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COLLAGE OF NATURAL AND COMPUTATIONAL
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REMOTE SENSING AND GEOINFORMATICS STREAM**

**APPLICATION OF REMOTE SENSING AND GIS IN FLOOD HAZARD
ASSESEMENT AND MAPPING IN ITANG WOREDA OF GAMBELLA REGION,
ETHIOPIA**

**A THESIS SUBMITTED TO
THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTERS OF SCIENCE IN REMOTE SENSING AND GEOINFORMATICS**

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ADDIS ABABA.
MAY 30, 2017**



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This is to certify the thesis prepared by Dame Tadesse entitled as “*Application of Remote Sensing and GIS in Flood Hazard Assessment and Mapping in Itang Woreda of Gambella Region, Ethiopia*” is submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geo-informatics compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Table of Contents	Pages
List of Tables.....	i
List of Figures.....	ii
List of Annexes.....	iii
List of Acronym.....	iv
Abstract.....	v
CHAPTER ONE	1
1. INTRODUCTION.....	1
1.1. Background of the study.....	1
1. 2. Statement of the problem.....	3
1.3. Objectives of the study.....	4
1.3.1. General objective.....	4
1.3.2. Specific objectives.....	4
1.4. Research questions.....	4
1.5. Scope of the study.....	4
1.6. Significance of the study.....	5
1.7. Limitations of the study.....	5
1.8. 1.8. Organization of the thesis.....	5
CHAPER TWO	7
2. LITERATURE REVIEW	7
2.1. Flood.....	7
2.2. How flood occurs.....	8
2.3. Types of flooding.....	8
2.4. Causes of flood.....	9
2.5. Flood hazard assessment.....	9
2.6. Flood hazard map.....	10
2.6.1. Benefits of flood hazard map.....	10
2.7. Floods in Ethiopia.....	11
2.8. Importance of remote sensing and GIS in flood hazard assessment and mapping.....	12
CHAPTER THREE	14
3. MATERIALS AND METHODS.....	14
3.1. Description of the study area.....	14
3.1.1. Location.....	14

3.1.2. Topography.....	14
3.1.3. Rainfall.....	15
3.1.4. Vegetation.....	17
3.1.5. Population.....	17
3.1.6. Soil.....	17
3.1.7. Hydrology.....	18
3.2. Data source.....	19
3.2.1. Primary Data.....	19
3.2.1.1. Digital Elevation Model (DEM).....	19
3.2.1.2. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS).....	20
3.2.1.3. Field data.....	22
3.2.2. Secondary Data.....	22
3.3. Methodology.....	22
3.3.1. Flood frequency analysis.....	23
3.3.2 Flood inundation area mapping.....	25
3.3.3. Flood hazard assessment.....	26
3.4. Spatial data preprocessing.....	27
3.4.1. Drainage Density.....	27
3.4.2. Slope and elevation.....	29
3.4.3. Land use/land-cover.....	30
3.4.4. Rainfall.....	31
3.4.5. Soil type.....	33
3.5. Multi criteria analysis.....	33
3.5.1 The analytic hierarchy process.....	34
3.5.2. Pairwise comparison method.....	35
3.6. The weighted overlay process.....	36
3.6.1. Weighted overlay analysis.....	37
CHAPTER FOUR.....	38
4. RESULTS.....	38
4.1. Flood frequency Analysis.....	38
4.2. Flooded inundation map.....	39
4.3. Flood factors.....	40
4.3.1. Slope and elevation.....	40

4.3.2. Rainfall.....	41
4.3.3. Drainage Density.....	43
4.3.4. Land-use/land-cover.....	43
4.3.5. Soil.....	45
4.4. Multi criteria analysis results.....	46
4.5. Flood hazard assessment.....	47
CHAPTER FIVE	51
5. DISCUSSION.....	51
CHAPTER SIX	54
6. CONCLUSION AND RECOMMENDATIONS.....	54
6.1. Conclusion.....	54
6.2. Recommendations.....	54
References.....	56

List of Tables	Pages
Table 3.1: Specifications of Landsat OLI data.....	21
Table 3.2: Data Source and Data Type.....	22
Table 3.3: Drainage density.....	28
Table 3.4: Slope ranking.....	30
Table 3.5: Elevation ranking.....	30
Table 3.6: Land-cover ranking.....	31
Table 3.7: Rainfall ranking.....	32
Table 3.8: Soil type ranking.....	33
Table 3.9: Saaty’s fundamental scale of absolute numbers.....	34
Table 3.10: Pairwise comparison matrix of the flood causative factors for Itang Woreda.....	36
Table 3.11: Random consistency index	36
Table 4.1(a): Gumbel based water discharge in Itang Woreda.....	38
Table 4.1(b): Log-Pears Type III based water discharge.....	38
Table 4.2: Reclassified rainfall of Itang.....	42
Table 4.3: Land-use/land- cover statistics.....	44
Table 4.4: Statistical information of the LULC accuracy assessment.....	45
Table 4.5: Normalized matrix of flood factors for Itang Woreda.....	47
Table 4.6: Flood hazard coverage.....	47

List of Figures	Pages
Figure 3.1: Location map of the study area.....	14
Figure 3.2: (a) Slope map and (b) Elevation map of the study area.....	15
Figure 3.3: Monthly average rainfall distribution of the study area.....	16
Figure 3.4: Annual average rainfall distribution of the study area.....	16
Figure 3.5: Population of Itang Woreda.....	17
Figure 3.6: Soil map of the study area.....	18
Figure 3.7: Mean monthly flow of Baro River.....	19
Figure 3.8: Elevation Map.....	20
Figure 3.9: Landsat OLI image of the study area.....	21
Figure 3.10: The Baro river geometry.....	25
Figure 3.11: Methodological flow chart of the study.....	27
Figure 3.12: Drainage density map of the study area.....	29
Figure 3.13: Rainfall distribution of the study area.....	32
Figure 4.1: Water surface of different recurrence intervals obtained through HEC RAS.....	39
Figure 4.2: Flood inundation area of different recurrence intervals.....	40
Figure 4.3: Reclassified slope (a) and reclassified elevation (b) of the study area.....	41
Figure 4.4: Reclassified rainfall map	42
Figure 4.5: Stream network (a) and reclassified drainage density map (b).....	43
Figure 4.6: a) Land-use/land-cover map and b) reclassified land-use/land-cover map.....	45
Figure 4.7: Reclassified soil map of the study area.....	46
Figure 4.8: Flood hazard map.....	48

List of Annexes	Pages
Annex 1: Format for thesis originality test report.....	61
Annex 2: Accuracy assessment of the land-use/land cover of Itang.....	62
Annex 3: Sample of some land-use/land-cover pictures.....	63
Annex 4: Location of meteorological stations.....	64

List of Acronyms

AHP	Analytic Hierarchy Process
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DIP	Digital Image Processing
DD	Drainage Density
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resources Data Analysis System
GIS	Geographic Information System
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
IDW	Inverse Distance Weighted
IPCC	Inter-governmental Panel on Climate Change
LULC	Land-use and Land-cover
MCA	Multi Criteria Analysis
MCE	Multi Criteria Evaluation
MLC	Maximum Likelihood Classification
MoWIEE	Ministry of Water, Irrigation and Electricity of Ethiopia
NMA	National Meteorological Agency
OLI	Operational Land Imager
TIN	Triangulated Irregular Network
TIRS	Thermal Infrared Sensor
UNICEF	United Nations Children's Emergency Fund
UNISDR	United Nations International Strategy for Disaster Reduction
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

Abstract

Application of Remote Sensing and GIS in Flood Hazard Assessment and Mapping in Itang Woreda of Gambella Region, Ethiopia.

Dame Tadesse, MSc. Thesis

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In the past decades, a large number of human life and enormous properties have been lost in different parts of the world due to flood hazard. Flooding is a common problem in different parts of the world including Ethiopia. Itang Woreda, which is located in Gambella Region of Ethiopia is one of the areas affected by flood of different frequency and magnitudes. This thesis is proposed with the aim of assessing and mapping flood hazard of Itang Woreda. Heavy rainfall from the region and surrounding highland areas is the major cause of flooding in Itang, by increasing the discharge level of streams and big rivers and making them overflow into adjacent flood plains. Baro River, which cross the study area from east to west and flow down to South Sudan is the major cause of flooding in this Woreda. Flood frequency of different recurrence intervals was calculated through the use of the most commonly used flood frequency analysis, i.e. Gumbel and Log-Pears type III. After obtaining the discharge level from the method with Chi Square test, flood inundation area of the 5, 10, 25, 50 and 100 year recurrence intervals were mapped. By using of remote sensing and GIS as a tool and slope and elevation, land-use/land-cover, rainfall data, discharge data and the soil type as input, the nature and characteristics of the flooding in Itang was analyzed. Finally, after evaluating and giving weight for the above mentioned criteria based on Analytic hierarchy process, flood hazard zones were mapped. Based on the results, the study area was classified into zones such as very high, high, medium, low and very low flooding and these zones were mapped. Majority of the land surface of the study area fall in the medium hazard zone (29.7%), followed by high flood hazard zone (27.8%), very high (12.7%), low (18.5%) and very low (11.4%), respectively. These maps are very useful to reduce the damages and losses that might arise from flooding. It is also inhabitants, and floodplain management authorities to minimize flood damage and loss of human lives in the study area.

Keywords: Analytic hierarchy process, Flood frequency, Flood hazard zone, Remote sensing, GIS

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Since long time various types of geo-hazard have been identified and recorded in different parts our globe. Most of these identified geo-hazards are serious events causing damage and destruction. Geo-hazard as defined by Guthrie and Cuervo, (2015) refers outcomes from different processes: geological, geomorphological, hydro-meteorological processes or combination of these. These processes have capacity to cause dangerous threat to the things that humans value (lives, property, infrastructure and the environment). Some of these geo-hazards are influenced or brought about by man, the rest can be purely natural. Natural hazards refers to event or process occurring naturally. These natural hazards may cause loss of life, injury or other health impacts, property damage, destruction of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009). These natural hazards commonly have deep, far-reaching consequences, especially for the communities affected.

Globally there are various types of natural hazards. Flooding is one these hazards. Flooding refers to “the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged.” (IPCC, 2012). Floods are natural phenomena, but they become serious issue when they are beyond the coping capacities of affected communities, damaging lives and livelihood of both urban and rural settlements (World Bank, 2012). Flooding affects many parts of the world including developing countries. According to World Bank (2010), Africa is one of the continents where highest mortality was recorded due to frequently occurring flooding. This problem is more sensitive and will be continuous event in countries like Ethiopia where over 80% of annual precipitation falls in the four summer high rainfall months (Getahun and Gebre, 2015). Since recent decades it is almost a common problem of people living throughout the country.

There are many factors that contribute to the occurrence of floods. These factors can be either natural or influenced by man. The natural causes are more of related to changing climatic condition of the world. Globally it was believed that changes in the nature of precipitation, whether it is in the form of rainfall or snow melt is due to this changing condition of climate. The nature of precipitation plays a big role in the formation of floods.

Among man-made factors triggering flood is increasing deforestation due to population pressure. Ethiopia receive Summer maximum rainfall, between June-August and this is the time disastrous flood take place in some parts of the country (Abebe Feyisa, 2007). Gambella

Region is one of the areas frequently affected by flooding, especially when the rainfall is at its peak. According to the most recent report from UNICEF (September, 2017) floods affected more than 53,000 people in Gambella and Oromia regions during the months of August and September, 2017. This indicates how much flooding is becoming a big problem in the country. In occasions where there is damage from flooding, it will be important to make a hazard assessment. The goal of flood hazard assessment is to understand the probability that a flood of a particular intensity will occur over an extended period of time (World Bank, 2016). On the other hand, mapping of flood hazard affected zone should be one of the aspects to be considered while making flood hazard assessment. Flood hazard map is a map providing the community with information related to flood occurrence and inundation, so that it will prevent them from damage.

The inundation or hazard mapping is an essential component of emergency action plans; 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 (Ajin *et al.*, 2013). Therefore, flood studies and flood mapping can help the people in understanding about flood behavior and risk.

Geographic Information System (GIS), Global Positioning System (GPS), and remote sensing are helping the floodplain managers to create accurate and current floodplain maps with improved efficiency and speed at a reasonable cost (Mina and Ying, 2015). Geographic Information System provides a broad range of tools for determining area affected by floods and for forecasting areas that are likely to be flooded due to high water level in a river (Woubet Gashaw and Dagnachew Legesse, 2011). It was extensively used to assemble information from different maps, aerial photographs, satellite images and Digital Elevation Model (DEM). GIS allows easier handling and integration of various spatial and non-spatial datasets, automates the development of the flood models, and facilitates risk analyses (Santillan *et al.*, 2016). Now days developing floodplain mappings integrating of HEC-RAS and GIS analysis is also common (Nareth Nut *et al.* 2015). On the other hand remote sensing technology along with GIS has become the key tool for flood monitoring in recent years. They are excellent tools in mapping spatial distribution of disaster related data within a relatively short period of time. Through modeling coupled with RS and GIS use, floods can be predicted and the flood vulnerable as well as flood risk areas can be mapped out (Opolot, 2013).

The central focus in this study revolves around delineation of flood zones and preparation of flood hazard maps for the vulnerable areas of Etang Woreda in Gambella Region of Ethiopia by integrating remote sensing, GIS and hydraulic simulation model, HEC-RAS.

1.2. Statement of the problem

According to Trenberth (2005), the changing condition of climate of the world due to human impact on the environment, is changing the precipitation and the hydrological cycles, especially the extremes. The change in the climatic condition of the world in general and hydrological and precipitation cycle in particular are making the world face different kind of natural hazards. One of the natural hazards that was becoming the hot issue at local, as well as global level is flooding. That is why we are hearing and reading different kind of reports and breaking news from here and there concerning the direct and indirect effects of floods on the life and wealth of the people.

Ethiopia is also among the countries under the pressure of different global environmental problems. Especially as the problem of flooding is touching almost every angle of our globe, it has become a commonly experienced problem with our people. Flooding had been increasing with its magnitude and frequency in the Gambella region. It has a long history in Itang Woreda, one of the areas frequently hit by flood hazard in the region, mainly due to the overflowing of one of the big rivers in the region, i.e. Baro. This flooding problem has been increasing from time to time in this area. The nature of this unstoppable, naturally occurring event in this specified woreda is the basic argument behind this proposed study. In addition to this, there is no significant research done recently in this study area related exactly with the title proposed.

Assessing and mapping flood hazard areas in the region will help in taking action in an attempt of flood hazard management.

1.3.Objective of the study

1.3.1. General Objective

This research come up with the general objective of flood hazard assessment and mapping by applying remote sensing and GIS techniques.

1.3.2. Specific Objectives

The following four specific objectives are intentionally formulated to achieve the above mentioned general objective of the study. These are:

- To identify and analyze the most important factors that influence flooding in the area.
- To analyze the relationship between flooding and population settlement of the area over time.
- To map inundation areas for the 5, 10, 25, 50 and 100 return periods.
- To produce flood hazard map of the study area and identify the most vulnerable areas.

1.4. Research questions

All activities made for the achievement of the objective of this study are planned in a manner of addressing the following research questions.

- What are the main causes of flooding or driving factors behind flooding in the area?
- Why is the area frequently affected by flood?
- When exactly is the time high flooding occur in the area?
- Which part of the study area is much vulnerable to flood hazard?
- What are the role of HEC GeoRAS and HEC RAS in mapping flood inundation of the study area?

1.5. Scope of the study

The present study was conducted in Itang Woreda of Gambella Region. Itang Special Woreda is one of the known peripheral lowlands found in Ethiopia characterized by frequently recurring flood. People of the specified woreda live along river bank of Baro, one of the four big rivers found in the region. This makes them vulnerable to flood.

In order to know the trend of flooding in this study area, different remote sensing and GIS techniques were employed. Different studies made previously were reviewed to support the study by research. Field verification was required in order to correlate different remote sensing and GIS techniques used with the actual local flood condition.

Increasing flood hazard resulting from climate change and seasonal fluctuation leads to different social, economic and environmental problems. These problems are assessed in identifying more vulnerable community. Therefore, to overcome these problems, this study

would contribute for decision makers as information and identifying different factors for the flood hazard in the area.

1.6. Significance of the study

This study could be significant in that:

- i. It will give information about the trend of flooding in the area.
- ii. It could be used as an input for government policy makers and other concerned body, especially on land use planning and land management by authorities and users.
- iii. For decision makers in the processes related to flood hazard mitigation and management.
- iv. For overall awareness building
- v. In addition to this, it can be a reference or initial step and as input for coming researchers based on the analysis of the study.

Generally, the results of this study will provide better information about flood hazard condition in the study area, especially when the assessment is made using techniques of remote sensing and GIS. It also provides the opportunity to understand the nature of flooding and its driving factors in the area under study.

1.7. Limitations of the study

The present study was attempted in achieving its general and specific objectives with all possible efforts in acquiring required inputs in the form of primary and secondary data collection, interpretation and analysis. However, the study has encountered certain limitations. One of the limitations was problem related with getting and collecting full and up to date secondary data from different organizations.

1.8. Organization of the thesis

This thesis is organized into six chapters: chapter one is introduction, where the background, statement of the problem, objectives of the study, research questions and significance of the study are discussed. In chapter two, review of related literatures is presented. A brief overview about floods, how they occur, and their types, causes of flood, flood hazard assessment and flood hazard map were presents in this section. Chapter three provides necessary background information about the study area in terms of location, topography, climate, soil, vegetation cover, land-use, general methodology of the study area. In the fourth chapter, results obtained from analysis made for the flood frequency, flood causing factors and MCA are provided. Moreover, in this chapter, flood hazard map of the study area was presented to show which areas are more vulnerable to flooding and which are less. In the fifth chapter interpretation and discussion of the results of the research from flood hazard are given. The sixth chapter provides

conclusion and recommendations based on results and discussions presented. In this chapter, key findings and critical points that need further treatment has been forwarded as a recommendation for decision makers and for future research.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Flood

Flooding is one of the most damaging natural hazards of the world. If not managed properly it causes inundation leading to disastrous consequences including the loss of human and animal lives and destruction of property (Dadson *et al.*, 2017). According to Jonkman, (2005) every year floods cause enormous damage all over the world. Africa is one of the most affected continents by flood hazard. “The majority of disasters in Africa are hydro-meteorological in nature, with droughts still affecting the largest number of people on the continent and floods occurring frequently along the major river systems and in many urban areas” (The World Bank, 2010). Flooding occurs both in urban and rural areas and are a cause for severe damage when they happen. In most of the case, they are the outcome of heavy or continuous rainfall exceeding soil absorption capacity and the flow capacity of rivers. Heavy rainfall results in the accumulation of water, mainly into water bodies (rivers, lakes, etc.) This accumulation of water lead to the rise of water above normal and water began to spill into adjacent flood plain areas. This is how flooding do in the riverine areas.

