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ADDIS ABABA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES, POSTGRADUATE PROGRAM

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Flood Hazard and Risk Assessment using GIS and Remote Sensing Techniques: A Case Study in Fogera Wereda, Ethiopia.

By:

Abebayehu Mnilu

Addis Ababa, Ethiopia

Jun, 2023

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Abebayehu Mnilu

Advisor: Molla Maru (Msc)

A Thesis submitted to

School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Art in Geographic information system, Remote Sensing and Digital Cartography

Addis Ababa, Ethiopia

Jun, 2023

Addis Ababa University

School of Graduate Studies

This is to certify that Thesis prepared by **Abebayehu Mnilu Desta**, entitled: "Flood Hazard and Risk Assessment using GIS and Remote Sensing techniques: A case study in Fogera Wereda, Ethiopia and submitted in partial fulfillment of the requirements for the degree of Masters of Art in Geographic information System, Remote Sensing and Digital Cartography complies with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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2. ………………………………………Signature____________ Date ____________

Advisor

MollaMaru (Msc) Signature ____________Date ____________

Co-Advisor

----------------------------- Signature_____________ Date ____________

Chairperson

----------------------------- Signature_____________ Date _____________

Acknowledgments

My heartfelt gratitude goes to my advisor Mr.Molla Maru for his in-depth comments, guidance, and shaping the general structure of my thesis. Indeed, the work would have not successfully been completed without his continued support. I would like to thank Molla Maru, not only for advising on this work but also for his academic and educational support in my stay at the university.

I acknowledge my office Ethiopian Statistical Service (ESS) for giving the sponsorship to learn my MA and every kind of support I get from the office. I would also like to express my gratitude to the Department of Geography and Environmental Studies for welcoming me to the university and for all of the support and cooperation I've received from the department and its academic staff throughout my studies.

I would like to convey my heartfelt gratitude to the European Space Agency (ESA) for supplying me with free SAR data to conduct my research.

I am grateful to the Ethiopian Metrological Agency for their thoughtfulness in supplying the required data and information for this study. Finally, I would like to give my heartfelt thanks to my work colleagues to Teshome Talema who always encourages me in all my works.

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Acronyms

APFL	Associated Program on Flood Management
ESS	Ethiopian Statistical Service
CR	Consistency Ratio
dB	Decibel
DEM	Digital Elevation Model
DN	Digital Number
ERDAS	Earth Resource Data Analysis System
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper Plus
EW	Extra Wide Swath
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
GRD	Ground Range Detection
IDW	Inverse Distance Weight
ILRI	International Livestock Research Institute
IWS	Interferometer Wide Swath
LU/LC	Land-use/Land cover
MCDM	Multi-Criteria Decision Making
MoA	Ministry of Agriculture
MCA	Multi Criteria Analysis
MSI	Multi-Spectral Instrument
NMA	National Meteorology Agency
NIR	Near Infrared
OLI	Operational Land Imagery
SRTM	Shuttle Radar Topography Mission
RADAR	RAdio Detection and Ranging
RMSE	Root Mean Square Error
RI	Random Index
RS	Remote Sensing
SAFE	Standard Archive Format for Europe
SAR	Synthetic Aperture Radar
SM	Strip Map
SNAP	Sentinel Application Platform
SWIR	Short Wave Infrared
TM	Thematic Mapper
TOA	Top of Atmosphere
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UTM	Universal Transverse Mercator

VH	Vertical transmission and Horizontal reception
WGS	World Global System
WOA	Weighted Overlay Analysis

Abstract

Flood is a major environmental problem in Ethiopia as it has devastating effects on life and property. The objectives of this study are to assess flood hazards and risks in Fogera Wereda by using GIS and remote sensing techniques. Flood causative elements such as rainfall, drainage density, slope, elevation, land use type, and soil type were developed in the GIS environment. The generated Eigenvector was used as a coefficient for the specific factor maps to be combined in a weighted overlay. The flood hazard layer, as well as the two at-risk aspects, population and land use, were used to assess flood risk. The flood hazard map of Fogera Wereda revealed that very low, low, moderate, high, and very high flood hazards affected 6,627.46 ha, 33,360.69 ha , 34,265.19 ha , 30,896.00 ha, and 10,579.90 ha of the area considered in Fogera Wereda, respectively. Fogera Wereda flood risk map indicated that, very low, low, moderate, high, and very high flood risks were present in 1,940.61ha , 30,906.17ha , 41,458.6 ha, 37,127.52ha , and 4,296.31ha of the area subjected respectively. Fogera woreda Disaster Risk Managment in the Amhara Region and Flood Management Units in the Abay Basin could use those maps as a reference to design development strategies and control Fogera Wereda's flood problems.

Keywords: Flood hazard; flood risk; GIS; MCA, AHP, FogeraWereda, Remote Sensing

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Natural disasters of tornadoes, floods, volcanic eruptions, hurricanes, tsunamis, and earthquakes strike people around the world(Birkholz, et al, 2014 & Chen, et al, 2019), with the resulting loss of life and economic harm (Chen, et al, 2019). Flooding is one of the most severe natural dangers in terms of social, economic, and environmental consequences, especially in cities and agricultural areas (Khosravi, et al, 2018). Flood disasters inhabit a unique position among natural hazards. Floods are the world's most devastating natural hazard, accounting for 31% of all natural disaster-related economic losses (Nwilo, 2013). In the greater Horn of Africa, floods are the most common cause of climate-related catastrophes (Hagos, 2011).

Ethiopia's rainy season, which lasts from June to September and accounts at about 80% of the country's yearly rainfall. According to Kebede (2012), Extensive flooding is uncommon, happening only in the lowlands where major rivers flow into neighbouring nations, due to the country's rugged terrain with clearly established watercourses. Strong rainfall in the highlands, on the other hand, could result in flooding of settlements near any stretch of river. Due to Ethiopia's topographical and altitudinal features, flooding is a typical occurrence. They have been happening in a variety of locations and at various times, with varying magnitudes (Woubet and Dagnachew, 2011). Kebede(2012) claims that, the Baro-Akobo Basin, the Awash River Basin, Wabi Shebelle, the Ribb and Gumara Area (Fogera Plain), and Localized Flooding Risks such as Lake Awassa, Lake Besseka, and Dire Dawa are areas commonly flooded annually in Ethiopia.

Flooding happens when river and stream runoff fills a stream channel beyond capacity, overflowing into the storm channel and spilling over. Also, where there is a lack of infiltration potential and inadequate drainage, an increase in the hydrological water table above the surface causes flooding, which may occur as a result of dam failure or heavy rainfall (Nwilo, 2013). The flood that recently ravaged Fogera Woreda was a classic example of river flooding. The problem of river flooding in Ethiopia is becoming increasingly severe as a result of human interference in the fragile highlands on an ever-increasing scale. The river and flash floods are expected to harm 2,066,683 people during the 2020 'kiremt' season and 434, 154 persons (21 percent of the total vulnerable population) were displaced all around the country that will cost US$103,314,395 to implement (UNOCHA ,2020). Woubet (2018), states that 1109.2 Area in Sq. Km ofFogeraWoreda were affected by flood Risk. The Wereda has long been known as one of Ethiopia's flood-prone regions, as these areas have been flooded almost every year. Ribb and Gumara are the two main rivers that drain the wereda. It is entirely contained within the Blue Nile basin's Ribb–Gumara catchment. This catchment encompasses large flat to gently sloping plains on Lake Tana's eastern side. Fogera Wereda is found primarily in the catchment's downstream portion.

This highlights the need for flood-related issues to be addressed by planning based on studies and detailed research on flood-prone areas, as well as the formulation of potential mitigation steps. To address the problem, flood-related data must be compiled in order to classify flood-prone areas and elements at risk, allowing for more efficient flood-related management and decision-making.

The Geographic Information System provides a broad range of tools for identifying flood-prone areas and predicting areas that will be flooded as a result of a river's high water level (Khan, 2013).In recent years, remote sensing technology combined with geographic information systems (GIS) has become the key tools for flood monitoring. In this study GIS and Remote Sensing techniques will be used for the delineation of flood hazard maps and risk assessments in Fogera wereda.

1.2 Statement of the problem

Among the natural hazards that can bring disaster, flood is by far the most hazardous, common, and widespread natural disaster on the planet (Choubin, et al, 2019). Flood impact is very high in African cities where urbanization has occurred with inadequate land use planning and a lack of early warning systems, after repeated droughts, it is Africa's second and largest environmental disaster (APFL, 2008). Because of most African countries lack real-time forecasting technology or resources for post-disaster recovery, their socioeconomic and ecological effects are devastating. Although floods are common in Ethiopia, the country has been threatened by massive flooding during rainy season, which has caused severe devastation (Kebede, 2012).

Ethiopia's northern Amhara region took the bulk of the damage, with 97,000 people impacted and 37,000 individuals losing their houses. In this location, large areas of cropland have been flooded.In the summer of 2006, overflows of the Ribb and Gumara Rivers, as well as backflows of Lake Tana, impacted and displaced 43,127 and 8,728 people in Fogera woreda, respectively (UNOCHA, 2006).

According to UNOCHA (2020) Floods in the Afar, Gambella, Oromia, and SNNP areas have impacted over 30,000 people since 20 July 2020. River and flash floods are expected to affect 2,066,683 people during the 2020 kiremt season. Out of which, 434,154 people across the country are likely to be displaced. On July 29, 2020, the Rib River overflowed, submerging the main route in Fogera woreda from Wereta to Gonder as well as from Debre Tabor to Gonder. 27,179 Peoples were affected at Fogera Woreda during this year.Over 1,000 people were affected in Shanna 'kebele' of Fogera Woreda.

A variety of methods for assessing flood-prone areas and predicting areas that are likely to be flooded owing to a river's high water level are accessible using GIS and remote sensing (Ishaya 2008). Advances in Remote Sensing technology and Geographic Information Systems help in real-time tracking, early warning systems, and rapid damage assessment during flood and drought disasters (Ishaya et al., 2008, Herold& Sawada , 2012 & Khan, 2013). Because of their strong reliance on agriculture, river flooding is a major problem in Africa's developing countries, but any attempt at flood estimation or hazard mapping in this area is hindered by a lack of high-resolution satellite data. Flood Hazard Mapping is an important part of land use planning in flood-prone areas. It generates charts and maps that are simple to read and use, making it easier for managers and planners to define risk areas and prioritize mitigation/response efforts.

Flood hazard zoning, along with the control of flood hazard areas and the enactment and enforcement of flood hazard zoning, could reduce flooding-related deaths and property damage in the short and long term. Flood management and control are vital not just because floods are a humanitarian disaster, but also because optimal land use and proper management and control of water resources are critical for bringing prosperity to this densely populated Wereda's predominantly agricultural economy. Without accurate flood hazard and flood risk maps, this is not technically practicable. Flood risk mapping is an essential part of both flood mitigation and land use planning. In Ethiopia, most flood hazard studies have been done using Optical data. The disadvantage of the optical data is cloud affected. Microwave Remote Sensing data is not affected by the cloud. Hence, this study will help to fill the existing gap by using Sentinel-1A RADAR data to validate the areas exposed for flood hazards and elements at risk done by Optical data.

Based on topographical, meteorological, satellite, and population data, this study will identify areas that are frequently flooded and develop flood hazard and flood risk maps.

1.3 Objectives

1.3.1 General objective

The general objective of this study is to assess flood risk in Fogerawereda using GIS and Remote Sensing technique.

1.3.2 Specific objectives

More specifically the research amid to:

- Identify causative factors contributing for flood hazards in the study area.
- Build a flood hazard map for the catchment
- Determine the rainfall-run off relationships of the study area
- Develop flood risk maps for the research area
- Analyse the impacts of land-use and land-cover changes in Ribb-Gumara Catchment

1.4 Research questions

- What are the main flood causative factors in Ribb-Gumara Catchment?
- Which parts of Ribb-Gumara Catchment suffer from more flood hazards?
- To What areal extent Fogera Woreda is exposed to flood risk
- What type of spatial feature more affected by flood in study area

1.5 Scope of the study

The study's geographical scope was limited to Ethiopia's Fogera Wereda. Its purpose is to use GIS and remote sensing techniques to undertake a flood risk and hazard assessment study on the Fogera Wereda. The study is however limited to river flooding estimation and flood hazard in the study area. The study also covered a temporal scope of 30 years i.e. 1980-2020 from which temporal analysis of flood disasters was carried out to assess its frequency and also enable proper suggestion of solutions in mitigating the risk of the flood disaster.

1.6 Limitation of the study

The major limitations concerned to this study were the data available at the relevant acquisition mode and the specific time of flood season, especially cloud-free Sentinel-2A optical images for Land-use/Land-cover classification.

1.7 Organization of the thesis

The thesis is divided into five sections. This chapter introduces the study's background, the problem statement, the objectives, the research questions, the study's scope, the study's limitations, and the paper's organization. The second chapter provides an overview of relevant literature. The materials and methods are discussed in the third chapter. There are two subtitles under this portion, materials, and methods. The subtitle materials deals with the description of the study area, data sources and software programs used in the study while the subtitle method deals with all the procedures followed in image pre-processing, thematic layer generation and analysis. Chapter four is all about results and discussions that deal with flood hazard and risk assessment. The last chapter discusses the conclusion and recommendations based on the research findings of the study.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2. Introduction

This chapter presents the literature review that provides the basic information regarding concept of flooding, definition of flooding and factors contributing to flood to identify the existing state of knowledge explored by researchers, experts and professionals in relation to the research problem. The review provide both theoretical and conceptual frameworks regarding the research problem at hand as well as geographic information system and techniques for flood risk assessment used in carrying out research in the area so as identify research gaps.

2.1 conceptual issues

2.1.1 Flooding

Flood is a naturally happening weather event that comes approximately in flooding of a huge sum of surface water over rivers that's not constantly immersed (Adeoye et al, 2009). Literally, flood is a large volume of water covering an area that is usually dry. It is a high water level above the banks of a stream channel, riverbank, lakeshore or ocean coast that inundated the land area along its boundary (Busari and Olaleye,2009).Flood as a natural hazard (like drought and desertification) which occurs as an extreme hydrological runoff. Floods are water-induced disasters that temporarily submerge dry areas and bring significant harm to the affected areas, including the loss of life, property damage, and infrastructure devastation. (Umar Iliyasu, 2017).

Floods can happen when water from bodies of water, such as rivers, lakes, or oceans, overflows or breaches the banks or levees, leaving its regular boundaries. Floods can also occur when the flow rates exceeds the capacity of a channel. The type of flood risks and their effects depend on the natural and human-made conditions in the floodplains, economic growth, and the adoption of flood protection systems, which have physical as well as political, economic, and social components (Nwafor, 2006).

2.1.2 Types of flood

Understanding the type of flood occurring in an area is very important in assessing flood risk.

There are several types of floods and each bears a different dimension in terms of impacts, Occurrences and risks (Umar, 2017)

River flooding: Heavy rains that exceed rivers' capacity, forcing them to overflow and burst their banks, are the most common cause of river flooding. Because it occurs as a result of prolonged rain and frequently occurs in the same locations on a regular basis, this is the most common type of flooding in the globe (Chris, 2018).

Coastal flooding: occurs when the sea or ocean surge inundates coastal areas. Coastal floods are occur when strong winds drive water onshore, overwhelming low-lying terrain and severely affecting, including the loss of life and property (Aliyu, 2019).

Flash flooding: is mainly caused by severe rain that overwhelms drainage systems or breaks flood barriers. These floods are extremely fast-moving and unpredictable, which makes them extremely hazardous. As climate change continues, this type of flooding is likely to become more common. More projects are being built on flood plains, and natural drainage systems are being concreted over to make way for construction (Chris, 2018).

2.2 Contributing factors for flood hazard and risk

Several factors have been found that contribute to the devastating potential of flood hazards. These factors are influenced by indicators like flood depth, duration, velocity, impulse (the product of water level and velocity) and the rate at which water levels rise, as well as warning time and frequency of occurrence (Matej& Jana, 2016).

The most common factor that causes flooding is prolonged intensive rainfall. Prolonged rainfall results in soil saturation which leads to increased surface runoff into the surrounding water channels, exceeding the channels' capacity and consequently floods occurs. Apart from precipitation, several other factors influence the generation of surface runoff which eventually leads to floods. The most common of these factors include: geology, topography, Land use/ Land cover, evapotranspiration, soil characteristics etc. (Hagos.*et al*2014).

