ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

APPLICATION OF GIS AND REMOTE SENSING FOR FLOOD HAZARD AND RISK ANALYSIS: THE CASE OF BOYO CATCHMENT.

Destaye Gobena

June, 2009

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

APPLICATION OF GIS AND REMOTE SENSING FOR FLOOD HAZARD AND RISK ANALYSIS: THE CASE OF BOYO CATCHMENT.

Destaye Gobena

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in the Partial Fulfillment of the Requirements for the Degree of Masters of Science in GIS and Remote Sensing

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

APPLICATION OF GIS AND REMOTE SENSING FOR FLOOD HAZARD AND RISK ANALYSIS: THE CASE OF BOYO CATCHMENT.

Destaye Gobena

APPROVED BY EXAMINING BOARD:	SIGNATURE
Balemwal Atnafu (Ph.D.) Chairman, Department Graduate Committee	______________________________
K.V. Suryabhagavan (Ph.D.) Advisor	______________________________
Mekuriya Argaw (Ph.D.) Examiner	______________________________
Balemwal Atnafu (Ph.D.) Examiner	______________________________

Acknowledgement

The achievement of this paper has come through the overwhelming help of many people. I wish to express my sincere gratitude to all those who offered their kind corporation and guidance throughout my project period.

First and for most, I would like to thank Jesus for his provisions, protections and support in my entire life.

I would like to convey my sincere gratitude to my advisor Dr. K.V. Suryabhagavan for his guidance and constant encouragement.

My deeper gratitude goes to my advisor, Prof. M. Balkrishnan who patiently corrected the manuscript and provided me valuable comments.

I remain indebted to the Addis Ababa university community in general and the Department of Earth Sciences staff in particular for their cooperation during my stay in this campus. Particular thanks go to Dr. Dagnachew Legesse, Dr. Tenalem Ayenew and Dr. Mohammed Umer.

I also thank my family especially my sister, Selam Gobena for supporting me without whom this work would not have been completed. I am highly indebted to my mother, W/ro Meseret Dejene for her blessings and encouragment.

My thanks are also extended to my beloved friend Tsegaye Abera for his invaluable coorporation, encouragment and support during the courses without whom this work would not have been completed.

Least but not last, I would like to convey special thanks to my friends Sintayehu, Emun, Mesi Azeb, Mery and all GIS department students for sharing unforgettable time during my stay in campus.

Table of Contents

List of Figures

List of Tables

List of Appendixes

List of Acronyms

CSA: Central Statistical Authority

DEM: Digital Elevation Model

ERDAS: Earth Resources Data Analysis System

ETM: Enhanced Thematic Mapper

FAO: Food and Agriculture Organization of the United Nations

GCP: Ground Control Points

GIS: Geographic Information System

GPS: Global Positioning System

Ha. : Hectare

IDW: Inverse Distance Weight

m.a.s.l: meters above sea level

MCE: Multi Criteria Evaluation

MER: Main Ethiopian Rift

MSS: Multi Spectral Scanner

PA: Peasant Associations

SNNPR: Southern Nations Nationalities and Peoples Region

SWARDO: Shashogo Woreda Agriculture and Rural development Office

TM: Thematic Mapper

Abstract

Flood is a natural phenomenon that will remain a major hazard as long as people live and work in flood prone areas. It occurs when the volume of water in a river or stream exceeds the capacity of the channel. It also takes place along lake when higher than normal water levels inundate low-lying areas. The present study was carried out to identify and delineate flood hazard and risk zones in the study area. In order to do this, it was found important to understand the catchment characteristics, and hence flood hazard assessment was done to the whole Lake Boyo catchment area. An integrated Remote Sensing and GIS approach was found to be very helpful to delineate flood hazard and risk zones in the study area. Factors that were found to be significant in triggering flood hazard in the study area in decreasing order of importance were: drainage, elevation, geomorphology, land use land cover, rainfall and slop. These factors were weighted in hierarchical order using the MCE approach to produce flood hazard map of the catchment. From the flood hazard map, the areas of flood hazard levels were calculated. Since all the areas of the very high and more than 90% of high flood hazard levels are found in Shashogo Woreda, flood risk analysis was done for the Woreda using the two elements at risk, viz., land use and population density of the Woreda. Major findings of the study revealed that, PAs in the down stream part of the catchment: Doesha, Mololicho, Shemo, Biramora, Musagesa, Urbecha and Kemetcho Borara PAs were subjected to very high flood hazard and risk and the different land uses in these areas are within high to very high flood hazard and flood risk level.

1 INTRODUCTION

1.1 Background

Flood is a temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff. Flood phenomenon is considered as one of the worst hazards in terms of magnitude, occurrence, geographical spread, loss of life and property, displacement of people and socio-economic activities (Myers and White*,* 1993). Flood can be defined as any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream. People may be washed away in a short span of time, and properties may be heavily damaged by flood. When a bank is overtopped, water spreads over the flood plains and generally becomes a hazard. Flooding is the most common environmental hazard due to the widespread geographical distribution of river valleys and coastal areas. By attraction of human beings to such areas for settlements and farming make it as a fatal obstacle to social progress both in developing and developed countries (Jayseleen, 2003).

Flood has different characteristics at different climate zones. A flood in a humid tropical region displays characteristics somewhat different from those in semiarid or temperate zones. Although snowmelt floods are common in the temperate parts of Europe and the northern part of North America, rainfall is the main cause of intensive floods in the south and south east Asia (Sanyal and Lu, 2004). In Ethiopia, flood is common during the long rainy season between June and September. During this period, the runoff of the rivers raises leading to overflow or burst of the river banks and inundate downstream plain lands.
Remote sensing technology along with GIS has become the major tool for flood monitoring in the recent years. The central focus in this field revolves around delineation of flood zones and preparation of flood hazard and flood risk maps for vulnerable areas.

This study has been conducted in Boyo Lake sub catchment of Upper Bilate Basin of Ethiopia. The study area is chosen for the fact that it is severely affected by the flood hazard. So it needs the attention of researchers, government officials, NGOs and other organizations to predict and to implement mitigation measures.

1.2 Problem Statement

Due to the rapid increase of population in Lake Boyo catchment area, people are exploiting natural vegetation and extending cultivation, which have led to land degradation and deterioration of the ecosystem. As a result, the area has become susceptible to erosion and flood events. Boyo Lake catchment has diverse topography ranging from very flat to dissected plateaus. Such relief types are fairly distributed, while the very flat part of the entire area in Shashogo Woreda takes about 85 % of all flat areas in the entire catchment. Such a topographic setup is believed to have been generating heavy flooding at the low and flat areas thereby widening the seasonal size of Boyo Lake in the heart of the Shashogo Woreda. Most of the tributaries of Lake Boyo initiate their courses from relatively higher elevations and the immediate catchment areas are poorly covered exposing the flat areas to heavy flood during the rainy season.

In practice, flooding occurs when the volume of water in a river or stream exceeds the capacity of the channel. It also takes place along the lake when higher than normal water levels inundate low-lying areas. The very flat lands of the area, especially flood plains in Shashogo Woreda are susceptible to flooding in every year during the rainy season. Flood waters remain stagnant for about one to two weeks over the flood plain of the Woreda. As a result, people have to evacuate. Further, crops in large extent of areas are submerged leading to human socio-economic sufferings. So, it is important to consider major factors that contributed more in the past flood hazard calamities. It has of paramount importance to take notice of these factors to arrive at wise and comprehensive solution towards mitigating the flood hazard.

Hence, GIS is the best assemblage of computer equipment and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis and display of the factors affecting flood hazard. One of the most common approaches in the flood risk and flood hazard study in other countries is using multi-criteria analysis approach in Geographic Information System (GIS).

1.3 Research Objectives

1.3.1 General Objectives

The purpose of this study was

- To assess flood hazard and risk in Boyo catchment using Multi-Criteria evaluation in GIS environment.

1.3.2 Specific Objectives

1. To construct the data base for different data layers used as the input for flood hazard and risk assessment of the study area;
2. To assess LU/LC change of the study area;
3. To recommend prevention strategies and techniques for flood events.

2 Literature Review

2.1.1 Flood risk and hazard management

Flood risk management in a narrow sense is the process of managing an existing flood risk situation. In a wider sense, it includes the planning of a system, which will reduce the flood risk. The purpose of these two aspects of flood risk management is to control the flood disasters in the sense of being prepared for a flood and to minimize its impact (Erich, 2002). These include the process of risk analysis, which provides the basis for long term management decisions for the existing flood protection system.

Risk analysis can be defined as "a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences (Granger, 2002). A good risk analysis process yields hazard or risk maps, which are drawn by means of Geographical Information Systems (GIS) based on extensive surveys of vulnerability combined with topographic maps. In order to do this, the hazards are to be combined with the vulnerability into the risk. The vulnerability of the persons or objects (the 'elements at risk') in an area, which is inundated if a flood of a certain magnitude occurs, is weighted with the frequency of occurrence of that flood (Kowalczak, 1999).

Flood risk can be assessed in quantitative terms as well as being accessible and understandable through qualitative investigation. A discussion of risk can suggest a move into the subjective world of perception, where different people and their belongings experience varying degrees of risk associated with flooding. The risk of flooding is therefore not only associated with the physical nature of the hazard. For example, frequency and magnitude and proximity to the hazard also relates to the ability to manage, adjust and adapt to the event itself. This implies that risk is the conjunction of the natural physical hazard leading to socio-economic vulnerability of the population in the area (Priest, 2003).

2.1.2 Effect of Flood: Global, National and Regional perspective

Flooding is a natural and recurring event for a river or stream. Statistically, streams will equal or exceed the mean annual flood once every 2.33 years (Leopold *et al.,* 1964). Even if it is a short term state and vary considerably in size and duration, a number of people and animals including domestic and wild ones are affected directly and indirectly. Globally, flooding is a leading cause of losses from natural disasters and responsible for a greater number of damages than most other types of elemental threats (Jeyaseelan, 2003). According to Debarati (2006), South-East Asia, which is part of the most flood hit continent in the world topped the list of disaster impacts over the first six months of 2006, with 85% of global deaths from natural disasters over this period. These were a total of 113 floods during this period, globall representing all-time high of 65% of all natural disasters.

According to Wu (1989), flooding is the most common of all environmental hazards. Every year, floods claim over 20,000 lives and adversely affect around 7.5 million people worldwide. The reason lies in the widespread geographical distribution of river floodplains and low lying coasts, together with their long standing attractions for human settlement. Bangladesh is by far the most flood prone country in the world, accounting for nearly three-quarters of the global loss of life from both river and coastal floods. China also suffers badly and some 5 million lost their lives in floods between 1860 and 1960, despite the fact that the flood defiance of cities goes back over 4,000 years.