The other important term related with flooding here is, flood plain. Flood plain is a land prone to flooding and found beside channel of river, stream, ocean, lake or other water course. Floodplain analysis is needed in many practical situations, mainly because is in lowlands that human activities are concentrated. The study of the inundated plain requires at the same time quite of effort in terms of modelling, computational resources and data acquisition (Pagliara, 2006). Several studies indicate that flooding is a frequently occurring natural hazard in different parts of the world (Doswell, 2003; Danumah *et al.*, 2016; Vojtek and Vojtekova, 2016).

Floods are usually presented in terms of their frequency.” Flood frequency is the concept of probable frequency of occurrence of flood “(Dunkan, 2005). For example, a “100–year flood” or “100-year flood plain” have a 1% probability of certain flood to occur in any given year. From this idea one may guess as if such a flood occur only once in hundred years. However such a flood have a probability occurring more than one time in a hundred years. Whether or not it occurs in a given year has no bearing on the fact that there is still a 1% chance of a similar occurrence in the following year. Since flood plains can be mapped, the boundary of the 100-year flood is commonly used in floodplain mitigation programs to identify areas where the risk of flooding is significant. Any other statistical frequency of a flood event may be chosen depending on the degree of risk that is selected for evaluation, e.g., 5-year, 10-year, 25 -year 50-year, 100-year floodplain.

Frequency of inundation depends on the climate, the material that makes up the banks of the stream, and the channel slope. Where substantial rainfall occurs in a particular season each year, the floodplain may be inundated nearly every year, even along large streams with very small channel slopes.

2.2. How flood occurs

Flooding is a naturally occurring event along riverine or coastal areas. On rivers, flooding occurs when there is heavy or continuous rainfall exceeding the flow capacity of the river channel. When water level become beyond the capacity of river channel it will pour onto the adjacent land or what we call as flood plain. On the hand the rise of sea levels and waves cause flooding on coastal areas. Generally flooding can be the result of: excess precipitation, rapid snowmelt, increasingly rapid accumulation or runoff of surface waters from any source, steepness of slopes, storm surges, tsunami, dam failure, and urban development (Doswell, 2003).

Most of the devastating floods, especially riverine floods are linked to excessive precipitation (rain or snow). The capacity of the ground in allowing the rain water or snow melt to infiltrate or storing it influences the size and timing of a flood (Bell, 1999). The water from rain or snow melt, either infiltrates or evaporates directly into the atmosphere. Vegetation may also intercept some portion of precipitation. Most of the time, frozen soil inhibit infiltration. Therefore, it is an important flood intensifying factor. The rest of the water, which is not infiltrated or evaporated becomes surface runoff flowing down slope over the surface. If rainfall is heavier than normal in a particular area, the probability of flood occurrence will also be increased. This can be due to the low infiltration, interception and evaporation rate which contribute for the occurrence of high surface runoff in the area (Subramanya, 2008).

2.3. Types of flooding

It is necessary to determine which types of floods are most common or destructive in the area, before carrying out a hazard assessment. This is because in most cases the selection of hazard and risk modeling methods will vary depending on the type of flood. Floods can be classified in several different ways. Flood causative factors are among the classification ways. When the cause is heavy or intense rainfall, floods can be classified as slow-onset riverine flood (fluvial), flash flood (rapid onset), and pluvial or surface water flood affecting sewers and urban drainage and groundwater flood. Glacial meltwater and snowmelt floods are the two types of floods due to thawing of ice. Dam break and dam overtopping can be caused due to dam failure whereas tidal wave or wave extremes can cause storm surge and tsunamis (WHO, 2013).

2.4. Causes of flood

Different issues can be raised when we talk about causes of flooding. However, the rapidly changing climatic condition of the world is considered to be the main cause of flooding. This is mainly because of it is physically changing many factors affecting floods. For example, changes in precipitation, snow cover, and moisture content of the soil, sea level, glacial lake conditions, and vegetation are among events changing the characteristics of floods (IPCC, 2012).

According to Tingsanchali and Karim (2005), floods are associated with heavy rainfall. These heavy rainfall could happen due to tropical storms, thunderstorms, orographic rainfall, widespread extratropical cyclones, etc. The changing condition of precipitation: variation from year to year and over decades, and changes in amount, intensity, frequency, and type (snow, rain) affect the environment and society causing damaging event (flooding).

The occurrence of precipitation can be in either snow or rainfall form and its intensity is inversely related to its duration and area coverage. That is, the more intense the precipitation is, the lesser is its duration and area coverage. “High intensity short duration rainfall is much more likely to exceed the capacity of the soil to infiltrate water and result in overland flow than a longer less intense rainfall (Tarboton, 2003). On the other hand, areas located around river channels are more likely to be affected by flooding as flooding could dramatically alter a spatial extent of rivers and flow paths (Wondzell and Swanson, 1999).

The other important flood causing factor is manmade cause. The impact of mankind in the occurrence of flooding, in terms of its frequency as well as magnitude had observed in many different ways. Intensive urbanization due to increasing human population of the world with poor or limited development of sustainable flood control strategies have paved ways for potential impacts of flooding (Jonkman, 2005). On the other hand deforestation, due to increasing human population of the globe is one of the main cause of flooding. Changing forested areas into farmland or housing developments will enhance increased flood runoff plus an associated decrease in channel capacity due to sediment deposition. These all activities will have their own significant contribution in increasing the magnitude and frequency of flooding, flow velocity and sediment load of rivers in a given area.

2.5. Flood hazard assessment

Studies aimed at the analysis of physical aspects and processes through the collection of information and data made on historical or near real time records are called hazard assessment (Jha *et al.*, 2012). These processes or events have a probability of occurrence within a specified

period, within a given area and having their own intensity. Flooding is one of these events. The goal of flood hazard assessment is to understand the probability that a flood of a particular intensity will occur over an extended period of time (World Bank, 2016). Hazard assessment aims to estimate this probability over periods of years to decades to support risk management activities. Intensity usually refers to the combination of flood depth and horizontal flood extent; although other intensity measures such as flow velocity and flood duration can also be important depending on the situation.

2.6. Flood hazard map

Flood hazard map is a map providing the community with information related to flood occurrence and inundation, so that it will prevent them from damage. Flood mapping can help the people in understanding about flood behavior and risk. They provide the foundation for flood risk management decisions. Development and implementation of flood studies and flood mapping provides key users in areas as diverse as land use planning, emergency management and community awareness (State of Queensland, 2016). Communication of this information helps to build flood resilience within the community and informs a framework for Council and State agencies to manage flood risk into the future.

2.6.1. Benefits of flood hazard map

Floodplain mapping, i.e. the assessment of the areas that can potentially be flooded, can help reduce the negative impact of flood events by supporting the process of land use planning in areas exposed to flood risk. Flood inundation modelling which will be used in this study is one of the most common approaches to develop floodplain maps.

Mapping the areas that undergo flooding is one of the task of flood hazard mapping. There are various importance of flood hazard mapping. Some of their uses are:

- Land use planning and land management both by authorities and users.
- Watershed management
- Water Management planning
- Hazard assessment on local level
- Emergency planning and management
- Planning of technical measures
- Overall awareness building
- Taking flood insurance and
- Underwriting of flood risk.

2.7. Floods in Ethiopia

Since recent times flooding is not a new issue in different parts of Ethiopia. Our people had also adopted to hearing damage and destruction caused by floods from here and there. Characterized by both highland, top flat plateaus and lowland areas, Ethiopia receive summer maximum rainfall (between June and September). This is the time that the major perennial rivers as well as their numerous tributaries enhance the country's drainage systems carry their peak discharges (Woubet Gashaw and Dagnachew Legesse, 2011).

At the same time, flooding, one of the catastrophic natural hazard occurs during this time. Areas of lower and flat topographic setting are commonly exposed to floods in Ethiopia. Intense and prolonged rainfall in the highland areas of Ethiopia is a cause for flooding at downstream part of rivers and to the floodplains which are normally located along river courses. Flash flood and riverine floods are the two commonly known types of flood in Ethiopia.

Flash flood: is a sudden and speedy rise of water along a stream or low-lying area. They result from intense and heavy rainfall occurring relatively within short time with their severe damage.

According to Quan, et al (2015), flash floods occur when there is rapid increase in water levels of catchments with steep slope, usually due to heavy rainstorms. As the name implies flash flood is a type of flood that occurs suddenly with little or no warning and occurs very rapidly (Elkhrachy, 2015). They are generally rapid onset of flood with a short duration and a relatively high peak discharge. Such type of flooding usually takes place in hilly or mountainous areas having steep slopes and narrow valleys. Topography of such catchments make runoff rush down the streams very fast.

Riverine flood: As the name implies, riverine floods are caused by the overflowing of rivers. Riverine flood is a type of flood occurring when a runoff water become above the capacity of channels (natural or artificial), and spilling to adjacent low lying areas (Adjei-darko, 2017). They are caused primarily by the downstream flow of run-off generated by heavy rainfall on wet ground. Topographic nature or terrain of a given area can determine dynamics of riverine flood. For example, runoff in areas with mountainous topography may occur minutes after heavy rainfall but in flat and low lying areas, water may cover the land for days or weeks. Riverine flood, which occur when the amount of water in a river exceeds the channel's capacity, will be given focus in our case.

2.8. Importance of remote sensing and GIS in flood hazard assessment and mapping

Now a days advancements in the remote sensing and GIS technology is universally accepted and used in issues linked to flood management. These two technologies can be used in real time monitoring, early warning and quick damage assessment of flood disasters. They are tools to study flood hazard and minimize its impact (Dhruvesh and Udan 2017). Pre-disaster and post disaster planning is done through these tools.

Geographical information system allows easier handling and integration of various spatial and non-spatial datasets, automates the development of the flood models, facilitates risk analyses (e.g., identification of communities, roads and cultivated lands that may be endangered in different levels of flooding), and efficient generation of inundation maps and statistics that can be used as bases in various stages of flood disaster management (e.g., from preparedness to mitigation) (Santillan *et al.*, 2016). They are successfully used to visualize the extent of flooding and also to analyze the flood maps to produce flood damage estimation maps and flood risk map.

GIS provides a broad range of tools for determining area affected by floods and for forecasting areas that are likely to be flooded due to high water level in a river. Geographic information system was extensively used to assemble information from different maps, aerial photographs, satellite images and Digital Elevation Model (DEM). Census data and other relevant statistical abstract were also used to make the risk map more oriented to need of the local inhabitants (Woubet Gashaw and Dagnachew Legesse, 2011).

On the other hand, recent advancements reached in remote sensing techniques were clearly shown their capability to monitor components of the water balance of large river basins on time scales ranging from months to decades. It has made substantial contribution in flood monitoring and damage assessment that leads the disaster management authorities to contribute significantly. They are excellent tools in the mapping of the spatial distribution of disaster related data within a relatively short period of time (Khanna *et al.*, 2009).

Remote sensing was proved useful in ecological, hydrological and geomorphological river studies. Precise mapping of the maximum flood extent is also required for detecting deficiencies in existing flood control measures and for arbitrating damage claims later. Satellite-derived flood inundation maps produced in near-real time are invaluable to state or national agencies for disaster monitoring and relief efforts (Smith, 1997). The satellite images provide valuable information about the surface covered by flood waters. The study of image interpretation through remote sensing helps in identifying flooded and non-flooded locations from different types of satellite images (Arvind *et al.*, 2016).

Approach of using satellite observation in flood hazard mapping is appreciated by scientific community. This is mainly due to its advantage of being accurate, robust, and applicable especially in regions where ground observations are not available (Giustarini *et al.*, 2015). More adequate methodologies will be available when there are adequate high resolution and information from field work. More specifically, the integrated use of remote sensing data, on spot data, and digital elevation models, could be particularly useful for obtaining hydraulic geometry data in flooded areas, and, therefore, for estimating discharges, water volumes stored in floodplains and hydraulic regime parameters. Remote sensing was also applied to map spatio-temporal variations of flood inundation. On the other hand remote sensing data, such as satellite images and aerial photos allow us to map the variability of terrain properties, such as vegetation, water, and geology, both in space and time. Remote sensing and GIS as recent technology and tools will enable the visualization and analysis of inundation area in flood hazard assessment and the development of a map for land development.

Consequently, the use of GIS and remote sensing is to delineate flood prone areas, and shows how to determine the relative sensitivity of the individual pixel of flood prone areas within the study area (Alemayehu Zewdie, 2007). This enhances the capability in the river basin to utilize GIS for water resources planning and management, and may help to implement or act as the basis for a hydrological decision support system to ascertain critical locations. This technique can be used from a local or regional scale to a global scale (Islam and Sado, 2002).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location

Itang is a special woreda found in Gambella, one of the nine regional states of Ethiopia. It is found to the south western part of the country almost on flat to gently sloping area. Geographically it is located between 08°00'00"-08°45'00" N latitude and 34°00'00" to 34°30'00" E longitude covering total area of 2190.42 km² (Fig. 3.1). The Itang Special Woreda encompasses 21 Kebeles, most of which are situated in the flood plain zones of Baro river basin.

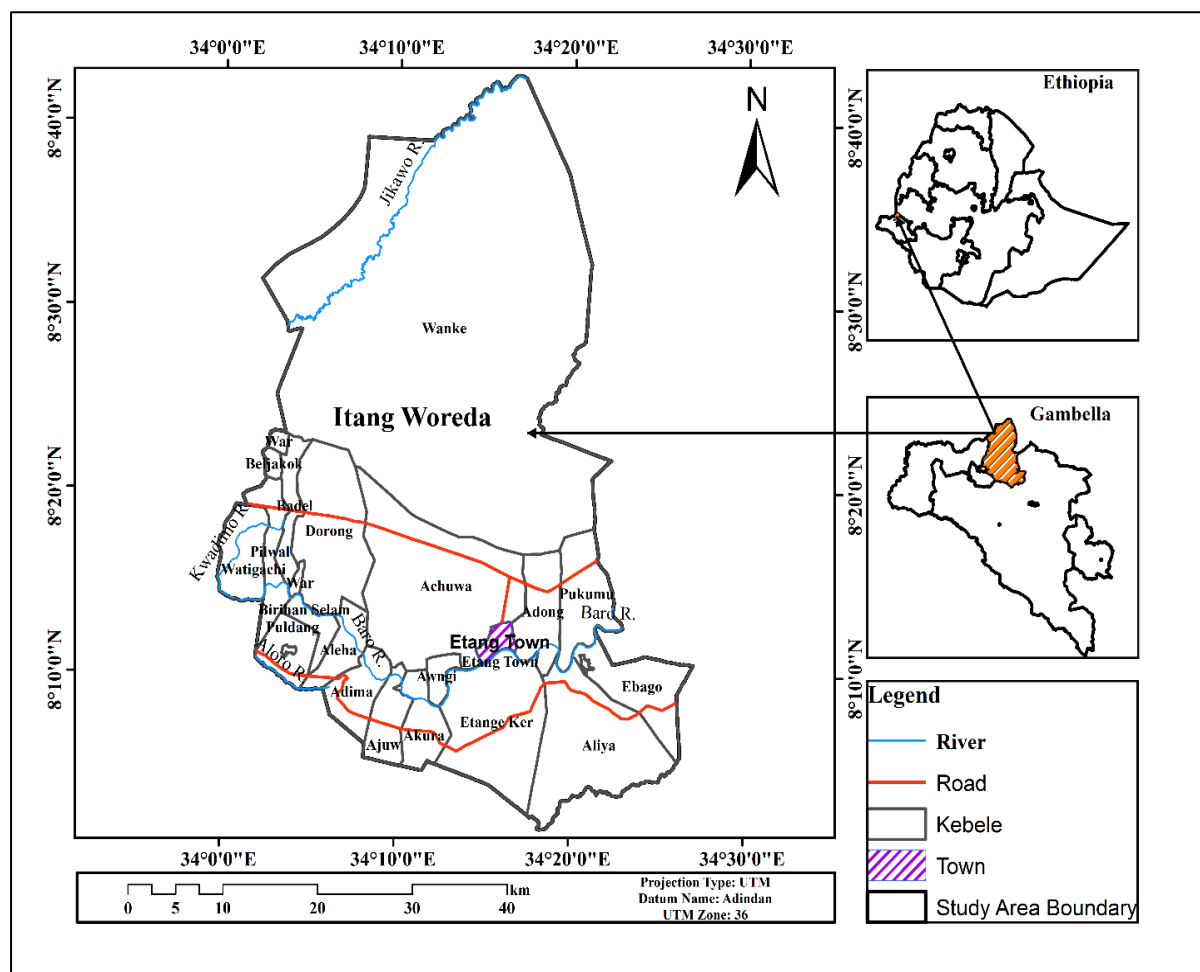


Figure 3.1: Location map of the study area

3.1.2. Topography

Itang Woreda is characterized by almost flat topography. It is bordered by Republic of South Sudan and Qellem Wollega Zone of Oromiya Region from North West and North respectively. Gambella Zurja Woreda, Abobo and Lare are other woredas of Gambella Region bordering this woreda from east, South and west. Baro River, one of the major rivers of Gambella Region

crosses this woreda and flow west to the South Sudan. It is the major cause of flooding in the study area. There are limited all weather gravel roads that connect the Woreda to other surrounding weredas. This shows that accessibility is one of the major constraints to the development in the area. Itang, the woreda's town is located about 45 km from Gambella town accessed through gravel road that links Gambella to Lare, the other woreda town West of Itang. Slope of Itang Woreda ranges 3–52 degree (Fig 3.2. a). Elevation of the study area ranges between 385.5–705.5 m and is depicted in (Fig 3.2 b).