2.3 GIS and remote sensing technology for flood hazard and risk assessment

Remote sensing and geographic information systems are highly valuable and effective technologies for assessing flood risk. Remote sensing is the science, technology, and art of gathering information about an entity or an environment without coming into direct contact with it. Remotely sensed images are often employed in delineating flood plains, mapping flood-prone areas, land use mapping, flood detection and forecasting, rainfall mapping, evacuation planning and damage assessment. Remotely sensed data, such as satellite images, have a vast synoptic overview that can be put to many different uses, such as mapping a variety of topography parameters for flood analysis (Priscilla, 2017).

According to Wubet (2007), GIS is becoming a powerful method for risk assessment and control of natural hazards. Using these techniques, it is now possible to plan natural hazard mapping and map flood-prone areas. Such maps will assist civil authorities in quickly assessing the possible effects of a natural disaster and initiating effective mitigation steps. Such information can assist planners and decision-makers in taking constructive and timely actions in the lead-up to a disaster. It will also assist them in assessing costs and injuries that arise as a result of flooding.

GIS stands for Geographic Information System, and it is a computer-based system that handles spatial data input, storage, retrieval, manipulation and analysis, and output. GIS provides a number of methods for analyzing flood-prone areas and predicting areas that will be flooded as a result of a river's high water level. Information from numerous charts, aerial photos, satellite images, and digital elevation models (DEM) will be compiled using GIS (Kebede, 2012).

In recent years, satellite image-supported remote sensing applications have made a significant contribution to establishing new methodological approaches in digital world. This includes multispectral image analyses of medium- and high-resolution remote sensing satellite imagery as well as data extraction from Synthetic Aperture Radar (SAR) (Keay et al., 2014)

2.3. Theoretical frameworks

In an effort to analyze possible risks associated with environmental hazards such as flooding, a variety of theoretical hypotheses have been proposed.

2.3.1 ANCOLD flood risk assessment model

The Australian National Committee on Large Dams (ANCOLD, 2003) provides a methodological framework for the identification and estimation of flood risks. Flood risk assessment based on this model is determined by the following:

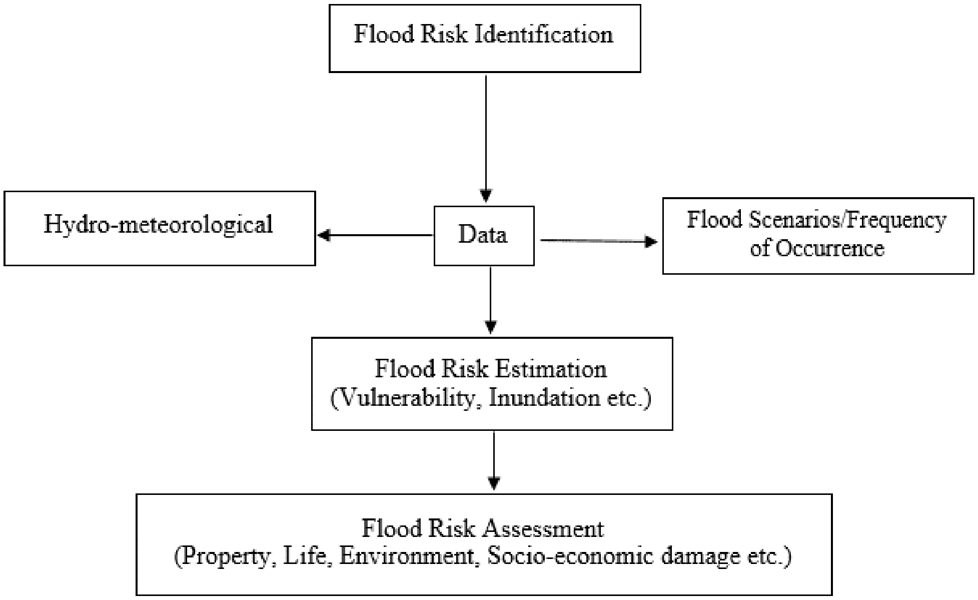

Figure 2. 1 Flood Risk Assessment Model (Umar Iliyasu, 2017)

Flood Risk Identification involves the identification of hazard source taking into account hydrological and meteorological data, flood scenarios, frequency of occurrence, damage assessment of the inundated areas etc. to determine whether there may be any flooding event and its anticipated consequence. Flood risk estimation involves the estimation of the flood risk occurrence, actual consequences and vulnerability estimation. Flood risk assessment is a process by which hydrologists measure the probability of a flood inundating a given region in order to provide a guide on low and high risk areas based on tolerance levels. The flood risk assessment helps in examining what level of risk can be tolerated and what mitigation measures will be implemented (Umar, 2017)

2.3.2 Multi-Criteria Evaluation (MCE)

In decision theory, Multi-criteria evaluation is the process of making use of a decision rule to a fixed of alternatives. A decision rule is a procedure through which criteria are mixed to reach at a specific evaluation, and by which evaluations are as compared and acted upon. A decision is a choice between alternatives together with alternative actions, land allocations, and so on. The basis for a decision is known as a criterion. Criteria may be of two types: factors and constraints. Factors and constraints can be combined in the MCE module using one of three methods

(Boolean intersection, Weighted Linear Combination and Ordered Weighted Average); each method is characterized by different levels of control over tradeoff between factors and the level of risk assumed in the combination procedure(Demessie,2007).

2.3.3 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is geographic raster representations of terrain elevations arrayed in series of south-north profile coordinates. The terrains elevations are sampled at regular spaced horizontal intervals and are popularly used in the manipulations and terrain analysis of an area. The digital elevation model (DEM) is an essential tool in carrying out analysis in various fields including geology, hydrology, geography, climatology, Meteorology, etc. Being an important utility of Geographic Information System (GIS), the Digital Elevation Model (DEM) provides an opportunity to, assess, analyze, digitize, display and demonstrate physical event like topography, relief, vegetation, drainage, hydrology, etc.(Suma, 2014).

2.4 Empirical literatures

Among all forms of natural disasters, Flood is considered the worst natural disaster in the world and one of the most frequent in terms of occurrences. Across the globe, flood has posted serious disaster to human Lives and properties. It usually claims over 20,000 lives yearly, and adversely affects about 75million people worldwide. According to the United Nations Environment Programme (UNEP), floods caused one third of all devastations from natural environmental disasters (Okwonko, 2013).

In china, floods considered to be a serious natural disaster. The catastrophic floods of 2008 in the Yangtze and Songhua river basins nearly affected one out of ten Chinese in the area. Although fewer lives were lost, significant damages to properties and infrastructures worth Millions of dollars was recorded. (Mwape, 2009).

In the arid areas of western Saudi Arabia, flash floods are generated after high-intensity rainfall events, particularly on steep mountainous terrain and hilly slopes that are barren and lack vegetation cover (Barbara and Helmut, 2019).

Adamson (1983) states that, extreme flood events in South Africa have resulted in loss of lives, massive property damages including crops and livestock. The risks of such events and their

Occurrences in the country are quit frequent. The Laingsburg flood disaster of 1981 has been described as South Africa’s greatest catastrophe. The flood resulted in considerable damages and claimed over 100 lives (Umar, 2017).

Many studies posited that problems with floods and flooding are strongly related to Population, population density and standard of living, especially in the developing countries. Flooding in Nigeria is the most common and recurring disaster with unprecedented damages especially the 2012 flood that was yielded remarkably due to heavy rainfall and surface runoff which contributed to flooding of human settlement sited along the Kainji, Jebba and Shiroro dams in Niger state; the Lagdo dam in Cameroun located on river Benue, the Kiri dam on the Gongola river and numerous additional irrigation dams (Aliyu 2019).

Flooding in Ethiopia mainly occurs during the first three months of the rainy season and is restricted to locations with a lower and flat geographical setting. It is usually the intense rainfall in the high lands that cause flooding at its downstream and disaster to settlements close to any stretch of river courses. Moreover, flood hazard is common to the floodplains which are normally located along the rivers at the downstream parts of the river courses. According to an ECHO report(2019), floods in Ethiopia's Amhara region during the first weeks of August 2019 killed two persons and flooded several homes in the South Gondar Zone. The flooding in the woredas of Fogera and LiboKemekem on the 11th and 12th of August was caused by the overflow of rivers that are tributaries of Lake Tana and the Blue Nile. 25,000 people have been affected, 6,653 homes have been flooded, 18 schools have been damaged, and 3,428 hectares of farmland have been flooded, according to ECHO reports (2019).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The Fogera Wereda is one of the Amhara Regional State's 151 Weredas. It is located in the Amhara Regional State's South Gondar Zone. It is divided into 33 rural kebeles and three urban kebeles. At the south-eastern shore of Lake Tana, Fogera Wereda located on the road connecting Bahir Dar and Gondar, which is 625 kilometers from Addis Ababa and 55 kilometers north of Bahir Dar City. Misrak Este wereda to the south, Dera wereda to the west, Lake Tana to the west, LiboKemkem wereda to the north, Farata wereda to the east, and Ebinat wereda to the northeast define the borders of Fogera. Geographically, it is bounded by latitude 11º38'41"–12º0'37"N and longitude 37º 31'28"–38º 0'29"E, covering a total area of 1,155.91 km² (Figure 3.1).

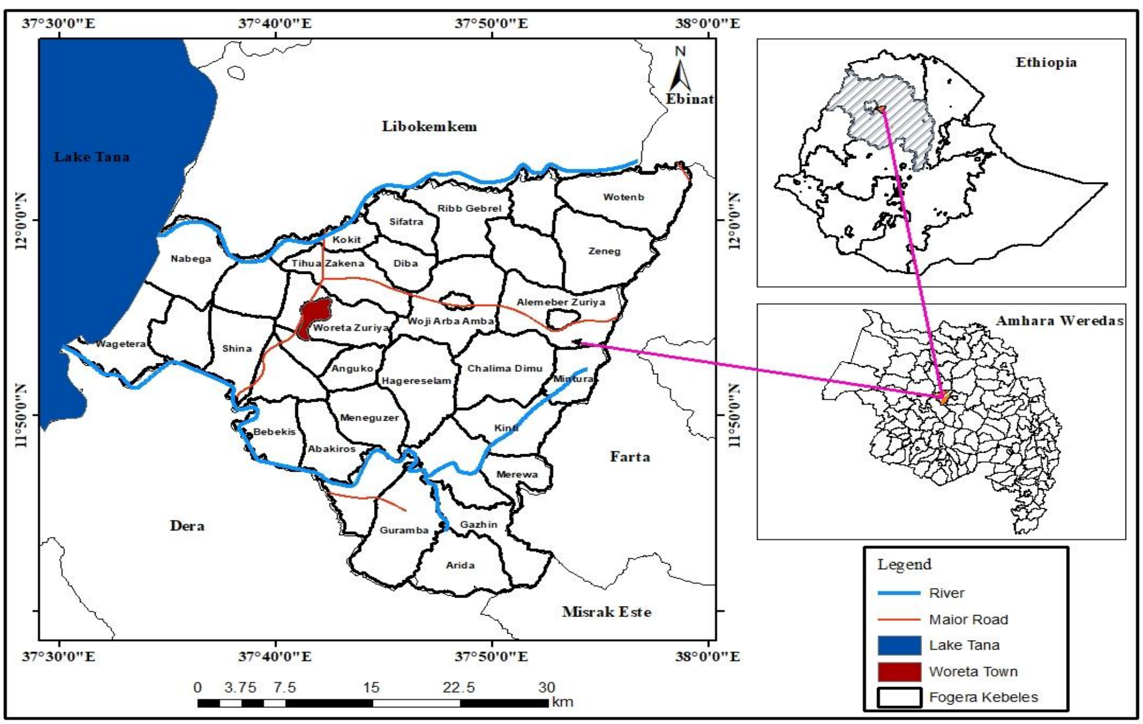

Figure 3. 1: Location map of the study area (Fogerawereda)

Source: Ethiopian statistical service

3.1.2 Population

According to the Ethiopian Statistical Service (ESS, 2007), the total population of Fogera Wereda was 228,449. The 2014-2017 population projection (Table 3.1.) shows, the wereda's population in both sex increases by ~2%.

Table 3. 1: Population projection of Fogera Wereda.

Year	Male	Female	Total
2014	134,511	130,001	264,512
2015	136,950	132,400	269,350
2016	139,355	134,704	274,059
2017	141,716	136,963	278,679

Source: Ethiopian statistical service

3.1.3 Topography

Flat topography dominates the study area, which is known as the Fogera plain, which is located near the eastern shore of Lake Tana.However, proceeding to the eastward, there is a rugged topography (Figure 3.2). The altitude fluctuates between 1781 and 2499 meters above sea level (m.a.s.l).The wereda consists mainly of flat land (76%), while mountains and hills and valley bottoms account for 11% and 13%, respectively (Tilahun*et al.*, 2012).

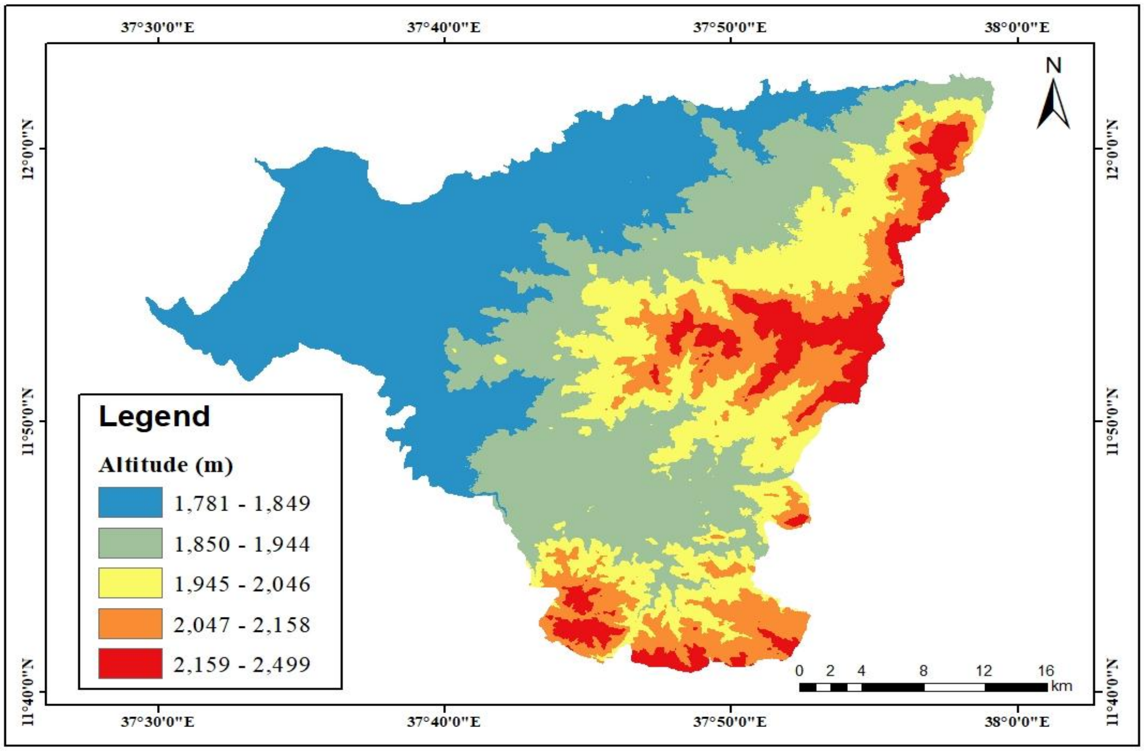

Figure 3. 2: Topographic map of the study area

Source: Digital elevation model

3.1.4 Climate

Do to the National Metrological Agency (NMA), the rainfall of the Fogera Wereda is characterized by a uni-modal distribution with a peak in July. The mean annual rainfall becomes 1216 mm starting from 1103 to 1336 mm from each the quick (March and April) and long rains (June to September). The mean monthly readings range from 0.6 mm in January to 415.8 mm in July, indicating that rainfall has a poor temporal distribution. According to data collected from National Meteorology Agency of Ethiopia for the years 1978-2020. The mean annual rainfall of Amedber (Figure3.3) and Woreta (Figure3.4) station of study area has

