timber, few down trees, little under growth, flow below branches	0.080	0.100	0.120
C.4.4	Same as above, but with flow into branches	0.100	0.120	0.160
C.4.5	Dense willows, straight, straight	0.110	0.150	0.200

(Source: ERADDM, 2002)

Table 4: Typical Hydrologic Soil Group for Ethiopia

Soil Types		Hydrologic Soil Group
Ao	Orthic Acrisols	B
Bc	Chromic Cambisols	B
Bd	Dystric Cambisols	B
Be	EutricCambisols	B
Bh	HumicCambisols	C
Bk	Calcic Cambisols	B
Bv	VerticCambisols	B
Ck	Calcic Chernozems	B
E	Rendzinas	D
Hh	Haplic Phaeozems	C
Hi	Luvic Phaeozems	C
I	Lithosols	D
Jc	CalcaricFluvisols	B
Je	EutricFluvisols	B
Lc	Chromic Luvisols	B

Lo	Orthic Luvisols	B
Lv	VerticLuvisols	C
Nd	Dystric Nitosols	B
Ne	EutricNitosols	B
Od	Dystric Histosols	D
Oe	EutricHistosols	D
Qc	Cambric Arenosols	A
Rc	CalcaricRegosols	A
Re	EutricRegosols	A
Th	Humic Andosols	B
Tm	Mollic Andosols	B
Tv	Vitric Andosols	B
Vc	Chromic Vertisols	D
Vp	PellicVertisols	D
Xh	Haplic Xerosols	B
Xk	CaloicXerosols	B
Xl	LuvicXerosols	C
Yy	Gypsic Yermosols	B
Zg	Gleyic Solonchaks	D
Zo	Orthic Solonchaks	B