All recorded flood disaster and associated flood impacts during the periods of 1964 to 1996 by continental area have been assessed. The results showed that flood event and associated impact are higher in Asia (Table 1). South America and Africa can be mentioned next to Asia by their flood events and related impact (OFDA, 1996 as cited in Smith and Ward, 1998).

Table 1. Percentage of all recorded flood disaster and associated flood impacts for different geographical locations.

Area	**Event (%)**	**Killed (%)**	**Affected (%)**	**Homeless (%)**	**Damage (%)**
Africa	16.0	4.5	1.0	5.1	1.9
Asia	41.1	82.2	95.3	85.1	65.6
Central America	7.1	1.7	0.1	0.5	1.3
Caribbean	3.2	1.2	0.3	0.2	0.2
Europe	8.7	2.1	0.6	0.5	20.1
Near East	4.1	1.5	0.2	1.0	0.7
Pacific	1.2	0.1	0.0	0.0	0.2
South America	18.6	6.7	2.5	7.6	10.0
Total	100.0	100.0	100.0	100.0	100.0

2.1.3 Application of Remote Sensing and GIS for Flood Hazard Assessment

Over the past two decades, advances in remote sensing and GIS techniques have provided valuable new data for flood monitoring, flow forecasting, dam control, and river system management. Current remote sensing tools include weather radar, aircraft measurement, the detection of atmospheric electrical disturbances and rain gauges providing reliable and cost-effective field data, allowing for continuous, large area, synoptic coverage of many variables (Jason *et al.,* 2005).

There are two major uses of remote sensing for flood research. These are, 1 as a tool for the delineation of flooded areas (detecting flood boundary river inundation, stage, and discharge); and 2, as a technique for flood hazard and risk mapping. The original uses of satellite remote sensing for monitoring floods and delineating the boundary of inundation used optical remote sensing, specifically data from the Landsat Multi Spectral Scanner (MSS) with 80 m resolution. The earliest applications involved flood-prone US regions, including the Mississippi River basin (Deutsch *et al.,* 1973; Rango and Anderson, 1974). By the early 1980s, the main source of data for flood monitoring and delineation was the Landsat Thematic Mapper (TM) imageries with 30 m resolution. MSS band 7 (0.8-1.1 μm) and Landsat TM NIR (near infra-red) band 4 proved valuable for distinguishing water (or moist soil) from dry land surface due to the strong absorption of water in the near infra-red range of the spectrum (Smith, 1997). For use in urban areas (industrial and commercial zones with asphalt), a combination of Landsat TM band 7 (2.08-2.35 μm) and band 4 was shown to successfully delineate inundated regions (Wang *et al.,* 2002).

At a larger scale, these medium-resolution imageries are often supplemented by more coarse resolution imageries such as National Oceanographic and Atmospheric Administration's Advanced Very High Resolution Radiometer (NOAA AVHRR). These imageries enable the monitoring of flood progress in near real time (high temporal resolution). Limitations of NOAA AVHRR imageries include a coarse resolution excluding local flood analysis and sensitivity to satellite viewing angle and weather conditions (Barton and Bathols, 1989; Wang *et al.,* 2002). The development of microwave remote sensing, particularly Synthetic Aperture Radar (SAR) images, permits the monitoring of flood progress during bad weather conditions because the radar can penetrate cloud cover and they have the ability to clearly distinguish between inundated and dry surfaces.

A combination of optical (Landsat TM imageries) and microwave remote sensing has yielded superior results for dealing with challenging flood management problems such as flood mapping in mountainous areas. In mountains, most areas appear dark or shaded, which makes it difficult to identify flooded areas only slopes perpendicular to the radar beam appear bright. However, using data obtained from different sensors remains challenging, often requiring iterative experiments and land cover maps to obtain better results. For example, land cover maps can minimize the risk of including permanent water bodies as flooded regions (Tholey *et al.,* 1997).

Remotely sensed and hydrologic data are often used together with GIS to determine flood hazard potential and flood risk maps. For example, NOAA AVHRR data superimposed over a digital elevation map can facilitate the assessment of flood depth by using the tonal difference of the flood water and supervised classification (to subdivide the flood affected area into different flood depth zones). Land development priority maps (a function of flood hazard and population) are often created with remote sensing data and GIS for flood counter-measures (Islam and Sadu, 2002). There are a number of advantages of remote sensing techniques over ground-based methods. In many developing countries affected by floods (Bangladesh and Mozambique) the density of gauging stations is quite low, leading to a shortage of ground data for flood risk assessment models (Sanyal and Lu, 2004). Further, ground stations may fail to accurately collect data in an extreme flood event. Multi-date satellite imageries can be used to monitor how human activities and natural phenomena affect land cover over time to reconstruct the history of the previous extreme hydrologic events.

The increasing availability of appropriate spatial data and the improved performance of computer technology have led to a growth in the use and application of GIS technology for analysing and visualizing spatial flood information, for empowering stakeholders, and for facilitating flood simulation, evacuation, and damage estimation. A temporal GIS system captures spatial, temporal and attribute data. Hence, it allows for the modelling of time-dependent flood processes and human activities, as well as the consideration of cross-correlations and dependencies in the composite spatio-temporal domain. Information about the timing and height of a flood peak, for instance, can greatly facilitate flood management decisions (Ott and Swiaczny, 2001).

There are three broad approaches for integrating GIS and flood modelling (Clark, 1998): pre-processing data into a suitable format; direct GIS support for hydrologic models; and post-processing data. Examples of data processing in the pre-modelling phase include automated floodplain delineation from digital terrain models, raster based models for flood inundation simulation and the parameterization of flood models (Zerger and Wealands, 2004). The second approach involves direct GIS support which include analysis, calibration and other tasks for flood modelling. The third approach for linking GIS and flood modelling involves post-processing data. These activities are becoming increasingly ubiquitous and typically include creating flood risk maps, performing cost-benefit analyses and creating a flood decision support framework (Vermieran and Watson, 2001).

2.1.4 A Decision Support System for Flood Disaster Management

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different classifications. Broadly speaking, a Decision Support System (DSS) is simply a computer programme that help one to make a decision. DSS provides a means for decision-makers to make decisions on the basis of more complete information and analysis. Inaccessibility of required geographic data and difficulties in synthesizing various recommendations are primary obstacles to issues related to problem solving. Studies have shown that the quality of decisions or the ability to produce meaningful solutions can be improved if these obstacles are lessened or removed through an integrated systems approach, such as DSS and a spatial decision support system (SDSS).

SDSS refers to those support systems that combine the use of GIS technology with software packages for selection of alternatives of location for different activities. In addition, multicriteria decision making (MCDM) and a wide range of related methodologies offer a variety of techniques and practices to uncover and integrate decision makers' preferences in order to solve "real-world" GIS-based planning and management problems. However, because of conceptual difficulties (i.e., dynamic preference structures and large decision alternative and evaluation criteria sets) involved in formulating and solving spatial decision problems, researchers have developed multicriteria-spatial decision support systems (MC-SDSS). Spatial multicriteria decision problems typically involve a set of geographically-defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Malczewski, 1999).

Natural variations in the global climate are governed by complex interactions among the atmosphere, oceans, and land cover. Modern climate models suggest that these variations will continue, but with larger magnitudes and greater variability due to human influences. This is expected to increase the risk of flood disaster events. To improve flood risk management, a flood decision support system is proposed that capitalizes on the latest advances in remote sensing, Geographic Information Systems (GIS), hydrologic models, numerical weather prediction, information technology and decision theory (Jason *et al.,* 2005). A flood decision support system consists of three main components: a flood database, flood modeling functions; and a graphical user interface (Consortium of Universities for the Advancement of Hydrologic Science, 2004 as cited by Jason *et al.,* 2005).

The first DSS component, flood database, includes meteorological, hydro-geologic, administrative, and population data to form a comprehensive depiction of a hydrologic region.

The second component of a flood DSS is a suite of flood modelling functions, modified to the client's needs. Flood models typically involve rainfall-run-off simulations, discharge levels, data exploration and assessment. In addition, information on flood magnitudes and their frequencies is needed for the design of hydrologic structures, floodplain zoning and the economic evaluation of flood management systems (Kite, 1988; Stedinger *et al.*, 1993).

Flood multiple-criteria decision-making (MCDM) models constitute a collection of methodologies to compare, select or rank flood alternatives that involve appropriate attributes. MCDM models are well suited to addressing flood management problems because decision makers must typically deal with large-scale and complex challenges. Specifically, MCDM models can identify alternatives that are dominated by at least one other alternative. Finally, MCDM models are helpful for exploring challenging and value-laden flood management trade-offs (Simonovic and Ahmad, 2005 as cited by Jason *et al.,* 2005).

The third component of a flood DSS is a human computer interface for interactive flood queries, reporting and display. Its display capabilities include spatial data handling, the editing of flood inundation maps, sensitivity analyses of flood model parameters at a variety of spatio-temporal scales.

2.1.5 Flood problem in Ethiopia

The rainy season in the country is concentrated in the three months between June and September when about 80% of the rainfall is received. Torrential down pours are common in most parts of the country during this period. As the topography of the country is rather rugged with distinctly defined watercourses, large scale flooding is rare and limited to the lowland areas where major rivers cross to neighbouring countries. However, intense rainfall in the highlands could cause flooding of settlements close to any stretch of river course. A major river basin that has serious flood problems is the Awash River basin located in the Rift Valley. Irrigation development in the river basin is quite advanced and is located in the flood plains on either side of the Awash River. High economic damage occurs during flooding along this river basin. Therefore, flood protection practices and river training are limited to this river basin. It is estimated that in the Awash Valley almost all of the areas delineated for irrigation development are subject to flood. An area in the order of 200,000-250,000 ha is subject to be flooded during high flows of the Awash River.
The other rivers where significant floods occur are Wabi-Shebelle River in south-eastern Ethiopia near the Somali border and Baro-Akobo/Sobat River in western Ethiopia near the Sudanese border. In the Baro-Akobo Plain (known as Gambella Plain), an area of about 300,000-350,000 ha is prone to flooding during the wet season and in the Wabi-Shebelle Basin not more 1han 100,000 ha may be flooded (Kefyalew, 2003). The areas commonly flooded annually in the country are: Baro-Akobo Basin, Awash River Basin which includes lower Awash, Middel Awash and Upper Awash, Wabishebele and Ribb and Gumara area.
Other localized flooding risk areas include Lake Awassa, Lake Beseka, Lake Tana, Addis Ababa and Dire Dawa.