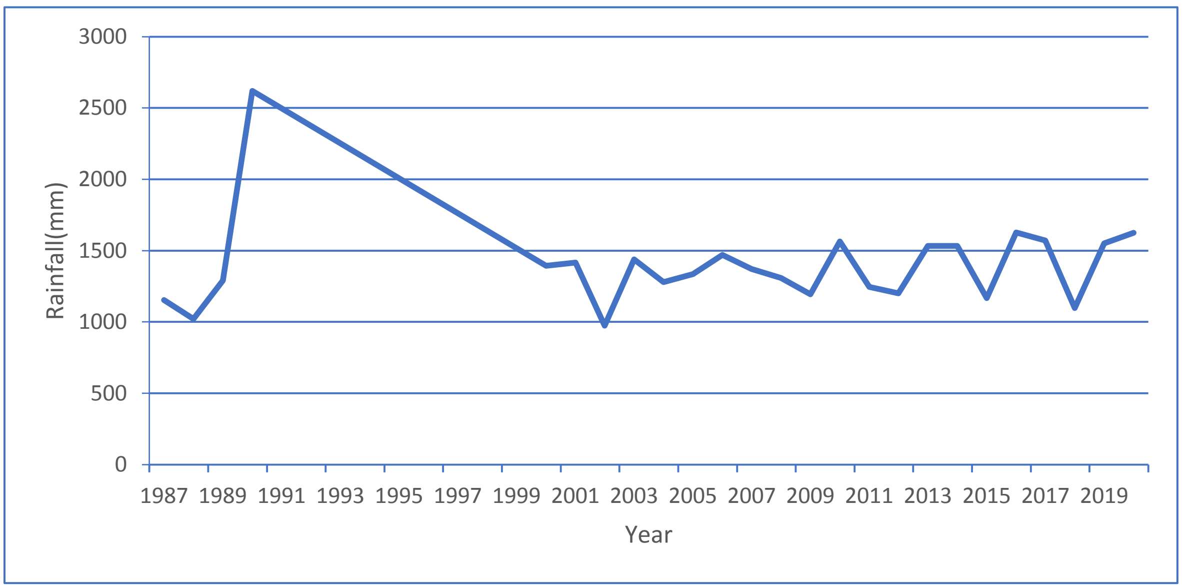

Figure 3. 3 : Rainfall (in mm) distribution of the study area

Source: National metrological agency

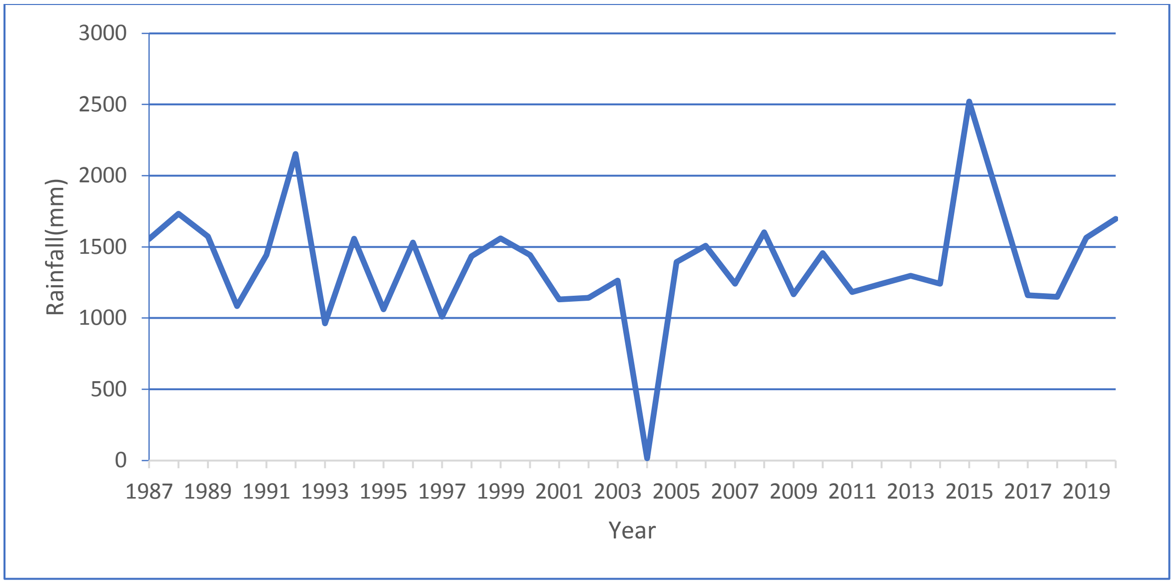

Figure3. 4 : Rainfall (in mm) distribution of the study area

Source: National metrological agency

3.1.5 Soils

Soils have a major influence on hydrological processes. Their physical properties govern the storage and transmission of water within the soil. Soils have different rainwater retaining capacity. This capacity is dependent on the soil type and their texture. Flooding problems will occur even where there is no heavy rainfall if the soil in an area will not hold enough rainwater (Getu, 2017).

In Fogera Wereda, the principal soil types have a general relationship with altitude and slope. According to the soil data from FAO (2013), the study area has 4 major soil types (Figure 3.4). Eutric Nitosols are the most common soil type in the area, accounting for 31.47 percent of the total soil. It is about 36,769.59 ha area followed by Chromic Vertisols that account for 35,346.6 ha area (Table 3.2). The soil type with the least area coverage is OrthicLuvisols that covers only 13,481.62 ha (11.55%).

Table 3. 2: Major soil types (area in ha and %)

Soil Type	**Area(ha)**	**Proportion (%)**
EutricNitosols	36769.59	31.47
Chromic Vertisols	35346.47	30.26
Chromic Luvisols	29984.64	25.67
OrthicLuvisols	13481.62	11.55
Water body	1229.05	1.05

Source: Food and agricultural organazation

In the Wereda, chromic Luvisol and chromic Vertisol are the most common soil types, especially in lowland flat plains, valley bottoms, and river banks. (Figure 3.4). These soils are sandy clay and sandy loam, respectively, in texture. Morphological properties of Luvisols are deep, well-drained, and have a loamy sand texture. The texture of Vertisols (VR) varies from clay on the surface to heavy clay in the subsoil and is poorly drained with a deep rooting zone.

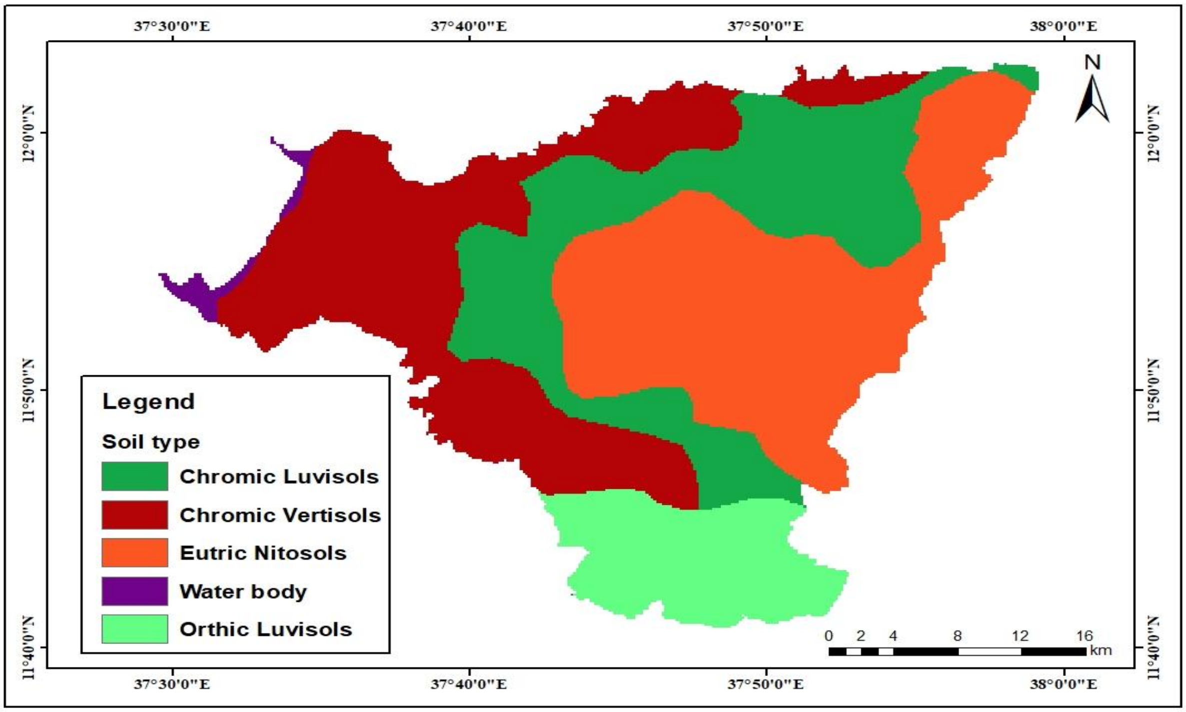

Figure3. 5: Soil type map of the study area

Source: Digital elevation model

3.1.6 Drainage System

The Rib River flow into Lake Tana through the Fogera Wereda, that is usually flat and open (Figure 3.5). It passes through Wetemb, Addis Betekerstian, RebGebriel, DebasiFatra, AbuaThua, Shaga, Naber and Shinakebeles. The Gumara River forms the southern boundary of the study area and it passes through FuafuatGajera, KintiMerewa, AbagundeSendega, Aba Kiros, Bebeks, QuahrMichiel, ShenaKidist Hanna, Wagatera and Gurambakebeles. Both rivers begin on a high plateau to the east, and as they descend towards the plains, the gradient drops, causing them to form meanders. As the Rib River approaches the level of Lake Tana during and after the rainy season, water spills its banks and floods the surrounding land. The Gumara River exceeds its banks as it approaches the lake, but it causes less flooding than the A persistent wetland has evolved around the mouths of those rivers. During the rainy season, Lake Tana, which serves as the area's western boundary, overflows up to 1.5 kilometers inland (Woubet and Dagnachew, 2011).

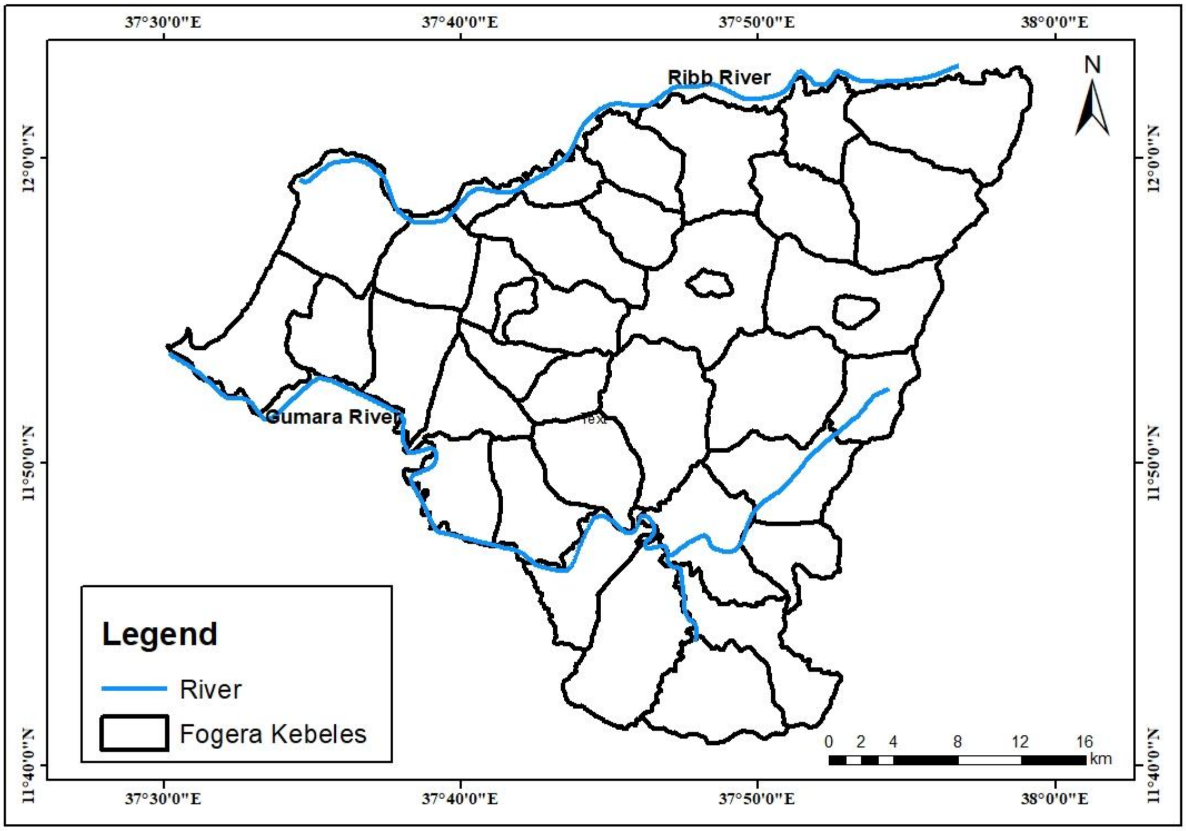

Figure3. 6: Drainage map of the study area.

Source: Digital elevation model

3.1.7 Ecology

Based on the agro-ecological classification technique (altitude and rainfall) the FogeraWereda divides into two zones: Moist WeyenaDega and Wet WeyenaDega (AstewulTakele, 2010). The Moist WeyenaDega accounts 4,845,459 ha (43.6 %) and Wet WeyenaDega accounts 6,267,856 ha (56.4 %) land of the wereda.

3.1.8 Agriculture

Rice, fish, horticulture, and livestock are the principal crops in the north and western sections of the wereda, which encompasses the Fogera plains and is inundated during the rainy season (AstewelTakele, 2010). Cereals, oil crops, horticulture, cattle, and apiculture are all part of the farming system in the south and east, which ranges from lowlands to highlands.A cattle farming remains a major activity, although crop agriculture has increased in importance. Fogera is unique from other weredas since it grows rice on the Fogera Plain and is known for the Fogera Cattle breed.

3.2 Data Description and Material Used

3.2.1 Data Description

The primary and secondary data used to identify parameter factors for analysis came from a variety of sources. (Table 3.3).

Table 3. 3: Datasets and their source

No.	Data	Data Type	Scale	Data Sources
1.	Slope and Elevation	Sentinel-1A	10 m	Copernicus Hub
2.	Land-use/land-cover	Sentinel-2A	10 m	Copernicus Hub
3.	Daily Max Rainfall	Rainfall records	Monthly Average	NMA
4.	Monthly Temperature	Temperature records	Monthly Average	NMA
5.	Drainage Density	Sentinel-1A	10 m	Copernicus Hub
6.	Soil	Soil Type Shape File		FAO
7.	Population	Population data	-	CSA
8.	Boundary	Shape File	-	CSA
9.	Ground Truth	Point data	-	Field survey

Sentinel 1 RADAR data and Sentinel-2A Multi-Spectral Instrument (MSI) provide satellite data.

Sentinel-1 collects data in four modes, namely Strip Map (SM), Interferometric Wide Swath (IW), Wide (EW) and Wave Mode (WM), with varying resolutions, extents, incidence angles and polarizations. Out of the four acquisition modes, the IW mode is the primary or default operational mode for Sentinel-1A over land, serving agricultural, forestry, and other natural resource applications (Skolnik, 2008).This mode observes in single and dual polarization VV; VH with a 250 km footprint in the range direction (vertical transmitting, vertical receiving; vertical transmitting, horizontal receiving). The ESA Data Hub makes all data freely available, and the Alaska Satellite Facility mirrors it (ASF). Using open access data archives, data for the entire region was retrieved as Standard Archive Format for Europe (SAFE), which provides general product information in XML. Metadata on acquisition, image attributes, polarization, Doppler information, swath merging, calibrations, and geographic position, among other things, are included in annotated data files. (Torbick et al, 2017).

Sentinel-2A is a two-satellite land observation constellation designed by the European Space Agency (ESA) and created by Airbus Defences and Space as part of the European Union's Copernicus program. The Sentinel 2 instrument has a swath of 290 km and a spatial resolution of 10 m (4 visible and near infrared bands), 20 m (6 red edge / shortwave infrared bands) and 60 m (3 atmospheric correction bands) and Consists of 13 spectral channels. It can enable a wide range of land studies and geophysical applications, reducing the time it takes to construct a large, cloud-free imaging collection around the world. The Sentinel-2A spectral bands provide land cover and change classification data (http://www.copernicus.eu). A Sentinel-2A image is composed of granules that have a fixed length (about 25 km across the track and 23 km along the track) and area (100 km2 in UTM/WGS84 projection). That can be downloaded in SENTINEL-SAFE format (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/data-formats). Sentinel-2A bands (2, 3, 4, 8, 11 and 12) were chosen for stacking in this study, which correspond to Landsat bands (blue, green, red, near-infrared, shortwave infrared 1 and shortwave infrared 2), resulting in a product that is similar to TM / ETM+ / OLI.

Table 3. 4: Band spatial resolution, central wavelength, and bandwidth of the Sentinel-2A image.