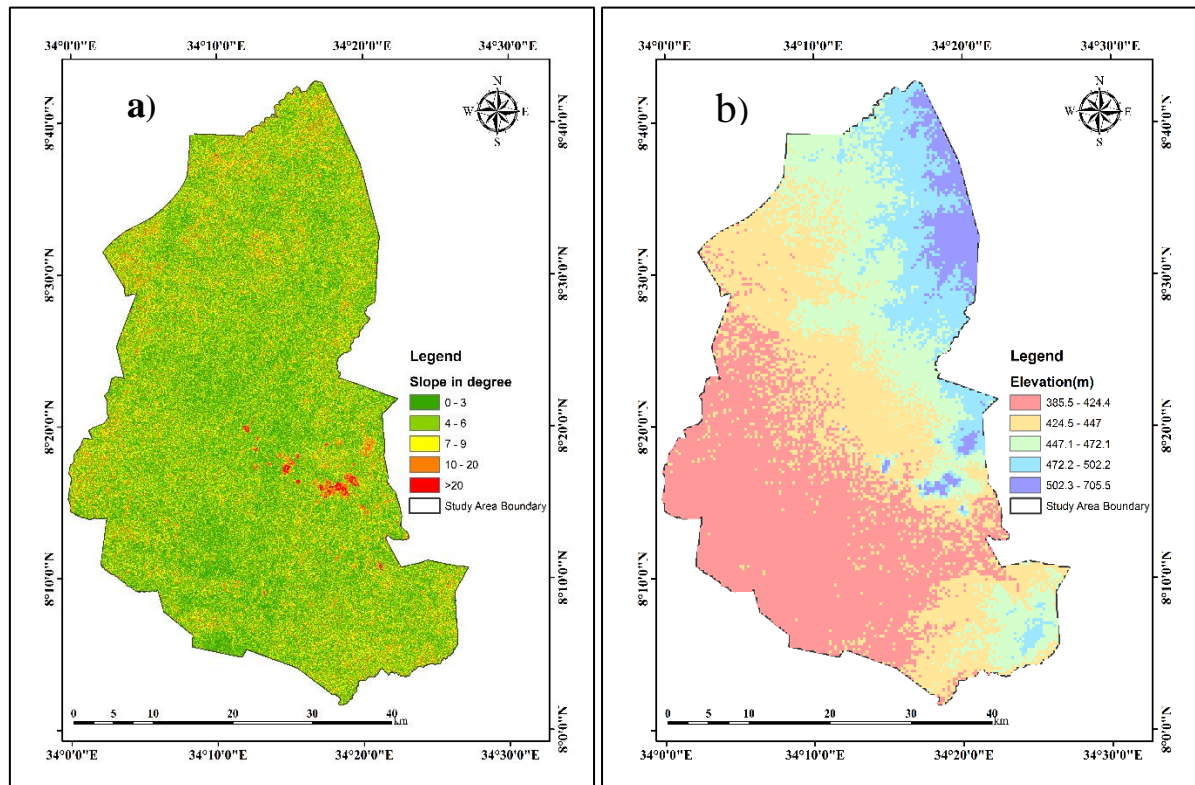


Figure 3.2: (a) Slope map and (b) Elevation map of the study area

3.1.3. Rainfall

Based on a long-term (30 years) rainfall record (1987-2017) obtained from Itang meteorological station, average annual rainfall of Itang is 894.9 mm. The maximum monthly average rainfall of the Woreda obtained from this station was 166.1 mm. This is the rainfall recorded in the month of July. However, most of the rainfall of the woreda is recorded from May-October with less rain registered between February-April. This is considered as all year rainfall. January is a month with least record of rainfall (Fig.3.3). On the other hand the annual rainfall record of Itang Woreda for the last 30 years (1987–2017) range between 239.2 and 1883.7. This distribution of rainfall is presented in (Fig.3.4).

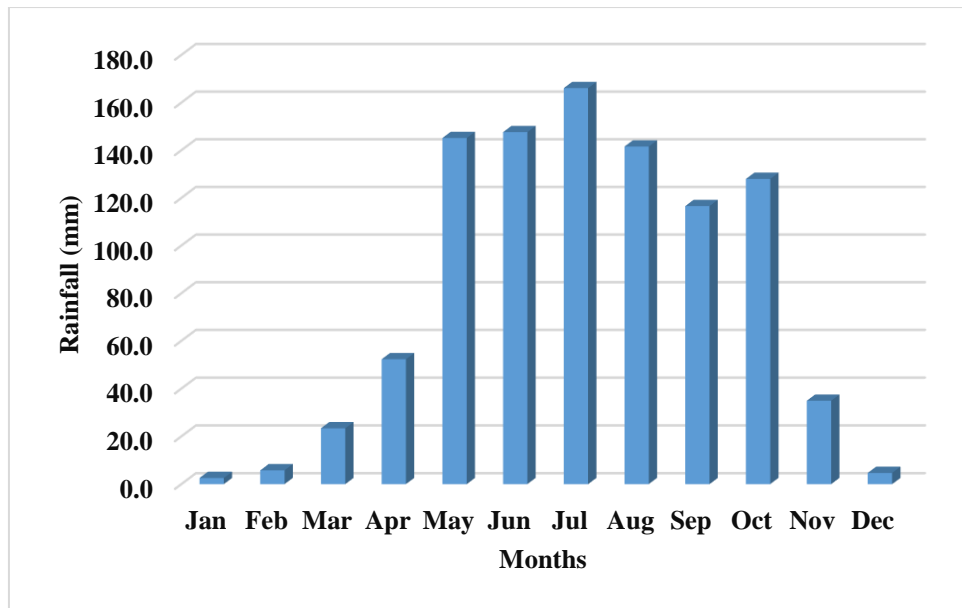


Figure 3.3: Monthly average rainfall distribution of the study area

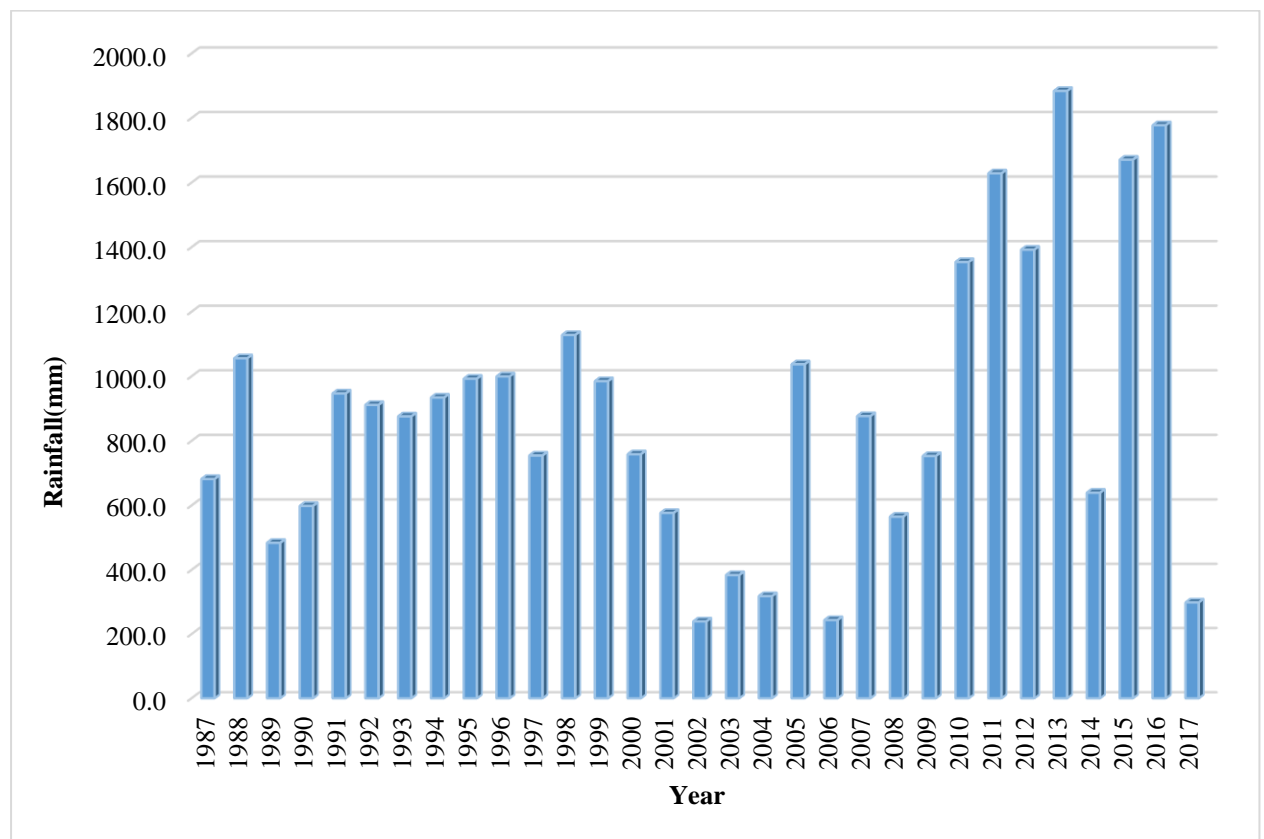


Figure 3.4: Annual average rainfall distribution of the study area

3.1.4. Vegetation

Itang is the woreda mainly dominated by woodland. Following rivers there are natural, broad leaf high forests. The vegetation distribution of the woreda is mainly dependent on the climate condition of the area which is purely tropical. Wheat, Barley, Maize and Sorghum are among the major crop types cultivated by the local people of the area. This cultivation activity is also practiced following one of the big river of the region (Baro), which cross Itang and flow to South Sudan.

3.1.5. Population

According to CSA (2016), the total human population of Itang Woreda including the Woreda's town (Itang Town) is about 47,280. Out of this, 23874 are men and 23406 are women. Majority of the population of Itang live in rural areas. The total urban and rural population of the woreda are 10,706 and 36,574, respectively (Fig.3.5).

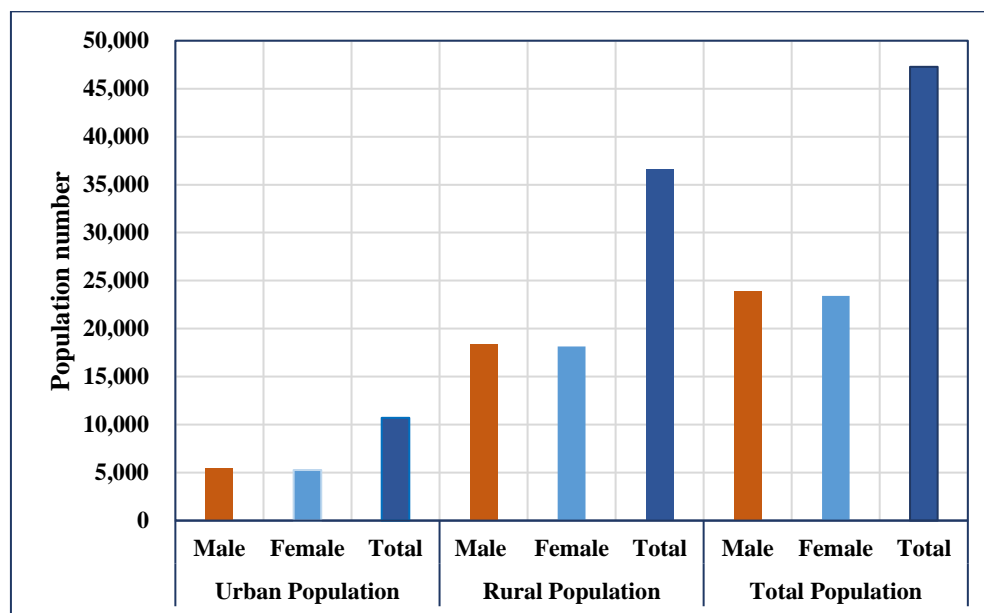


Figure 3.5: Population of Itang Woreda

3.1.6. Soil

Based on the data obtained from the MoWIEE, Itang Woreda was divided into seven soil categories. They are:

- Eutric vertisols: they are the dominant soil type of the study area and are commonly known in seasonally water logged and are generally fertile.
- Fluvisols that include both dystric and eutric fluvisols are the second dominant soil type of the study area.

- Cambisols: weathered and often shallow with coarse top soils. They include both dystric and chromic cambisols and are the third dominant soil type of the study area.
- Plinthosols: includes both dystric, eutric and covers some locations of the study area.
- Planosols: these are associated with drainage lines, swamps and water logged areas for part of or all the year.
- Eutric gleysols: These are soil types found in areas characterized with seasonal water logging.
- Leptosols: these class include rock scree, lithic and eutric leptosols and are found in areas with very high erosion hazard. Only limited location of the study are dominated by this type of soil. (Fig.3.6)

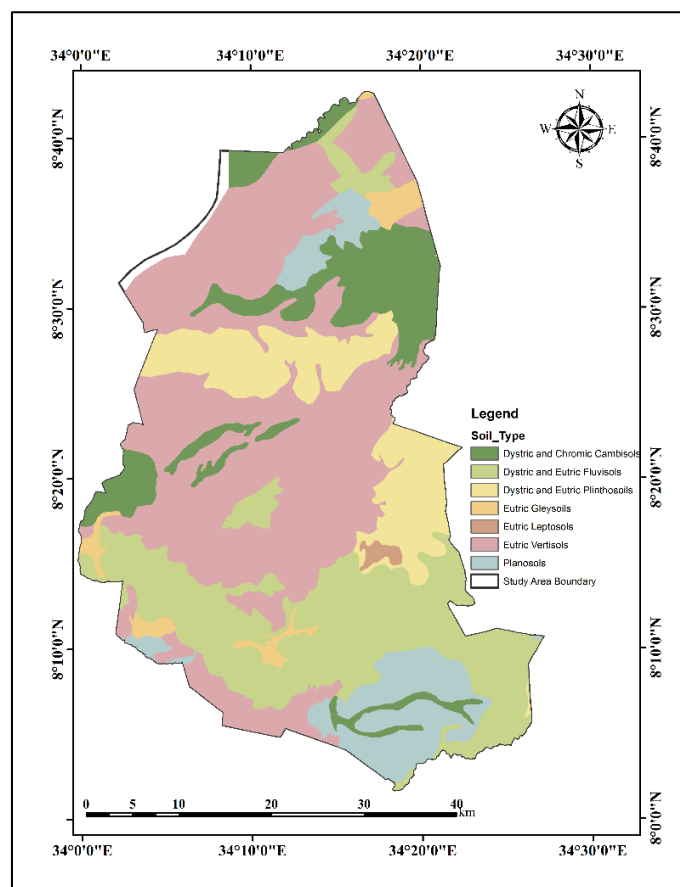


Figure 3.6: Soil map of the study area

3.1.7. Hydrology

Four major rivers and various tributaries are found in Gambella Region. These major rivers of the area are Baro, Akobo, Gilo and Alwero. Among these major rivers, Baro is the river flowing through the study area and is the main cause of flooding in this area. The general flow direction Baro is from east to west crossing the Gambella plain and eventually to the South Sudan. The long time flow data obtained from MoWIEE indicate that the river discharge

increases from May to September (the main rainy season) and decreases from October to April. The area receive high rainfall during this mentioned time. Figure 3.7 shows the long time mean monthly flow data of Baro at Itang Station.

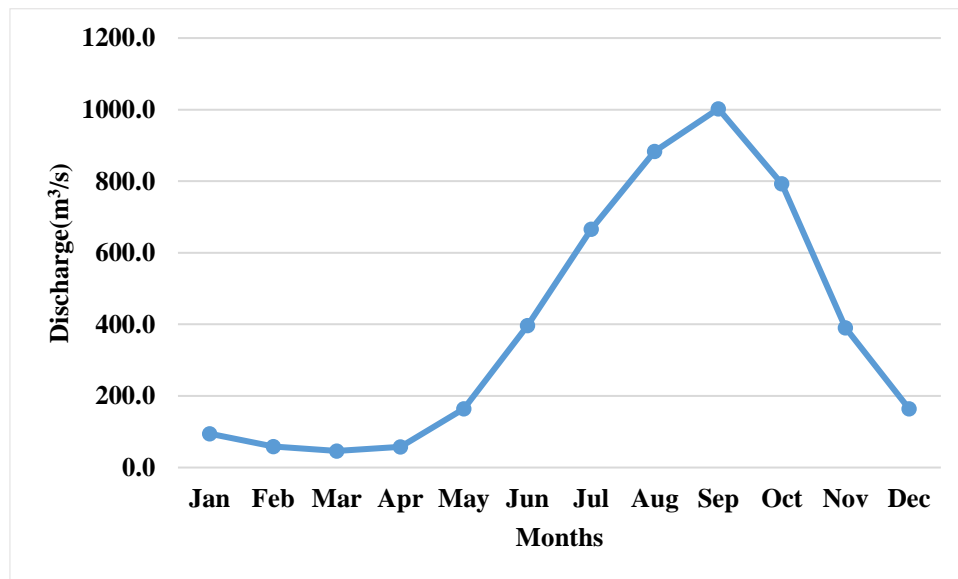


Figure 3.7: Mean monthly flow of Baro River

3.2. Data source

Both primary and secondary data are used for the successful achievement of the general and specific objectives of the study. Different websites providing freely downloadable data, governmental and non-governmental institutions responsible for different geospatial data related to the land and rivers in the country are the major sources for these data.

3.2.1. Primary Data

3.2.1.1. Digital Elevation Model (DEM)

One of the primary data sources used within this study is DEM. “A DEM is a representation of the terrain in a grid form where every grid center represents an x, y location in the datum plane having a height associated with it.” (Schott, 2007). The elevation, slope and orientation data which can be extremely useful in engineering and hydrological applications of remote sensing and other more application areas can be derived from DEM. With this study, DEM data with its 30 m resolution is used for delineating the watershed of the study area, extracting the drainage density and for mapping the elevation and slope of the area. Figure 3.8 shows DEM of the study area

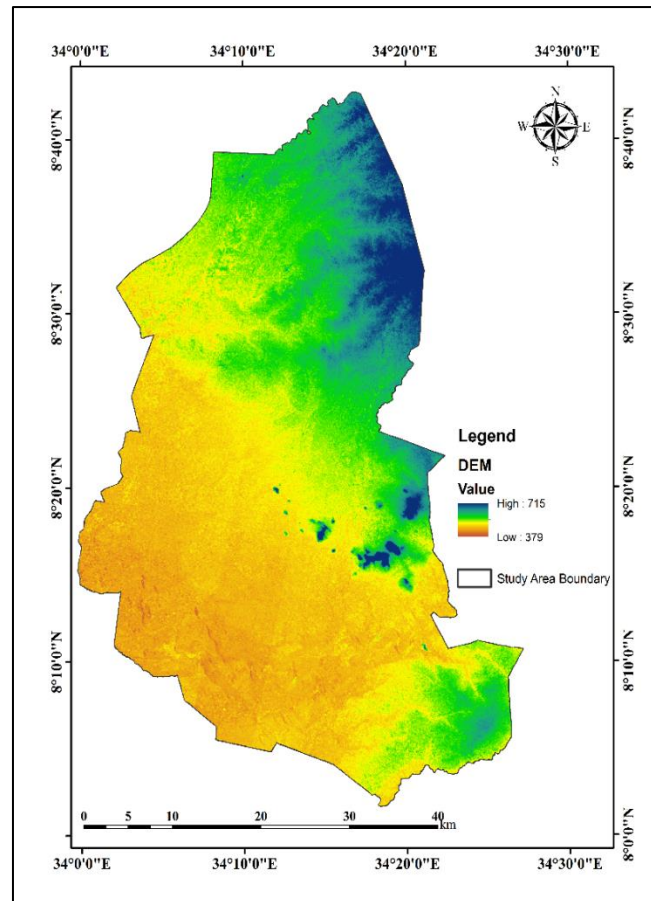


Figure 3.8: Elevation map

3.2.1.2. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

The L8 Observatory which was launched in February 2013, came up with many improvements over the previous Landsat missions. The Landsat 8-OLI sensor collects image data for 9 shortwave spectral bands over a 190 km swath, with a 30 m spatial resolution (for all bands band 1-7, 9) and 15 m for the panchromatic band (band 8). The two bands, i.e. band 10 and 11 are TIRS. List of all these bands and their relative wavelength are presented in (Table 3.1). Two additional bands are also introduced by the Landsat 8OLI. The first one is band 1, which is termed as Coastal or Aerosol band is mainly used for ocean color observations. The other one is a new infrared channel (band 9) which is for the detection of cirrus clouds (USGS, 2016). Figure 3.9 shows Landsat OLI image of Itang.