Lake Awassa

The level of Lake Awassa has been gradually increasing causing damage to infrastructure in the town of Awassa. Attempts to contain the lake with the construction of a dike between the lake and the town have so far not brought about tangible results. Detailed technical and environmental studies to fully understand the nature of the continued growth of the lake have been carried out and proposals of effective measures to be taken to protect Awassa town from further flooding are being prepared by a consultant.

Lake Beseka

Lake Besseka which is located near Metahara town has been growing in size and causing problems on the Addis Ababa-Djibouti railroad and the Assab/Djibouti highway. It has also inundated some area in the sugarcane plantation and grazing areas in the neighborhood. The water of the Lake is highly saline. A scheme aimed at controlling the rising level of the lake and to reclaim the inundated farmland and grazing area is being implemented.

Addis Ababa

Metropolitan Addis Ababa, sprawling at the foothill of Entoto mountain range is traversed by several small streams originating from the mountain range. Torrential rains which are common during the rainy season in the city, cause sudden rise in flow of these streams which bring about flood damages to settlements along the bank of these streams. Such damages have often caused losses of property. Recently a study of flood risks and measures of intervention along these streams has been carried out by the municipality and an implementation program over a 15-year period to contain flood waters within their banks have been drawn out (Kefyalew, 2003).

Dire Dawa

This town lies at the foothills of a mountain range. There is a large waterway often dry with no water, which divides the town into two. This waterway during the rainy season suddenly grows to a large river threatening the loss of property and human life. The damage is reduced substantially with the construction of a bridge and enforcement of zoning regulations.

2.1.6 Previous Work

Different researches have undertaken dealing with the application of Remote Sensing, GIS and MCDE in flood hazard and risk assessment. Nawaz (2006) used integrated approach of remote sensing and GIS for flood hazard assessement in the district Muzaffarabead (capital of Azad Kashmir) in Pakistan. The area is situated at the confluence of river Jhelum and Neelum. River Neelum is the main contributor of flood in this area. In order to delineate flood hazard zones, in general, different thematic layers viz., floor of building, age of building, land use, vulnerability map and building material map were developed from topographic sheet, field survey and Muzaffarabead guide map. Then classified hazard zones were developed for the district Muzaffarabead. The study has demonstrated the capabilities of using remote sensing and GIS for detailed mapping of flood hazard zone.

In order to produce flood hazard map of the Kosi River Basin, North Bahir, India, a GIS model was used to integrate various factors such as topographical, land cover, elevation, vegetation, distance to active channel, geomorphic and population related data (Bapalu, 2006). Each factor was divided into sub factors. This study represents some exploratory steps towards developing a new methodology for inexpensive, easily-read, rapidly-accessible charts and maps of flood hazard based on morphological, topographical and demographic data. The study has also focused on the identification of factors controlling flood hazard in the study area. It accomplishes this goal by combining Spatial AHP technique with GIS-based overlay analysis.

3 Materials and Methods

3.1.1 Materials

The data used and their sources in this study are reported below in Table 2.

Table 2. Data and their sources.

No.	Data	Data Type	Scale	Data Source
1	Boundary, road, drainage	Topographic maps	1:50,000	EMA
2	Monthly rainfall	Rainfall record	-	NMA
3	Monthly temperature	Temperature record	-	NMA
4	Land use	Landsat imageries	-Landsat TM (28.5m) -Landsat ETM+ (15m)	A.A.U
5	Population density	Population record of 2007 G.C	-	CSA
6	Boundary of Woreda and PAs	Shapefile	-	CSA

3.1.2 Methods

In order to assess the flood hazard and risk zones of the study area, the following methods was used.

The topographic maps were scanned by A4 size canon scanner. It produced 24 pieces of A4 size topographic sheets. These pieces were imported to Global Mapper software and each piece was georeferenced based on the topographic map projection: UTM zone 37, spheroid Clark 1880 (modified) and datum Adindan. It was again re-projected to UTM zone 37, spheroid and datum WGS 84 in order to work with images that have this map projection. Digitization of terrain features like main road, towns, Meteorologic stations and drainage networks were done on the adjoined topographic sheet. Then the drainage density was done using the spatial analyst of line density tool using ArcGIS 9.2 software.

The SRTM data of the area was patched in order to fill the missing data using 3dem software and exported into ArcGIS 9.2 software; where this vector elevation map was converted into raster grid format to extract elevation information and slop was calculated in percent for overlay analysis. The satellite imageries of Path 169 Row 55 of 1973, 1984, 1995 and 2005 were georeferenced to UTM zone 37, spheroid and datum Adindan. From the georeferenced imageries of the full scene, the area was subsetted and different image enhancement techniques were applied to extract the land cover information for image classification using ERDAS IMAGINE 9.1 software. Moreover, ENVI 4.2 was used to compute change detection analysis on land use land cover map of classified images. On screen digitization was done on the 2005 Landsat imagery to delineate the different geomorphological features in the study area. The land use land cover change of the study area has been assessed using two Landsat imageries of the year 1984 and 2005.

The monthly rainfall data from the five meteorologic stations within and around the catchment were collected from NMA. Flood hazard and risk assessment requires an areal rainfall intensity data, however, NMA provides point rainfall data. In order to convert those point rainfall data to areal rainfall data Inverse Distance Weight (IDW) technique were used in ArcGIS software. IDW interpolation determines cell values using a linearly weighted combination of a set of sample points.

The factor map development was carried out using ArcGIS9.1 software package. The factors that are input to for multi-criteria analysis should be preprocessed in accordance to the criteria set to develop flood hazard analysis. So Eigen vector for the selected factor was computed using Weight module in IDRISI 32 software. The general workflow showing the methodology to delineate flood hazard and flood risk area explained in the Figure 1.

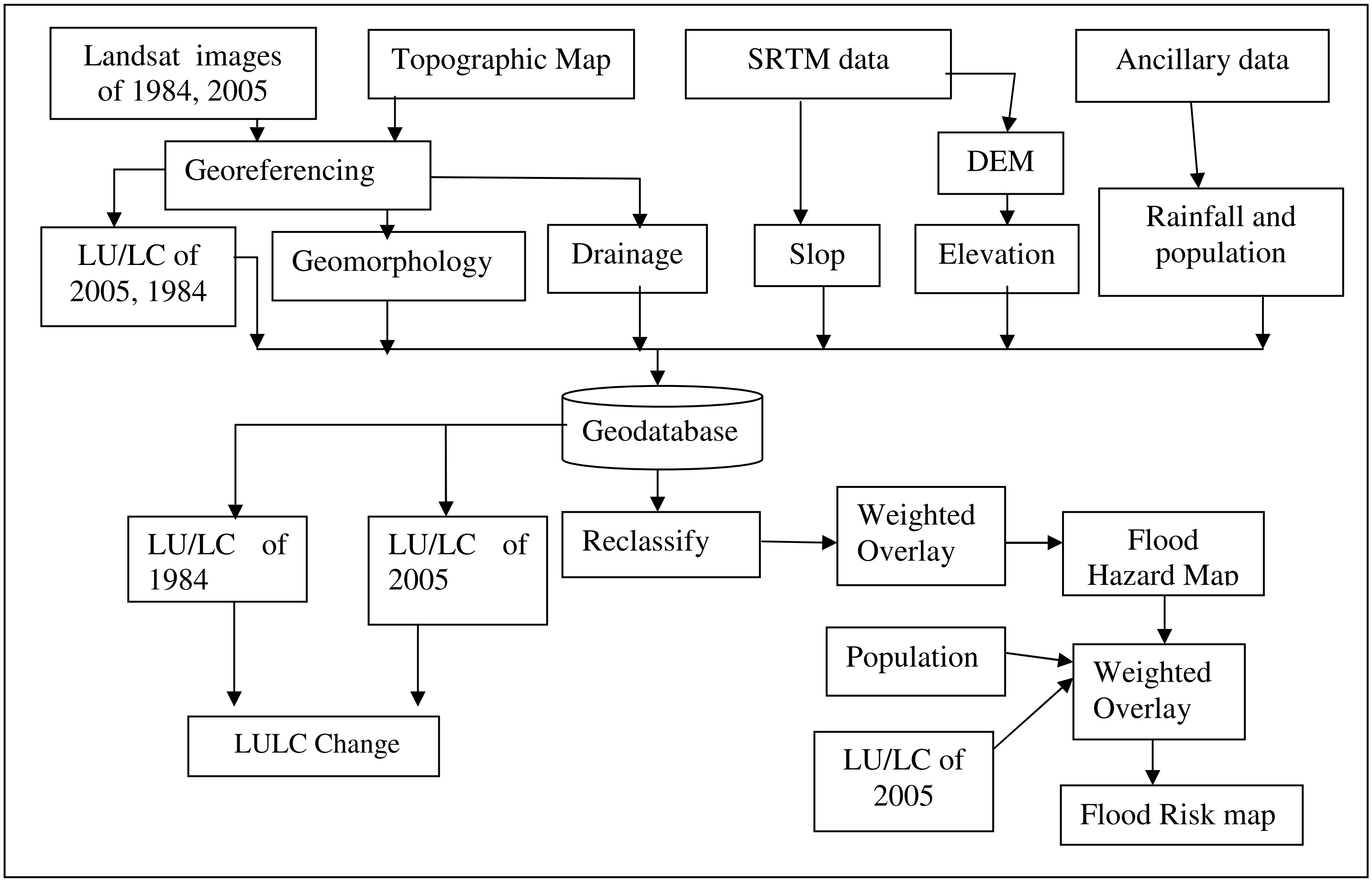


Figure 1. General work flow of the study.

3.2 Study Area Description

3.2.1 Location

The study area is situated in the Upper Bilate basin in Southern Nation and Nationalist People Region (SNNPR). Its absolute location extends south-north from zone 37 UTM grids of 804682 meter N to 859133 meter N, and its east-west extension is from 365454 meter E to 400509 meter E. This area covers about 1143 km^2 and includes parts of three administrative zones, viz., Hadiya, Silte and Kembata-Tembaro. Which includes four Woredas of Hadiya zone (Lemmo, Annalemmo, Misha and Shashogo), three Woredas of Kembata-Tembaro zone (Doyogena, Damboya and Angacha) and one Woreda of Silte zone (Wulbareg).