Band Number	**Spatial Resolution (m)**	**Central Wavelength (nm)**	**Bandwidth (nm)**
B1	60	443	20
B2	10	490	65
B3	10	560	35
B4	10	665	30
B5	20	705	15
B6	20	740	15
B7	20	783	20
B8	10	842	115
B8A	20	865	20
B9	60	945	20
B10	60	1375	30
B11	20	1610	90
B12	20	2190	180

Source: USGS, sentinel-2A

A single cloud free Sentinel-2A image acquired on 31 April 2021 was used in this study.

3.2.2 Material used

In order to achieve the objectives of this study, the following hardware and software were utilized:

Hardware used

External Hard disk: 1 TB storage size.

Handheld GPS receiver: Garmin 78, with 3 m positional accuracy was used for sample point collection for LU/LC verification.

Laptop with a monitor display of 1366x768 pixels, Memory, 4.0 GB RAM and 2.7 GHz processor speed was used.

Software used

The different software that was used for this study includes;

ArcGIS 10.8.1: ArcGIS 10.8.1 was used storing and managing geographic data in geodatabase package, compile and edit GIS datasets and display and analyze spatial data in both vector and raster format and finally to prepare each thematic layer.

ERDAS Imagine 2016: This was used for mosaicking, classification and post-classification of the Sentinel-2A image for LU/LC preparation.

IMPACT-Toolbox: IMPACT-Toolbox software was used for atmospheric correction and layer stacking of sentinel-2A images.

IDRISI Selva 17.00: IdrisiSelva was used for aggregation of reclassified factors based on AHP criterion weight.

Microsoft Office Package (2019): Provides the necessary environment for MS Excel, MS Word, MS Powerpoint and MS Access.

3.3 Methods

The following methodological approach was employed in carrying out this research.Multicriteria and AHP analyses were used to calculate the flood hazard analysis. To run MCA, selected flood causing factors were established and weighted, including soil type, elevation, slope, drainage density, land use, and rainfall.The flood hazard map was then created using a weighted overlay technique. Given that the degree of loss is typical for the study area, the vulnerability is assumed to be one.Finally, to create a flood risk map for Wereda, a hazard element (population density and land use) layer and a flood hazard map were overlaid using a weighted overlay analysis method in the ArcGIS 10.8.1 environment.

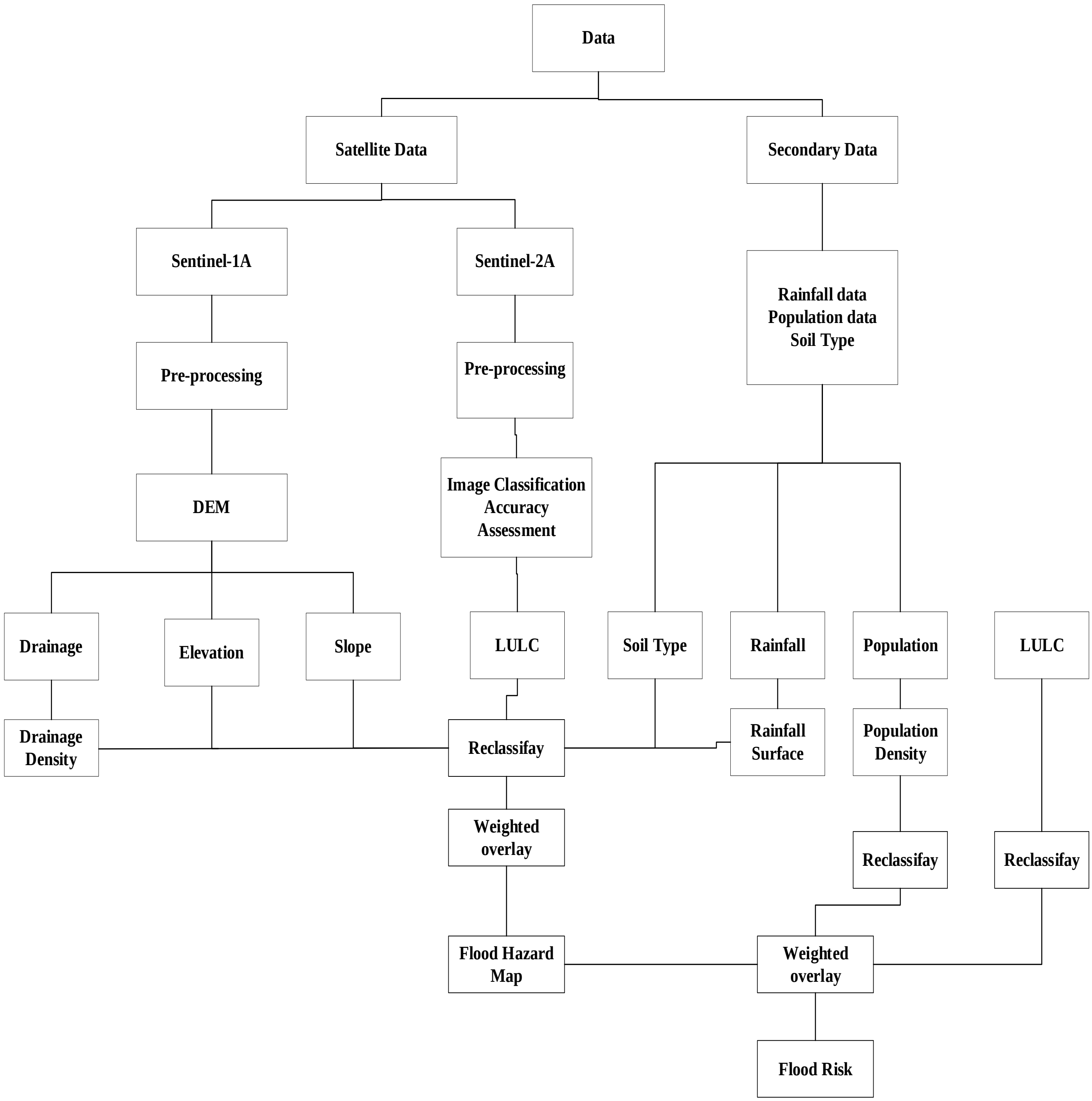

Figure3. 7: General workflow of the thesis

Source: own construction

3.3.1 Pre-processing

Pre-processing was done on the raw data of the two sentinel family images (sentinel-1A and sentinel-2A). The pre-processing which was done on these data includes the radiometric and geometric correction.

3.3.1.1 Image calibration

Radiometric corrections are not included in typical SAR data processing, which results in a level 1 image with severe radiometric bias. As a result, in order for the pixel values to appropriately represent the RADAR backscatter of the reflecting surface, the radiometric correction should be applied to SAR images.Image calibration was performed as one of the SAR image pre-processing steps using sentinel application platform (SNAP). SAR calibration's objective is to provide images with pixel values that are proportional to the scene's RADAR backscatter measured in decibels (dB) (GetuTesema, 2017). According to Martinis and Rieke (2015), calibration of the data compensates for the radiative effects of different angles of incidence – caused by the geometry of the sensor and the topographical properties of the surface. The product metadata contains all of the necessary information for converting digital pixel values to radiometrically calibrated backscatter. In this study, Sentinel 1A image was used, at L1 GRD (Ground Range Detection) level and IW mode with the polarizations (VH). These are Digital Number (DN) data that needs to be converted to the backscatter value of the surface reflection. RADAR cross-section sigma naught (σ0) is used as a data calibration product for Sentinel 1. The sentinel-1 GRD product can be automatically calibrated using the SNAP toolbox through equation (1).

$$\sigma^0 = \frac{DN^2}{A\sigma^2} \qquad (3.1)$$

Where:

DN: is the pixel digital Number of GRD pixel amplitude directly taken from the measurement file

A: is the value of sigma nought (σ^0)

The backscattering coefficient is expressed in decibels using equation (2) (Navarro *et al*, 2016):

σ° (dB) = 10*log10σ° (energy ratio), whereby;

$$\text{Energy Ratio} = \frac{\text{Received energy from the sensor}}{\text{Energy reflected in an isotropic way}} \tag{3.2}$$

3.3.1.2 Speckle Filtering

Synthetic aperture radar images contain a salt and pepper like composition called speckles that reduces image quality and makes features more difficult to interpret. Speckles are created by random constructive and destructive interference of the de-phased yet coherent return waves scattered by the elementary scatters within each resolution cell. Spatial filtering or multi-look processing can be used to reduce speckle noise.Speckle is a signal-dependent noise which is natural to any images obtained by coherent radiation, including SAR. SAR images are influenced by speckle, unlike optical remote sensing images, which have very clean and uniform characteristics. (Babu et al., 2013). The speckle filtering carried out in this study was single product speckle filter type focused on the single date SAR image filter using Lee Sigma filtering type with the same window kernel size (7×7) which is the optimal SAR filtering kernel (Table 3.5).

Table 3. 5: Speckle Filtering

Single product speckle filter	
Source Band	Amplitude VH
Filter	Lee sigma
Number of looks	1
Window size	7×7
Sigma	0.9
Target window size	3×3

3.3.1.3 Range-Doppler terrain correction

Distances in SAR images can be distorted due to topographical variations in a scene and the tilt of the satellite sensor. There is some distortion in image data that is not directly at the sensors

Nadir position.Terrain corrections are used to compensate for these distortions so that the image's geometric representation is as close to reality as possible. Using the Universal Transverse Mercator (UTM) zone 37 N, the calibrated Sentinel 1 RADAR images were automatically terrain corrected using range-Doppler terrain correction to provide 10 m square pixel resolution images. For this study, using sentinel-1A SAR image, different processing parameters (Table 3.6) have used for Range Doppler terrain Correction and automatic DEM extraction. The backscattered value is different from place to place. This is because when microwaves strike a surface, the amount of energy scattered back to the sensor depends on various factors like geometric factors (surface roughness, slopes, orientation of the objects), physical factors of surface material (moisture content), the types of land-cover (soil, vegetation or man-made objects) and microwave frequency, polarization and incident angle. The value of the processed image is expressed in decibel (dB) which shows the backscattered value. Areas which have more dB value is due to double bounce of microwave energy.

Table 3. 6: Range Doppler terrain correction method

	Processing parameter
Source band	Amplitude VH
DEM resampling method	Bilinear interpolation
Image resampling method	Bilinear interpolation
Pixel spacing in (m)	10
Map projection	UTM Zone 37 WGS 1984

Source: Mansaray,2013

3.3.2 Digital elevation model extraction from sentinel-1A

Digital elevation models that are used for visualizing the earth are growing with update technology. Radar technology and connected technologies like SAR and InSAR, grow up day by day fast (Makineci and Karabork, 2016). For this study, DEM image was automatically generated while terrain correction from the Sentinel-1A SAR image. Digital Elevation Model (Auto download) with bilinear interpolation method was used to derive. The DEM image has the same dimension as the processed SAR image. The pixel value of the DEM image is the elevation of the corresponding pixel in the SAR image.

3.3.3 Sentinel-2 optical image pre-processing

The standard sentinel -2 level -1C product was utilized in this study, which was produced using radiometric and geometric corrections, including ortho-rectification and spatial registration on a global reference system with sub-pixel accuracy. The Sentinel-2 Level-1C product is composed of 100 km × 100 km tiles in the UTM/WGS84 projection and provides the Top-Of-Atmosphere (TOA) reflectance. One scene of the Sentinel-2 Level-1C image acquired on 31January 2021was downloaded from the ESA Sentinel-2 Pre-Operations Hub (https://scihub.copernicus.eu/). A Sentinel-2 Level-1C zipped (.zip) archives data was pre-processed and converted into a single Geo Tiff, TOA-Reflectance file using IMPACT tool v1.3b. The bands employed are [B03, B04, B08, B11, B12] corresponding to Sentinel-2 [G, R, NIR, SWIR1, SWIR2] and the output resolution is selected to "highest" (among selected bands) while staking together bands of different resolution to pan sharp the image to 10 m spatial resolution. A linear transformation will be used to convert the output radiometric resolution into Byte (8 bit).

$$\text{TOA RefByte} = (DN*0.0255) \qquad (3.3)$$

Image DN values [0-4095] are converted to TOA Reflectance [0, 1] using the provided conversion factor (10000) and multiplied by 255 to obtain a byte TOA Reflectance [0,255].

3.3.4 Field data

Field data collection was conducted from June 5 to July 30, 2021, to obtain training and validation datasets. Figure 3.7 shows GPS point data taken during the 2021 field campaigns and using Google Earthpro during 2020 most flooding year of the area.

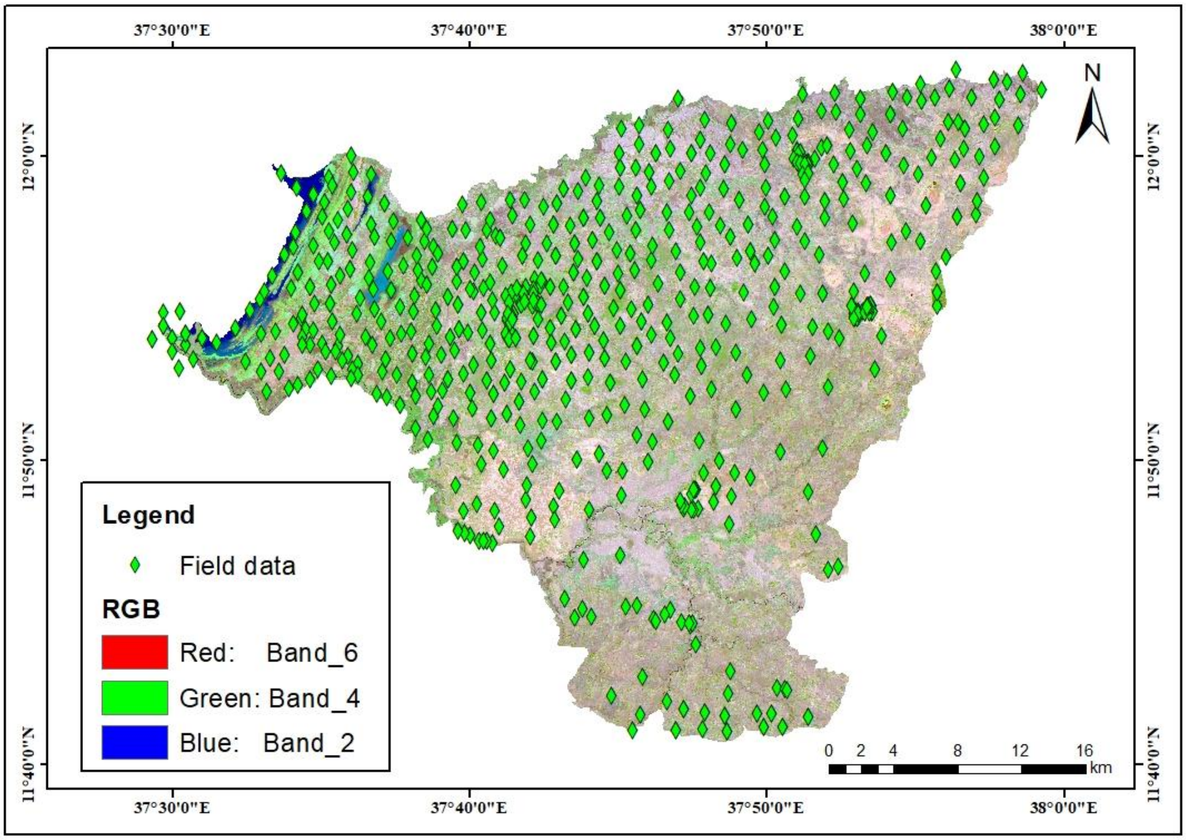

Figure 3. 8: Field data Points were used for training and validation of 2020/21.

Source: GPS field data

3.3.5 Criteria thematic layer preparation

The major causes of floods include intensity; duration and spatial distribution of rainfall on catchments; sedimentation on river channels and overflow of water from the river banks; steep slopes, deforestation, and poor soil infiltration capacity; failure of hydrologic structure and sudden release of waters from dames; and landslides.

These factors influence the magnitude, run-off, or velocity of the flood and increase the risk of flood damage.

Field surveys and literature were used to identify flood causative factors, particularly in Fogera Wereda. Rainfall, drainage density, slope, elevation, land use type, soil type, and population density are all prioritized in that order. The criterion of thematic layers was converted into raster data format using one of the required attributed columns to form each layer. All converted layers were reclassified according to reviewed literature and some of them were customized in order to meet the site-specific requirement.

All criteria for thematic layers have the same cell size. Resampling technique was used for cell size similarity of 10 m. The reclassification was used to simplify the interpretation of raster data by changing a single input value into a new output value.