Table 3.1. Specifications of Landsat OLI data

Satellite	Sensor	Path/Row	Year	Resolution(m)	Wavelength(μm)
Landsat	OLI	171-54	2017	30	Band 1 (Coastal/Aerosol): 0.435–0.451
				30	Band 2 (Blue): 0.452–0.512
				30	Band 3 (Green): 0.533–0.590
				30	Band 4 (Red): 0.636–0.673
				30	Band 5 (NIR): 0.851–0.879
				30	Band6 (SWIR-1):1.566–1.651
				30	Band7 (SWIR-2):2.107–2.294
				15	Band8 (Pan): 0.503–0.676
				30	Band 9 (Cirrus): 1.363–1.384
				100	Band10 (TIR-1):10.60–11.19
				100	Band11(TIR-2):11.50–12.51

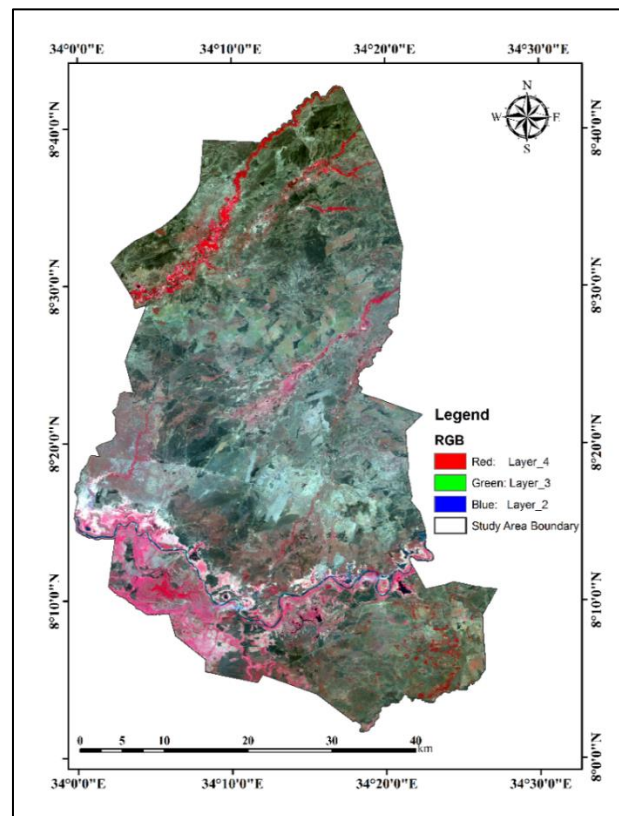


Figure 3.9: Landsat OLI image of the study area

All the primary, other ancillary data used for the achievement of this study and their source are presented in (Table 3.2).

Table 3.2. Data Source and Data Type

Data	Data source	Data Type
DEM	United State Geological Survey	Raster
Landsat-8 OLI imagery	United State Geological Survey Earth Explorer(USGS - EE)	Optical
Soil type	MoWIEE	Shapefile
Rainfall (precipitation)	EMA	Point data (Excel)
Discharge data	MoWIEE	Point data (Excel)
Study area boundary	CSA	Shapefile
Population data	CSA	Excel

3.2.1.3. Field data

Field visit was made for the accuracy assessment of the prepared land-use/land-cover map of the study area. This is an assessment made based on the ground truth. Additionally, necessary information related with the flood inundated area are collected. These include information related with the areas frequently hit by flood. After generating randomly selected 150 points, GPS point was collected and pictures captured showing different land-use/land-cover classes which are later used for the correction of misinterpreted classes.

3.2.2. Secondary Data

Meteorological (rainfall), soil type data, population and river discharge data are all the secondary data type used in this study. These data are obtained from different corresponding governmental and non-governmental agencies. The soil type data was acquired as shapefile from MOWIEE and had projected into suitable projection type. Then it was converted into raster and reclassified into seven soil classes. Rainfall data was acquired as point data and saved to be used in ArcGIS.

3.3. Methodology

The objective of this thesis is to develop a flood hazard map for the Itang Woreda of Gambella Region, using remotely sensed data in ArcGIS environment. Acquisition of data from different sources and websites was made. DEM with its 30 m resolution was acquired from USGS. It was extracted based on the study area shapefile using extraction tool of Spatial Analyst in ArcGIS and corrected into necessary projection type. Then Arc Hydro 10.2 which works as an extension on ArcGIS10.2 was used to delineate the watershed for which flood hazard analysis was made. 1D/2D Hydraulic modeling was made for the delineation of flood plain extent of the area through the use of DEM, HEC-GeoRAS/ HEC-RAS modeling software and ArcGIS.

3.3.1. Flood frequency analysis

Among important things in the flood related studies is the flood frequency analysis. Flood frequency analysis is a statistical measure of probable occurrence of flood of a given magnitude.

The probability of occurrence for the large and destructive floods is low when compared to small and less destructive ones. Such type of floods are infrequent by nature and have a long recurrence time. In contrary to this, small and less destructive floods have a chance of happening frequently. That means, they have relatively low recurrence interval.

It is possible to calculate probability of occurrence for major and destructive floods in terms of stream water discharge for a specified time. This can be done through different statistical and different probability distribution methods. There are different well known and commonly used frequency analysis techniques applied in the hydrological and meteorological related hazards. Gumbel extreme value distribution, Log-Pearson Type-III and Log Normal methods are among the universally and commonly applied flood frequency analysis techniques (Subramanya, 2008).

Using these methods, one can predict the probability of occurrence of any major flood events in terms of discharge or water level for a specified return period by making a detailed study on distribution of random variables and its parameters such as standard deviation, skewness etc. and applying probability theory. With this study two of the above mentioned flood frequency analysis methods (Gumbel and Log-Pears Type III) were tested through Chi Square Test method and method with better result (Gumbel) was used for further analysis.

Gumbel's Method

This is the most commonly and widely known probability analysis, especially in the meteorological and hydrological studies related with flooding prediction. This method was first introduced in the year 1914 by Gumbel. Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. In this study an attempt was made to compute water levels at 5, 10, 25, 50, and 100 return periods, where this method has been used as alternative. The Gumbel's equation is given as:

$$X_T = X_{avg} + K * STDV \quad (1)$$

Where, X_T = value of variate with a return period 'T'

X = mean of the variate

STDV = standard deviation of the sample

K = frequency factor expressed as

$K = Y_T - Y_n / S_n$ or $= Y_T - 0.577 / 1.2825$ where, Y_T is the reduced variate of given return period 'T' and is given by

$$Y_T = -(\ln * \ln(T/T-1)) \text{ or } -(0.834 + 2.303 \log \log(T/T-1))$$

T= return period

Y_n = reduced mean obtained from Gumbel frequency table

S_n = reduced standard deviation from table

Results obtained from the Gumbel frequency method are presented in chapter four of this study.

Log – Pearson type III method

Is a sort of the Pearson type III distribution which was first proposed by Foster in 1924 revised by U.S. Weather Resources Council in 1967 (Lee, 2005). It is extensively used in hydrologic frequency analysis particularly for flood peak data (Rao, 1990). In this frequency analysis method, the variate is first transformed in to logarithmic form and the transformed data is then analyzed. If 'X' is the variate of a random hydrologic series, then the series of 'Z' variates where $Z = \log X$ are first obtained. For this 'Z' series, for any recurrence interval 'T' the equation is:

$$Z = Z_{avg} + K_z * STDV \quad (2)$$

Where, K_z = frequency factor taken from table with values of coefficient of skew 'Cs' and recurrence interval 'T'

STDV = Standard Deviation of the 'Z' variate sample

Cs = Co-efficient of skew of variate "Z"

$$Cs = (N \sum (Z - Z_{avg})^3) / (N-1) (N-2) (STDV^3) \quad (3)$$

Where, Z_{avg} = mean of the ' Z_T ' variate

N = sample size = number of years of record

After finding Z_a with the equation above, the corresponding value of X_T is obtained by

$$X_T = \text{Antilog } Z_T.$$

Recurrence Interval can be calculated as: $(n + 1)/m$ (4) where

n=number of samples (years), and

m=rank of a given gauge level.

3.3.2 Flood inundation area mapping

The river geometry information are the basic and important requirements in developing flood inundation area using the HEC-GeoRAS/HEC-RAS hydraulic modeling software. These basic river geometries required in flood modeling include the river cross-sections, stream centerline, bank lines, flow lines, and other river geometry information. These necessary river geometry are extracted after Triangulated Irregular Network (TIN) was created from DEM. They are extracted from the developed TIN of the study area for the HEC-GeoRAS model. The Manning's n value for the individual cross-sections was also acquired after the land-use/land-cover map of the study area is developed. After the RAS geometry data preparation, the HEC-GeoRAS model was used to generate the RAS GIS file (final river geometry file) that can be used as input for HEC-RAS (Fig.3.10).

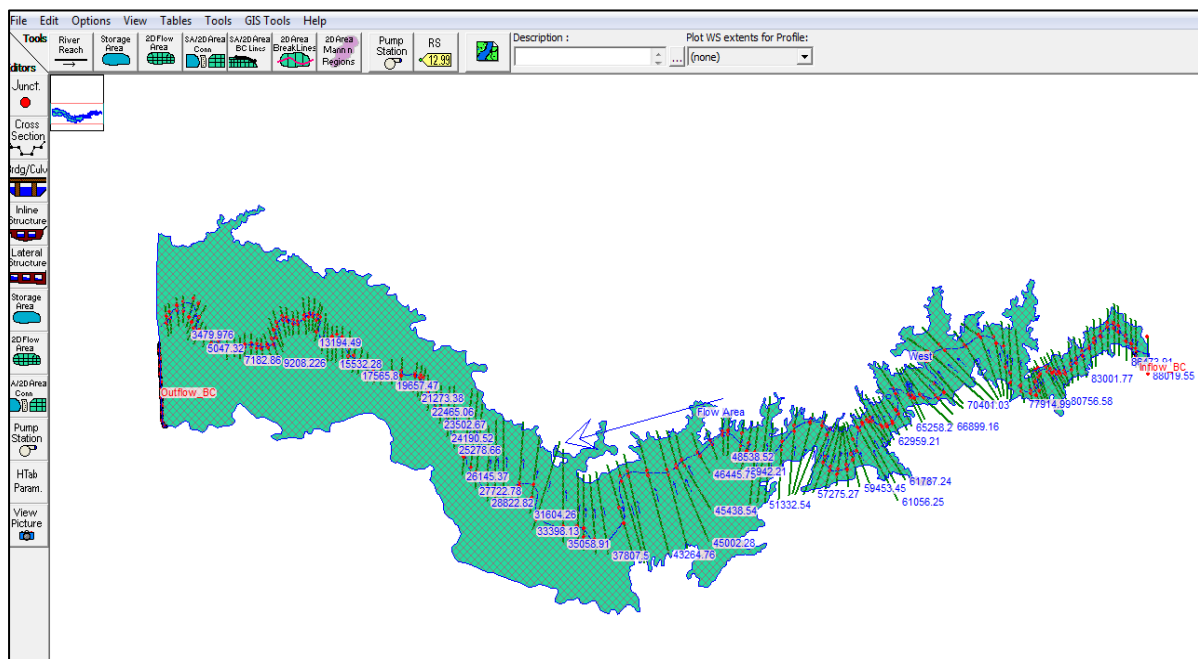


Figure 3.10: The Baro river geometry

After checking the cross-section and editing the river geometry based on the field verification, final correction of the river geometry file in the HEC-RAS model was carried out. Then highest flows imported from Itang gauging station will be used to generate water level for different return periods. The water surface level for each return period has been exported in HEC-GeoRAS for final inundation area mapping along the river which will be presented in the next coming chapter.

3.3.3. Flood hazard assessment

Flood hazard is not simply the overflow of rivers due to heavy rainfall, rather it is a combined result from the physical exposure and human vulnerability to that geophysical processes. Physical exposure refers to the damage to the physical structures such as buildings, bridges and property of the people (World Bank, 2016).

Flood hazard assessment can be made through different approaches. Statistical, hydrological, geomorphological or meteorological are among the approaches. Statistical discharge frequency analysis approach relies on the existence of long year records of stream discharge measurements (World Bank, 2016). According to Alexander (1993, as cited in Muianga, 2004) hydrological approach comprises methods of calculating or analyzing mainly variables like discharge recurrence intervals, water levels. On the other hand, figuring out how much volume of water is likely to flow down the river and where that water goes are the two crucial components in the flood hazard assessment.

Hydrological method is one of the most dependable and most frequently used approach for predicting stream flow (Bell, 1999). Analysis related to the landforms and fluvial system supported by information about past flood records and detailed topography of the area will be made through geomorphological approach. In the present study, historical flood record of the area along with the long year discharge data were used for the flood hazard assessment. Historically, the year 2007 is one of the time high flooding hit Itang, causing different damage.

According to European Union (2016), the geographical area which could be flooded based on different probabilities, along with some hazard related information associated to those areas should be presented when preparing flood hazard maps. With this study, areas under very high to the very low flood hazard zone were mapped after data collection and analysis was made on topographic nature of the area (slope and elevation), long year meteorological record (precipitation), drainage density, land-use/land-cover of the area and soil type.

Multi Criteria Analysis (MCA), a technique adopted in various approaches of decision analysis is used to determine flood hazard zones of the study area. This technique was done in two phases. First of all it was necessary to determine the weights for the criteria used in the study. To do so, a multi criteria decision tool called Analytical Hierarchy Process (AHP) is used. This tool helps in arranging hierarchy of decision criteria making comparison between each pair of criteria developed in the form of matrix. Comparison made between each pair of criteria help

in producing weighting scores. The produced weighting scores indicate the identification for the hierarchy of importance for the selected criteria.

The second phase of this technique weighted overlay process was applied to produce the final output of this study, i.e. the development of the flood hazard map of the study area. Figure 3.11 shows the general flow diagram of the methodology.

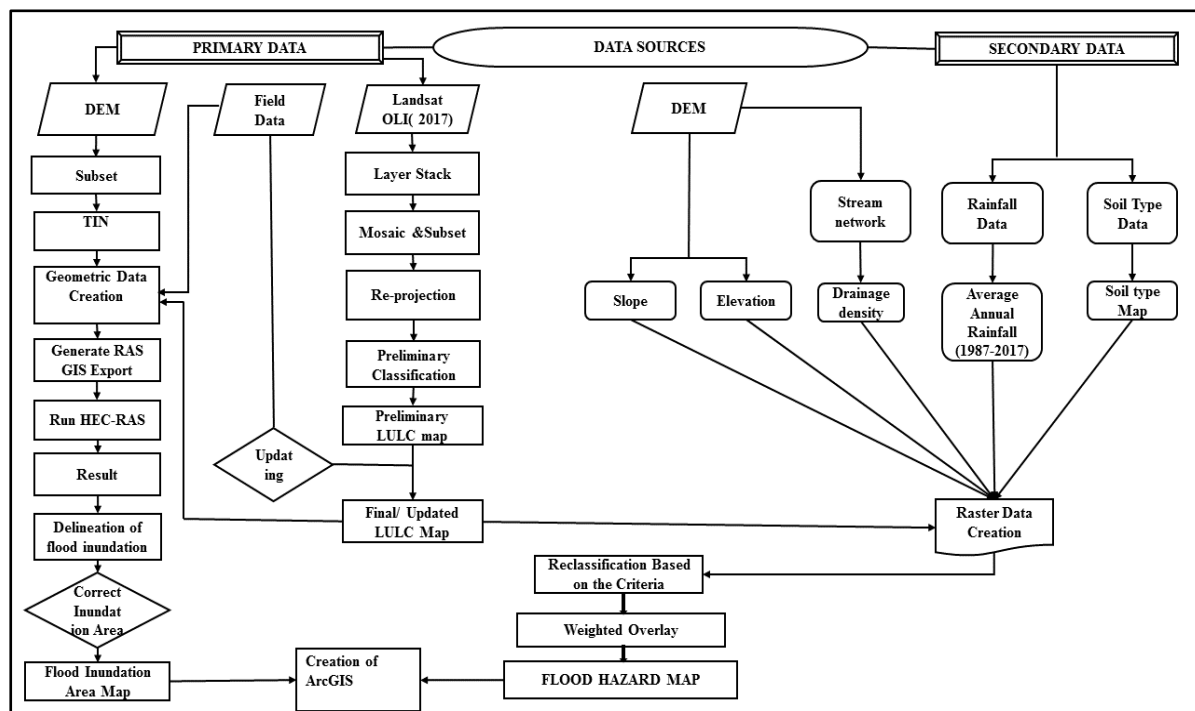


Figure 3.11: Methodological flow chart of the study

3.4. Spatial data preprocessing

Spatial data are the most important data acquired in flood analysis. For this study they are used as the base for the criteria being used (weighted overlay process). Elevation data, rainfall data, drainage density, slope, soil and land-use/land-cover are those criteria used within the study. Spatial data is required for the criteria being used for the weighted overlay process. Raster maps for elevation, slope, and drainage are derived from DEM. A raster map is created for precipitation through surface interpolation. A polygon map for land cover is created from a Landsat 8 image and a polygon map for soil type is obtained from MoWIEE.