Source: Ministry of Agriculture

**B .List of Figures flood plain for the study area at different return period**

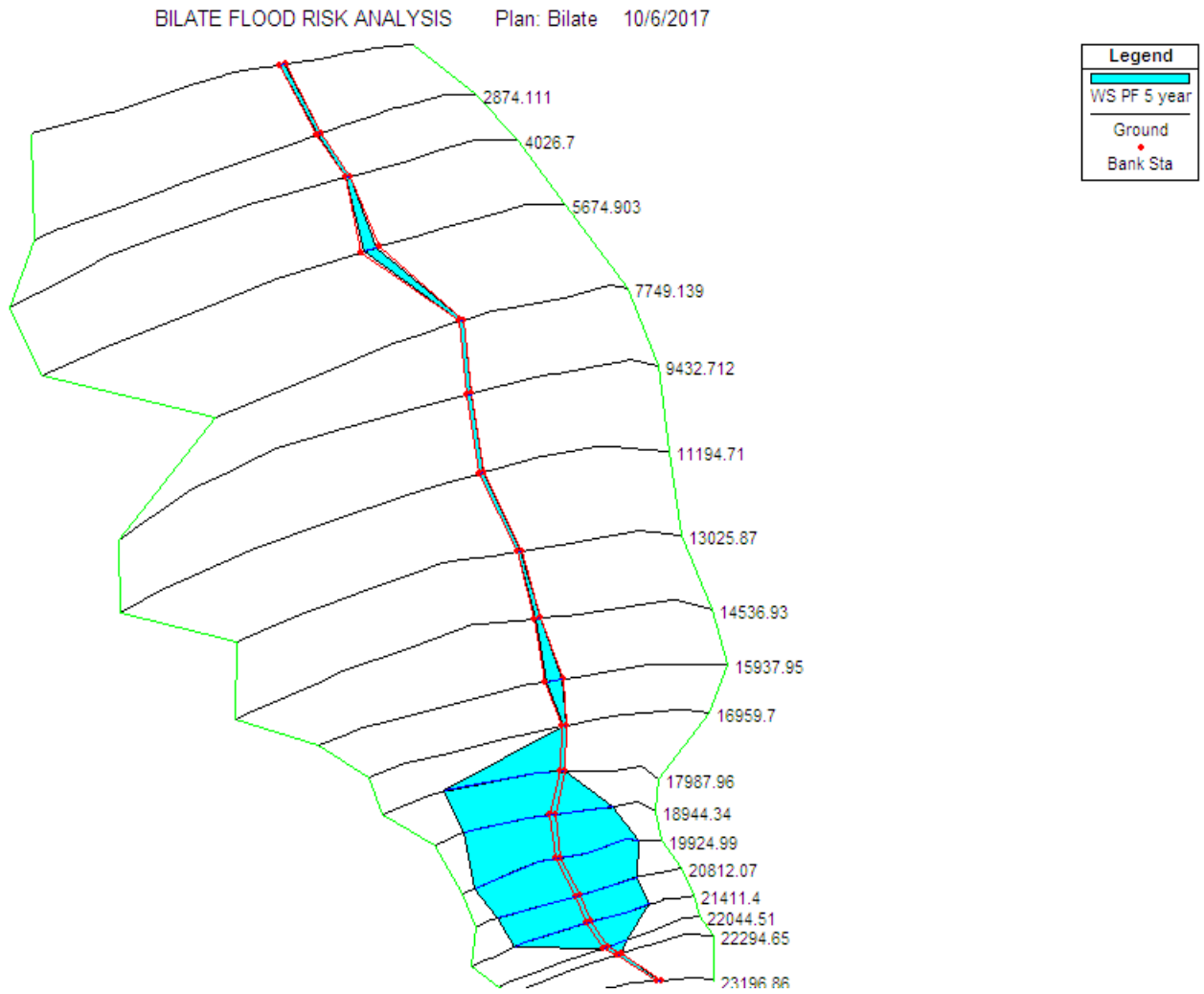


Figure 1 for 5 years return period