3.3.5.1 Rainfall factor

Aerial rainfall intensity data is required for flood hazard and risk assessment. Although rainfall intensity is the best data for flood hazard analysis, this type of data is not available for the majority of Ethiopia's meteorological stations, hence annual maximum rainfall was utilized instead. In addition, the point rainfall was converted to areal rainfall using the ordinary Kriging technique in ArcGIS 10.7.1 geostatistical analyst extension. Kriging is a geostatistical interpolation approach that uses the surrounding measured values to calculate a prediction for an unmeasured location.This rainfall surface was then reclassified on a common scale, assuming that the higher the rainfall amount, the greater the flood hazard. (Figure 3.8). The rainfall in the study area ranges from 1364 to 1383 mm (Table 3.7).

Table 3. 7: Rainfall classification for flood hazard rating

Rainfall in mm	Ranking	Classification
1380 – 1383	1	Very High
1377 – 1379	2	High
1373 – 1376	3	Moderate
1369 – 1372	4	Low
1364 – 1368	5	Very Low

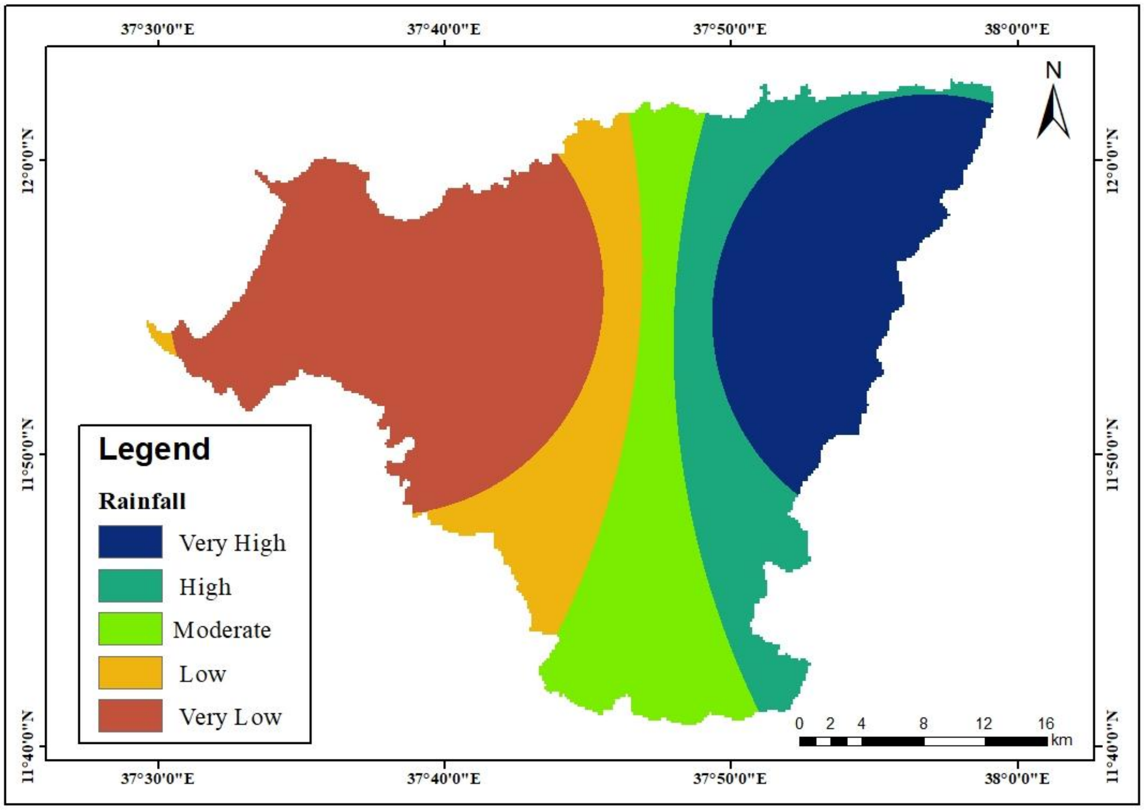

Figure 3. 9: Reclassified Rainfall map of the study area

Source: Geostatistical method

3.3.5.2 Drainage density factor

Because of nature of the soil and its geotechnical features are determined by the density of the soil, drainage is an important habitat for hazard control (Pareta, 2004). The drainage system that develops in a given area is influenced by the slope, the nature and attitude of bedrock, and the regional and local fracture pattern (Alemayehu, 2007). The ratio of the length of drainage per basin area is described as drainage density (DD), an important concept in hydrologic analysis. Permeability, erodability of surface materials, vegetation, slope, and time all influence drainage density. Drainage density is a reverse function of infiltration (Ajin et al., 2013). Greater drainage density specifies high runoff for basin area along with erodible geologic materials, and less prone to flood (Waikar and Nilawar, 2014). As drainage density increases, the rating for drainage density drops. In this study, the hydro processing tool was used for extraction of drainage from DEM of Sentinel-1A. In the present study, the following hydrological parameters were extracted from hydrological tools of ArcGIS environment to prepare layers for drainage density. The methods followed to calculate the drainage density and stream order calculation was done as shown below.

The drainage density of the research area was calculated using the spatial analyst's line density module. From poly line features that fall inside a radius around each cell, the Line Density module calculates a magnitude per unit area. The density layer is then divided into five sub-groups using quantiles, a standard classification scheme. This classification scheme separates the range of attribute values into equal-sized sub ranges, allowing you to define the number of intervals while ArcMap determines the breaks. Finally, drainage density was reclassified into a continuous scale based on flood hazard rating (Figure 3.9). The drainage density varies from 0.1 to 7.6 km/km2 in the sub-basin (Table 3.8).

Table 3. 8: Drainage classification for flood hazard rating (equal interval method)

Drainage density in km/km^2	**Ranking**	**Classification**
0.1 – 4.8	1	Very High
4.8 – 5.2	2	High
5.2 – 5.5	3	Moderate
5.5 – 5.7	4	Low
5.8 – 7.6	5	Very Low

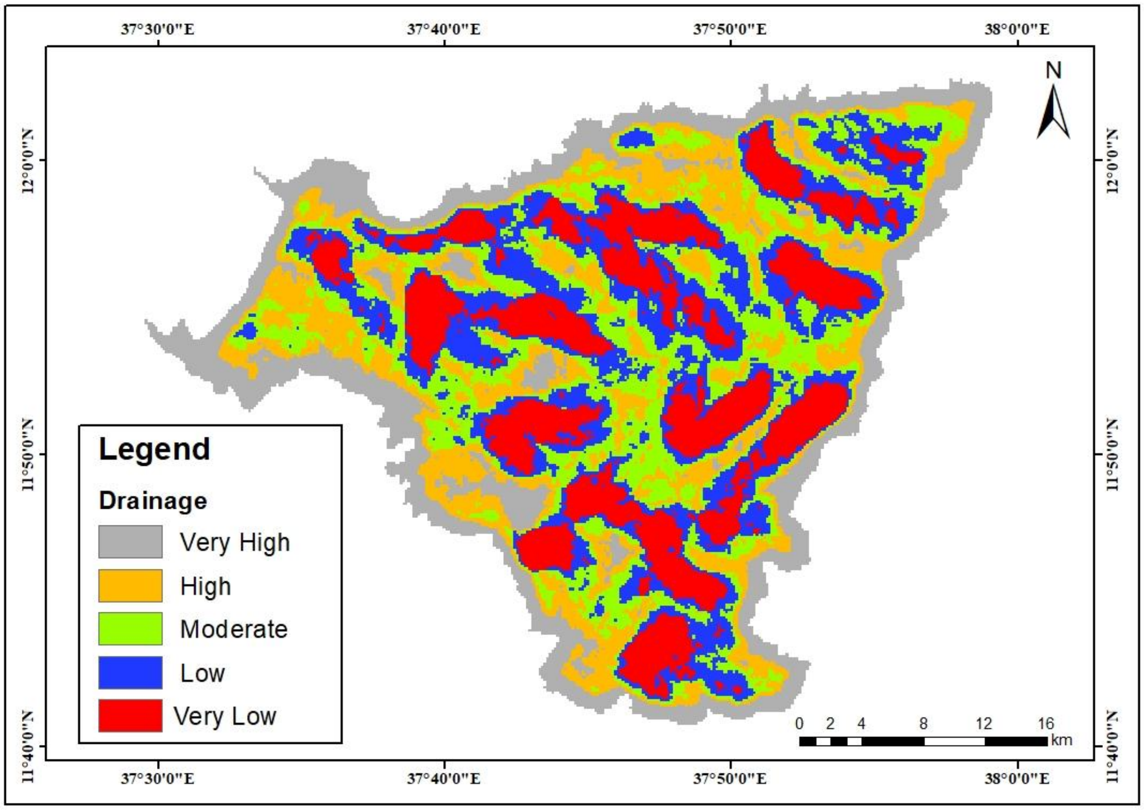

Figure3. 10: Reclassified Drainage map of the study area

Source: Hydrology tool

3.3.5.3 Slope factor

In flood hazard mapping, slope is quite important (Alemayehu, 2007).It affects the amount of surface runoff produced, the precipitation rate, and the displacement velocity of water over theequi-potential surface, and hence has a significant impact on flood hazard assessment. Poor slopes receive a high rating because to the smooth gradient of the floodplain, but large slopes receive a low grade. The slope map was produced by the processing the Sentinel-1A (10m resolution), using ArcGIS software, 3D Analyst Tools, Slope. The slope raster layer was further reclassified in five sub group using standard classification schemes namely Quintiles. This classification scheme separates the range of attribute values into equal-sized sub ranges, allowing you to define the number of intervals while ArcMap determines where the breaks should be. Finally the slope was reclassified in to continuous scale in order of flood hazard rating (Figure 3.10). The slope in the study area ranges from 0 to 69.9 degrees (Table 3.9).

Table 3. 9 : Slope classification for flood hazard rating

Slope in degree	Ranking	Classification
0 - 1.3	1	Very High
1.3 - 2.6	2	High
2.6 - 4.9	3	Moderate
4.9 - 9.7	4	Low
9.7 - 66.9	5	Very Low

Source: Alemayehu,2007

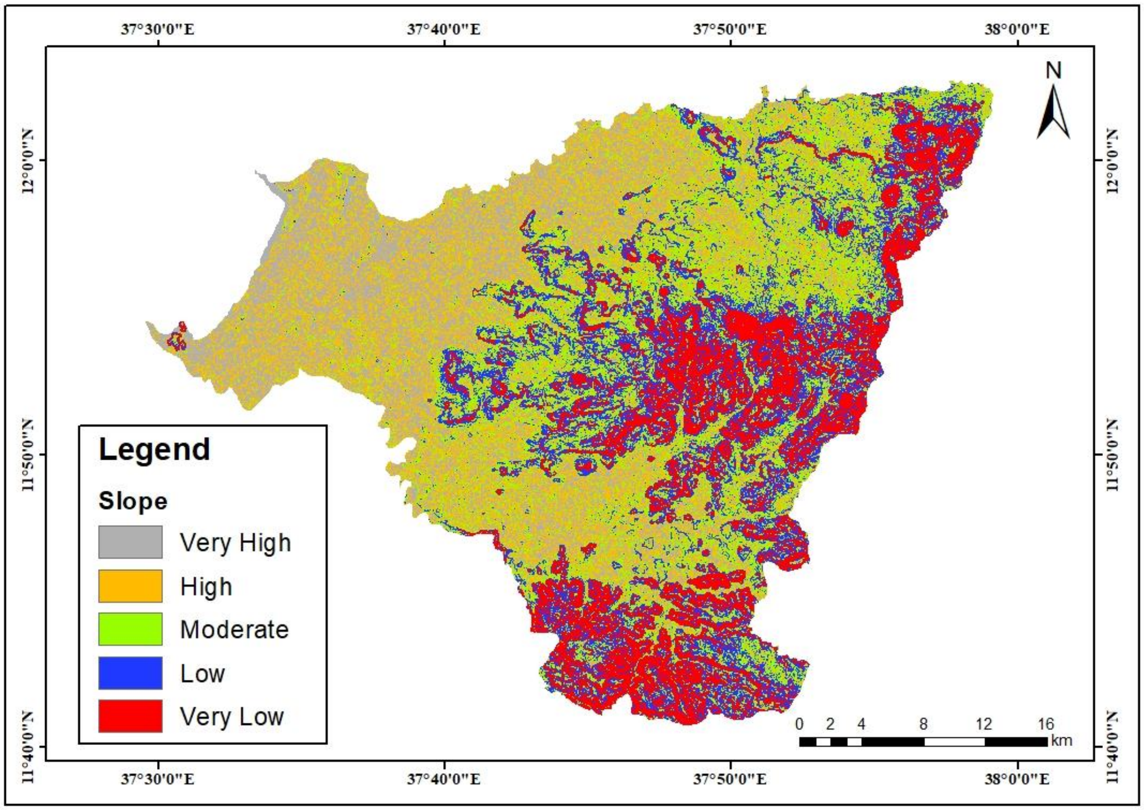

Figure 3. 11: Reclassified Slope map of the study area

Source: Digital elevation model

3.3.5.4 Elevation factor

All of the techniques for developing the elevation factor are the same as those for developing the slope factor. The raster layer is then reclassified into a common scale based on its impact on flood hazards (Figure 3.11).The lower the elevation, the higher will be its vulnerability to flooding (Table 3.10).

Table 3. 10: Elevation classification for flood hazard rating

Elevation in meter	Ranking	Classification
1781 - 1797	1	Very High
1797 - 1873	2	High
1873 - 1933	3	Moderate
1933 - 2042	4	Low
2042 - 2499	5	Very Low

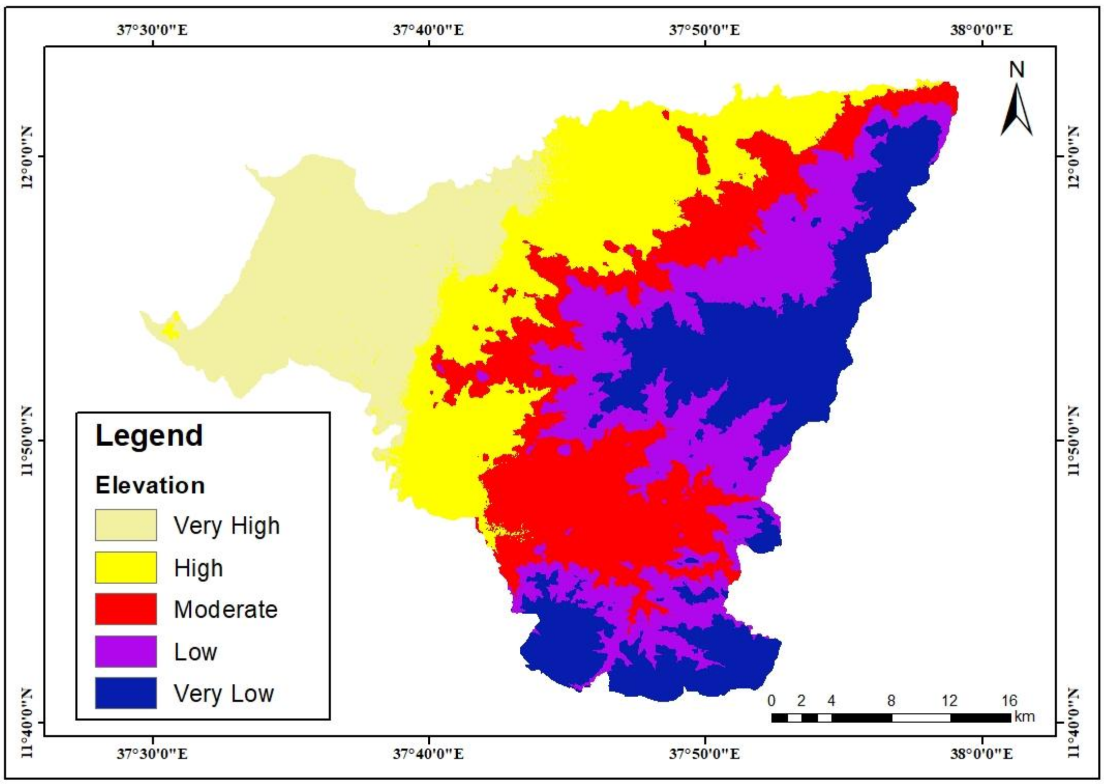

Figure3. 12: Reclassified elevation map of the study area

Source: Digital elevation model

3.3.5.5 Land-use/Land-cover classification

Land-use/Land-cover of the study area was prepared from sentinel-2A using maximum likelihood classification technique with the integration of field and Google earth verification. The type of LU/LC includes Agriculture, Bare Land, and Built up, Forest, Swamp, Shrub Land and Grass Land (Figure 3.12).