This area comprises of Lake Boyo, Guder, Metenchose River and other streams. Guder originates from near Hossaena and flows east to reach Lake Boyo while Metenchose originates from north and flows south to reach Lake Boyo. Lake Boyo discharges its water to Bilate River through Fofo stream (Fig 2). Lake Boyo is flooded from July to February reaching its highest elevation of 1891.5m.a.s.l towards the end of August and minimum elevation of 1889.4m.a.s.l in March (WRDA/FAO Report, 1986). Boyo Plain is characterized by active sedimentation and marsh. Bilate River bounds the lake from the north and east and flows towards south after joining with the overflow of the lake. The over flow from Boyo Lake together with Weira River forms Bilate River outside Lake Boyo catchment.

3.3 Geology

3.3.1 Regional Geology

Bilate basin lies within the Main Ethiopian Rift, which forms part of the 5000 km. long down faulted trough. The rift floor and escarpments are highly faulted. The faults in the MER are parallel and sub-parallel to the NE–SW trending rift axis (Woldegebriel *et al*., 1990). The Rift floor is affected by several faults that form smaller horst and graben structures. The NNE-SSW and N-S trending faults are the dominant faults, while the E-W and N-S faults control stream courses in the southern and southwestern part of the catchment.

Except patchy Precambrian rocks, the rift is covered with Cenozoic volcanics and Tertiary and quaternary sediments (Mohr 1967; Woldegebriel *et al*., 1990). The volcanic rocks are dominantly fissural basaltic lava flows, rhyolites and ignimbrites associated with volcano-clastic tuff and ash deposits (Ayenew et *al*., 2008).

Older volcanic units (Pre-Pliocene) outcrop on the rift escarpment or margin and the recent volcanics cover the entire rift (Kazmin *et al*., 1980). The Main Ethiopian Rift Valley (MER) contains abundant acidic lavas and ignimbrites and they are associated with central volcanoes containing wide calderas. The axial rift is covered by Quaternary central volcanic products. On the MER, peralkaline silicic ignimbrites, unwelded pyroclastics and minor lavas related to fissural eruptions of regional extent are the most abundant volcanic rocks.

The general stratigraphy of Bilate Basin which has been investigated by Ethiopian Geological Survey comprises volcanic and sedimentary unites. The stratigraphy summery of the river basin from the oldest to the youngest is as follows;

A. Pre – Rift Basaltic succession with minor silcic members (Jima volcanic – Tertiary volcanic) are well exposed on the plateau and escarpments adjoining the Bilate River Valley which rests unconformable on the Precambrian basement. The basalt flows form an unbroken succession and several hundred meters thick in some places. They are intensely jointed, hydrothermally altered and spheroidally weathered basalts out crop in the western escarpment of Lake Abaya graben. Tertiary volcanic succession has been down faulted into rift floor which in part is covered by rift valley lakes including Abaya and Boyo.
B. Upper - Miocene (9 – 5 my) succession (Nazereth – Series). According to Meyer et al., (1978) cited in Mengesha *et al*., (1996) the name Nazereth Series was given to a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite folws and domes with rare intercalations of basalt flows which occur in the MER, rift margins and adjacent plateaus.This formation includes what was mapped by Di Paola *et al*., (1972) as basalts and ignimbrites of the plateaux Trap Series.The Nazereth Group volcanic products are exposed over the surrounding areas along the rift margins and escarpments. The ignimbrite of the Nazereth series is considered to be products of eruptions mainly from marginal centers in the rift (Morbedelli *et al*., 1973). An age range of 9 – 3 Ma has been given to the Nazereth Series (Mengesha *et al*. 1996).
C. Mursi and Bofa Basalt – Late Pliocene (4 – 1.6 Ma) flood basalt volcanism is widespread in MER rift and other related rifts (Mengesha *et al.* 1996). According to Kazmin *et al*., (1981) cited in Mengesha et al. (1996), the Bofa basalt are well developed in the northern and centeral part of the MER forming a wedge between Nazereth Series and Dino formation and a lower age limit of 3.5 Ma. In the rift floor, the Nazereth Group is overlain by succession of flood basalt of Pliocene age.
D. Dino Formation – in this river basin the Bofa Basalt and Nazereth Series are in most places overlain by green and gray ignimbrites with well developed fiamme and associated

unwelded pyroclastic and waterlain pyroclastic with occasional intercalated lacustrine beds and aphyric basalts. The pyroclastics of the Dino Formation may have sources from axial felsic volcanic eruptions complexes. The felsic lava of the Dino formation are peralkaline in composition and the ignimbrite members are not confined only to the rift floor but extensively developed on the escarpments.

E. Quaternary Ignimbrite – this formation overlay Bofa Basalt of Pliocene age. It comprises of Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The volcanic products of Wonji Group (including those from axial volcanic centres) are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of Pleistocene).

   With the formation of Wonji Fault Belt during the Upper – Miocene – Quaternary times tectonic movement and volcanic activity occurred in the MER, which produced steep – like structures and related volcanic activity, represented mainly by basaltic lava fields together with aligned scoria and spatter cones. The fault zone is frequently marked by central volcanoes, which erupts significant amount of felsic products.

F. Quaternary Pumacious Pyroclastic – They are grey and yellowish coloured, poorly sorted and consist of accidental fragments of rhyolites and basalt. This pumacious pyroclastic belong to the explosive episode of the older rhyolitic volcanic centres.

G. Abaya Rhyolite (Rhyolitic Volcanic Complexes) – The Quaternary central volcanic complexes which are situated along the axial zones of MER (Wonji - Fault Belt) (Mengesha *et al*., 1996).They are strongly banded in situ with alignment of fine vesicles and brittle thinly banded layers of few centimetres. They are exposed on the flanks and caldera rim of Obitchaka and Donga (Simbura) area.

H. Alkaline Olivine Basalt (Tena Bilate) Basalts – Pleistocene to Holocene fissural basaltic volcanism in the MER are mainly concentrated along the WFB. The basalts are clearly controlled by extensional fractures with chains of scoria cones aligned along fractures and generally displaying fresh surfaces (Mengesha *et al*., 1996). The NNE trending fault along the axis of the rift floor has been a conduit for basaltic eruptions with lines of scoria cones making fault traces. They are interstratified with the earlier succession of lake sediments. They are exposed over a broad area between Lake Abaya and Dugna – Fango and all along

Bilate river bed and banks with adjoining rift floor being covered by the overlying intensely denuded lacustrine sediments.

I. Dugna – Fango Rhyolite – These outcrop mainly at the base of Dugna – Fango volcano. Exposures are concentrated along the N – E to S - W trending, intensely tectonized stripe of land in the central part of the Wonji - Fault belt axis upon which the mountain building activities of Dugna – Fango took place.

J. Recent Basalt – The younger episode of basaltic eruption outcrops along an axial zone of more recent volcano – tectonic activity of the Sawla – Dore – Hako and North West Abaya hydrothermal field.

The next sedimentary sequences are:

K. Pleistocene Volcano – Sediments:- they are essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during Pleistocene time (Mohr 1967). They are generally yellowish – grey colored, horizontally bedded and poorly sorted with fragments of rhyolites, obsidian and basalt in a matrix of ash and silty clay.

L. Holocene Lake Beds – they outcropped in localities surrounding Lake Abaya and Boyo. Lithologically they are mainly constituted by poorly compacted, well sorted and friable and fairly reworked yellowish clay and silt material.

M. Recent Alluvial and Fluvial deposits – the lower course of Bilate River covered with fluvial deposits along its gentler slope. There are also lacustrine deltas on the northern part of Lake Abaya which are a few kilometers wide. Colluvial and outwash debris is found widespread in the area particularly along the foothills of the major fault scarps. Recent deposits in the area include soils and alluvial sand deposits. The soils are mainly residual weathering deposits, whose composition is controlled more by the physical condition of formations than by the type of rock form which they were derived. On the older basaltic area dark brown cotton soil is common while the soil outcrop of the ignimbrites is red lateritic.

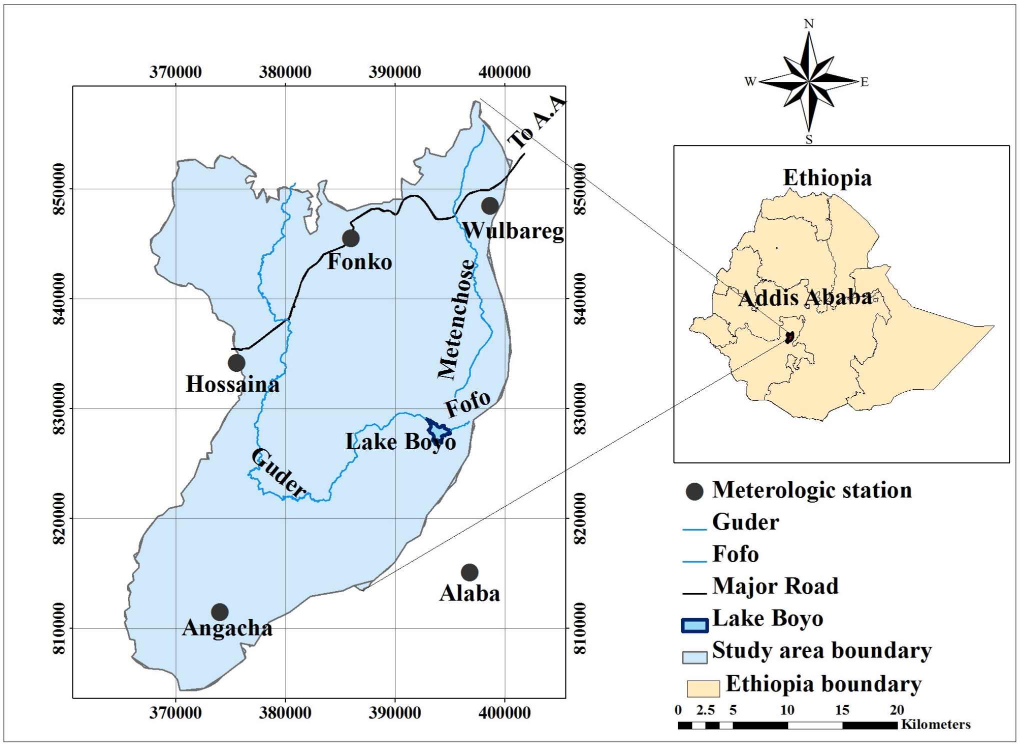


Figure 2. Location map of the study area.