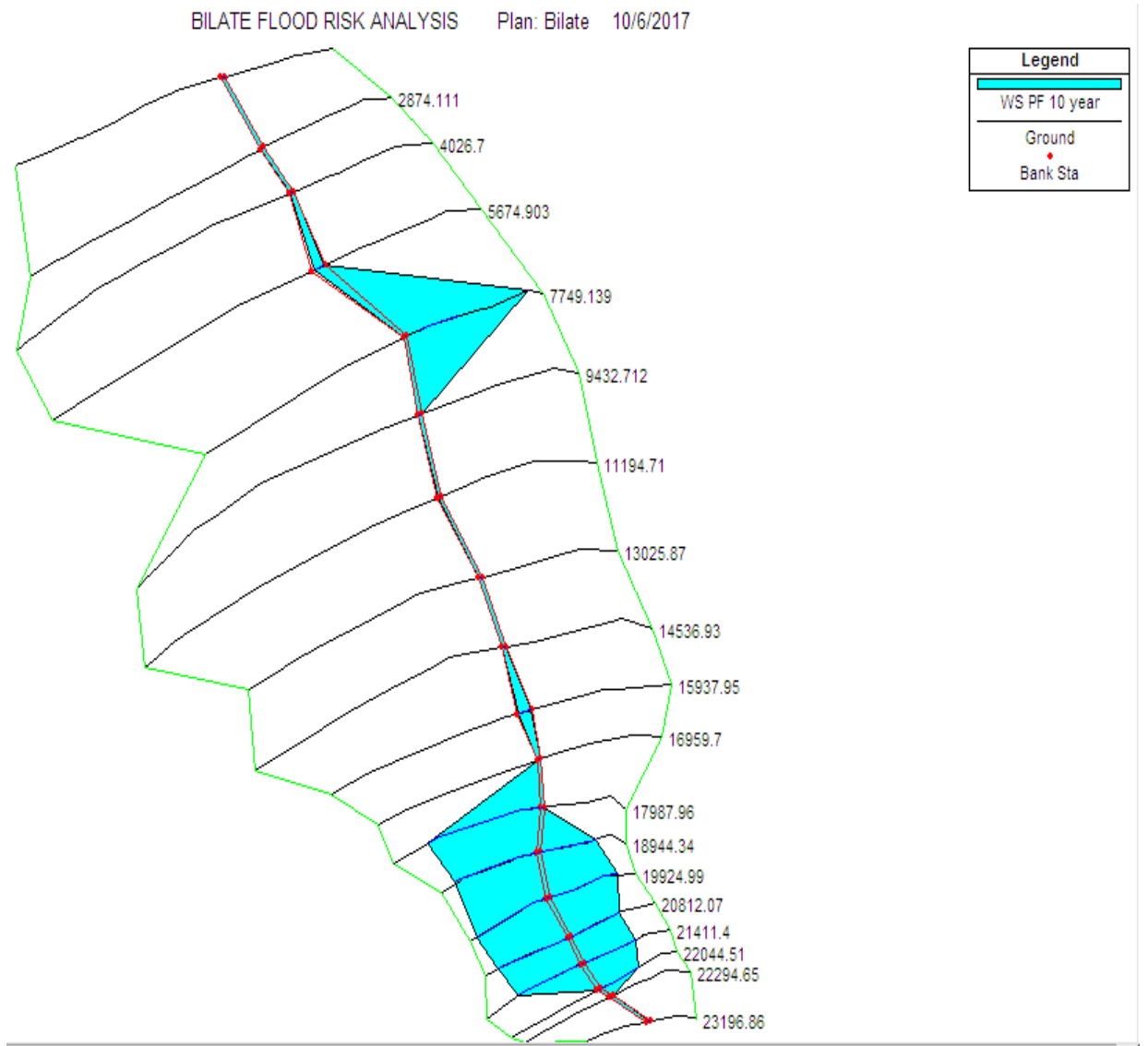


Figure 2: for 10 years return period

BILATE FLOOD RISK ANALYSIS Plan: Bilate 10/6/2017

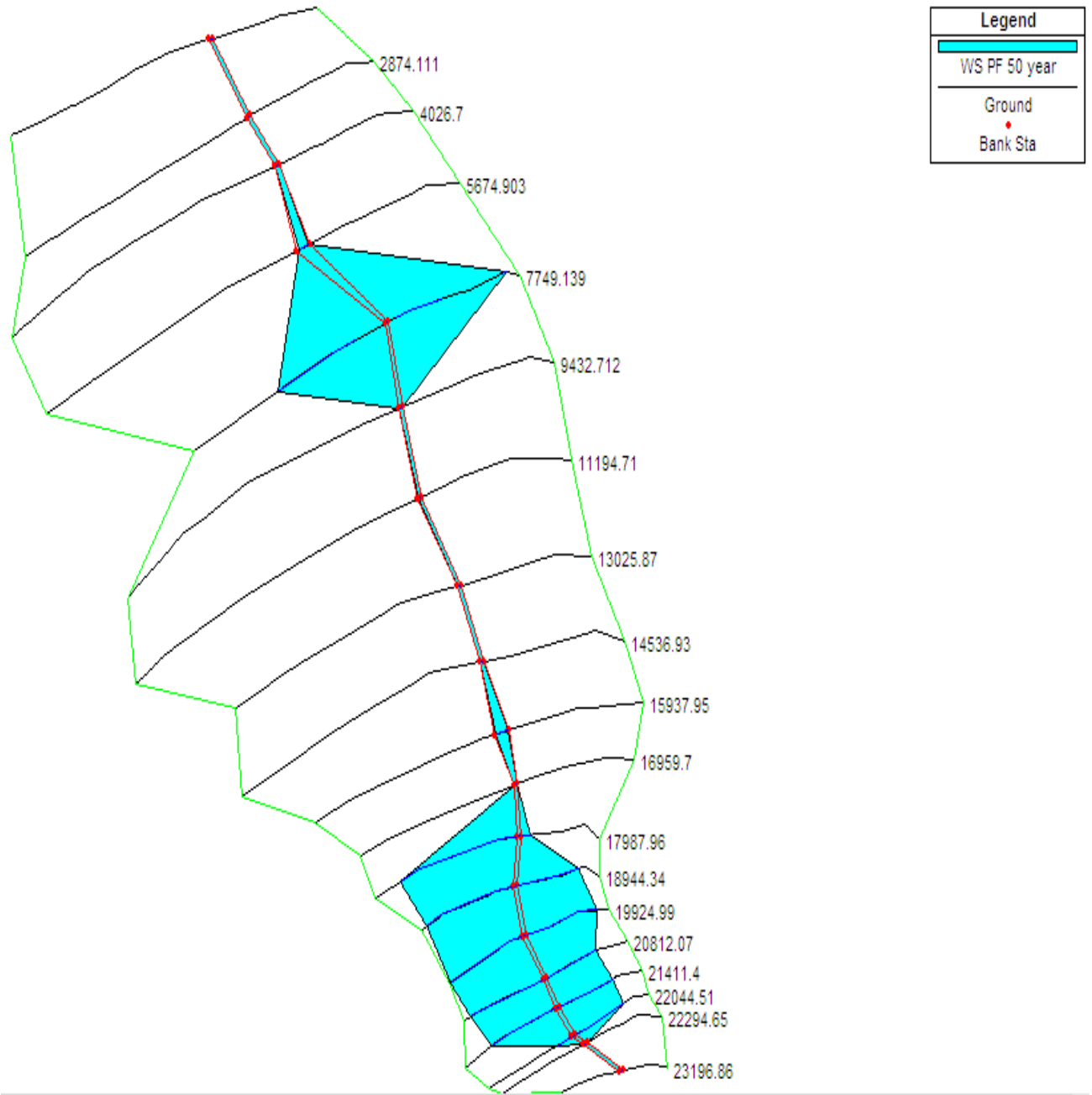


Figure 3: for 50 years return period