3.4.1. Drainage density

Drainage density of the area is derived after the stream network was obtained from the DEM by using the Archydro 10.2. The first step of stream network delineation is to have a DEM with less depression. Therefore Arc Hydro 10.2 which is used as an extension of ArcGIS is used to locate and solve for the sink problem. Under the Terrain Processing tool of Arc Hydro there is a tool called DEM Manipulation. This is where the Fill Sink tool is used to fill the identified sinks. The direction of flow for every cell found within the depression removed DEM is

computed using Flow Direction tool and Flow Accumulation calculates the number of cells flowing into each cell of the filled DEM. Areas with cells of very high values are possibly considered as perennial streams or rivers, whereas areas with lower values may be sporadic streams. This is cross checked with the stream shapefile obtained from the CSA and also Google Earth. The Flow Accumulation grid is considered to allow for the determination of areas draining to points on the DEM. Using conditional statement to the flow accumulation, stream definition of the location made. Finally based on the prepared stream segmentation or stream order, the stream network of Itang were prepared.

Drainage densities of a given area were calculated by summation of the lengths of all the streams and rivers in the area divided by the total area under study. It helps to measure how much the area is drained by the river or stream channels. Drainage density depends upon both climate and physical characteristics of the drainage basin. Drainage system is among factors affecting the flooding condition of a given area. Drainage system of a given area can be affected by various different factors. Slope, difference in rock resistance or hardness are among these factors. Drainage density is controlled by permeability, erodibility of surface materials, vegetation (affects erodibility) slope and time. The prepared drainage density was classified in to five classes based natural breaks, as area of very high drainage density, high, medium, low and very low. Drainage density of very high class = 6.31-9.4 km/km², high = 5.22 - 6.3 km/km², medium= 4.17 - 5.21 km/km², low= 2.97 - 4.16 km/km² and very low= 0.43 - 2.96 km/km² (Fig.3.12).

Table 3.3: Drainage density

Rank	Drainage Density(km/ km ²)
Very high	6.31–9.4
High	5.22–6.3
Medium	4.17–5.21
Low	2.97–4.16
Very low	0.43–2.96

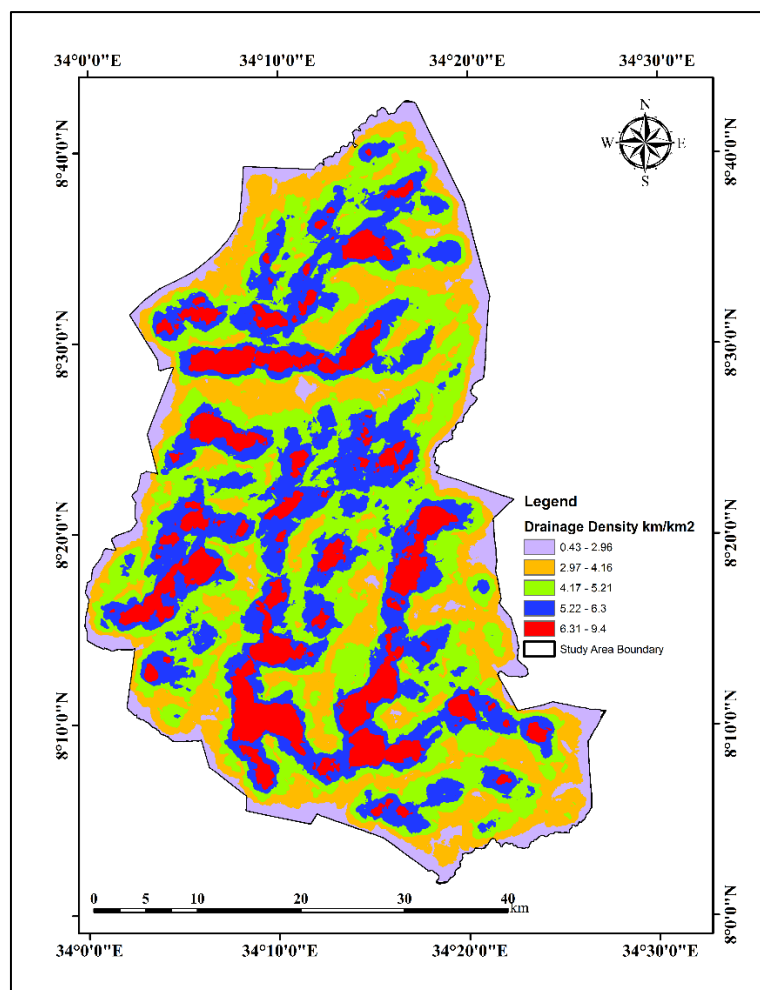


Figure 3.12: Drainage density map of the study area

3.4.2. Slope and elevation

Slope and elevation are among the important factors controlling flooding of a given area. They can be determined by the use of DEM. In this study, surface analysis tools under the spatial analyst tool bar in ArcGIS 10.2 was used to determine the elevation and slope of the study area from the DEM.

The nature of slope affects the flow and inundation of a particular area. During the flooding season, areas with steep slope have low tendency to be inundated when compared to low-lying areas with gentle slope. The nature of the terrain of a given area have also its own effect on the surface runoff. For example when there is a flat terrain there will be a decreased water runoff that lead to high infiltration rate where there is open soil. It may also be followed by stagnation in the areas where there is impermeable surface leading to water logging condition.

With this study slope of the area is classified in to five classes which are then given ranking. (Class 1: 0–3°, class 2: 4–6°, class 3: 7–9°, class 4: 10–20° and class 5: >20°) (Figure 3.2(a), Table 3.4). The elevation map of the area is also classified into five using natural breaks as

(Class 1: 385.5–424.4 m; class 2: 424.5–447 m; class 3: 447.1–472.1; class 4: 472.2–502.2; class 5: 502.3–705.5 (Fig.3.2 (b), Table 3.5).

Table 3.4: Slope ranking

Slope in degree	Ranking
0–3°	Very high
4–6°	High
7–9°	Moderate
10–20°	Low
>20°	Very Low

Table 3.5: Elevation ranking

Elevation(m)	Ranking
385.5–424.4	Very high
424.5–447.0	High
447.1–472.1	Moderate
472.2–502.2	Low
502.3–705.5	Very low

3.4.3. Land-use/land-cover

Landsat-8 OLI satellite imagery acquired on January 15, 2017 is used and classified for the land use/cover map of Itang. Maximum Likelihood Supervised Classification (MLC) was carried out to generate the land-use/land-cover map of the study area. Before the land-use/land-cover classification map of the study area developed, image pre-processing was carried out. To prepare the input satellite images for further processing, the following pre-processing steps were performed: layer stack, subset, radiometric calibration and atmospheric correction.

In supervised classification, it is necessary to have enough training samples for all the classes up on which the classification take place. For this study a total of 380 training samples were selected for the MLC from which 100 for the cropland area, 100 for woodland, 60 for wetlands, 30 for shrub and bushland, 20 for the water class, 20 for bare/non-vegetated, 20 for the grassland area and 30 for the high forest or tree-cover class. Training sample locations for each class were delineated using Google Earth as a background and a prior local knowledge of the region. In order to avoid the mix-up of the settlement area with the other features or classes due to similarities of reflectance value, settlement areas are digitized before the training area for other classes were developed and masked out from the study area. Then MLC was done based on the prepared training areas. Accordingly, nine land-use/land-cover classes are developed. Ranking is given based on their exposure and classes highest and least prone to flooding are identified. Based on the rank given for these land-use/land-cover classes, Wetland and waterbody are very high flood prone, whereas cropland, settlement and grassland/bare soil

are highly prone to flooding. Woodland is medium prone to flooding, shrub and bushland low flood prone and high forest is very low flood prone (Table 3.6).

Table 3.6: Land-cover ranking

LULC classes	Rank
Cropland	High
Woodland	Medium
Grassland/bare soil	High
Wetland	Very high
High forest	Very low
Shrub and bushland	Low
Settlement	High
Waterbody	Very high

3.4.4. Rainfall

A rainfall interpolation surface made based on Inverse Distance Weighting (IDW) method was created for the study area from the annual rainfall point data obtained from the EMA. Spatial interpolation of data can be made through the use of different interpolation methods. Inverse distance weighted is one of the interpolation methods in which the sample points are weighted during interpolation such that the impact of one point to another with distance declines from the unknown point. Inverse Distance Weighted is the simplest interpolation method and deterministic models. Deterministic models include IDW, rectangular, natural neighbors and spine. Interpolation uses vector points (feature data) with known values to estimate unknown locations to create raster surface covering an entire area (Legates and Wilmont, 1990). All the interpolation methods have their own advantages and short comings. Some of the advantages for which IDW is used for interpolating the rainfall distribution of the area are:

- Different distances are integrated in the estimation
- The distance weighting is able to precisely regulate the impact of the distances
- It permits for very fast and simple calculation

Therefore, in the present study rainfall data obtained for the woreda was interpolated using sample points in ArcGIS 10.2 environment and finally the interpolated maps were used for validation (Fig.3.13).

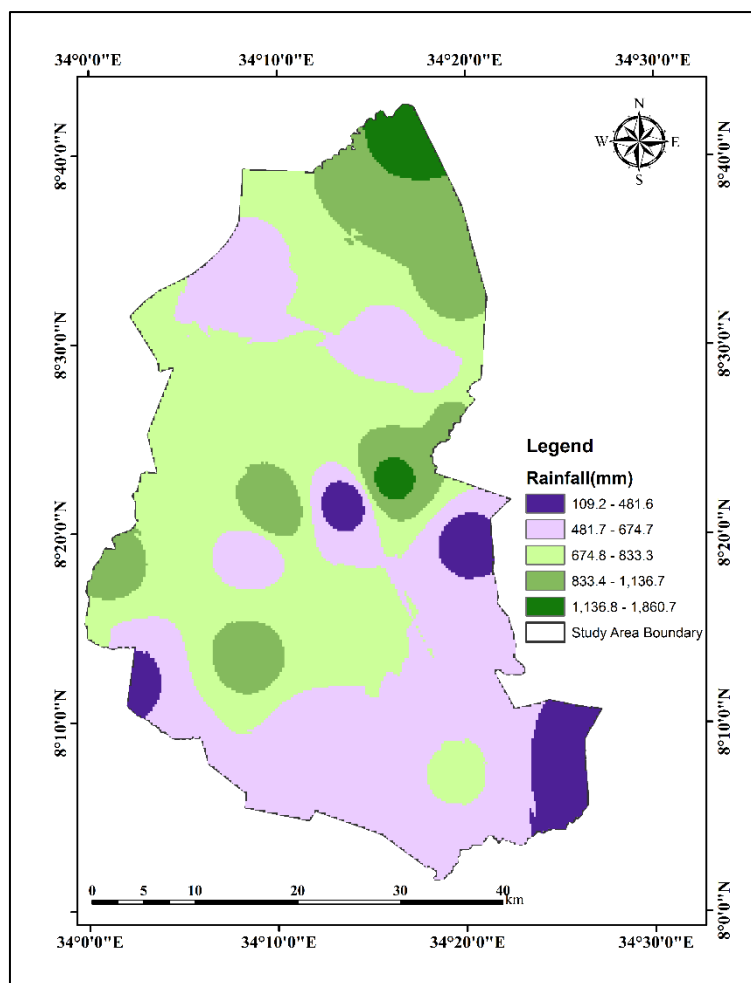


Figure 3.13: Rainfall distribution of the study area

The rainfall data is then classified into five classes as; class 1: 1,136.8–1,860.7, class 2: 833.4–1,136.7, class 3: 674.8–833.3, class 4: 481.7–674.7 and class 5: 109.2–481.6. These rainfall classes given based on natural breaks (Jenks) are ranked and presented in (Table 3.7). Based on this classification, ‘class 1’ is area of very high rainfall, ‘class 2’ is area of high rainfall, ‘class 3’ is area of medium rainfall and ‘class 4’, ‘class 5’ are areas receiving low and very low annual rainfall.

Table 3.7: Rainfall ranking

Annual rainfall (mm)	Ranking
1,136.8–1,860.7	Very high
833.4–1,136.7	High
674.8–833.3	Moderate
481.7–674.7	Low
109.2–481.6	Very low

3.4.5. Soil type

The soil type data obtained from the MoWIEE was developed by its seven classes. These soil type of the area are again given ranking of flood causing capacity based on their infiltration potential where dystric and eutric fluvisols are classified as very highly prone to flooding and dystric and chromic cambisols, dystric and eutric leptosols and eutric vertisols are classified as highly prone to flooding. Dystric and eutric plinthosols, planosols and eutric gleysols are medium, low and very low prone to flooding (Table 3.8).

Table 3.8: Soil type ranking

Soil Type	Ranking
Dystric and Eutric Fluvisols	Very high
Dystric and Chromic Cambisols	High
Dystric and Eutric Leptosols	High
Dystric and eutric Plinthosols	Medium
Eutric Vertisol	High
Eutric Gleysol	Very low
Planosols	Low

3.5. Multi criteria analysis

Different types of decision making tools had been developed in solving of various complex problems. One of these decision making tools is a structured decision making tool called Multi Criteria Analysis.

MCA describes any of the intentionally and systematically arranged technique used to decide among alternative preferences. These alternative preferences are given ranks from the very important to the least important preferences by the decision makers. Weights will be given for the alternatives to view the outcomes of the Multi Criteria Analysis. Technically there are different ways of developing MCA. Some techniques of MCA include:

- Aggregated Indices Randomization Method (AIRM)
- Analytic hierarchy process (AHP)
- Analytic network process (ANP),
- Best worst method (BWM)
- Characteristic Objects Method (COMET)
- Choosing By Advantages (CBA), etc.

With this study the Analytic hierarchy process (AHP) technique was applied, because that is the technique which, based on research, is widely used for flood analysis.

3.5.1 The analytic hierarchy process

The AHP is one of the multi criteria decision making technique which is used to solve a set of complex and conflicting problems. This multi criteria decision making approach was first introduced by Saaty in the year 1970s. The use of this decision making tool was applied to solve both the qualitative and quantitative complex problems. For doing so, Saaty developed the Pair-wise Comparison Method, so that decision makers arrange the problems into hierarchies and give them weight for prioritization and this is done through the scale of numbers to show the importance of one element over the other. Number of times one element is important over the other will be decided by using this scale of number (Table 3.9.)

Table 3.9: Saaty's fundamental scale of absolute numbers

Numeric Rating	Reciprocal (decimal)	AHP Scale of Importance for comparison pair
1	1 (1.000)	Equal Importance
2	1/2(0.500)	Equally to Moderately
3	1/3(0.333)	Moderate Importance
4	1/4(0.250)	Moderately to Strong
5	1/5(0.200)	Strong Importance
6	1/6(0.167)	Strongly to very strong
7	1/7 (0.143)	Very strong Importance
8	1/8 (0.125)	Very strong to extremely
9	1/9 (0.111)	Extreme Importance

When using AHP the first and important thing to be done is building hierarchy for decisions (Mu and Pereyra-Rojas, 2017). Accordingly, a decision problem is broken down and arranged into a hierarchy of goal, criteria and alternatives. It is then activity of the decision maker to make a pairwise comparison by the use of the above stated Saaty's fundamental scale of numbers. Then a pairwise comparison that led to the formation of the grid of matrix for the multi criteria decision are created.

With the goal of flood hazard mapping for the area under study (Itang), flood producing factors or Criteria used in this study are listed below

- Criteria 1(C1)= elevation
- Criteria 2(C2)= precipitation
- Criteria 3(C3)= slope
- Criteria 4(C4)= drainage density
- Criteria 5(C5)= soil type
- Criteria 6(C6) = land cover

Priorities of the decision criteria are then estimated. Based on the decision maker's preferences, values are computed from the grid of matrix made from the pairwise comparison.

3.5.2. Pairwise comparison method

In the matrix of pairwise comparison, each of the criteria considered as causative factors of flooding in Itang is compared to one another where one of the two criteria is expected to have more influence. In the comparison it should be clear that all the criteria won't have the same influence. If for example, both the criteria C1 and C2 have the same influence, the pair receives an index of 1. But when compared to criteria C2, if criteria C1 come up with more influence, then the pair receives its value from 9 to 2 (Table 3.10). In the reverse comparison for each of the criteria, the reciprocal for the assigned value, i.e. from 9-2 is applied. After all the comparison is completed for each pair, normalization of the matrix is made in the way each column sums up to one. Then the values with each of the criteria used as flood causative factor is divided by the total value or sum of that column. Then the mean value across each row is calculated. Calculating the mean value across each row is important to give the priority vector or what we call as Criteria Weights {W}. By doing so, the ranking of the criteria being compared is designated. After values were assigned for all the criteria, the more and less important criteria are identified. The final values for the decision were made after the lowest consistency ratio was reached.

It is obvious that individual decisions are never the same and even do not agree perfectly. This is only because of the subjective preferences of individuals. That is why inconsistency of decisions always appear. Therefore it is necessary to know the degree of consistency achieved in the pairwise comparison, in terms of the scaling of the matrix. To do so, Consistency Ratio (CR) that shows probability that the scaling were generated randomly was applied. According to Saaty, 1977 a CR below or equal to 0.1 said to be at an acceptable reciprocal matrix, whereas a ratio over 0.1 is said to be unacceptable which makes the matrix to be reexamined. To identify and locate inconsistent decisions with regards to their importance, the pair-wise comparison were made.

Table 3.10: Pairwise comparison matrix of the flood causative factors for Itang Woreda

	C1	C2	C3	C4	C5	C6
C1	1	2	2	3	5	7
C2	0.5	1	3	3	3	5
C3	0.5	0.333333	1	3	3	3
C4	0.333333	0.5	0.333333	1	2	4
C5	0.2	0.333333	0.333333	0.5	1	3
C6	0.1428571	0.25	0.333333	0.25	0.333333	1
Sum	2.6761905	4.416667	7	10.75	14.33333	23

Calculating Consistency Ratio (CR)

First it is necessary to determine the weight sums vector {Ws}

$$\{Ws\} = [C]\{W\} \quad (5)$$

Where, C is the pairwise comparison matrix and W is the priority vector

The Eigen value λ is then determined.

$$\lambda = \{Ws\} * \{1/W\} / n \quad (6)$$

Where, n=number of criteria.

After that, a Consistency Index (C.I.) is computed using the following formula

$$C. I. = \lambda - n / n - 1 \quad (7)$$

The Consistency Ratio (C.R.) is then calculated to determine if the comparisons are consistent or not.

$$C.R. = C.I. / R.I. \quad (8)$$

Where, R.I. is the Random Inconsistency index

Table 3.11: Random consistency index

n	1	2	3	4	5	6	7	8	9	10
R. I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The normalized matrix and the results for the equations will be presented in the next chapter.