3.3.2 Local Geology

The area comprises various lithologic units originated from the rift formation and local volcanic domes creation. The dominant type of geology in the study area is older undifferentiated rocks of Nazret Group and Dino formation. Nazret Group (9-5my) includes ash flow, tuffs, pantelritic ignimbrites and unwelded tuff. It widely covers the central and northern parts of the study area including Mierab Azerinet and Lemmo (Fig 3).

Dino – Formation are green and gray ignimbrites with well developed fiamme and associated unwelded pyroclastics mainly tuff, ignimbrite, pumice and waterlain pyroclastics with occasional intercalated lacustrine beds, which overlies the Nazereth Series. It is exposed at areas where the Nazereth Series eroded and washed away such as at quarry sites of Angacha, Danboya, Lemo, Analemo and Shashogo woreda . The tuff is exposed along Bonesha ridge named as Doisha Ambericho fault scarp in Shashogo Woreda.

The Rhyolitic Volcanic Complexes: is outcropped at south central part of Misha Woreda which overlies quaternary ignimbrite and forms ridges at the Woreda.

Lacustrine Sediment: Which includes lacustrine silts and fine sands occur on Boyo plain of Shashogo Woreda.

3.3.3 Geologic Structures in the Study Area

Since the study area is found at western margin of the rift it is tectonically active and structurally controlled. The activity of the Faulting in the escarpment areas which comprises the older undifferentiated rocks of Nazreth Group and Dino Formation down faulted these units in a step fault fashion towards the rift floor resulted in the development of Boyo plain. This graben like flat plain is formed of a slightly curved down-faulted graben extending from west of Wulbareg via Fonko town, which terminates at Mount Ambericho. In the northeast it is also bounded by semicircular fault extending from mount Gafat, near Wulbareg town, towards southeast of Boyo plain.

3.4 Geomorphology

The geomorphology of the study area is controlled mainly by geological structures and rock types. Normal fault escarpments and volcanic domes form most of the elevated ridges in the study area. The main geomorphological features that characterize the study area are described below (Fig 4).

- Boyo plain
- Highly rugged terrain
- Ridges
- Plateau
- Mountainous

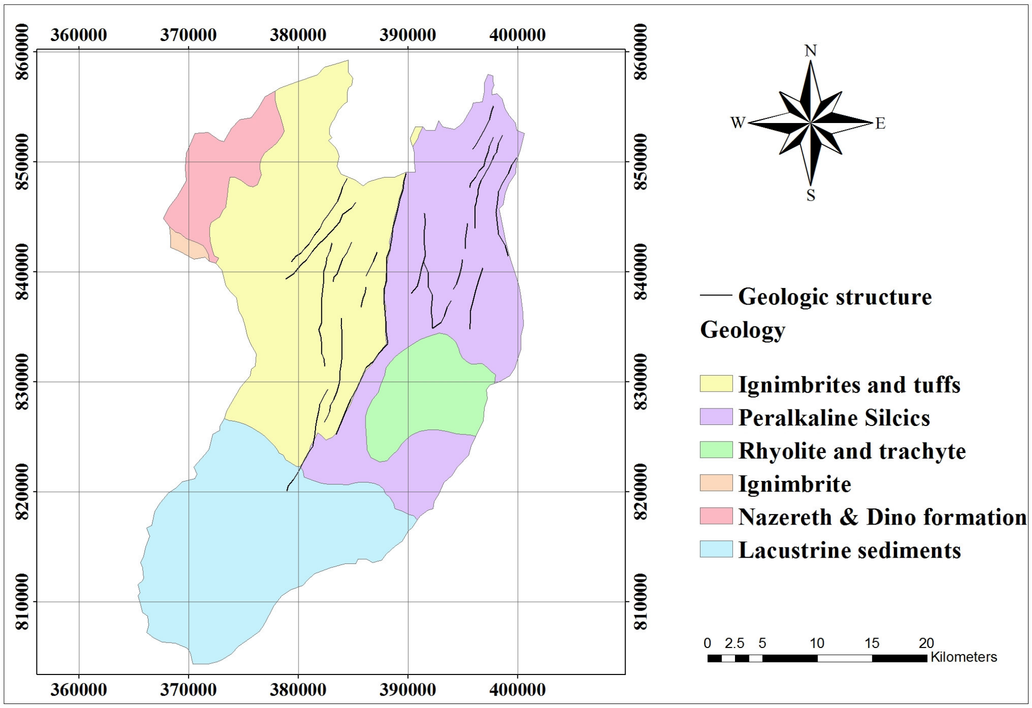


Figure 3. Geologic map of the study area (Source, AG Consult, .20007).

1. Boyo plain

This trough runs approximately N-S and confined from east by Lemo structural ridges and from the west by Ambericho fault. The Ambericho fault scarp forms cliff in the north, but gradually gently slopes until it terminates at Bilate River, south of Bonosha town. The floor of the plain is mainly covered by lacustrine and alluvial, debris flow or talus deposits.

2. Highly Rugged Terrain

The north western and south western part of the area, especially Misha Woreda is highly rugged and dissected by parallel and sub-parallel drainages. The rocks in the area are mainly rhyolite, and ignimbrite.

3. Sharp Crested Ridges

This are N-S trending structurally controlled ridge found in north east part of the catchment. Lithologically, they are Nazereth and Dino formation .

4. The plateau

This area serves as the head of Guder River and the western boundary to the Boyo plain . Acidic to intermediate lava rock units and pyroclastic deposits such as ignimbrites and subordinate tuff characterize this region. The cliffs facing towards Boyo plain abruptly terminate at Boyo plain and the lithology abruptly changes to lacustrine sediments.

5. Mountainous

The mountainous features are located in the north western, south western and south eastern parts of the catchment. Lithologically, they are also ignimbrite and rhyolite.

3.5 Soil

According to the soil classification of FAO (1997), there are five soil types in the study area: vertic andosol, eutric vertisol, chromic luvisol and lithic leptosol.
Chromic luvisol is the dominant type of soil in the area covering the northern parts of the study area including Lemmo, Analemmo, Wilbareg, Misha and Mierabazerinet Woreda. Vertic andosol cover the whole areas of Shashogo Woreda. Eutric vertisol covers the southern parts of the study area including most parts of Doyogena and Angacha. Humic nitosol covers Danboya Woreda and some parts of Lemmo, Doyogena and Angacha.

3.6 Drainage

The drainage pattern of the study area is influenced by the geologic structures of the area. It has been digitized from the topographic map of the area and it shows dendritic drainage patterns (Fig 5). The major streams form parallel drainage pattern oriented in a general North-South direction, following the direction of major structural lines and drained to Lake Boyo.

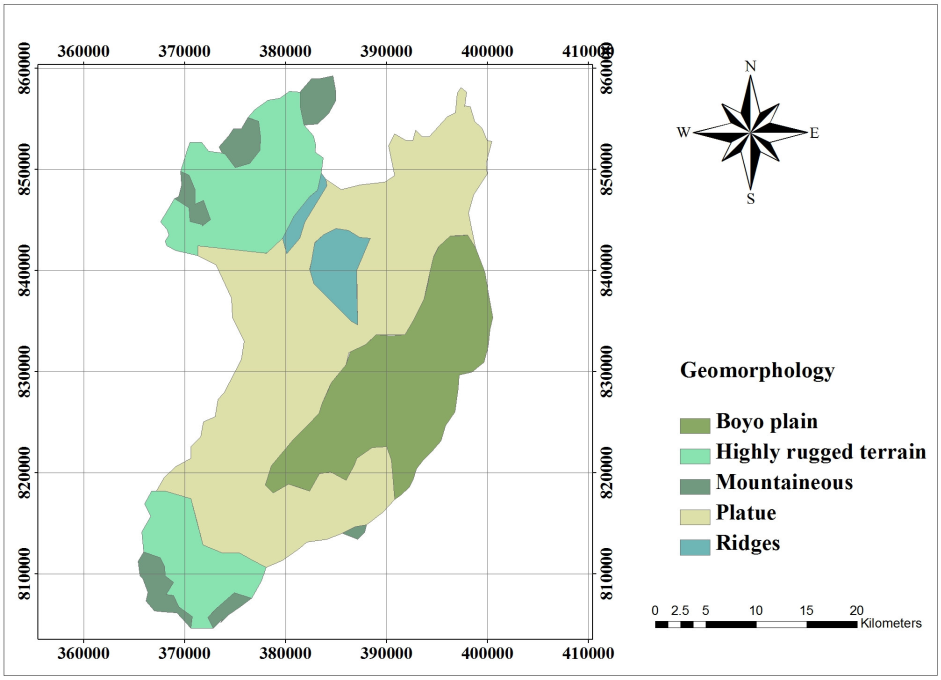


Figure 4. Geomorphology of the study area (based on onscreen digitization of Landsat imagery).

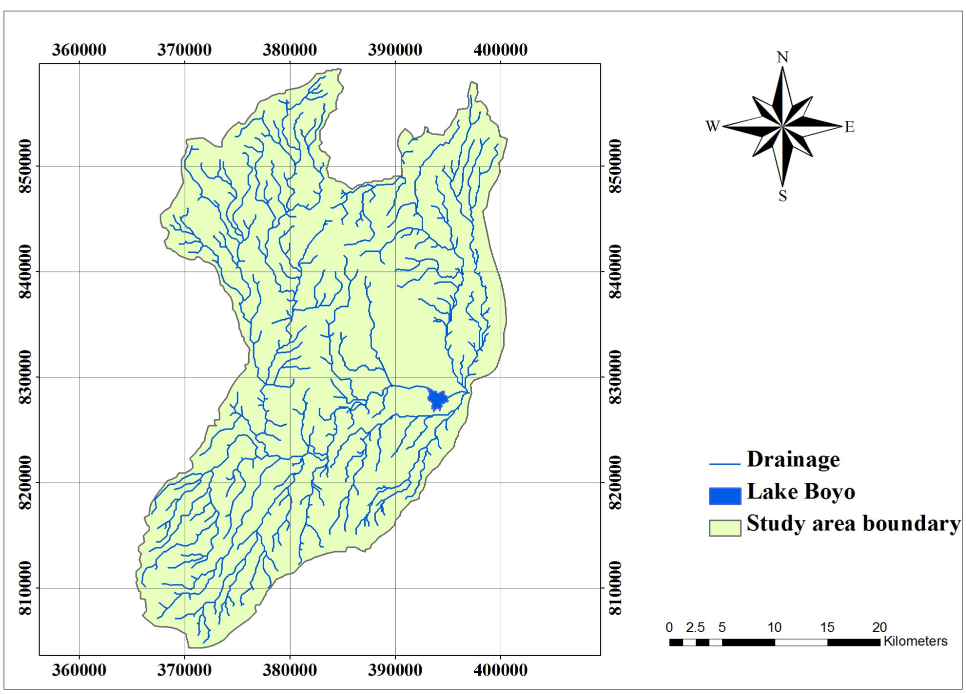


Figure 5. Drainage map of the study area (digitized from the topographic maps).