### C. List of Figures Floodplain inundation map

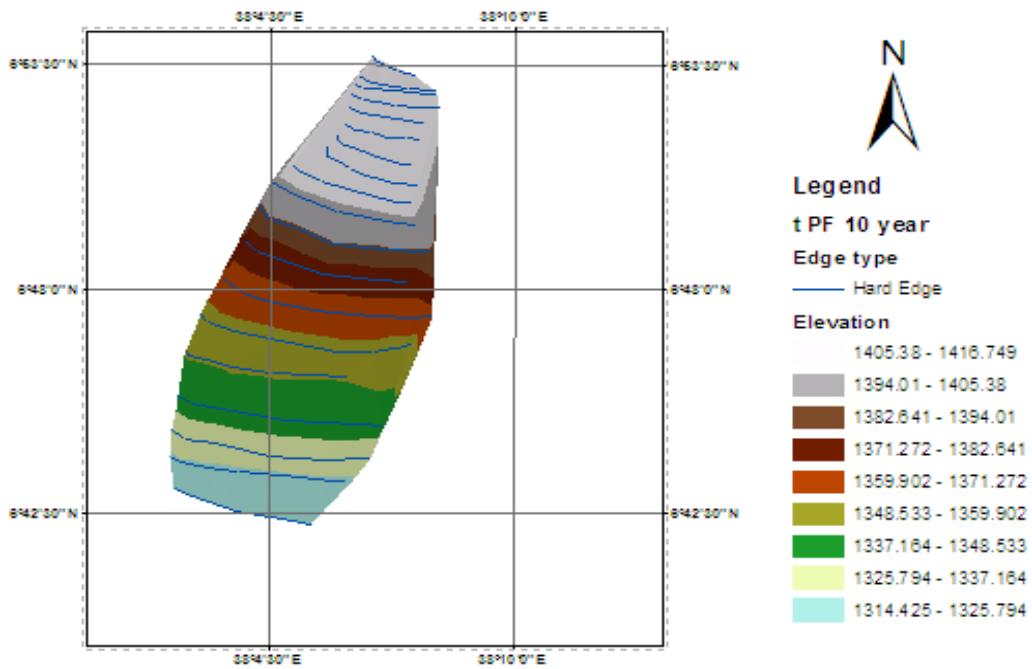


Figure 1 for 10 years return period

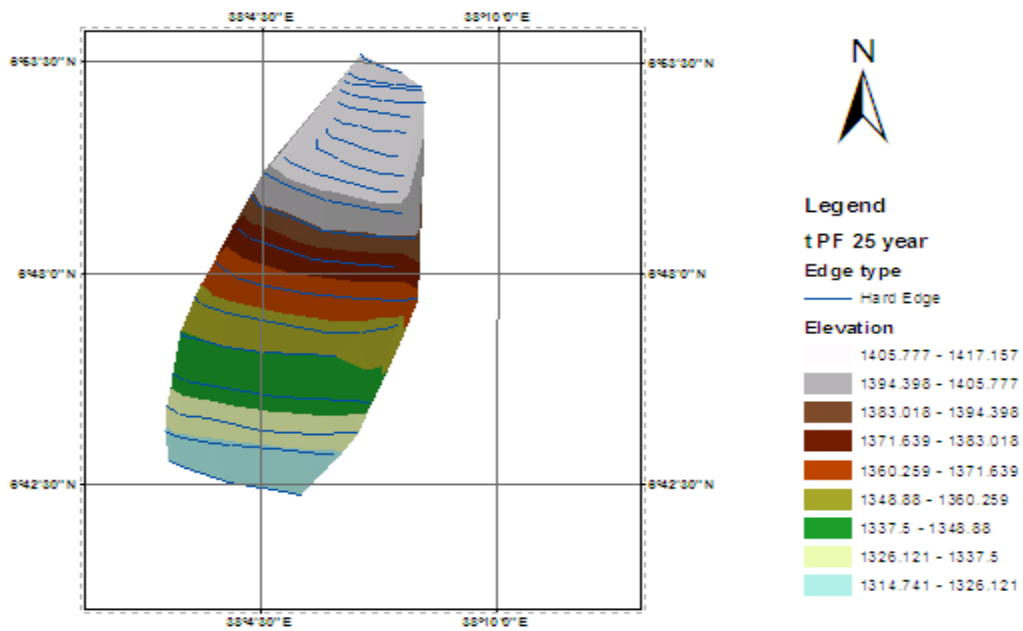


Figure 2 for 25 years return period

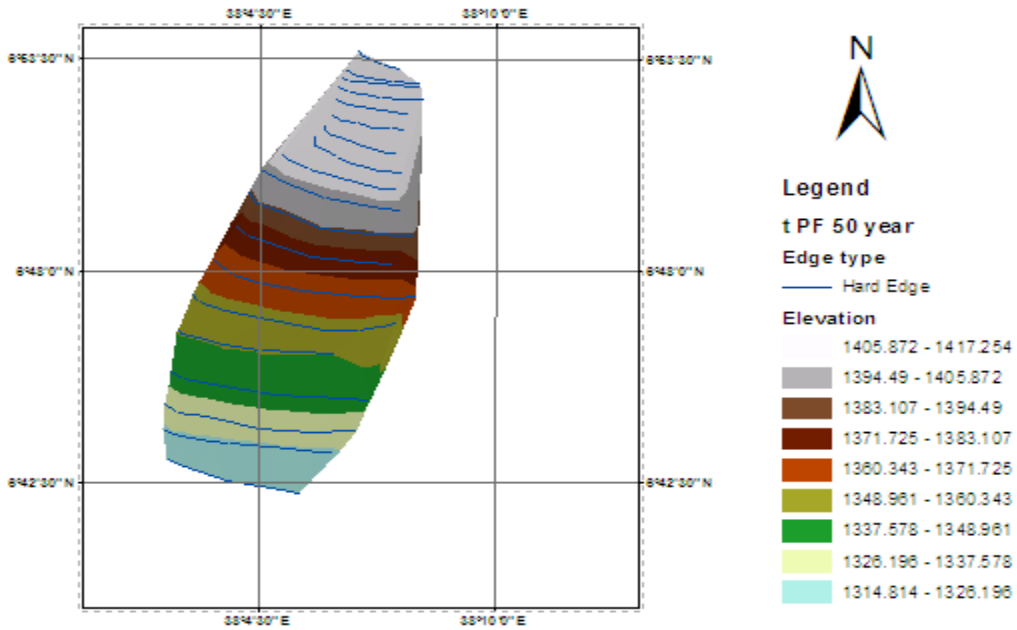