3.6. The weighted overlay process

According to Esri 2016, application of the weighted overlay can be understood when the following different conceptual steps are applied. At the very beginning it is necessary to assign percentage weight for the raster layer created for all the flood influencing factors. This value is assigned through the weights decided using the AHP stated above. Next the assigned values of the raster layers presented will be given rank in the way of comparing the layers and identifying their relative importance and finally all the raster layers are overlaid. Then the

ranking value given for individual raster cells is multiplied by the weight given for the layer and totaled with the values of other raster cells it overlays. This is the way suitability value is derived. Two types of ranking can be used in ranking of the criterion in the way they are presented in their order of preference. The first one is straight ranking (that is; most important = 1, least important = 9) or the inverse ranking (most important = 9, least important= 1). The ranking applied to this analysis corresponds to the level of flooding, which are, very high = 5; high = 4, moderate = 3; low = 2 and very low =1.

3.6.1. Weighted overlay analysis

Analysis of this flood hazard mapping was performed with the use of the weighted overlay under of spatial analyst tool ArcGIS 10.2. The prepared raster layer for all the parameters were reclassified and given weight based the pairwise comparison. Based on the ranking given, the reclassified raster layers are combined together. The final output raster was produced based on the weighted overlay process indicated previously where the cell values of each input raster are multiplied by the raster's weight then the resulting cell values are added together. The final output raster is a flood hazard map that shows which areas falls within the different levels of flooding defined above.

CHAPTER FOUR

4. RESULTS

4.1. Flood frequency Analysis

By using Gumbel's Method, the calculated discharge for 5, 10, 25, 50 and 100 year return period flood were 1394 m³/s, 1535 m³/s, 1712 m³/s, 1844 m³/s, and 1974 m³/s, respectively while the calculated discharge of Baro River from Log-Pearson Type III Method are 1389 m³/s, 1432 m³/s, 1461 m³, 1473 m³/s, 1480 m³ respectively. These values from Gumbel and Log Pears Type III are presented in (Table 4.1(a), 4.1 (b)).

Table 4.1(a): Gumbel based water discharge in Itang Woreda

Return period (T) (Year)	Probability (P) (%)	Gumbel variate y	Flood discharge Q (m ³ /s)
5	20	1.5	1394
10	10	2.25	1535
25	4	3.199	1712
50	2	3.902	1844
100	1	4.6	1974

Table 4.1(b): Log-Pears Type III based water discharge

Return period (T) (yr)	Probability (P) (%)	Frequency factor K	y = log (Q)	Flood discharge Q (m ³ /s)
5	20	0.809	3.143	1389
10	10	0.973	3.156	1432
25	4	1.081	3.165	1461
50	2	1.124	3.168	1473
100	1	1.15	3.17	1480

These flood discharges were tested for their goodness of fit through Chi square Method. Accordingly, Log-Pears Type III method showed low Chi Square result (3.836), P value of 0.429 and Gumbel Method showed Chi Square of 127.959, P value of <0.001. Even if Log-Pears Type III showed minimum Chi Square result, the result is not significant at $p \leq 0.05$. Result from Gumbel's P-Value is < 0.001 and the result is significant at $p \leq 0.05$. Therefore, result from Gumbel method is selected for further processing.

4.2. Flood inundation map

After calculating the discharge level for all the recurrence intervals through the above indicated techniques, Gumbel based water levels of each recurrence time were interred into HEC RAS hydraulic modeling software to map the flow areas. Then subcritical steady flow analysis was made for all the recurrence intervals. Based on the result from HEC RAS, elevation of water surface of areas to be inundated within the 5, 10, 25, 50 and 100 year recurrence intervals are identified (Fig. 4.1). Then mean elevation of these areas were calculated and then joined with the water levels of each recurrence intervals. This average elevation such as 413.99 m, 414.21 m, 414.45 m, 414.82 m and 415.58 m, respectively. Knowing such mean elevation values will help to know areas to be flood inundated. Accordingly, if floods of 5, 10, 25, 50 or 100 years occur, inundation will be expected to occur in areas with elevation lower than computed mean water levels. HEC RAS has a capability of modeling the steady and unsteady hydraulic analysis. Steady flow analysis was applied for those recurrence intervals.

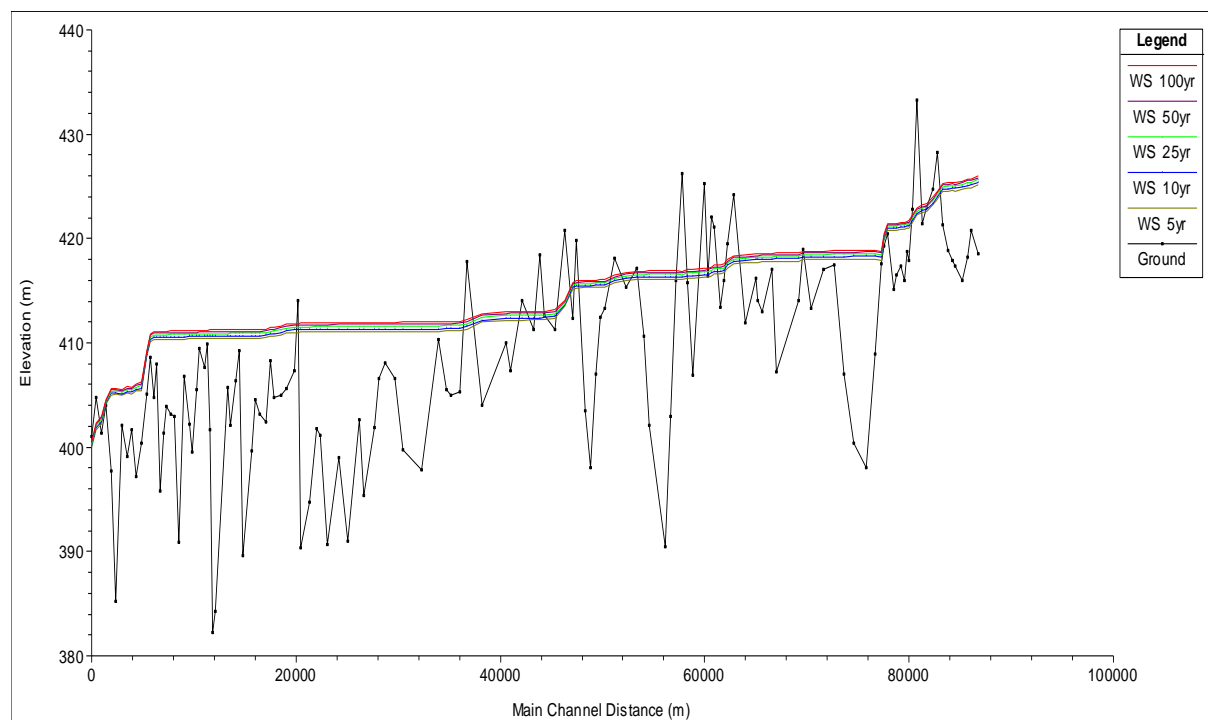


Figure 4.1: Water surface of different recurrence intervals obtained through HEC-RAS

Figure 4.2 depict areas to be inundated within previously indicated recurrence intervals. Accordingly, 76.66 km², 80.78 km², 84.15 km², 87.34 km² and 100.34 km² of land area are expected to be inundated by flood of 5 year, 10 year, 25 year, 50 and 100 years of recurrence intervals. From these inundation maps, locations found along Baro River banks, especially the flat flood plain area and to the western direction of the study area would be flooded in all the five recurrence intervals.

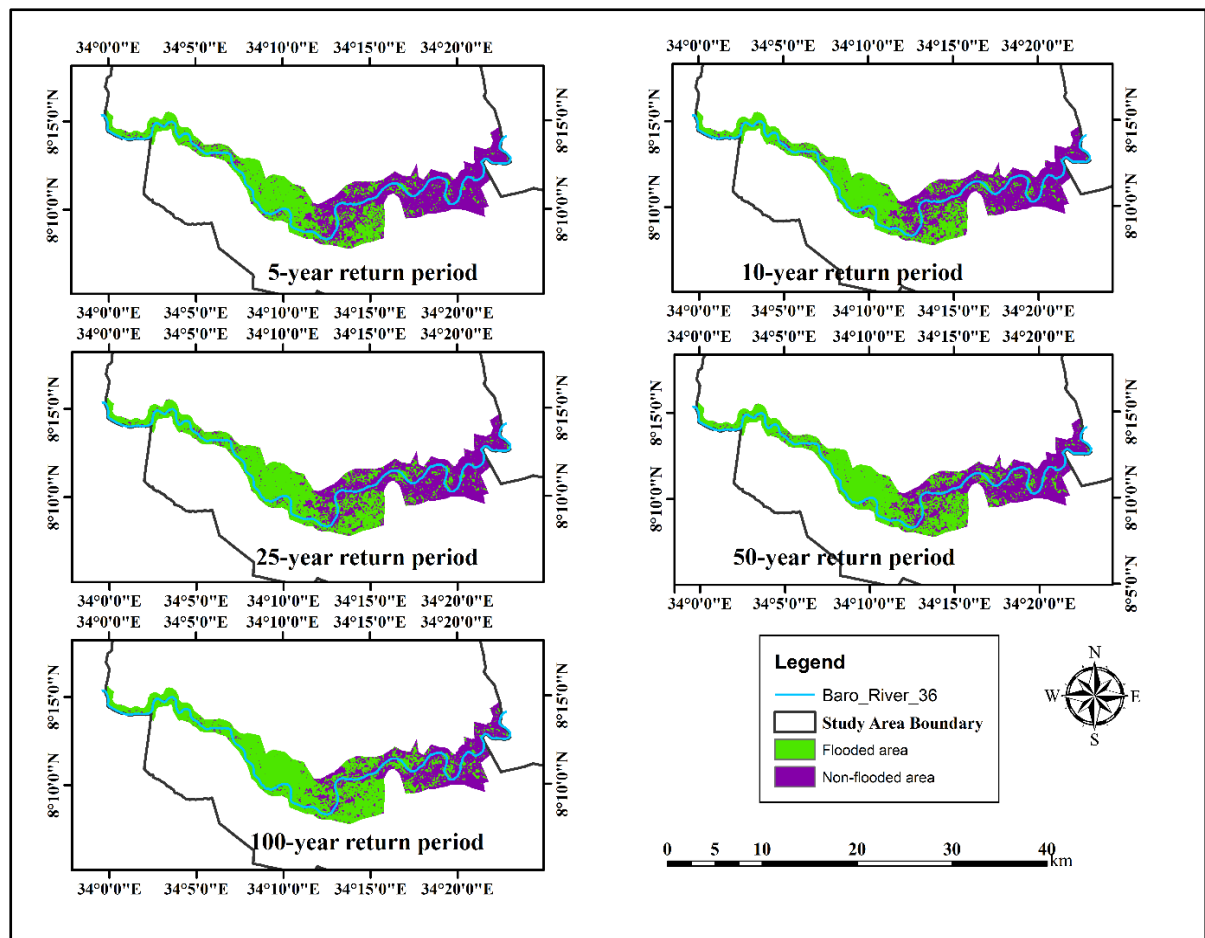


Figure 4.2: Flood inundation area of different recurrence intervals

4.3. Flood factors

4.3.1. Slope and Elevation

Slope and elevation of a given area play an important role in the occurrence of flooding. Slope of an area has an effect on the nature of flooding of a given area. Slope affects the amount of surface run off and its volume which result the discharges to rivers or streams. As slope increases, the run off also increases which results to flood occurrence. Additionally, slope play an important role in the infiltration rate and direction of flow. Low lying flat areas with relatively gentle to flat slope are more prone to flooding due to the run off coming from high slopes. Therefore residents found to such a slope are more affected by flooding. Areas found to the eastern part of this study area (upstream of Baro) that merge with the adjacent lands experience relatively limited flooding when compared to the flat areas found at the downstream part of the river which has longer continuous flat slope (Fig. 4.3(a)).

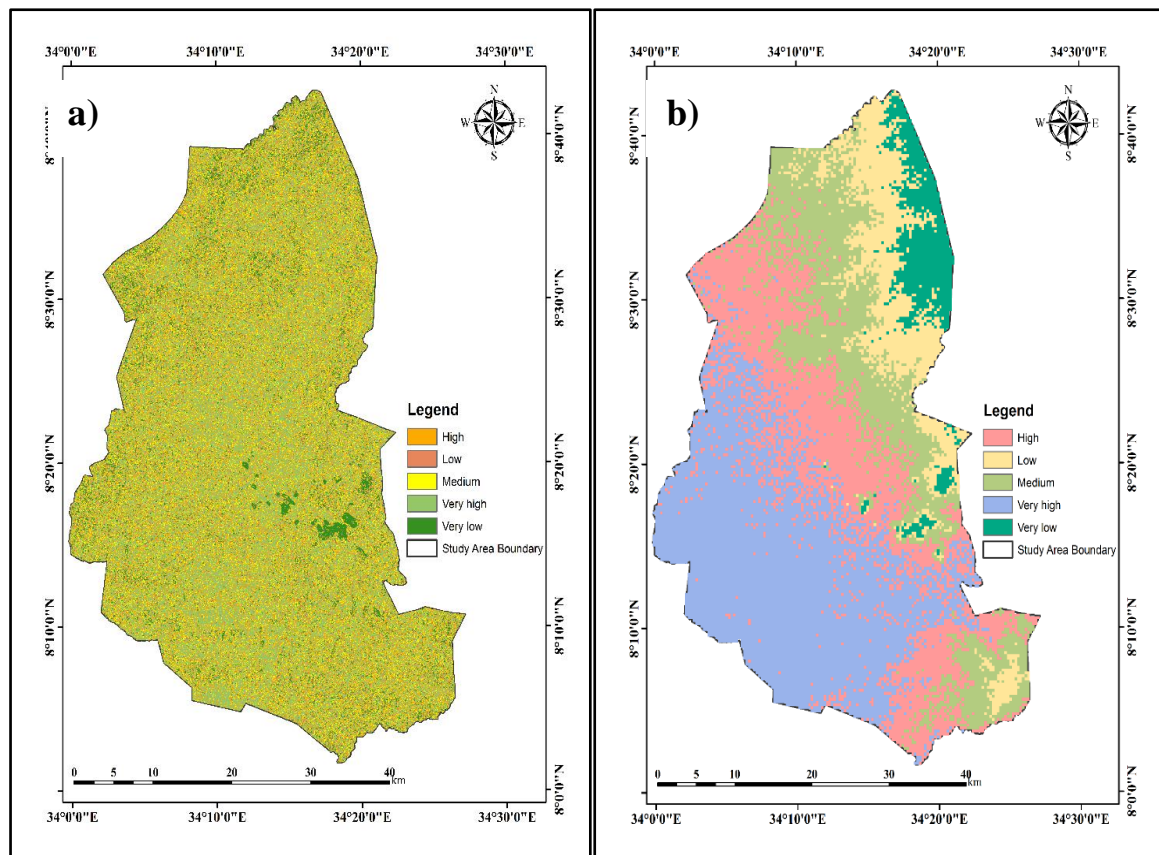


Figure 4.3: Reclassified slope (a) and reclassified elevation (b) of the study area

From different altitudes in the woreda, areas which are found at lower elevation are more exposed to flood hazard. Areas found along flood plain of Baro River and the low land areas bordering with Lare, one of the woredas found in Gambella are more affected by flooding. These areas are found to the western part of the study area. Large part of this specific area remain covered by water during the time of either normal or above normal rainfall. This is part of the large wetland area found to the western part of Gambella Region. Due to this fact transportation to these areas and other activities of the people face problem during summer season. The reclassified elevation based on the natural break (Junk) indicate that about 776.52 km² (35.67%) of Itang has low elevation which is very high prone to flooding. 567.96 km² (26.09%) is highly prone to flooding based on their elevation. 440.48 km² (35.67 %) is medium prone to flooding, whereas, 263.67 km² (12.11%) and 128.23km² (5.89%) are low and very low prone to flooding (Fig. 4.3(b)).

4.3.2. Rainfall

Heavy rainfall from the region and the surrounding highland areas of Oromiya is the main cause of flooding which lead to the overflow of river banks in the study area, mainly Baro. It is noticed that areas at the south western part of the study area have relatively lower precipitation than the northern and eastern part. From the study area, there are places with

annual rainfall more than 1800mm and there are also places where annual rainfall is less than 481.6 mm. The rainfall map (Fig. 4.4) developed based this data is used to develop the final flood map of the study area. From the map, areas with very high and high rainfall classification are high lands, especially the northern and north eastern part adjoining with the surrounding Oromiya Zones. Based on the reclassified rainfall data, about 885.66 km² or 40.7% of Itang receive medium rainfall, followed by 814.24 km² or 37.41% of area receiving low rainfall per annum and 304.11 km² or 13.97% receiving high rainfall per annum. Areas receiving very low and very high covers 122.59 km² or 5.63% and 49.72 km² or 2.28% of the total area of Itang (Table 4.2).