3.6.1 River System

The river system of the study area comprises of the two major rivers, namely Guder River and Metenchose River. Guder originates from near Hossaena and flows east to reach Lake Boyo while Metenchose originates from Silte zone and flows south to reach Lake Boyo. Lake Boyo discharges its water to Bilate River through Fofo stream. Fifteen years of gauge data (water levels and flow) was available for Guder River at the gauging station near Hossaena. Using this data, the flow condition of the river was interpreted. The flow of Guder River increase from June through September and decrease from October to February, and then slightly increase from March to May (Fig 6).

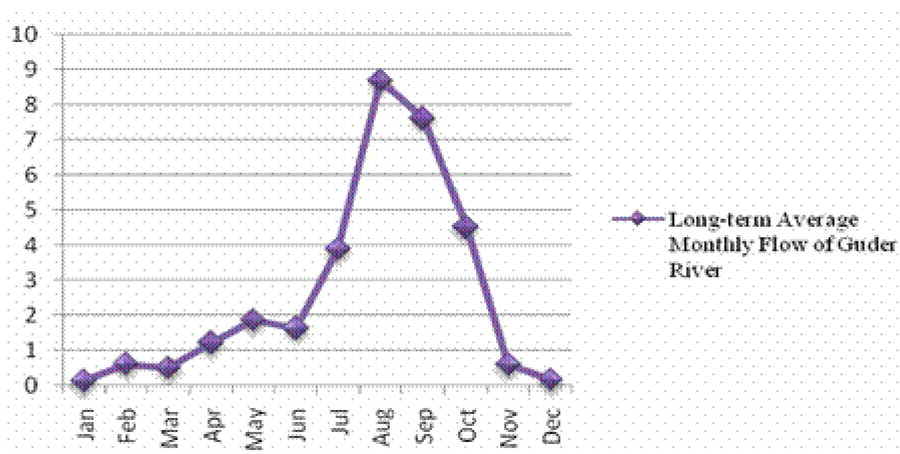


Figure 6. The flow of Guder River near Hossaina station (Source: Ministry of Water Resource).

3.7 Climate

Based on the topographic condition, the climatic condition of the catchment varies from one area to another in terms of both temperature and rainfall. The long year rainfall and temperature data were collected from the following five stations: Alaba, Angacha, Fonko, Hossaina and Wulbareg.

3.7.1 Rainfall

Rainfall data from the five meterologic stations have been collected and analyzed. The rainfall pattern has a bimodal nature in which the months from March to May and June to September are marked by relatively higher rainfall records; while months from November to February are dry (Fig 7). The long rainy season in the area is between June to September, during which crop cultivation takes place in the catchment. Monthly rainfall data was available for the years from 1978 to 2006 at two meterologic stations (Hossaina and Wulbareg), and for the years from 1985 to 2006 was available at Alaba, Fonko and Angacha stations. The total annual rainfall ranges from 1005.1 mm to 1651.7mm at Alaba and Angacha meterologic stations, respectively (Appendix 1).

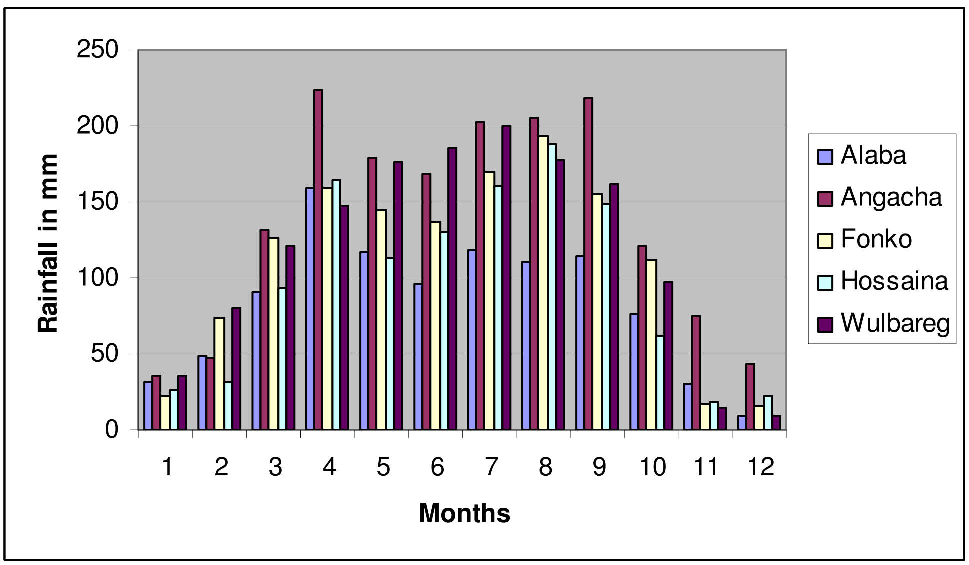
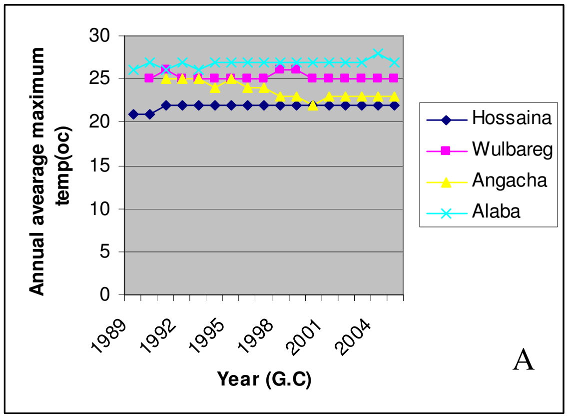


Figure 7. Average monthly rainfall showing bimodal rainfall at all meterologic stations**.**

3.7.2 Temperature

The monthly maximum and minimum temperature for the years from 1989 to 2005 was available at four meterologic stations. The highest mean maximum monthly temperature was generally observed during the dry season. In all stations, the mean maximum temperature was greater than 27 ^{o}C, occurred during January to March, while the mean minimum temperature was less than 25 ^{o}C occurred during July to August (Fig 8).



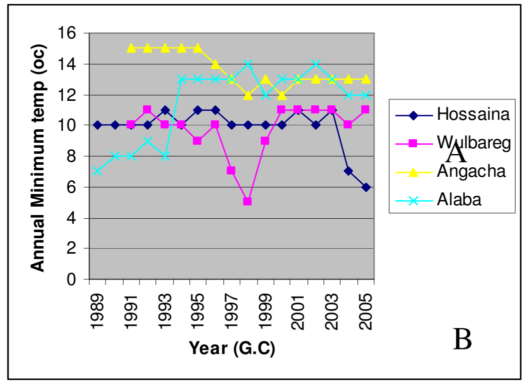


Figure 8. Maximum (A) and minimum (B) Annual Average Temperature of the four meterologic stations.

3.8 Physiography

The study area has diversified nature of topography, ranging from very flat to rugged topography. In the north western and south western parts of the area exist mountaneous land forms relatively rugged and ranging from 2400 to 2900 m.a.s.l with associated river gorges. The elevation of the study area ranges from 1892m.a.s.l to 2900m.a.s.l. The lowest elevation is at the south eastern part of the area, situated in the Main Ethiopian Rift (MER) at the flood plains of Shashogo Woreda. Generally, altitude decrement is observable from west to east (Fig 9).

3.9 Population and settlement

According to the current administrative structure, the study area lies on four zones: Hadiya, Silte, Guraghe and Kembata Tembaro zone. Based on the 2007 census, the total population size of the catchment is 1,429,875 of which 70,784 (4.25%) is urban population and 1,387,180 (95.75%) is rural population. Population of various zones in the study area was computed from CSA data 2007 and presented in the Table 3. The data show that the rural population is significantly higher than the urban population. Generally, the population density is higher in Hadiya, Silte, Kembata and Guraghe zones in the decreasing order. High density areas occur in most parts of the catchments in Hadiya zone having Misha (163,920), Lemmo (148,063) and Shashogo Woreda (123,588).

Table 2. Population of various zones in the study area (Source: CSA, 2007).

No.	Zone	Number of population	Percent
1	Hadiya	525,538	36.75
2	Silte	46,361	34.01
3	Kembata	17,976	29.23
	Total	589,875	99.98

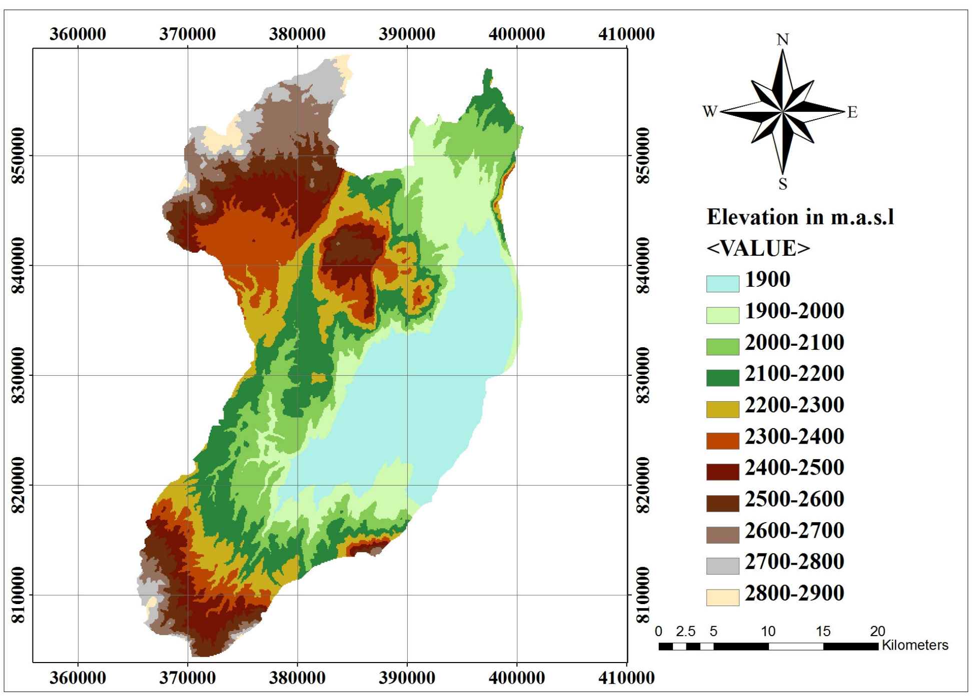


Figure 9. Elevation map of the study area (based on SRTM data of 2000 G.C).