Figure 3 for 50-year return period

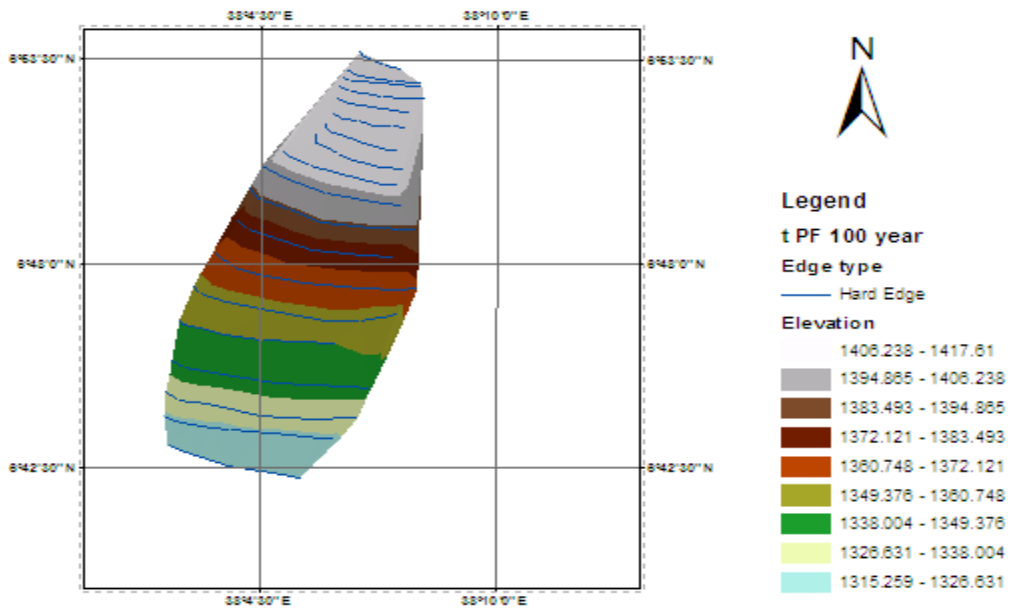


Figure 4 for 100-year return period

D. List of Figures Depth of flood plain map

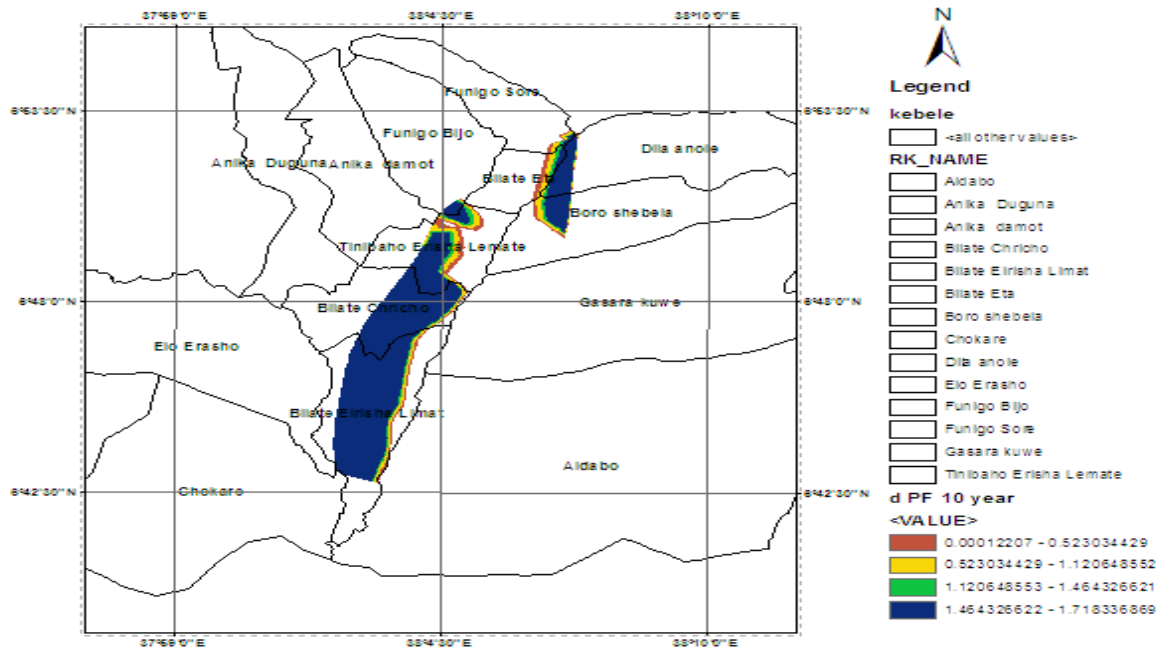