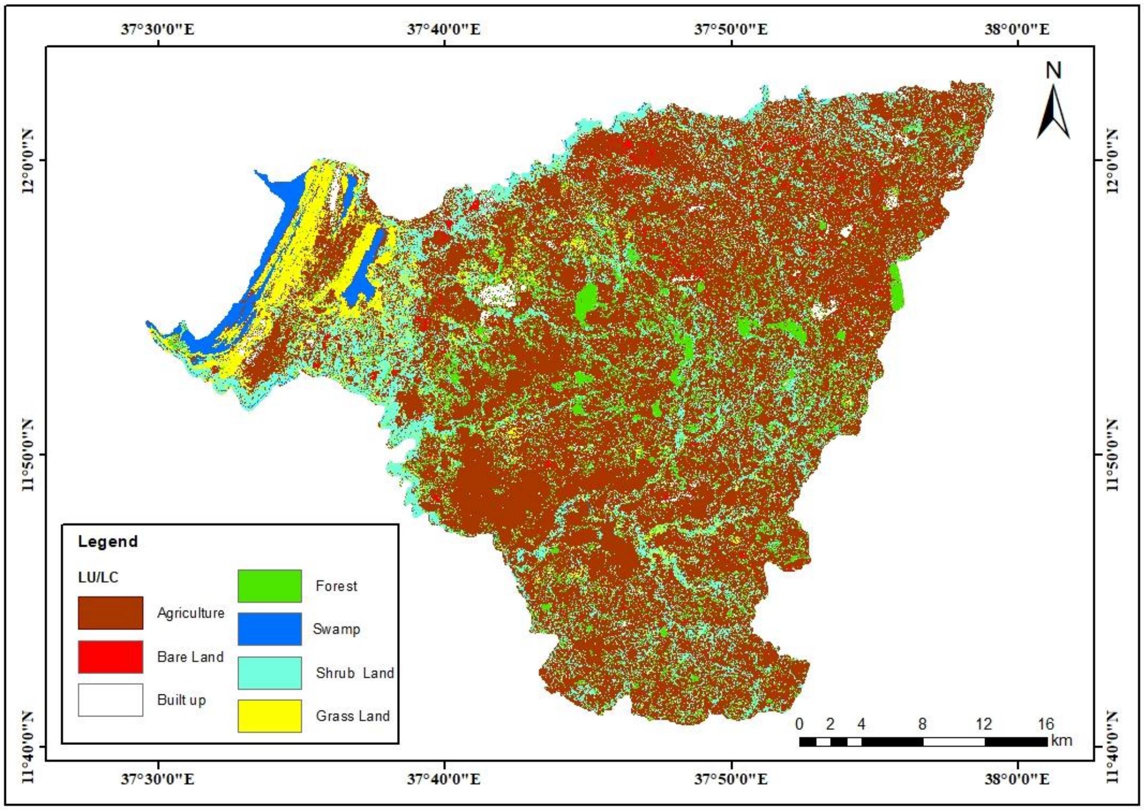

Figure 3. 13: Land-use/Land-cover map of the study area 31/01/2021

Source: USGS, sentinel-2A

Accuracy Assessment

The Maximum Likelihood procedure is the most commonly used procedure for classification in remote sensing. Bayes' Theorem, which states the link between evidence, previous knowledge, and the chance that a certain hypothesis is correct, is the basis for this approach (Lillesand, 2004).Validating LU/LC products provides critical data quality information to users and producers of these maps. A common practice is to conduct an accuracy assessment of the classified map based on a spatially explicit comparison of the map to a higher-quality reference data (Stehman and Wickham, 2011). The classification accuracy of this study was done based on field and Google earth reference data. The total reference data were 678, and the overall classification accuracy was 86.3%. From the total study area, farmland covers most of the area and water body covers small area relative to others (Table 3.11).

Table 3. 11: Confusion matrix of 2021 land use classification of the study area.

Classes	**Agriculture**	**Bare Land**	**Built up**	**Forest**	**Water**	**Shrub Land**	**Grass Land**	**Row Total**
Agriculture	107	7	0	0	4	5	7	130
Bare Land	3	74	5	0	0	0	1	83
Built up	0	9	71	0	0	0	0	80
Forest	0	0	0	115	0	3	0	118
Swamp	0	0	0	0	54	0	0	54
Shrub Land	2	4	1	7	0	86	4	104
Grass Land	8	6	3	4	2	8	78	109
CT	120	100	80	104	60	102	90	678
PA (%)	89.2	74.0	88.7	90.4	90.0	84.3	86.6	
UA (%)	82.3	89.4	88.8	97.5	100.0	86.0	71.6	

3.3.5.6 Land use/Land cover factor

Infiltration can be assisted by vegetation by slowing the flow of water over the surface and providing passageways for water to enter the soil through root systems. The kind and density of the plant cover affects the infiltration capacity of a particular soil (Ziegler, 2004). Infiltration capacity grows exponentially with increasing vegetation, rising percentage of organic matter, and decreasing bulk density of the soil (Ziegler, 2004). Infiltration will be reduced in desert regions and areas that have recently been deforested, either by fires or by humans, resulting in increased runoff and a shorter lag period. The research area's land use/cover types were reclassified into a comparable scale in order of their ability to draw rainwater for the flood hazard analysis into flood rating result for land cover factor map (Figure 3.13).

Table 3. 12: Land Use/cover classification for flood hazard rating

1	Agriculture	73875.54	63.84	2	High
2	Bare Land	1907.71	1.65	2	High
3	Built up	4170.99	3.6	1	Very High
4	Forest	9406.81	8.13	5	Very low
5	Swamp	2265.7	1.96	1	Very High
6	Shrub Land	18202.01	15.73	4	Low
7	Grass Land	5900.48	5.09	3	Moderate

Source: Ziegler; 2004

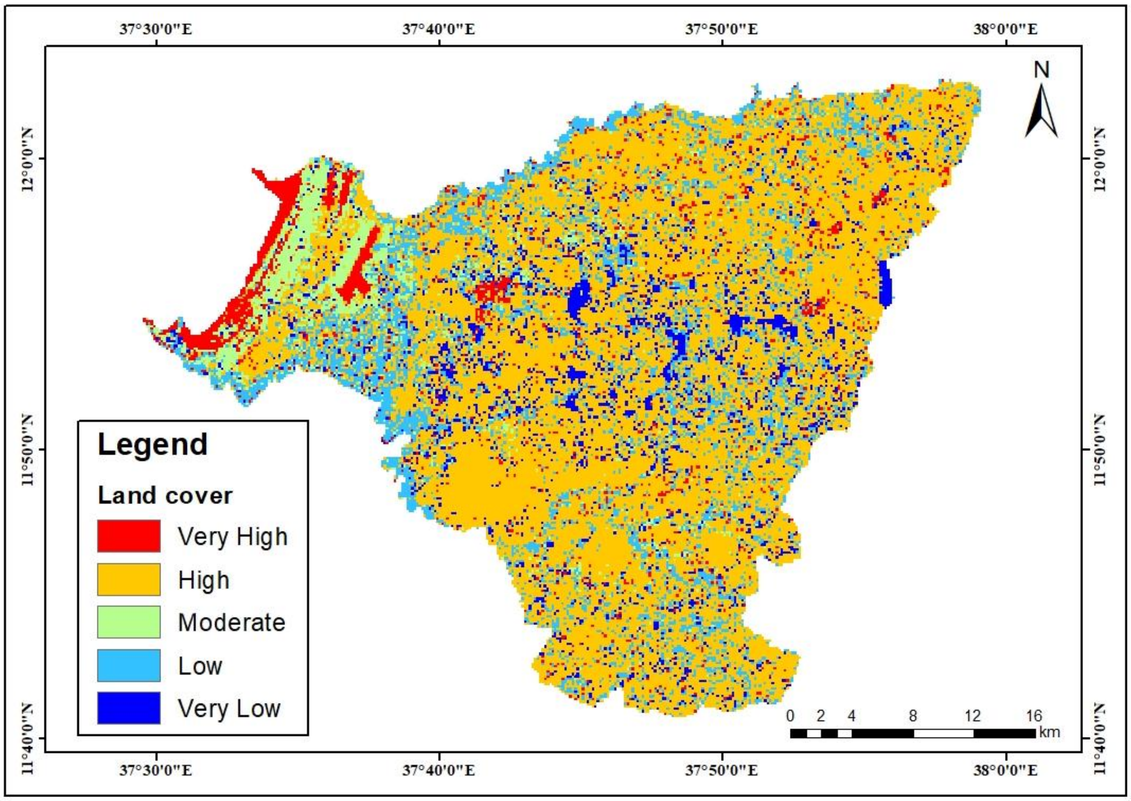

Figure3. 14: Reclassified Land Use/Land Cover Map of the study area.

Source: sentinel-2A

3.3.5.7 Soil Type Factor

The ability of different soil types to infiltrate water varies.Infiltration is a critical component that strongly influences the rainfall-runoff process and helps to limit the amount of water available for surface runoff after a rainstorm (Morgan 1995).The total amount of pores (soil porosity), the particle size distribution and structure of pores (grain size distribution), soil structures (size distribution and structure of aggregates), and the organic matter content of the soil are all factors that influence the rate of infiltration (Franzluebbers, 2003).Major soil types in the study area include Chromic Luvisols, Chromic Vertisols, EutricNitosols and OrthicLuvisols. These soil types are converted to raster format and finally reclassified based on their water infiltration capacity (Franzluebbers, 2003).

Table 3. 13: Soil type classification for flood hazard rating

Soil type	**Ranking**	**Classification**
Waterbody	1	Very High
Chromic Vertisols	2	High
Chromic Luvisols	3	Moderate
OrthicLuvisols	4	Low
EutricNitosols	5	Very Low

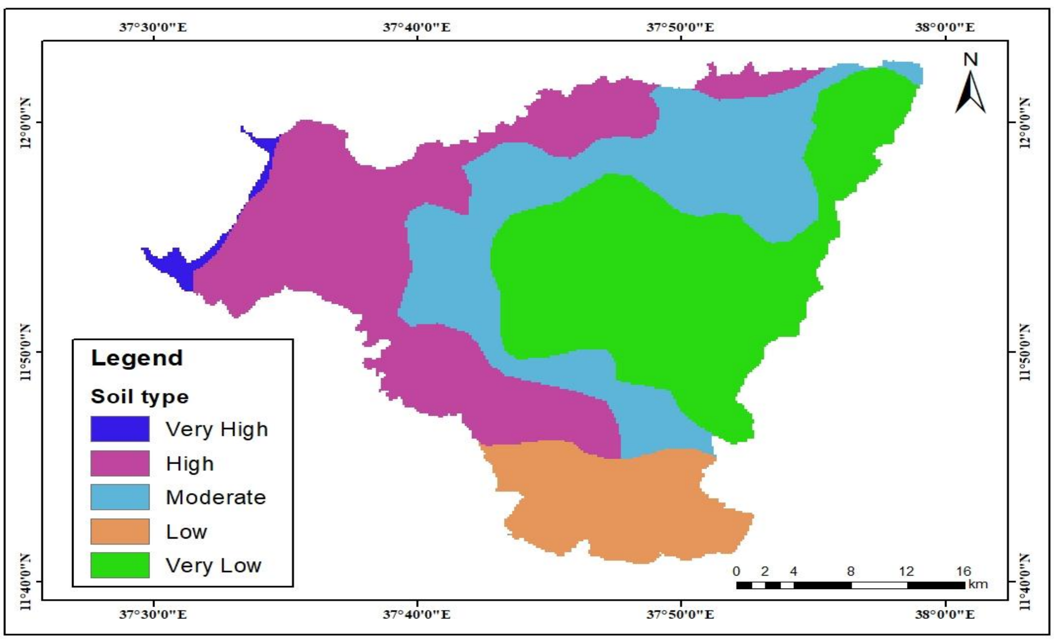

Figure 3. 15: Reclassified Soil type map of the study are

Source: Franzluebbers;2003

3.3.5.8 Population Density Factor

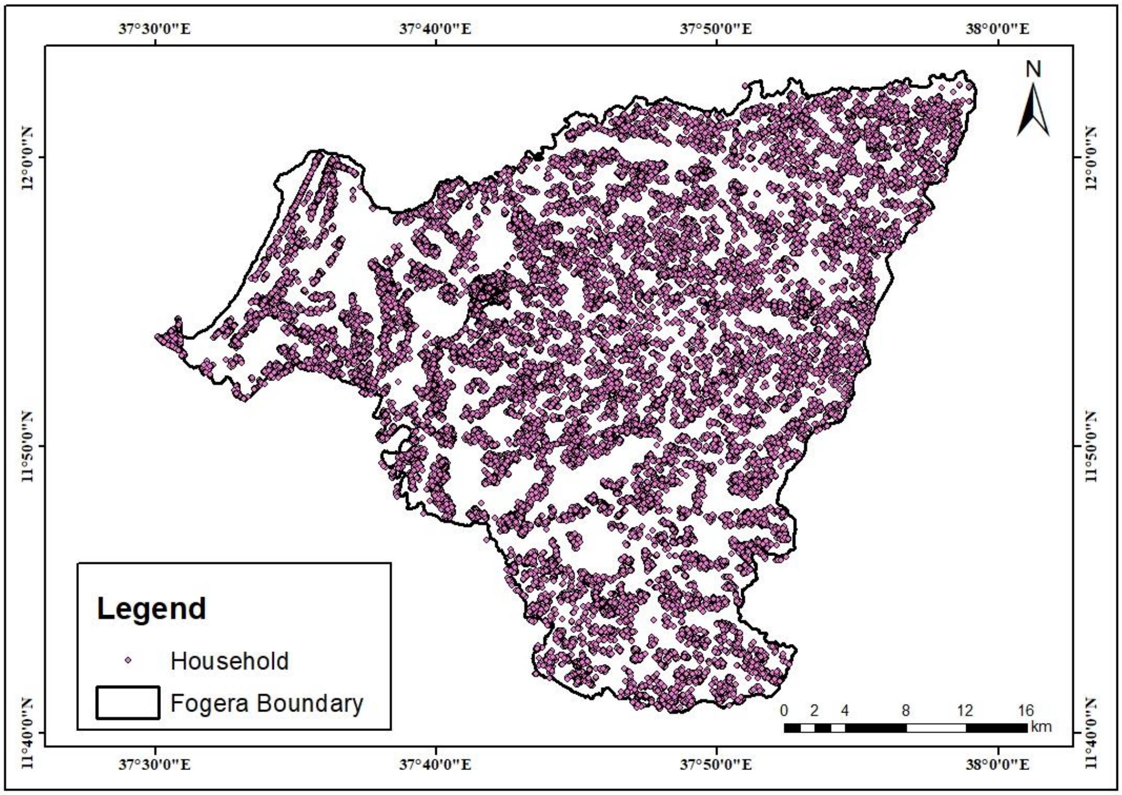

Figure3. 16: GPS point Household data Map of the study area.

Source: Ethiopian statistical service

Point household data of Fogera Wereda from ESS was used to prepare population density map of the study area **(**Figure 3.16**)**. For this study, thirty three rural and three urban point household data were used for population density interpolation using deterministic and geostatic methods of IDW and kriging respectively. Based on root mean square error (RMSE) of IDW and ordinary kriging results, IDW was selected for interpolating the population density for the entire study area. This is because interpolated population density results from IDW have less RMSE than ordinary kriging. IDW algorithm estimates cell values by averaging the values of nearby sample data points.

The interpolated data was reclassified into five sub-factors using the equal interval method of classification. And new values were allocated in order to increase the number of people who are vulnerable to flooding. The population density was reclassified based on the notion that the denser a population is, the more prone it is to flooding (Figure 3.17).