3.10 Flood problem in the study area

Flooding has been a problem in some parts of Shashogo Woreda in Lake Boyo catchment having the natural topography, which varies from the very mountainous to the very flat lands. The flat lands of the catchment are found in Shashogo Woreda and hence it is severly affected by flooding every year.

Lake Boyo has a drainage area of 1143 km^2. There are some streams feeding it. The major stream feeding the lake comes from the nearby highland at a higher elevation than the lake. During rainy seasons, the level of lake water rises. As a result, it inundates low lying areas of Shashogo Woreda.

Metenchose River, which is one of the tributaries of Lake Boyo is the major source of flood waters in the human settlements in the eastern flood plains of the Shashogo Woreda. The origin and the immediate catchment areas of the river are poorly covered rendering the lower ends north of Doesha Town to heavy floods full of sands during the rainy season.

The severity of flood risks posed by Metenchose River could also be justified by the fact that, the river reaches the low lying areas without any topographic hindrance throughout its course until it reaches Doesha Town in the south. Doesha town, which is located at 24km from the Shashogo Woreda capital, is one of the most severely affected places in the area as a result of the flood of Metenchose River. It claims considerable amount of property every year.

As it carries a large amount of soil from the Guraghe highlands, there will be sedimentation after each flooding event. In 1998, the level of sediments swallowed one elementary school in the area, as it was observed during the field work.

The flood has frequently devastated agricultural crops. A total of 8505ha of land, which were covered by different types of agricultural crops were drowned by the flood in the year 2007 (Table 4). The expected crop lost was 67898 quintals. The reduction in agricultural output due to flooding results in price increase of agricultural products in the following year, which in turn leads to poverty and related socio-economic problems. Ethiopia lost 14,202,660 birr due to loss of agricultural crops caused by flooding in Shashogo Woreda in the year 2007 (SWRDO, 2007).

As a result of heavy rainfall, 21 Kebeles was damaged during July 2 –August 15, 2007. The Woreda Rural Development office has classified the Peasant Associations according to the degree of damage taken place (Table 5).

Table 3. Agricultural crops damaged by the flood in the year 2007 (Source: SWRDO, 2007).

No	**Crop type**	**Area covered (ha)**	**Damaged crop (ha)**	**Degree of damage**		**Price**	
				In %	**In Quintals**	**Price per Quintal**	**Total price, birr**
1	Maize	4213	1935	46	48450	230	11143500
2	Sorghum	1462	790	54	12632	180	227376
3	Pepper	1239	514	41	5080	65	330200
4	Green Bean	327	100	31	912	210	191520
5	Suenu Greeck	264	103	39	824	320	263680
Total		8505	3442		67898		14202660

Even though, the absence of satisfactory local record at Shashogo Woreda, the effects of flood were well explained by the local people. On the western side, the flood waters entering the lake through Guder River contribute voluminous amount to the flood waters entering from other directions and overflow in Musagesa and Hablera Kebeles.

Table 4. Number of Kebeles damaged by flood in the year 2007(Source: SWARDO, 2007).

No.	**Level of damage in PAs**		
	Highly damaged	Moderately damaged	Less damaged
1	Urbecha Antata	Biramora	Shemsa Jemaya
2	Suta	Bechagola	Afto Aturancho
3	Kemecho Borara	Shiyembe	Ajacho Shiro
4	Musa Gesa	Hirko Fofo	Ajacho Boye
5	Golicho Boye	Jelo	Doesha Beleye
6	Mololicho	Shemo Boye	Doesha Ambericho
7	Bidika		Doesha Gola
8	Amerkeba		

The physical expansion of Doesha town has been dictated by the flooding effects posed by Metenchose. At one time in the past, the expansion town to the southern direction of topographically suitable scenery had been halted as floods claimed considerable extent of property. Despite the retreat made by the residents, the level of sediments, which swallowed one elementary school, has constantly grown to the extent of potentially endangering the town (SOS/Sahle, 2008).

Inundation and water loggings limit the availability of grasses for livestock in the area. Also it causes food shortage by damaging the agricultural crops. The consequences of the flood hardly allow the use of flood waters even for livestock as swamps and the quality of water become hazardous for health.

In effect, almost all areas in the catchment contribute to erosion in the uplands, which instantly develops to flooding in most parts of Shashogo. On the eastern and northern parts of the lake, the pace of flooding becomes faster regardless of rainfall intensity levels, while the indirect and relatively slow movement of storms in the west reaches the lake through Guder River in high volumes and more disastrous impetus (SOS/Sahel, 2008).

3.10.1 Flood Protection Mechanisms in the Study Area

Flood defenses are laid in advance of flood events. As it was observed during the field survey, flood defense structures built around flood prone villages (Fig. 10) looked locally and environmentally acceptable. However, the retaining capacity and strength of the structures seemed to be limited in respect of the volume of water intruding those places and the level reached during storm precipitation. In addition, the small defenses constructed through safety net program looked so poor in quality and size. It is, therefore, necessary that special program emphasizing on flood protection be designed in order to lay a ground for constructing dependable and locally sound structures.

Figure 10. Flood protection structure on flat area of Shashogo, in Suta Kebele (Source, Author).

4 Data Analysis

In order to generate flood hazard and risk map, seven interrelated components of the environment were used as input data sets (factors) for the incidence of flood disaster. Accordingly the selected input datasets were drainage density, elevation, geomorphology, land use, rainfall and slop. Each of the factor maps were produced from remote sensing image, topographic maps and different available maps. Before combining them, the following procedures were taken place:

- Rasterization was done for the vector data layers in order to produce similar data layers to perform GIS analysis.
- Standardization of each data set to a common scale of 1 to 5 was done in IDRISI Software.

Prior to combining the factors, weights have to be given based on Satty's Analytic Hierarchy Process (AHP), where a pair-wise comparison matrix will be prepared for each map using a nine point importance scale (Table 5). Weighting is used to express the relative importance of each factor relative to other factor. The larger the weight, the more important is the factor in overall utility. The relative comparisons between the six data layers were performed based on iteration of the layers and verified by field GPS point data layer taken on flooded areas in the past. Based on the given pair-wise comparison, IDRISI calculates hierarchical weights for all layers. It also calculates consistency ratio that shows if the given pair-wise weights are accepted or if another arrangement is necessary. The comparison conducted indicated that highest weighting for the drainage data layer followed by the elevation data layer, geomorphologic data layer, land use data layer, rainfall data layer and slop data layer (Table 7).

Table 5. Pair-wise comparison, 9-point continuous rating scale (adapted from Saaty,1989 as cited in Malczewsk, 1999).

1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**
Extremely	Very Strongly	Strongly	Moderately	**Equally Important**	Moderately	Strongly	Very Strongly	Extremely
Less Important					**More Important**			

The pair-wise comparison matrix used for the weight computation for flood hazard assessement using the six parameters of drainage density, elevation, geomorphology, landuse land cover, rainfall and slop is shown in Table 6.

Table 6. Weight of factors that control flood hazard in the study area the pair-wise ratio matrix.

	Drainage density	Elevation	Geomorphology	LULC	Rainfall	Slop
Drainage density	1					
Elevation	1/3	1				
Geomorphology	1/3	1/3	1			
LULC	1/3	1/3	1/3	1		
Rainfall	1/5	1/3	1/5	1/3	1	
Slop	1/7	1/3	1/5	1/3	1/3	1

The computed Eigen vector is used as a coefficient for the respective factor maps to be combined in weighted overlay in ArcGIS environment.

Table 7. The weights of each factor map obtained after pairwise comparison.

The eigenvector of weights	
Drainage density	0.3827
Elevation	0.2308
Geomorphology	0.1827
LULC	0.1022
Rainfall	0.0617
Slop	0.0399
Consistency ratio is 0.09	

The complete pair-wise comparison matrix contains multiple paths by which the relative importance of criteria can be assessed. The consistency ratio (CR) indicates the probability that the matrix ratings were randomly generated so that matrices with CR ratings greater than 0.10 should be re-evaluated. In this study, the consistency ratio calculated as 0.09, which is acceptable. Therefore, each of the parameters can be assigned by these weights.

4.1 Research Geodatabase Design

All the above listed factors were stored in the geodatabase in order to store the collected data and the analysis results in a logical arrangement. The factors involved were examined according to their relative importance towards delineating areas of high flood risk and flood hazard and assigned weights. The classes in each factor layers were also compared one another and ranked by their contribution to the output.

The collected data were automated (scanned, digitized, and clipped by the study area boundary) and organized into logical groupings of the factors. The six factor layers that were grouped into three according to their nature as:

A. Physiographic Factors:
  - Elevation factor
  - Geomorphology
  - Landuse/Cover
  - Slop

B. Hydrological Factors:
  - Drainage

C. Metrologic Factor:
  - Rainfall

The research geodatabase was then designed to include the input datasets, their derived datasets, the weighted analysis maps, and the final result. The vector files were exported to the corresponding feature data sets and the raster files were exported as individual rater datasets in the geodatabase.

The coordinate system selected to be used for analysis was projected coordinate system, UTM. Thus the geodatabase was set to this spatial reference and all the maps were projected to it while exporting to the geodatabase.

4.2 Factors governing Flood Hazard in the study area

4.2.1.1 Slop factor

The slop raster was derived from the DEM using the ArcGIS Spatial Analyst extension of surface module, which enabled to classify the area according to the steepness and the gentleness of the terrain. The Slop function could calculate the maximum rate of change between each cell and its neighbours. Every cell in the output raster had a slope value. The lower the slop value, the flatter the terrain was and the higher the slop value the steeper was the terrain. Then the slop raster was reclassified in to five sub group manually in to five classes of slop percent by examining the value and the frequency of slop percent in the study area on the histogram (Fig 11). The reclassified slop was given a value 1 to 5 with the higher value of 5 showing high influence, resulting in very high flood rate, while the lower value of 1 showing very low influence, resulting in very low flood rate. The break values and the description of the new slope classes are given in Table 9.