Figure 1 for 10-year return period

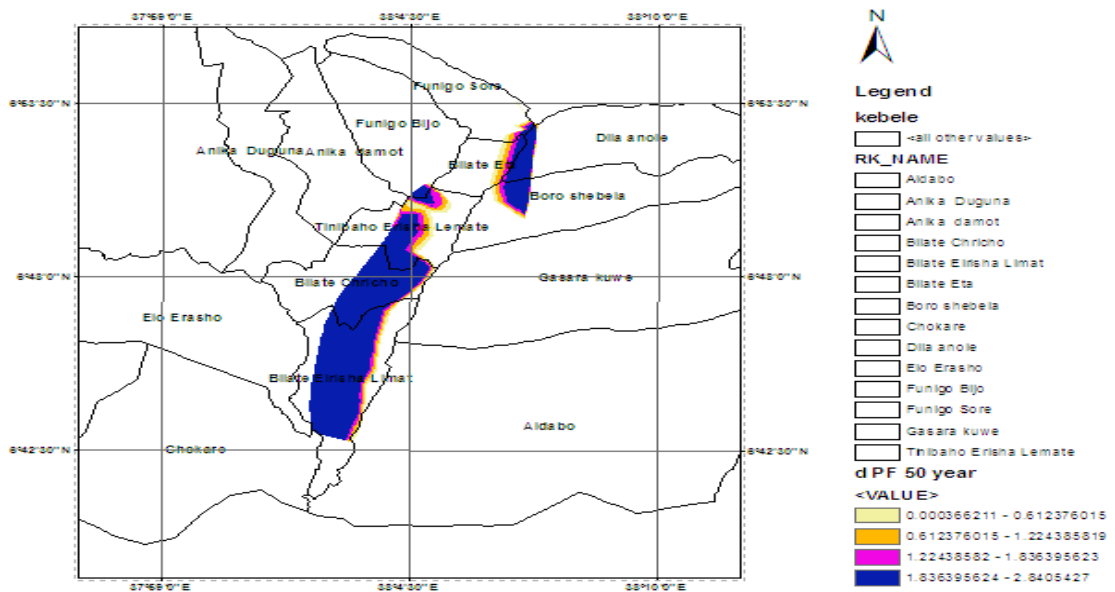


Figure 2 for 25-year return period

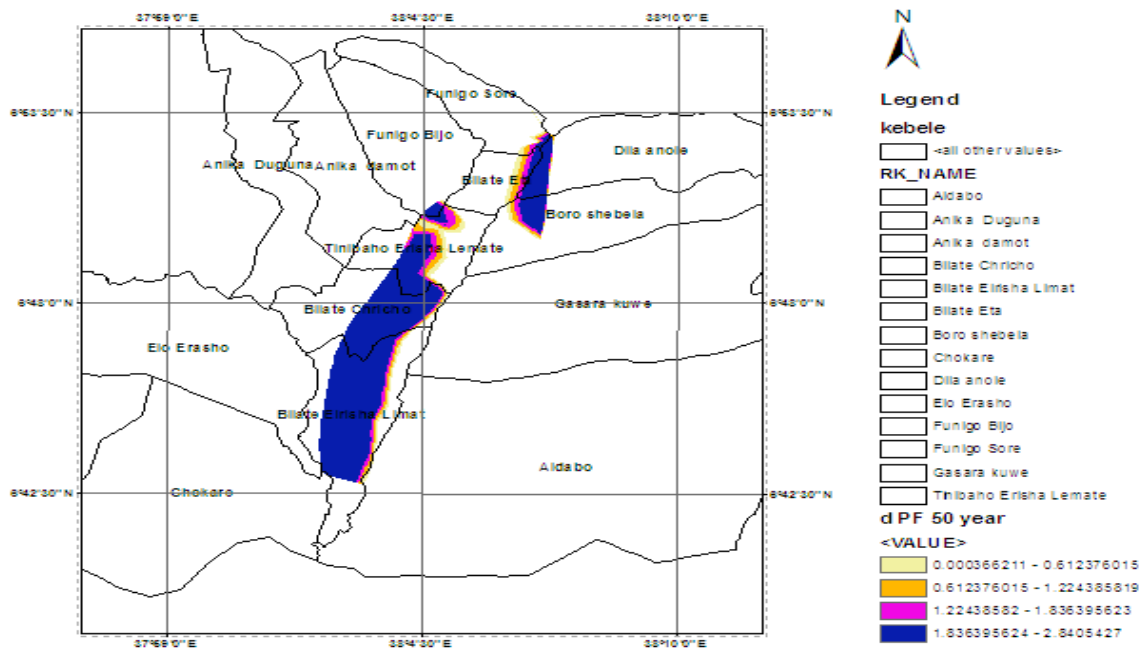


Figure 3 for 50-year return period