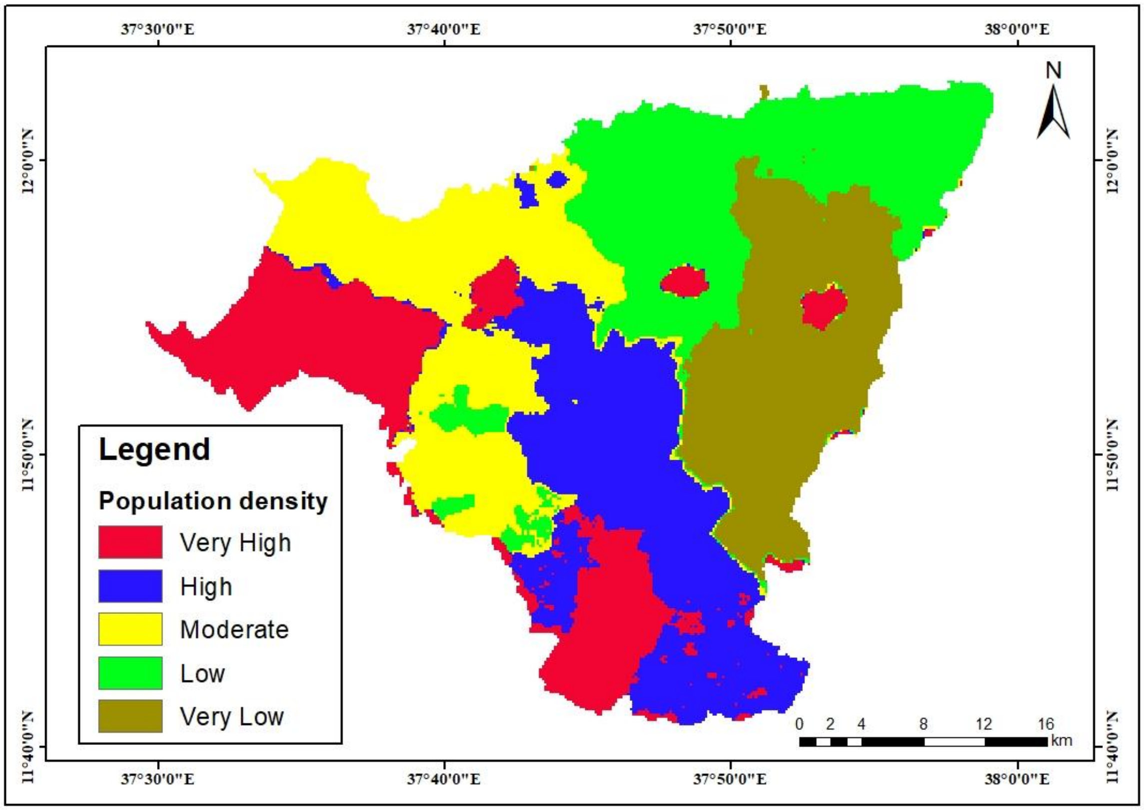

Figure3. 17: Reclassified Population density Map of the study area.

Source: Ethiopian statistical service

3.3.6 Flood hazard analysis

The weighted sum overlay of rainfall, drainage density, slope, elevation, land use/cover, and soil types developed components was used to perform flood hazard analysis. The weights for each factor were formed by interviews conducted with various experts and based on literature. A pairwise comparison matrix is derived using Satty's (1980) nine-point importance scale. The relative relevance values are determined with 1–9 scale (Table 3.14), in which a score of 1 represents equal importance between the two themes and a score of 9 indicates the extreme importance of one theme compared to the other one. Satty (2008) proposed that a nine-point scale with ranges between 1.1 and 1.9 to compare alternatives that differ slightly.

Table 3. 14: Scale of relative importance

Scale	Definition
1	Equal importance
2	Weakly importance
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong importance
8	Very, very strong
9	Extreme importance
1.1–1.9	The factors are closely importance

Source: Satty, 1980 and 2008

With the use of AHP, a relative significance of the relevant factors after pairwise-comparison matrix has been constructed. The weights of each parameters area defined after they are ranked according to their relative importance. (Table 3.15) shows the pairwise comparison matrix using 6 x 6 matrixes with diagonal elements equal to 1. To calculate the rating score, the values of each row are compared to the values of each column.

Table 3. 15: Pair-wise Comparison matrix for assessing the comparative importance of six factors to flood hazard mapping of Fogera Wereda.

Flood hazard Causative Factors	**Rainfall**	**Drainage Density**	**Slope**	**Elevation**	**Land use**	**Soil Type**
Rainfall	1	3	3	5	7	5
Drainage Density	1/3	1	3	3	7	5
Slope	3	1/3	1	3	3	3
Elevation	1/3	1/3	1/3	1	3	3
Land use	1/7	1/7	1/3	1/3	1	1/3
Soil Type	1/5	1/5	1/3	1/3	3	1

Source: Satty, 1980 and 2008

Table 3. 16: Normalized flood hazard Causative Factors.

Flood hazard Causative Factors	**Rainfall**	**Drainage Density**	**Slope**	**Elevation**	**Land use**	**Soil Type**
Rainfall	0.2051	0.5989	0.375	0.3947	0.2917	0.2885
Drainage Density	0.0684	0.1996	0.375	0.2368	0.2917	0.2885
Slope	0.6152	0.0665	0.125	0.2368	0.125	0.1731
Elevation	0.0410	0.0665	0.0417	0.0789	0.125	0.1731
Land use	0.0293	0.0285	0.0417	0.0263	0.0417	0.0192
Soil Type	0.0410	0.0399	0.0417	0.0263	0.125	0.0577

3.3.7 Evaluation of matrix consistency

The value of pairwise comparison matrix relies on the subjective judgment which might lead to an arbitrary result with bias. Due to this, pairwise comparison matrix evaluation is needed. The AHP consistency ratio method was used to determine whether the weight criteria layers are consistent or not. Satty (1980) gave a measure of consistency, called Consistency Index as deviation or degree of consistency using equation (3.4).

$$CR = \frac{\mathrm{CI}}{RI} \quad (3.4)$$

Where:

CR the consistency ratio, CI the consistency index and RI the random index.

In Table 3.17**:** Random consistency Index (RI) is tabulated. Thus, in this study the RI = 1.25. The acceptable CR must be < 0.1. CI is calculated using equation (3.5). Where calculated λmax = 6.01. RI values are given in specific tables.

$$CI = \frac{\lambda\mathrm{max} - \mathrm{n}}{n-1} \quad (3.5)$$

Eventually, calculated consistency ratio is 0.002 that is lower than the threshold 0.1, the weights' consistency is affirmed.

Table 3. 17 Random index (RI) used to compute consistency ratios (CR)

N	1	2	3	4	5	6	7	8	9	10
Random index(RI)	0	0	0.55	0.89	1.11	1.25	1.35	1.40	1.45	1.49

3.3.8 Calculating the final weight of each criteria layers

The weight final (Wf) of every criteria layer to the main objective of the decisional hierarchy (flood hazard) was calculated for each factor.

Table 3. 18: Flood hazard Causative Factor Criteria weights

Flood hazard Causative Factors	**Criteria Weights**
Rainfall	0.3589
Drainage Density	0.2433
Slope	0.2236
Elevation	0.0877
Land use	0.0311
Soil Type	0.0552

Table 3. 19: Waited flood hazard inducing causative factors

Factor	**Criteria Weights**	Sub-factor	Rating	Scale (hazard)
Rainfall	0.3589	1380 – 1383	1	Very High
		1377 – 1379	2	High
		1373 – 1376	3	Moderate
		1369 – 1372	4	Low
		1364 – 1368	5	Very Low
Drainage	0.2433	0.1 – 4.8	1	Very High

Density		4.8 – 5.2	2	High
		5.2 – 5.5	3	Moderate
		5.5 – 5.7	4	Low
		5.8 – 7.6	5	Very Low
Slope	0.0877	0 - 1.3	1	Very High
		1.3 - 2.6	2	High
		2.6 - 4.9	3	Moderate
		4.9 - 9.7	4	Low
		9.7 - 66.9	5	Very Low
Elevation		1781 – 1797	1	Very High
		1797 – 1873	2	High
		1873 – 1933	3	Moderate
		1933 – 2042	4	Low
		2042 – 2499	5	Very Low
Land use	0.0311	Built up and Swamp	1	Very High
		Agriculture and Bare Land	2	High
		Grass Land	3	Moderate
		Shrub Land	4	Low

		Forest	5	Very Low
Soil Type	0.0552	Lake	1	Very High
		Chromic Vertisols	2	High
		Chromic Luvisols	3	Moderate
		OrthicLuvisols	4	Low
		EutricNitosols	5	Very Low

3.3.9 Weighted overlay analysis

After computation of weights for each raster layer using analytical hierarchy process (AHP), weighted overlay analysis (WOA) is performed on an ArcGIS environment. Weighted overlay is an intersection of standardized and differently weighted layers during suitability analysis (Zolekar and Bhagat 2015). The weights quantify the relative importance of the flood hazard criteria considered. The flood hazard scores assigned for the sub-criteria within each criteria layer were multiplied with the weights assigned for each criterion to calculate the final flood hazard map using the WOA technique (Equation. 3.6).

$$S = \sum_{i=1}^{n} WiXi \qquad (3.6)$$

where S is the total flood hazard score, Wi is the weight of the selected flood hazard criteria layer, Xi is the assigned sub criteria score of flood hazard criteria layer i, and n is the total number of flood hazard criteria layer (Cengiz and Akbulak 2009; Pramanik 2016).

3.3.10 Flood risk analysis

Flood risk in Fogera Woreda was assessed using the flood hazard layer and the two elements at risk, population and land use. Vulnerability was assumed to be one. In the Weighted Overlay process, these three factors remained equally important (Table 3.14).Flood risk assessment and mapping for Fogera Woreda was done by combining the Woreda's degree of flood hazards with the population and land use/land cover elements that are at risk.

Table 3. 20: Waited flood risk inducing causative factors

Flood hazard	0.0877	0 - 1.3	1	Very High
		1.3 - 2.6	2	High
		2.6 - 4.9	3	Moderate
		4.9 - 9.7	4	Low
		9.7 - 66.9	5	Very Low
Population density(km^2)	0.0311	525-2461	1	Very High
		324-525	2	High
		246-324	3	Moderate
		184-246	4	Low
		151-184	5	Very Low
Land use	0.0311	Built up and Swamp	1	Very High
		Agriculture and Bare Land	2	High
		Grass Land	3	Moderate
		Shrub Land	4	Low
		Forest	5	Very Low

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Flood Hazard

The flood hazard map (Figure 4.1) below shows 10,579.90, 30,896.00, 34,265.19, 33,360.69, 6,627.46 hectare area of Fogera Wereda were subjected respectively to very high, high, moderate, low and very low flood hazards (Table 4.1).

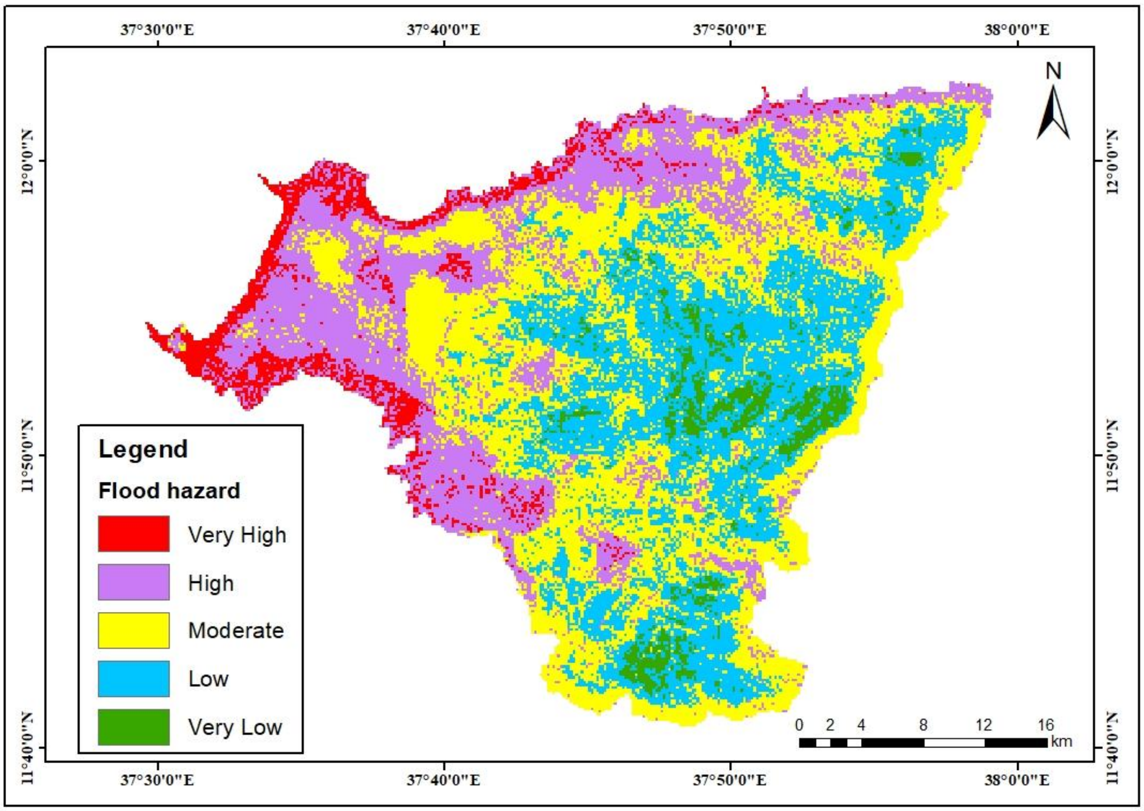

Figure 4. 1: Flood Hazard map of FogeraWereda

Source: Weighted overlay analysis

Table 4. 1: Area of FogeraWereda by Flood Hazard Level

Flood Hazard	**Area (hectare)**	**Percentage (%)**
Very High	10579.90	9.15
High	30896.00	26.69
Moderate	34265.19	29.61
Low	33360.69	28.82
Very Low	6627.46	5.73
Total	115729.24	100

4.2 Flood Hazard Level of LU/LC classification

Table 4. 2: LU/LC of FogeraWereda by Flood Hazard Level

		Flood Hazard (Area in hectare)					
No.	LU/LC Type	Very High	High	Moderate	Low	Very Low	Total
1.	Agriculture	3473.66	18317.85	24567.13	23402.84	4114.06	73875.54
2	Bare Land	158.18	556.24	458.43	657.53	77.33	1907.71
3	Built up	453.74	1153.47	1165.43	1087.95	310.4	4170.99
4	Forest	345.16	2082.9	2805.14	3102.7	1070.91	9406.81
5	Swamp	1526.93	684.72	46.36	7.1	0.59	2265.7

6	Shrub Land	2858.48	4809.52	4627.89	4843.49	1062.63	18202.01
7	Grass Land	1951.17	3088.41	567.89	250.72	42.29	5900.48
8							115729.24

The flood hazard table (Table 4.3) below shows Land-use/Land-cover, 97.61 % swamp, 85.4% Grass land, 42.12% Shrub land , 38.52% Built up ,37.44% Bare land 29.49% Agricultural land and 25.8% Forest land were under high to very high flood hazard.

Table 4. 3 LU/LC of FogeraWereda by Flood Hazard Level in Percentage

	Flood Hazard (in %)		
LULC	**Very High (in %)**	**High (in %)**	**Total (in %)**
Agriculture	4.70	24.79	29.49
Bare Land	8.29	29.15	37.44
Built up	10.87	27.65	38.52
Forest	3.66	22.14	25.8
Swamp	67.39	30.22	97.61
Shrub Land	15.70	26.42	42.12
Grass Land	33.06	52.34	85.4

4.3 Flood Hazard of FogeraWereda by Kebele Level

Table 4. 4: Flood Hazard of FogeraWereda by Kebele Level

Flood Hazard (Area in Hectares)

No.	Kebele Name	Very High	High	Moderate	Low	Very Low	Total
1.	AlemberTown	0	0	0	278.47	117.90	396.37
2	Maksegn Town	0	0	64.66	240.54	0	305.2
3	Woreta Town	0.33	468.25	93.07	0	0	561.65
4	AbagundaSendega	0	28.94	2601.76	1305.12	3.89	3939.71
5	Abakiros	176.64	2276.32	573.84	0	0	3026.8
6	Adisbetekrstiyan	0	1.95	1296.52	1677.16	22.44	2998.07
7	AlemeberZuriya	0	0	228.12	3861.29	848.33	4937.74
8	Anguko	10.50	1105.37	658.83	2.68	0	1777.38
9	Arida	0	0	1516.66	2324.15	0	3840.81
10	Bebekis	992.86	1779.20	5.84	0	0	2777.9
11	ChalimaDimu	0	0	19.71	2566.27	2590.64	5176.62
12	Diba	0	678.77	1204.91	126.61	0	2010.29
13	Eribkidanemihret	0	289.08	973.74	699.79	1.95	1964.56
14	Gazhin	0	2.36	1523.04	1837.48	0	3362.88
15	Guramba	0	429.07	3852.84	1155.51	0	5437.42
16	Hagereselam	0	32.84	3078.57	1807.61	25.54	4944.56
17	Kidist Hana	978.63	1710.53	0.47	0	0	2689.63

18	Kinti	0	0	606.36	2654.52	429.94	3690.82
19	Kokit	847.00	783.62	2.42	0	0	1633.04
20	Kuhar Abo	0	1077.95	343.44	0	0	1421.39
21	Kuhare Mikael	227.03	1893.65	427.35	0	0	2548.03
22	Meneguzer	0	606.51	2397.65	297.67	0	3301.83
23	Merewa	0	8.20	733.76	1076.49	18.04	1836.49
24	Mintura	0	0	3.24	1118.37	945.96	2067.57
25	Nabega	1795.27	2339.38	31.61	0	0	4166.26
26	RibbGebrel	0	1510.60	2378.76	202.54	0	4091.9
27	Shaga Maryam	736.67	2140.00	27.32	0	0	2903.99
28	Shina	926.48	2436.26	31.63	0	0	3394.37
29	Sifatra	21.47	1974.30	257.80	0	0	2253.57
30	SostuDelmo	0	660.82	2295.91	81.84	0	3038.57
31	TihuaZakena	34.26	2981.62	737.75	21.55	0	3775.18
32	Wagetera	2733.01	1238.88	0	0	0	3971.89
33	WojiArbaAmba	0	34.53	2147.62	3205.16	236.05	5623.36
34	WoretaZuriya	189.54	1842.37	1837.83	16.16	0	3885.9
35	Wotenb	0	160.12	1416.46	2621.32	684.46	4882.36
36	Zeneg	0	0	477.21	3882.08	702.78	5062.07

The flood hazard kebele level table (Table 4.5) below shows, 68.8 % Wagetera, 51.9% Kokit, 43.1% Nabega, 36.4% Kidist Hana ,35.7%Bebekis, 27.3%Shinaand 25.4% Shaga Maryam were under very high flood hazard.