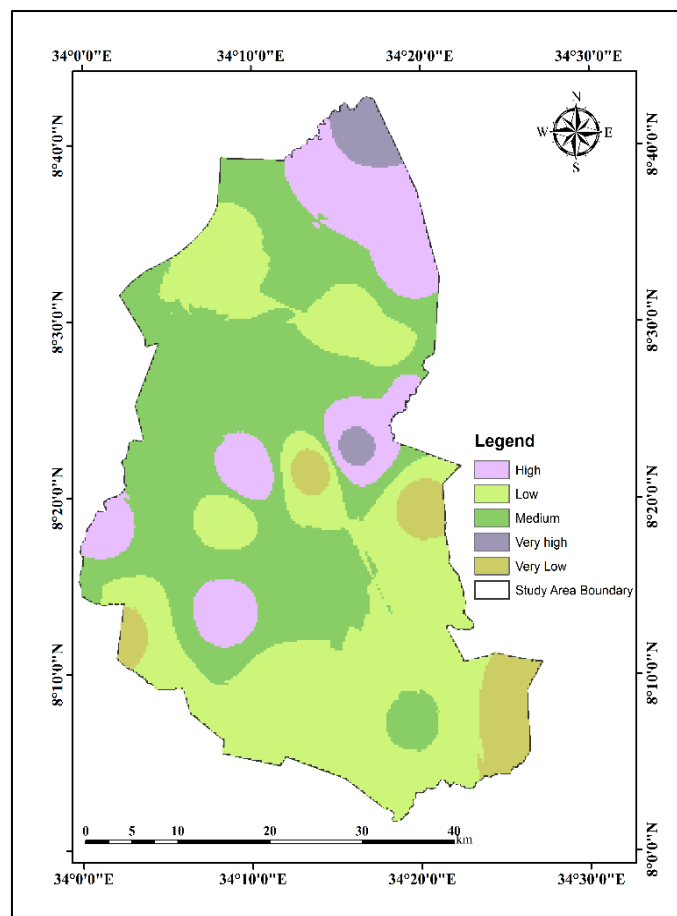


Figure 4.4: Reclassified rainfall map

Table 4.2: Reclassified rainfall of Itang

Rank	Annual rainfall (mm)	Area (km ²)	Area (%)
High	833.4–1,136.7	304.11	13.97
Low	481.7–674.7	814.24	37.41
Medium	674.8–833.3	885.66	40.70
Very high	1,136.8–1,860.7	49.72	2.28
Very low	109.2–481.6	122.59	5.63

4.3.3. Drainage Density

The reclassified drainage density map of Itang shows that, 681.32 km² or 31.31% of the study area are areas with medium drainage density, 551.41 km² or 25.34% are high, 513.49 km² or 23.6% are low, 253.35 km² or 11.64% are very high and 176.36 km² or 8.1% very low (Fig. 4.5 (b)). High surface runoff would be expected if there is high drainage density in a given area. From this reclassification, areas around big rivers like Baro River have very high drainage density. Drainage density of the study area is calculated as 2.5 km/km².

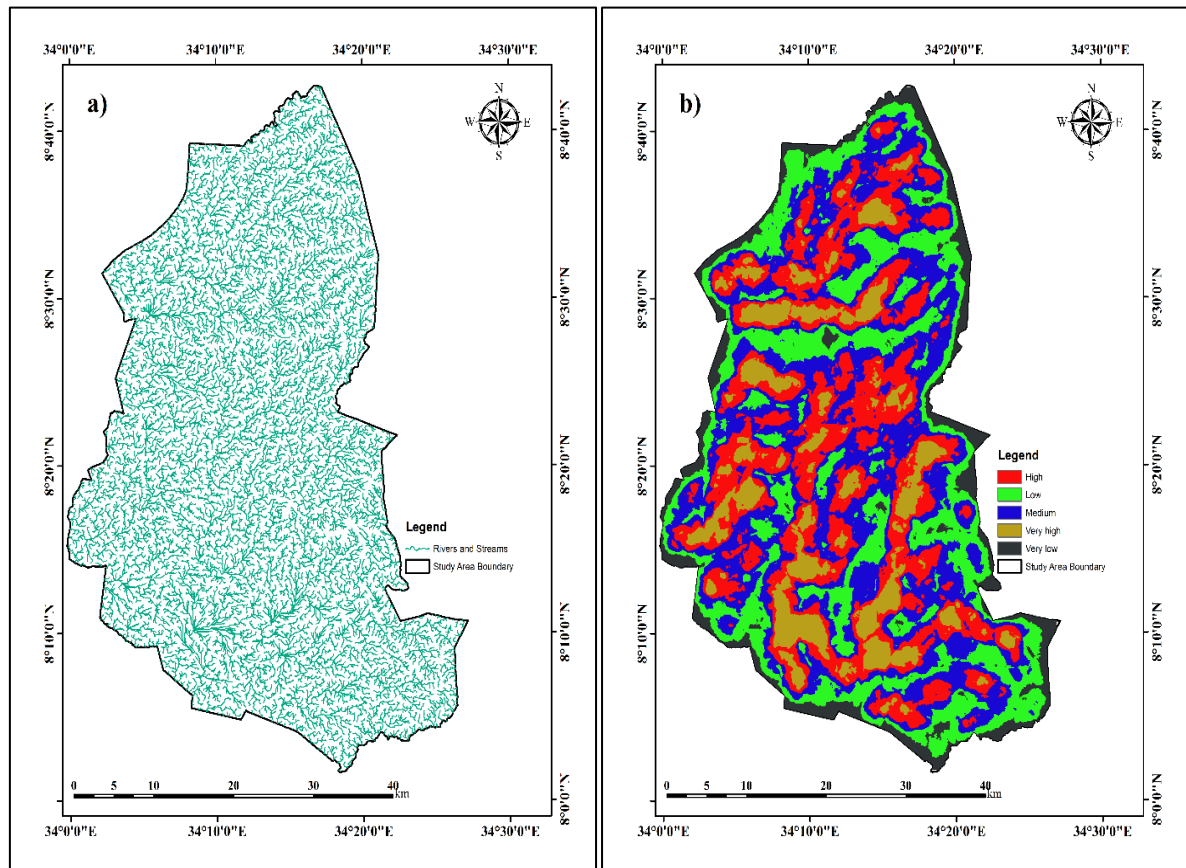


Figure 4.5: Stream network (a) and reclassified drainage density map (b)

4.3.4. Land-use/land-cover

The heterogeneous land use / land cover of the study area has been developed by the use of Landsat 8 OLI of the year 2017(Fig. 4.6 (a)). Visual interpretation of the land-use/land-cover classification of the area was made before the field verification for some randomly selected sample points has been carried out. Some of these points were also checked by the use of Google Earth. Based on the field verification and the use of the Google Earth, further classification was made and some of the areas which are misinterpreted during preliminary classification were able to be corrected. Accordingly areas, especially misinterpreted between shrub and bush, croplands and woodlands were corrected. Accuracy assessment was finally

made to see the accuracy level the final land-use/land-cover which showed acceptable 90.6% overall accuracy and Kappa of 0.86 (Table 4.4).

The nature of land-use/land-cover of one area has an effect on the flooding as it controls the characteristics of the runoff. Existence of vegetation or forest cover in a given area reduces and controls the occurrence of flood. The vegetation cover in Itang was reduced mainly due to the increased large and small scale agricultural activities in the area. The moisture content of land has also an effect on the flooding condition. Lands with less moisture content has capability of absorbing water in compared to areas with more moisture content. The wetlands along Baro and adjacent areas of Lare are among the areas highly affected by flooding. On the other hand, there will be increased runoff with settlement and agricultural areas due to their less absorption capacity resulting from paved surfaces. Therefore such an area has also a probability to be affected by flooding. From the prepared land-use/land-cover map about 1069.9 km² (49.2%) of land is covered by cropland, which is followed by woodland (798 km²) or 36.7% of the total land area. Wetland is another class covering large area with its 83.9 km² (3.9%). Grassland/bare soil is a class with areal extent of 60.7 km². This is 2.8% of the total area. High forest covers about 36km² (1.7%), whereas water body covers 14.7 km² (0.7%). Finally, 12.1 km² (0.6%) and 7 km² (4.6%) of Itang Woreda is covered by settlement and shrub and bush, respectively (Table 4.3).

Table 4.3: Land-use/land- cover statistics

Land-use classes	Area(km²)	Area (%)
Cropland	1069.9	49.2
Woodland	798	36.7
Grassland/Bare soil	60.7	2.8
Wetland	83.9	3.9
High forest	36	1.7
Shrub and bushland	4.7	4.6
Settlement	12.1	0.6
Waterbody	14.7	0.7

From the accuracy assessment done for the land use/land-cover, the final result for the producers and user's accuracy of each classes will be presented in (Table 4.4). Cropland (producers accuracy=98.98% and 85.09%), woodland (producers accuracy=87.23% and 98.80%), wetland (producers accuracy=87.88% and 100.00%), grassland (producers accuracy=20.00% and 100.00%), shrub and bushland (producers accuracy=100.00% and 68.42%)

Table 4.4: Statistical information of the LULC accuracy assessment

Land-use/land-cover classes	Producers accuracy	Users accuracy
Woodland	87.23%	98.80%
Wetland	87.88%	100.00%
Water body	---	---
Shrub and bushland	100.00%	68.42%
Settlement	---	---
High forest	100.00%	100.00%
Grassland	20.00%	100.00%
Cropland	98.98%	85.09%
Bare soil	---	---
Overall classification accuracy	90.63%	
Overall kappa statistics	0.8642	

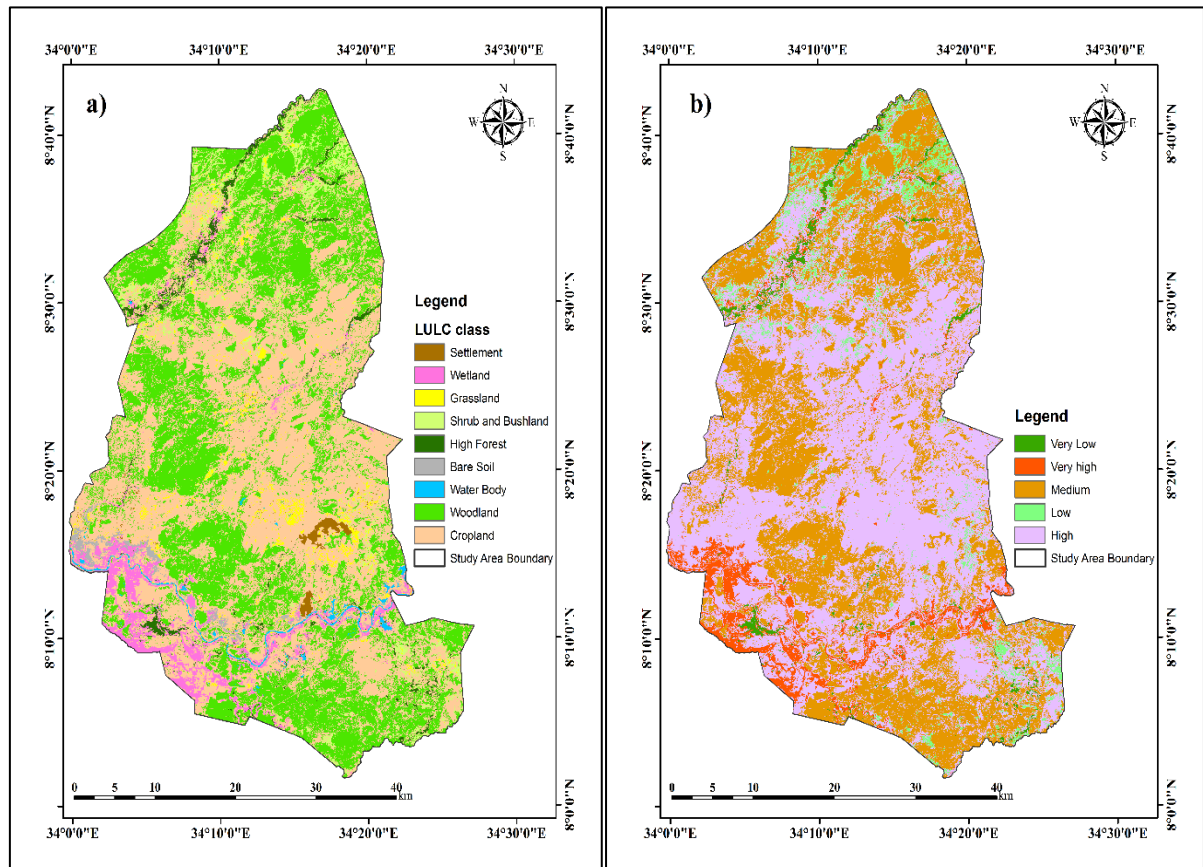


Figure 4.6: a) Land-use/land-cover map and b) reclassified land-use/land-cover map

4.3.5. Soil

The nature of soil in a given area can have influence on the flood condition as it can determine the infiltration capacity. For example soils with porous texture such as sandy soils, absorbs water easily and creates less runoff whereas less porous soils such as clay, holds water for long

periods. According to the soil classification of the MoWIEE most of the different soil types in Itang (1149.5 km²) are highly vulnerable to floods based on their type, i.e. Dystric and Eutric Fluvisols. This is about 53.2% of the total area. Next, Dystric and Chromic Cambisols, located in very high flood zone covers an area of 514.2 km² or about 23.8%. Dystric and eutric Plinthosols classified as soil type of medium flood hazard zone covers an area of 252.5 km² (11.7%). About 195.4 km² (9.1%) and 47.6 km² (2.2%) area of land are covered with soil type of low and very low flood prone type. These are: Planosols and Eutric Gleysol. Figure 4.7 shows the reclassified soil map of the woreda.

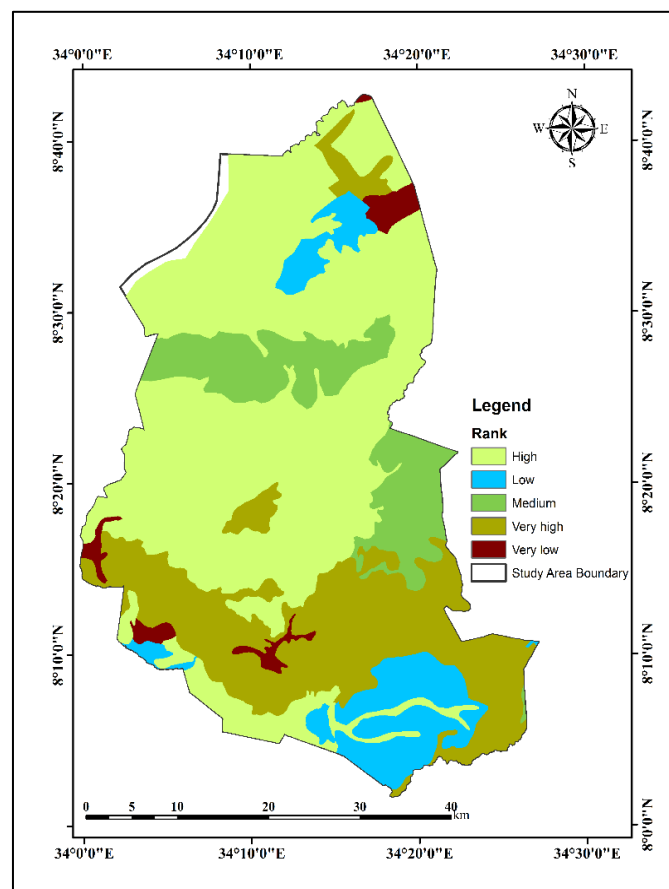


Figure 4.7: Reclassified soil map of the study area

4.4. Multi criteria analysis results

The pairwise comparison process made in chapter three of the thesis helped to identify the level of influence for each of the criteria used in this study. The following table (4.5) presents results of the pairwise comparison made. The criteria weight given for each factors is presented under the column W. It indicates the level of influence each criteria has on flooding. Based on the result of this criteria weight, Criteria ‘C1’ (elevation) has the most influence of all (0.057). Criteria ‘C2’ (Rainfall) with its weight of 0.043 comes next, then Criteria ‘C3’ (Drainage Density) with weighted value 0.028, Criteria ‘C4’ (0.019) and finally Criteria ‘5’ soil type

(0.012) and Criteria 'C6' (land-use/land-cover (0.007)). The weighted value of all the criteria are presented in the following (Table 4.5).

Table 4.5: Normalized matrix of flood factors for Itang Woreda

Criteria	C1	C2	C3	C4	C5	C6	Scores	Score/6 (W)	{Ws}
C1	0.374	0.453	0.286	0.279	0.349	0.304	0.341	0.057	0.367
C2	0.187	0.226	0.429	0.279	0.209	0.217	0.258	0.043	0.286
C3	0.187	0.075	0.143	0.279	0.209	0.130	0.171	0.028	0.187
C4	0.125	0.113	0.048	0.093	0.140	0.174	0.115	0.019	0.121
C5	0.075	0.075	0.048	0.047	0.070	0.130	0.074	0.012	0.078
C6	0.053	0.057	0.048	0.023	0.023	0.043	0.041	0.007	0.044
Sum	1	1	1	1	1	1	1	1	

Eigen value $\lambda = 6.466$

Consistency Ratio = 0.075

From the result, consistency ratio of 0.075 is less than 0.1 which implies that the criteria is consistent.

4.5. Flood hazard assessment

The prepared flood hazard map indicate that majority of the land in the study area (636.6 km²) or 29.7% fall in the medium flood hazard zone. The second flood hazard zone covering large area is high flood hazard zone, which cover 596 km² (27.8%). Low flood hazard zone is 396.5 km² (18.5%), then very high is 271.8 km² (12.7%) and very low is 244 km² (11.4%), respectively. Areal coverage of flood hazard zones are presented in the following (Table 4.6). Some selected flood prone areas were observed during the time of field verification. Interview was made for the local people to understand previous flood condition and damage it caused. Areas within the flood plain can be affected due to the land-use/land-cover characteristics.

Table 4.6: Flood hazard coverage

Zones	Area (km ²)	Area (%)
Very High	271.8	12.7
High	596.0	27.8
Medium	636.6	29.7
Low	396.5	18.5
Very low	244.5	11.4

The prepared flood hazard map was connected with the kebeles found under Itang to understand status of the kebeles. Accordingly, out of the 21 Kebeles found under the study area, six of them (Itang Town, Birhan Selam, Puldang, Ajuw, Akura and Awngi) are situated within very high flood zone. Watigachi, Pilwal, Beljakok, Dorong, Aleha, Adima, Etange Ker, Achuwa, Pukumu, Ebago are the ten kebeles situated within the high flood hazard zone. War, Badel, Adong and Aliya are rural kebeles that fall within the medium flood hazard zone, whereas Wanke, the less affected kebele is found within the low hazard zone. This has similarity with an information obtained from Itang Woreda officials during the field visit, except for their classification as high and medium flood vulnerable kebeles. The following (Fig4.8) elaborate the location of Itang Kebeles in flood hazard zones.