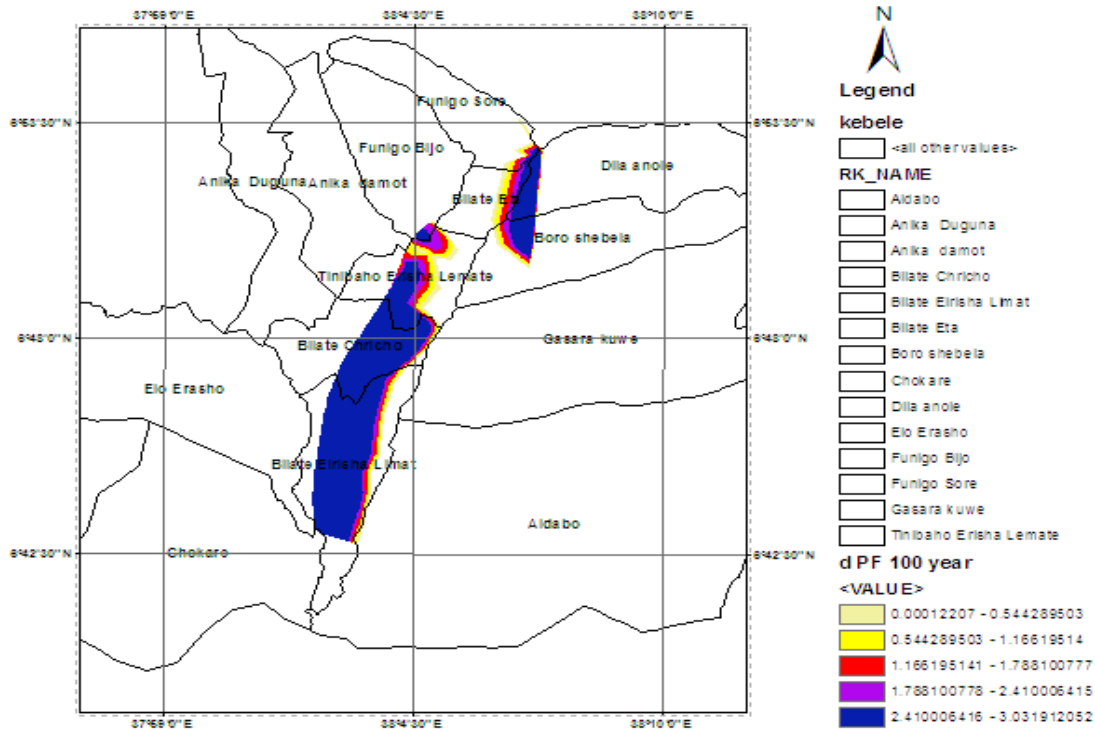


Figure 4 for 100-year return period

### E. Velocity of flood plain map

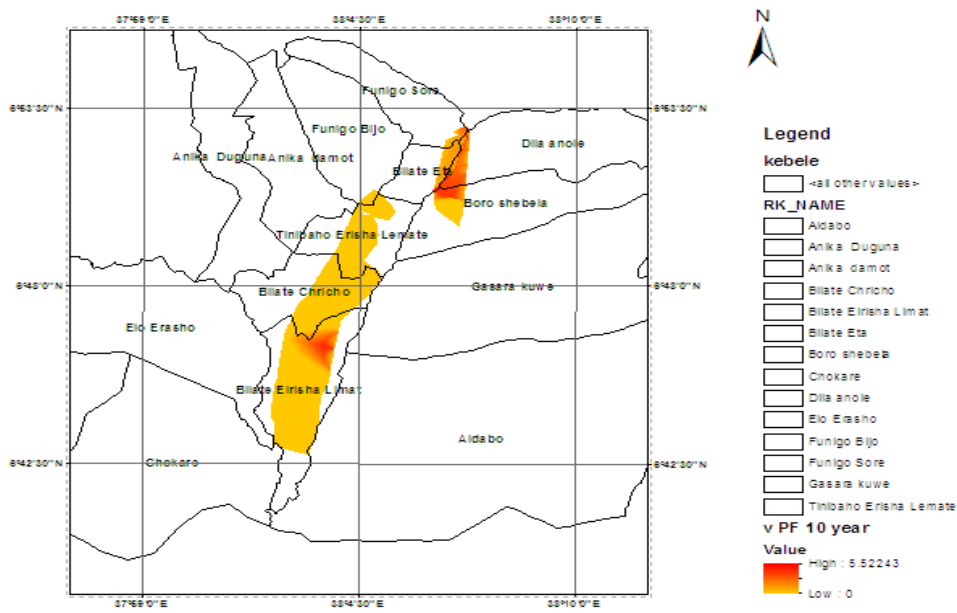


Figure 1: for 10-year return period

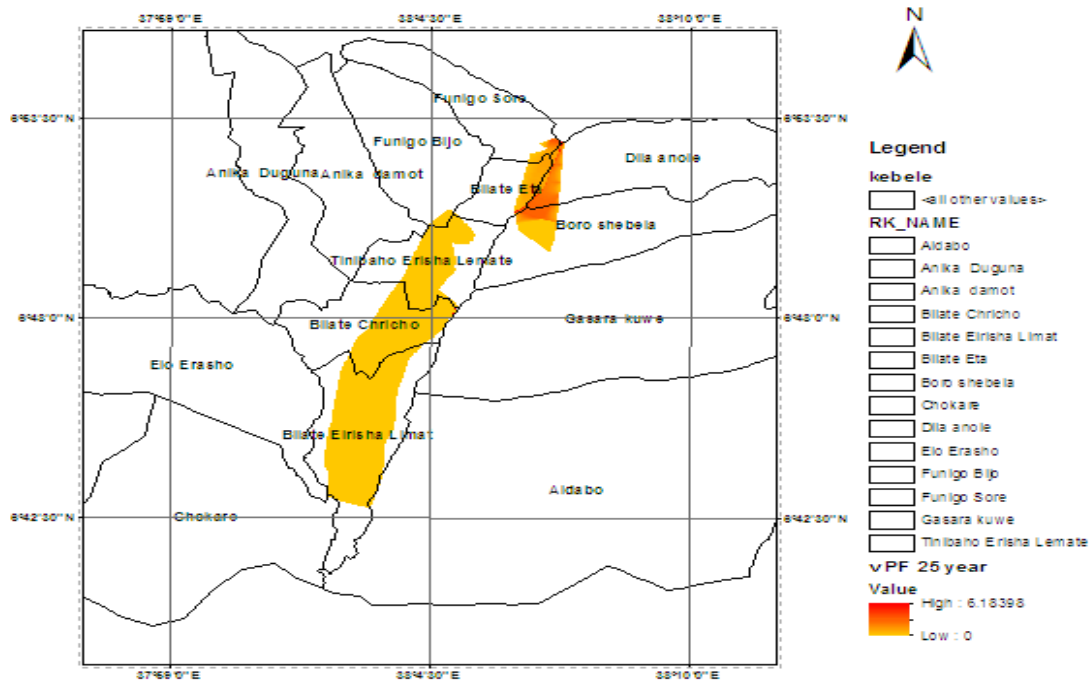