Table 4. 5: FogeraWeredaKebele Flood Hazard Level in Percentage

Kebele Name	**Very High (Area in Hectares)**	**Very High (in %)**
Wagetera	2733.01	68.8
Kokit	847	51.9
Nabega	1795.27	43.1
Kidist Hana	978.63	36.4
Bebekis	992.86	35.7
Shina	926.48	27.3
Shaga Maryam	736.67	25.4
Kuhare Mikael	227.03	8.9
Abakiros	176.64	5.8
WoretaZuriya	189.54	4.9

4.4 Flood Risk

Flood risk mapping and assessment for FogeraWereda was done using at-risk population and land-use/land-cover aspects, as well as the Wereda's degree of flood threats.According to the flood risk map (Figure 4.2), it was estimated that 4296.31, 37127.52, 41458.6, 30906.17 and 1940.61 hectare areas of FogeraWoreda were subjected respectively to very high, high, moderate, low, and very low flood risk (Table 4.6).

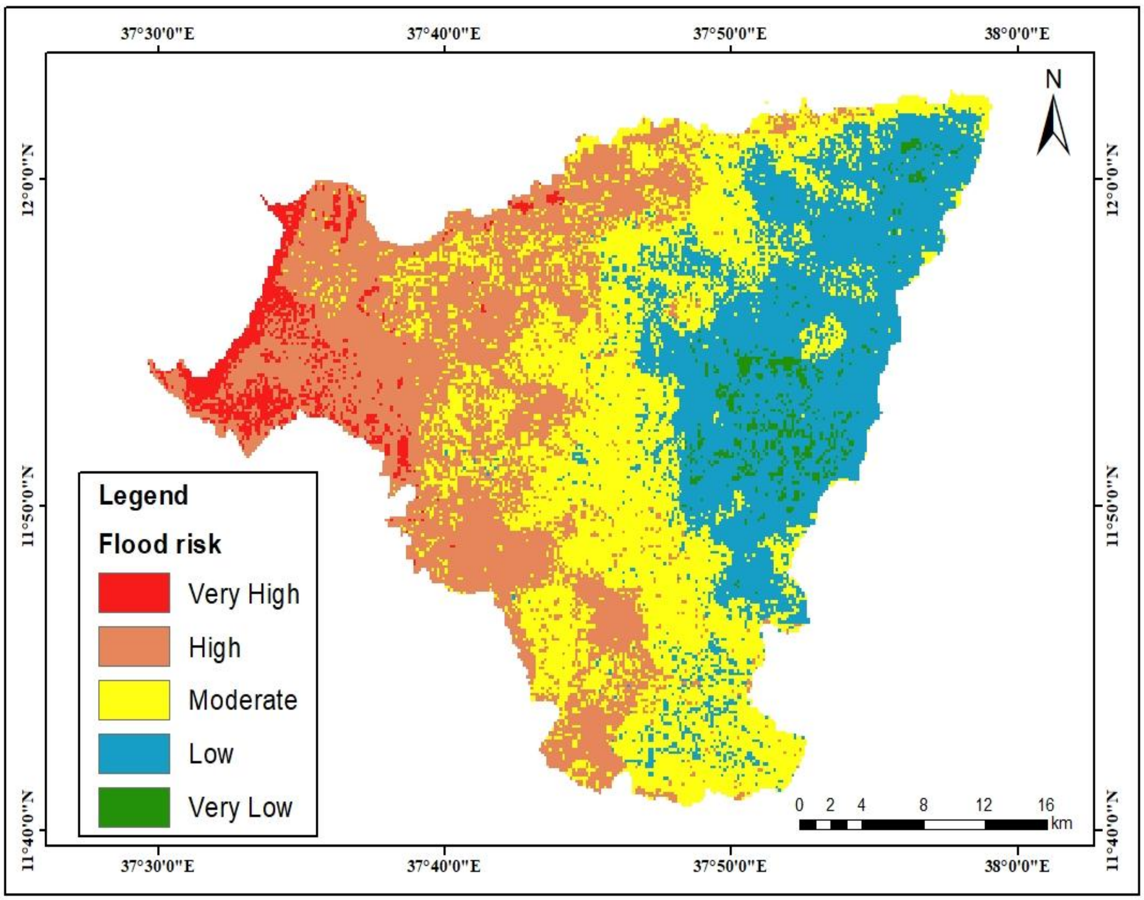

Figure 4. 2: flood risk maps of FogeraWoreda.

Source: Weighted overlay analysis

Table 4. 6: Area of FogeraWereda by Risk Level.

Flood Hazard	Area (hectare)	Percentage (%)
Very High	4296.31	3.72
High	37127.52	32.09
Moderate	41458.6	35.82
Low	30906.17	26.7
Very Low	1940.61	1.67
Total	115729.24	100

4.5 Flood Risk Level of LU/LC classification

Table 4. 7: LU/LC of Fogera Wereda by Flood Risk Level

		Flood Hazard (Area in hectare)					
No.	LU/LC Type	Very High	High	Moderate	Low	Very Low	Total
1.	Agriculture	1522.58	21980.3	28243.66	21298.78	830.22	73875.54
2	Bare Land	96.88	599.48	547.27	655.49	8.59	1907.71
3	Built up	186.99	1420.72	1421.35	1017.35	124.58	4170.99
4	Forest	91.85	2047.35	3611.79	3075.87	579.95	9406.81
5	Swamp	1388.78	815.61	57.07	4.17	0.07	2265.7
6	Shrub Land	505.01	6180.18	6545.86	4430.35	540.61	18202.01

7	Grass Land	895.55	3920.03	828.53	241.66	14.71	5900.48
8							115729.24

The flood risk table (Table 4.8) below shows Land-use/Land-cover, 97.28 % swamp, 81.6% Grass land, 38.54% Built up, 36.72% Shrub Land, 36.49% Bare land 31.81% Agricultural land and 22.73% Forest land were under high to very high flood risk.

Table 4. 8: LU/LC of FogeraWereda by Flood Risk Level in Percentage

Flood Hazard (in %)			
LULC	**Very High (in %)**	**High (in %)**	**Total (in %)**
Agriculture	2.06	29.75	31.81
Bare Land	5.07	31.42	36.49
Built up	4.48	34.06	38.54
Forest	0.97	21.76	22.73
Swamp	61.29	35.99	97.28
Shrub Land	2.77	33.95	36.72
Grass Land	15.17	66.43	81.6

4.6 Flood Risk of FogeraWereda by Kebele Level

Table 4. 9: Flood Hazard of FogeraWereda by Kebele Level

		Flood Risk (Area in Hectares)					
No.	Kebele Name	Very High	High	Moderate	Low	Very Low	Total
1.	AlemberTown	0	0	267.43	128.94	0	396.37
2	Maksegn Town	0	45.56	233.79	25.85	0	305.2
3	Woreta Town	0	494.09	67.56	0	0	561.65
4	AbagundaSendega	0	141.06	3516.85	281.8	0	3939.71
5	Abakiros	0	2345.44	677.96	3.4	0	3026.8
6	Adisbetekrstiyan	0	1.95	1122.26	1859.57	14.29	2998.07
7	AlemeberZuriya	0	0	313.51	4353.02	271.21	4937.74
8	Anguko	0	989.32	777.90	10.16	0	1777.38
9	Arida	0	137.17	3147.78	555.86	0	3840.81
10	Bebekis	23.68	2411.27	342.95	0	0	2777.9
11	ChalimaDimu	0	0	17.45	4260.43	898.74	5176.62
12	Diba	0	512.90	1246.93	250.46	0	2010.29
13	Eribkidanemihret	0	202.15	1024.70	736.78	0.93	1964.56
14	Gazhin	0	99.02	2806.40	457.46	0	3362.88

15	Guramba	0	3508.42	1841.24	87.76	0	5437.42
16	Hagereselam	0	66.59	4336.89	518.17	22.91	4944.56
17	Kidist Hana	447.26	2237.83	4.54	0	0	2689.63
18	Kinti	0	0	530.33	3010.81	149.68	3690.82
19	Kokit	135.14	1343.34	154.56	0	0	1633.04
20	Kuhar Abo	0	820.09	601.30	0	0	1421.39
21	Kuhare Mikael	9.23	1528.98	970.92	38.9	0	2548.03
22	Meneguzer	0	616.93	2612.83	72.07	0	3301.83
23	Merewa	0	17.94	592.80	1196.81	28.94	1836.49
24	Mintura	0	0	12.42	1810.51	244.64	2067.57
25	Nabega	595.30	3384.21	186.75	0	0	4166.26
26	RibbGebrel	0	1130.69	2696.66	264.55	0	4091.9
27	Shaga Maryam	49.83	2197.09	657.07	0	0	2903.99
28	Shina	311.64	3049.77	32.96	0	0	3394.37
29	Sifatra	0	1691.80	522.94	38.83	0	2253.57
30	SostuDelmo	0	1046.00	1989.85	2.72	0	3038.57
31	TihuaZakena	2.55	2272.38	1484.86	15.39	0	3775.18
32	Wagetera	2154.79	1817.10	0	0	0	3971.89
33	WojiArbaAmba	0	55.80	2241.00	3293.82	32.74	5623.36

34	WoretaZuriya	11.09	1856.04	2000.14	18.63	0	3885.9
35	Wotenb	0	91.20	1414.91	3121.90	254.35	4882.36
36	Zeneg	0	0	519.66	4501.38	41.03	5062.07

Elements at risk considered in this study show different levels of risk. The flood hazard kebele level table (Table 4.10) below shows, 54.25 % Wagetera, 16.62% Kidist Hana, 14.28% Nabega and 9.18 % Shina were under very high

Table 4. 10: FogeraWeredaKebele Flood Risk Level in Percentage

Kebele Name	Very High (Area in Hectares)	Very High (in %)
Wagetera	2154.79	54.25
Kidist Hana	447.26	16.62
Nabega	595.3	14.28
Shina	311.64	9.18
Kokit	135.14	8.27
Shaga Maryam	49.83	1.71
Bebekis	23.68	0.85
Kuhare Mikael	9.23	0.36
WoretaZuriya	11.09	0.28
TihuaZakena	2.55	0.06

In this study, the result is similar to other results which revealed flood risk is assessed with the integration of various indicators of soil type, elevation, slope, drainage density, rainfall, population density and land use category, using Multicriteria and AHP analyses (Wubet,2007;kebede,2012). The finding of this study is consistent with studies conducted in the application of geospatial techniques and quantitative research method for the assessment and analysis of flood risk and vulnerability assessment along the River Benue Basin of Kogi State to use weighted overlay analysis in multi criteria evaluation (MCE) to carry out flood hazard and risk analysis as well as most of the land use types in the study shows low to moderate flood hazard and flood risk level (Demessie, 2007). The same study that was done to assess the flood vulnerability areas of Fetam watershed. Slope, elevation, land use/land cover, drainage density, rainfall, and soil types were rated and collected to identify flood vulnerability zones applying a multi-criteria evaluation technique within the Geographic Information System for the analysis of this issue. Findings from this study revealed that flood is the most common environmental disaster in the study area, which causes serious damages to socio-economic and environmental features. Findings also revealed that heavy rainfall, inadequate drainage facilities and mismanagement of water reservoirs (mainly dams) are the major causes of the flood hazard. Moreover, other factors like infestation of water channels, topography, vegetation and soils of the study area also contributes to the occurrence of flood disaster in the affected areas. Finding of this study is in line with flood risk assessment in parts of Hadejia-Jama'are river basin of Jigawa State, Nigeria (Umar, 2019)

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The fundamental objective behind flood hazard and risk assessment and mapping, as done in this study, is to use flood plain zoning to regulate land use and reduce damage. Flood risk mapping, as a non-structural flood management tool, will go a long way toward decreasing flood damages in flood-prone areas. The study's geo-database contains information about FogeraWereda's flood hazard and risk, and it can be used as an effective decision support system for flood hazard managers.As a result, land use planners in the Amhara Region and Flood Management Units in the Abay Basin and other respective bodies could use those two maps to make environmentally sound land use decisions and control flooding in FogeraWereda.If the required data are standardized to a common scale in a personal geodatabase, the pair wise comparison method of flood hazard map production is a smart strategy to arise a sound decision for a future flood disaster. This study demonstrated that the technique could combine all flood hazard causative factors as well as flood risk components in a GIS context. To assess FogeraWereda's flood risk, composite maps were constructed in this manner. In a GIS setting, one of the Multi Criteria Evaluation approaches known as Weighted Overlay was demonstrated to be beneficial for defining areas with different flood hazard and flood risk ratings. Furthermore, the Weight module's factor weight computation, which is based on a series of pair-wise assessments of the relative relevance of factors to the suitability of pixels for the activity being evaluated, has generated useful data. This could actually be helpful for disaster research in the future. As a result, it has been demonstrated that combining MCE and GIS-based models can provide a rational and non-biased approach to disaster decision-making.

The flood hazard map of FogeraWereda indicated that downstream plains of Ribb and Gumara Rivers part: 68.8 % Wagetera, 51.9% Kokit, 43.1% Nabega, 36.4% Kidist Hana ,35.7% Bebekis, 27.3% Shina and 25.4% Shaga Maryam kebeles were within very high flood hazard. Despite the fact that huge portions of the Wereda are susceptible to high and very high flood hazard zones, only a small portion of the Wereda is at risk of high flooding. The flood risk kebele levels of the wereda were, 54.25 % Wagetera, 16.62% Kidist Hana, 14.28% Nabega and 9.18 % Shina were under very high.

As a result, it is reasonable to conclude that the vulnerability of vulnerable elements, such as people and sensitive land use types, to flood risk in flood-prone areas or those associated to it, is low relative to the flood hazard. In the Wereda, there are towns, kebele centres, and settlements that are at high risk of flooding. As a result, those settlement areas require immediate attention in order to reduce the risk of future flooding. Although flooding is a natural occurrence that we cannot totally prevent, we can reduce its negative consequences by better planning. With the help of GIS and remote sensing, the study found that automatic flood map delineation for large river systems may be done in a short amount of time.

5.2 Recommendations

This study provides information on flood hazard and risk at the Wereda level, which can be used by appropriate decision makers to modify the current land use strategy in Fogera Wereda to reduce vulnerability to flood disasters. As a result, the Wereda's and Region's responsible bodies should include flood hazard and risk assessment studies in their developmental projects. Watershed management practices such as constriction and strengthening check dam ,flood diversion canals, terracing, vegetating in the uplands of the Wereda are vital in reducing future flood disasters in the study area. The importance of land use planning in reducing the negative effects of flooding is critical. In flood-prone areas, it is suggested that adequate land use planning be implemented. The ideal plan would be to completely evacuate flood-prone communities, but, this is not realistic due to the high costs and social issues involved. Changes in the functional characteristics of floodplain areas are possible. Most flood-prone regions in Fogera Wereda have since been converted to rice-growing fields. It would be better to strengthen this technique and revilagize the population in these places to the safe ground in order to lessen the flood dangers that occur on a regular basis.

Disaster related research activities should be undertaken. There is also a need to apply advanced techniques in GIS and remote sensing, soil physics, geotechnical engineering, to assess flood risks and reduce risks. There is no hydrodynamic modelling or estimation of flood depth inundation in this work. As a result, future research in Fogera should focus on generating flood hazard maps that can identify the depth of inundation using hydrodynamic simulate.

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