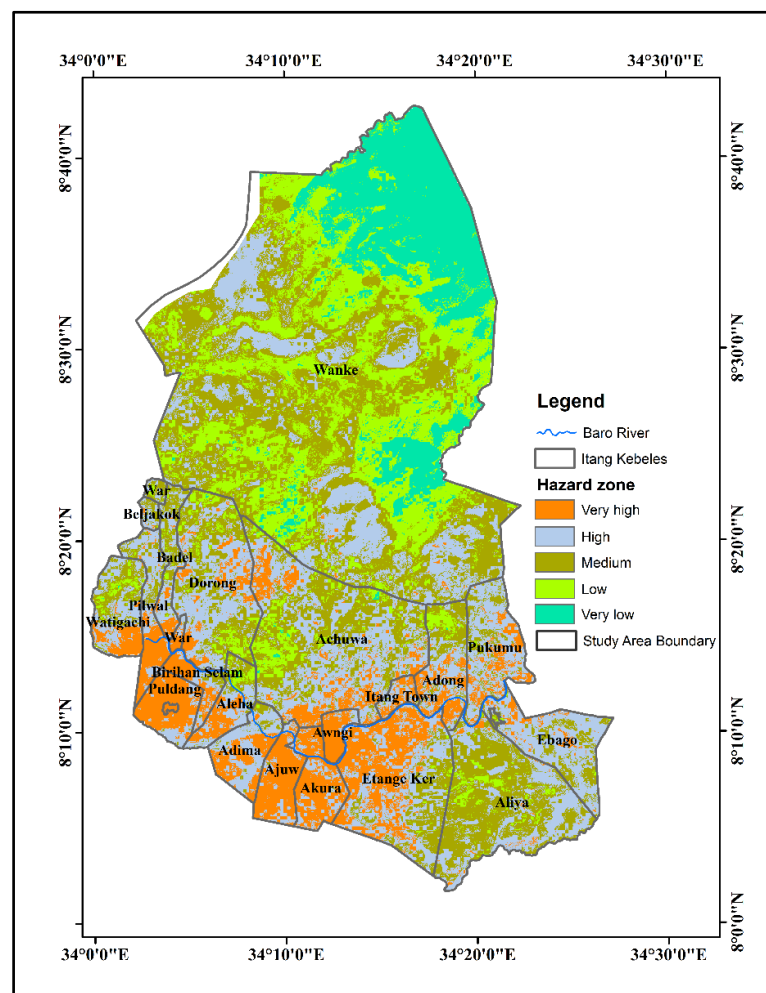


Figure 4.8: Flood hazard map

At last the prepared land-use/land-cover map was joined with flood hazard zone to see how much they are vulnerable to flood. Land-use/ land-cover classes and their areal distribution in hazard zone is presented as follows.

Cropland: Majority of the total cropland (351.53 km²) is located in high flood hazard zone. This is about 33.15% of the total agricultural land of Itang, followed by 321 km² (30.27%) of the total agricultural land which is located in medium hazard zone. Then, 168 km² (15.84%) is located in low hazards zone, whereas 155.8 km² (64.12%) and 64.12 km² (60.5%) area of cropland is found in low and very low hazard zones, respectively.

Grassland: From the total area covered by grassland/bare soil, 21.82 km² (36.18%) is found in medium hazard zone, 15.99 (26.52%) is high, 14.7 (24.38%) is low, 3.91 (6.48%) is very low and 3.88 km² (6.44%) in very high hazard zone.

High Forest: From area of land covered by high forest, 9.19 km² (25.95%) is found in medium flood hazard zone, whereas 8.82 km² (24.95%) is high, 7.96 km² (22.48%) is very low, 5.5 km² (15.53%) is low and 3.94 km² (11.14%) is very high hazard zones, respectively.

Settlement: Areas covered by settlement and respective hazard zone they are found in shows that 5.92 km² (49.17%) area is located is high, 3.5 km² (29.05%) is medium, 2.34 km² (19.44%) is very high, 0.25 km² (2.06%) is low and 0.03 km² (0.28%) is in very low hazard zones.

Shrub and Bushland: Majority of the total land covered by shrub and bush class (30.88 km²) or 31.67% is located in very low hazard zone, whereas 26.42 km² (27.1%), 23.35 km² (23.94%), 15.67 km² (16.07%) and 1.19 km² (1.22%) areas covered by this class are found is medium, low, high and very high hazard zones, respectively.

Water Body: It covers 6.88 km² of land or about 47.82% of land area covered by water bodies are located in high flood hazard zone and 2.31 km² (16.06%) is located in medium hazard zone. On the other hand areas found in very high, low and very low hazard zones are 2.31km² (16.06%), 1.46 km² (10.15%), and 0.15 km² (1.04%), respectively.

Wetland: Wetland is the land-use/land-cover class which is highly prone to flood in Itang. It is found along river banks and to the western corner of the study area. From the total area covered by wetlands, 44.69 km² or about 54.03% is located in the very high flood hazard zone. Followed by area of land found in the high hazard zone, i.e. 28.22 km² (34.12%) of area. Then comes, 2.6km² (3.15%) of wetland which is located in the medium hazard zone. Wetland area covered by 2.6 km² (3.15%) and 1.01 km² (1.23%) in Itang are located in the low and very low hazard zones.

Woodland: The distribution of areas covered by woodland, the second dominant land-cover class found in the study area is presented as follows. 244.92 km² (31.3%) is medium, 180.67 km² (23.09%) is low, 162.96 km² (2082%) is high, 136.39 km² (17.43%) is very low and 57.6 km² (7.36%) is very high

CHAPTER FIVE

5. DISCUSSION

Flood hazard is the damage from flooding to development and people, and effects of floodwaters to personal safety, infrastructure and agricultural lands (Daffi *et al.*, (2014). Studies related to flood hazard assessment can have contribution in giving different flood related information for the people. Necessity of preparing flood maps for civil protection or planning purposes has also become widely understood (Pagliara, 2006). Itang is one of the flood prone locations in Ethiopia where flood hazard assessment and mapping was carried out and remote sensing and GIS methods are used as tools to do so. Different processes and data analysis techniques were applied to reach the final objective of this study. Flood triggering factors like slope, elevation, rainfall data, discharge data, soil type data and land-use and land-cover data are evaluated and given weight through adopted techniques of AHP. Consistency of the weight given for each of the criteria used was also checked through consistency ratio before applying MCE technique which is used for the preparation of the final flood hazard map. It is actually time consuming and costly if it was thought to construct flood control facilities to lower the damage from floods. However information related to flood hazard areas can easily reach the local people through flood hazard maps (Kikuchi, 2003). This can aid the people in giving awareness about the vulnerable area they are living in.

Lower areas around rivers part can be divided into series of hazard zones based on their level of flooding (Bell, 1999). With this study Itang Woreda, which is found in different levels flood hazard was classified into very high, high, medium, low and very low hazard zones. From the prepared flood hazard map, almost all the areas found along Baro River and mainly at the downstream of the River are more exposed to flooding. These areas are considered as a very high and high flood hazard corresponding mostly to the western part of the study area and following Baro River. This can be due to water logging depressions, land use changes and the flat slope of these locations. The nature and types of vegetation and soils that covered this area has also contributions to flooding. The terrain of these areas are generally flat when compared to other parts of the Woreda. There is also very high to high drainage density in this location. Areal wise, the very high and high flood hazard zones together cover about 867.8 km² (40.5%) of Itang. Large part of the study area (636.6km²) or about 29.7% are situated in the moderate flood hazard zone. Areas located within moderate flood hazard zone are somehow far from Baro River, when compared to high and very high flood hazard zones. Large part of War, Badel, Adong and Aliya kebeles are found in this zone.

Wanke Kebele, the largest Kebele in Itang is area of low flood hazard. It is found to the northern part of the study area. The northern most part of Wanke has high vegetation cover and there is low influence of inhabitants due to accessibility problem. Elevation is higher in this location than other parts of Itang with steep slope.

During the field data collection, especially for the areas close to Itang Town and accessible surrounding rural Kebeles, the situation of people along Baro River is observed. They live along the river carrying out different economic activities. Agricultural activity and fishing is more practiced in these areas, which is then affected in the event of flooding. Due to the disconnection of transportation, different practices like commercial activities also get weakened.

Flooding has a long history in Itang and Gambella in general (Alemseged Tamiru, Kusters and Negash Wagesho, 2013). Historical record indicate that flooding has increased over years, becoming a common phenomenon in the region and high rainfall from June-September and sometimes to October is the major flood causing factor. According to information from DPP of Gambella, an estimated 40,000 people have been affected by floods in eleven chronically flood prone woredas of the region: Gog, Jor, Lare, Itang, Wanthoa, Akobo, Jikaw, Makuey, Dima, Abobo, Gambella and Gambella town in the year 2017. However information obtained from the local people and different reports indicate that there is no enough disaster preparedness and prevention strategies in the woreda. On the other hand due the level of economy of the country in general, structural measures were also not taken by the regional government. (Samson Wakuma, 2008). Relocation method is taken as a common solution applied during the flooding event. Even information from the local people show that there are cases in which people are accommodated in schools, churches, and others migrate to the highway/ road at the time of flooding. However additional more strategies should be applied to cope up with the flooding situation of the area.

The warm climatic condition of Gambella region by itself invite the people of the area to settle close to rivers seeking for water. However, this settlement of the local people is not planned-one and happens without considering the future hazard that might happen to them. Therefore, studies should be made on the drainage system and even land-use plan of the area on how to mitigate or prevent flood problem in the area. Adjei-darko, (2017) suggest that planning on integrated drainage master plan considering existing built up areas, areas currently under development and future development areas will benefit in such occasions. With regards to preparedness, anticipated flooding events need to be appropriately estimated based on satellite

imagery, updated rainfall intensity and duration data. Therefore, it would be better if there is an integrated design for the land resource management especially for such flood hazard areas. Woreda officials should also strengthen the already formed flood committee in informing and teaching residents.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Flood hazard mapping is an essential component for relevant land use planning in flood plain areas and it aids planners (urban or rural) and administrators to prioritize their mitigation or relief response.” A flood plain management plan involves the determination of such zones.” (Bell, 1999). By this thesis it was attempted to delineate or map the flood prone areas of Itang and identify more vulnerable part of the study area. The achievement of this objective was made through the integration of remote sensing and GIS techniques. According to Aggarwal, Thakhur and Dadhwal (2009) Satellite Remote Sensing and GIS techniques can serve us as a powerful tool to deal with various aspects of flood management in prevention, preparedness and relief management of flood disaster. Multi criteria method was applied in combining the decision criteria used in the study, i.e. elevation, slope, rainfall, drainage density, land cover and soil type. Based on the methodologies applied for the achievement of the study, majority of the area along Baro River are likely to experience high level of flooding. However the whole area of Itang Woreda is found in flood hazard of different levels, i.e. from very high to very low level. About 278 km² (12.7%) out of the total land area is found in the very high flood hazard zone. These areas have flat slopes and relatively low elevations. 244 km² (11.4%) fall in the very low hazard zone.

6.2. Recommendations

The methodologies presented in the thesis are applicable to other flood prone areas. However to obtain increased accuracy of the results, the researcher recommends the use of high resolution DEM data and other satellite imageries.

The use of SAR data in the flood extent mapping and analysis, especially for the immediate study after flooding days will be expected to improve results (Adjei-darko, 2017). Therefore it is recommended to use SAR data, especially to help the real time mapping of flood hazard in terms its magnitude and extent. The use of high resolution real time satellite imageries along with SAR data will also be much effective in the flood hazard assessment and analysis.

The resulting flood hazard map from the analysis made through remote sensing and GIS techniques along with the MCA can be used as a guide for decision makers in the area of land use planning and flood risk management. As this investigation provides information on flood hazard zones at the woreda level, decision makers to act upon the current land use policy for reducing vulnerability to flood disaster in the region generally and Itang woreda, specifically could be benefited from the map.

Thus the responsible bodies of the woreda as well as the Region should incorporate the flood hazard assessment studies in their development strategies.

It is obvious that well studied land use planning can play very important role in reducing or mitigating disaster caused by flooding.

Therefore, it is recommended to adopt an appropriate land-use planning in flood prone area incorporating professionals, woreda officials and local residents.

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Annexes

Annex 1: Format for thesis originality test report

**Addis Ababa University
School of Earth Sciences**

Name of Student:	Dame Tadesse
Id. No:	GSR/1786/09
Stream:	Remote Sensing and Geo-informatics
Thesis title:	Application of Remote Sensing and GIS in Flood Hazard Assessment and Mapping in Itang Woreda of Gambella Region, Ethiopia
Online site used for originality test	https://www.paperrater.com/plagiarism_checker

Particulars	Test 1		Test 2		Test III		Test IV		Test V		Average		Remark
	Org. (%)	Pl. (%)	Org. (%)	Plg. (%)	Org. (%)	Plg. (%)	Org. (%)	Plg. (%)	Org. (%)	Plg. (%)	Org. (%)	Plg. (%)	
Abstract	100	0	100	0	100	0	100	0	100	0	100	0	
Introductory	100		100	0	100	0	100	0	100	0	100	0	
Chapters	100		100	0	100	0	100	0	100	0	100	0	
Literature	87	13	89	11	97	3	100	0	100	0	94.5	5.5	
Review	100	0	100	0	100	0	100	0	100	0	100	0	
Methodology	100	0	100	0	100	0	100	0	100	0	100	0	
Result and Discussion	100	0	100	0	100	0	100	0	100	0	100	0	
Conclusion	100	0	100	0	100	0	100	0	100	0	100	0	
Overall	97.83	2.16	98.16	1.83	99.5	0.5	100	0	100	0	99.098	0.89	
Thesis													

Key	
Orig. (%):	Originality (%)
Plgr. (%):	Plagiarism (%)

	Name	Signature
Student		
Advisor(1)		
Advisor(2)		

Annex 2: Accuracy assessment of the land-use/land cover of Itang

ACCURACY TOTALS						
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	
Unclassified	0	0	0	---	---	
Wetland	33	29	29	87.88%	100.00%	
	0	0	0	---	---	
Grassland	5	1	1	20.00%	100.00%	
Shrub and Bushl	13	19	13	100.00%	68.42%	
High Forest	10	10	10	100.00%	100.00%	
Bare Soil	0	0	0	---	---	
Settlement	2	0	0	---	---	
Water Body	1	0	0	---	---	
Woodland	94	83	82	87.23%	98.80%	
Cropland	98	114	97	98.98%	85.09%	
Totals	256	256	232			
Overall Classification Accuracy =		90.63%				
----- End of Accuracy Totals -----						
KAPPA (K [^]) STATISTICS						
Overall Kappa Statistics =		0.8642				

Annex 3: Sample of some land-use/land-cover pictures



Settlement



Wetland



Shrub and bush land



Grassland

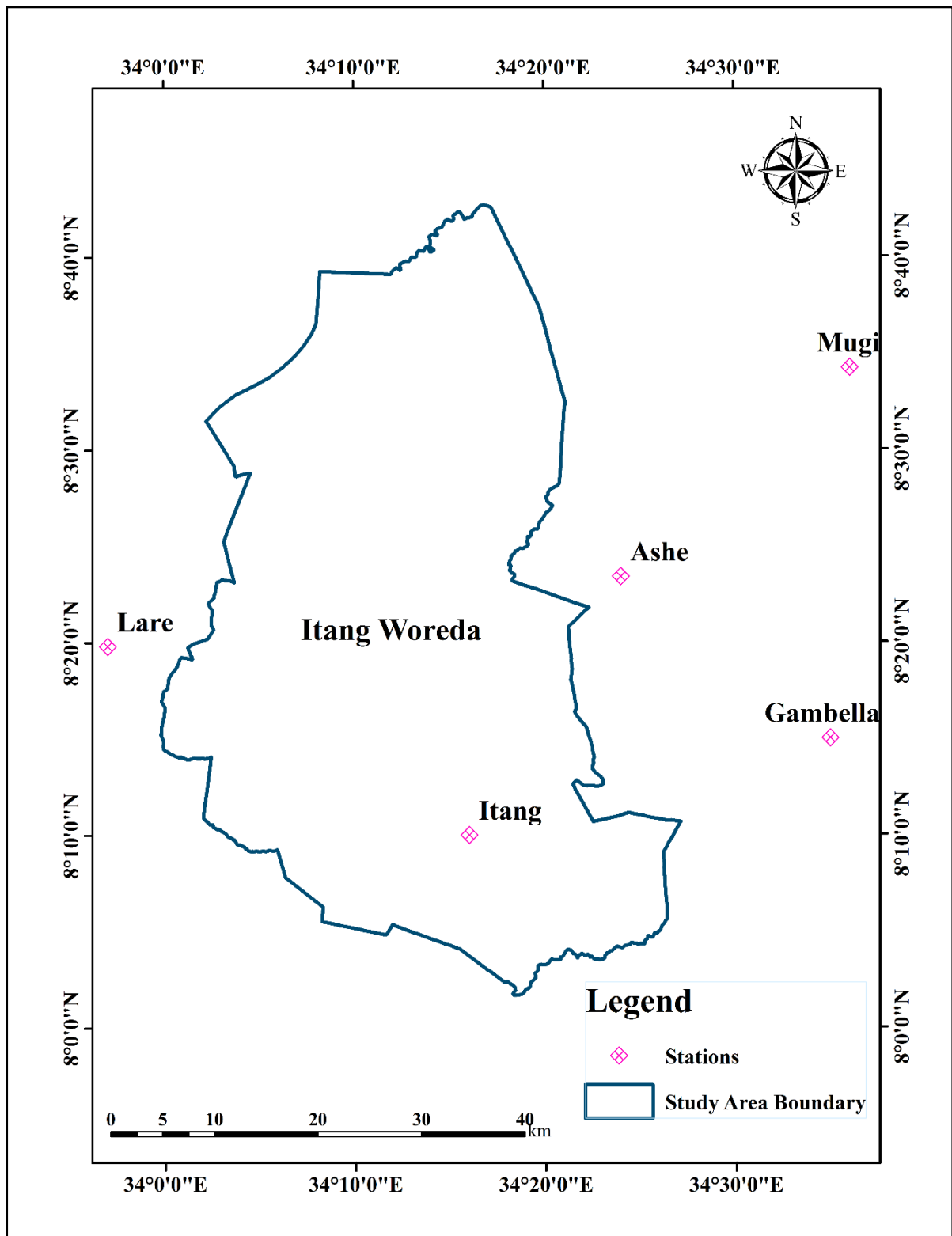


Cropland



Woodland

Annex 4: Location of meteorological stations



Declaration of originality

I, undersigned, declare that this thesis entitled “*Application of Remote Sensing and GIS in Flood Hazard Assessment and Mapping in Itang Woreda of Gambella, Ethiopia*” is my original work and has not been presented for a degree in any other university and that all sources of materials used for this thesis have been properly acknowledged.

Dame Tadesse Tola

Signature _____

Date _____

Addis Ababa University

Addis Ababa

May, 2017

This is certified that the thesis entitled “*Application of Remote Sensing and GIS in Flood Hazard Assessment and Mapping in Itang Woreda of Gambella, Ethiopia*” is original work of Mr. Dame Tadesse Tola for the partial fulfillment of the Degree of Masters of science in Remote Sensing and Geo-informatics from Addis Ababa University under our guidance and supervision.

This is

Dr.K.V.Suryabhagavan

Dr. Dessie Nedaw

Signature _____

Signature _____

Date _____

Date _____

School of earth science

Addis Ababa University