Figure 2: for 25-year return period

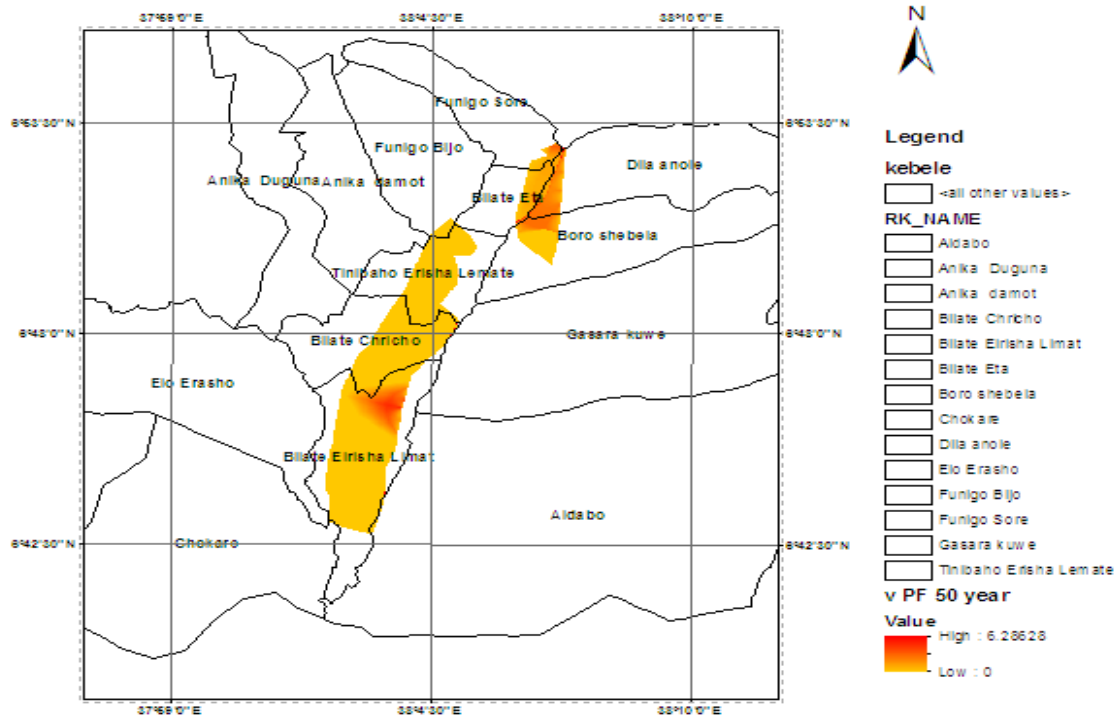


Figure 3: for 50-year return period

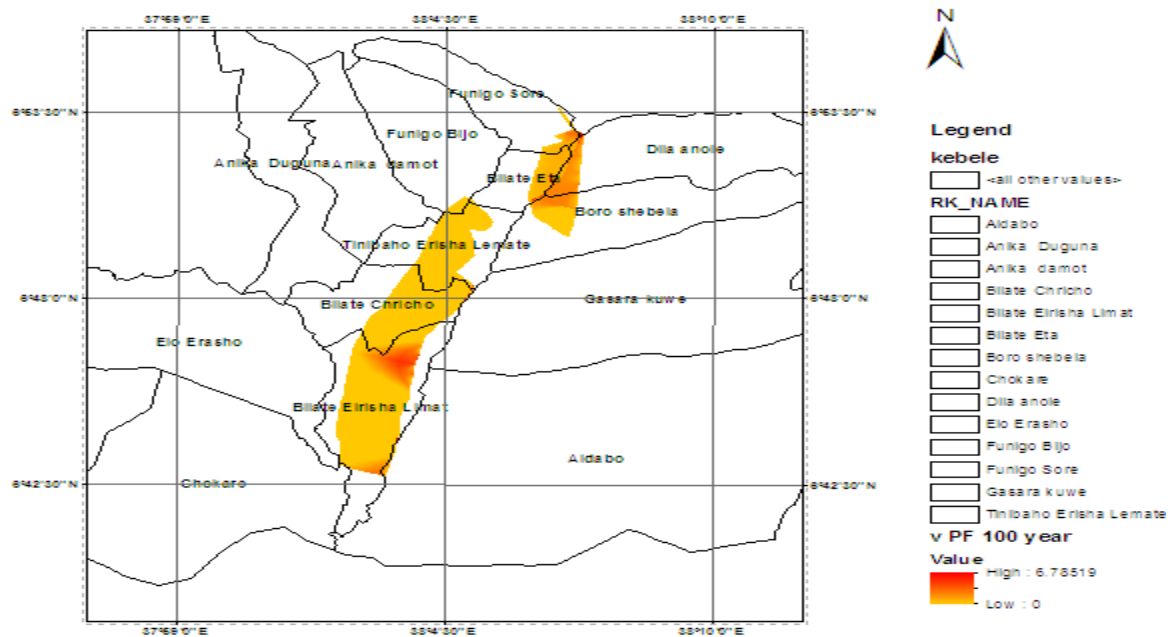


Figure 4: for 100-year return period