Table 8. Reclassification of slops

Slope (%)	**Class**	**Rank**	**Level of Hazard**
0-3	Flat plain	5	Very High
3-15	Undulating plain	4	High
15-36	Undulating to rolling	3	Moderate
36-50	Rolling to hilly	2	Low
>50	Mountainous	1	Very Low

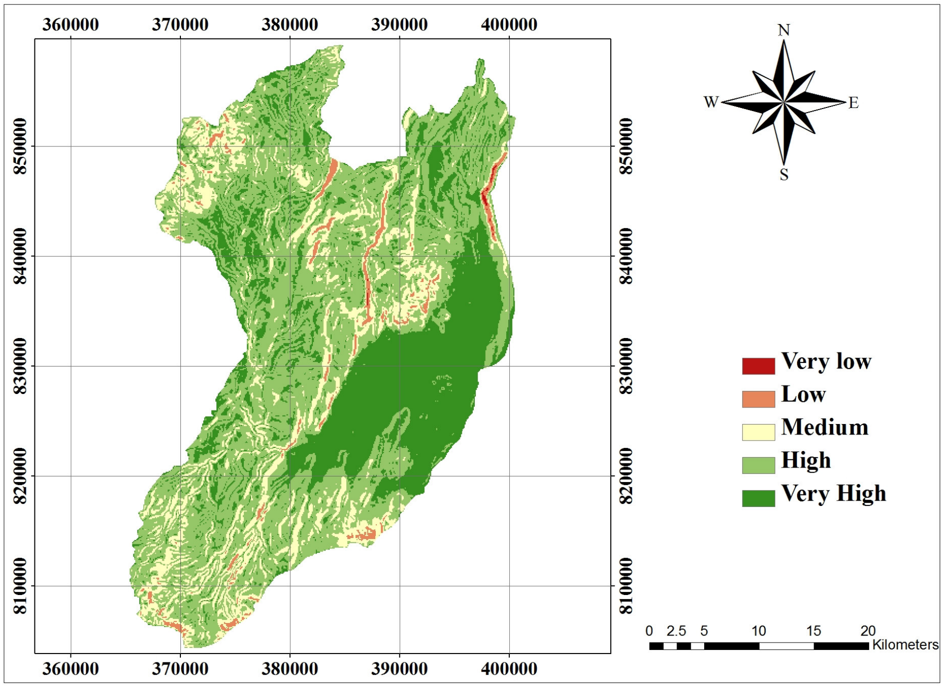


Figure 11. Reclassified slop map of the area

4.2.1.2 Drainage Density Factor

Analyzing the drainage density is of paramount importance in assessing flood hazard and risk in the study area. Four topographic maps of 1: 50,000 0737B4 (Hossaina), 0738C1 (Kulito), 0738A2 (Wilbareg) and 0738C1 (Angacha) were collected from EMA, scanned, georeferenced, mosaiked and clipped by the study area boundary. From the mosaiked topo-map, the drainage of the area was digitized. Then the drainage density was generated from the digitized vector layer using ArcGIS spatial Analyst extension of line density module. Line density calculates a magnitude per unit area from polyline features that fall within a radius around each cell and density was calculated in units of length per unit area. The drainage density was reclassified in to five classes of drainage density using equal interval classification scheme (Fig 12). Highest scale is given for the denser class and the scale decreases as density decreases. The ranks given to individual slope classes are shown in Table 10.

Table 9. Reclassification of Drainage Density.

Drainage Density (km/km^2)	Rank	Level of Hazard
0 - 0.56	1	Very Low
0.56 - 1.125	2	Low
1.125 – 1.68	3	Moderate
1.68-2.25	4	High
2.25-2.81	5	Very High

4.2.1.3 Elevation factor

The SRTM data of the area was patched in order to fill the missing data and exported into ArcGIS, where this vector elevation map was converted into raster grid format using ArcGIS conversion tool extension of DEM to raster module, which applies the spatial resolution value stored in the DEM. The resulting raster had elevation values. Then the elevation was reclassified into five groups using equal interval scheme. Based on their susceptibility to flooding, the lower the elevation value the higher the flood hazard was and the higher the elevation value the lower was the flood hazard (Fig 13). The rank and the level of hazard of the elevation classes are given in Table 11.

Table 10. Reclassification of elevation

Elevation in m.a.s.l	Rank	Level of Hazard
1982-2102	5	Very High
2102-2312	4	High
2132-2522	3	Moderate
2522-2732	2	Low
2732-2942	1	Very Low

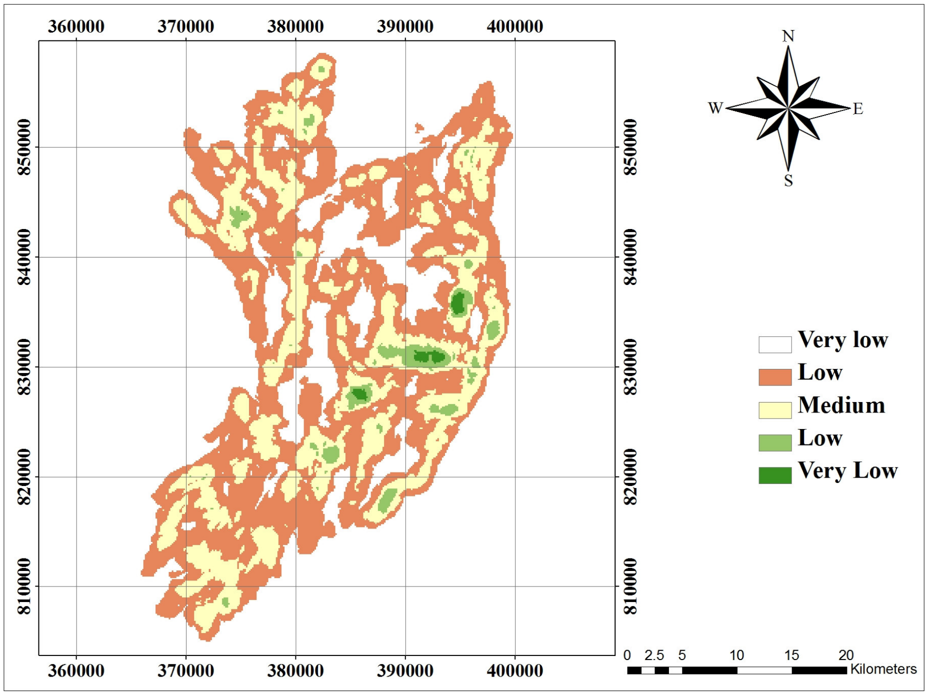


Figure 12. Reclassified drainage density map of the study area.

4.2.1.4 Land use Factor

The land use of the study area was classified using Landsat ETM+ acquired on 11/26/2005, having path and row of 169/55. The image was georeferenced to a Projection: Universal Transverse Mercator, Grid: UTM 37 N, Datum: Adindan. The study area was subsetted from the full scene. Then the subsetted image was undertaken supervised classification with the aid of 129 ground control points collected during field survey (Appendix 6). Classified pixels were clustered into the following seven more general categories: water body, marshy lands, cultivation, degraded land, woodland, grass land and shrub land (Fig 14).

Then each of the land use types was further reclassified for the overlay analysis. Accordingly, marshy land and water body were given more weight, which was equal to 5, degraded land was given weight 4, and cultivated land was given weight of 3, wood land and shrub land was given weight 1, and grassland was given weight of 2 (Fig 15).

4.2.1.5 Rainfall Factor

The long year rainfall data has been collected from the different metrologic stations within the study area and outside the study area. The annual average of the rainfall data from each metrologic station was calculated and interpolates rainfall surface from the point data using an Inverse Distance Weighted (IDW) technique. IDW interpolation determines cell values using a linearly weighted combination of a set of sample points (Fig 16). The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable. Then the interpolated surface was converted to raster layer, which was finally reclassified into five classes using equal interval scheme (Table 12). The reclassified rainfall was given a value 1 to 5 with the higher value 5, showing high influence resulting in very high flood rate, while the lower value 1, showing very low influence resulting in very low flood rate. Therefore, an area with very high rainfall was ranked as 5 and an area with very low rainfall was ranked as 1. Accordingly, the raster and the reclassified rainfall data are shown below (Fig 17).

Table 11. Reclassification of rainfall

Rainfall in mm	Rank	Level of Hazard
1169.8-1252.2	1	Very Low
1252.2-1334.6	2	Low
1334.6-1417.0	3	Moderate
1417.0-1499.4	4	High
1499.4-1581.8	5	Very High

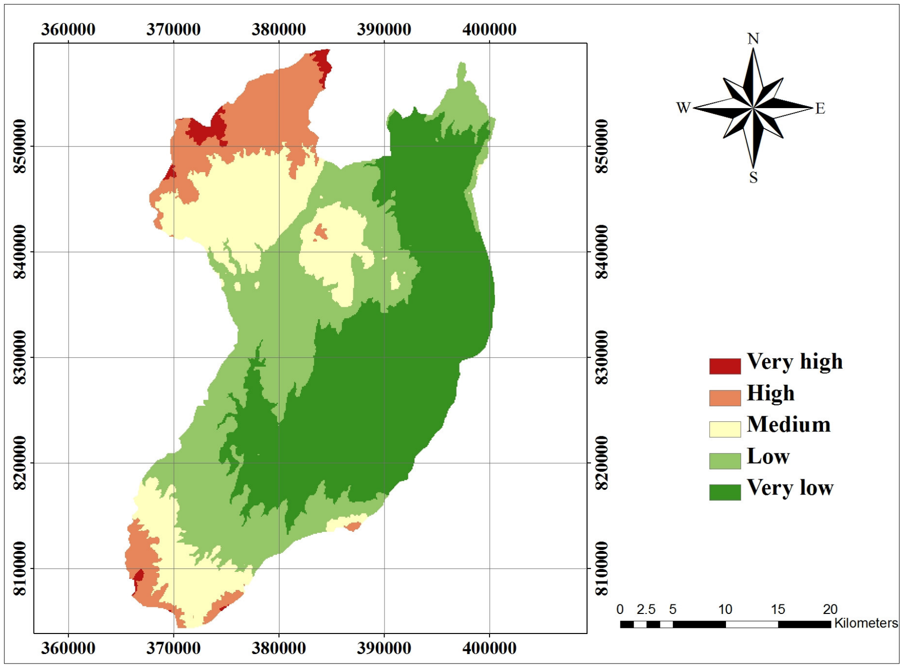


Figure 13. Reclassified elevation map of the study area.

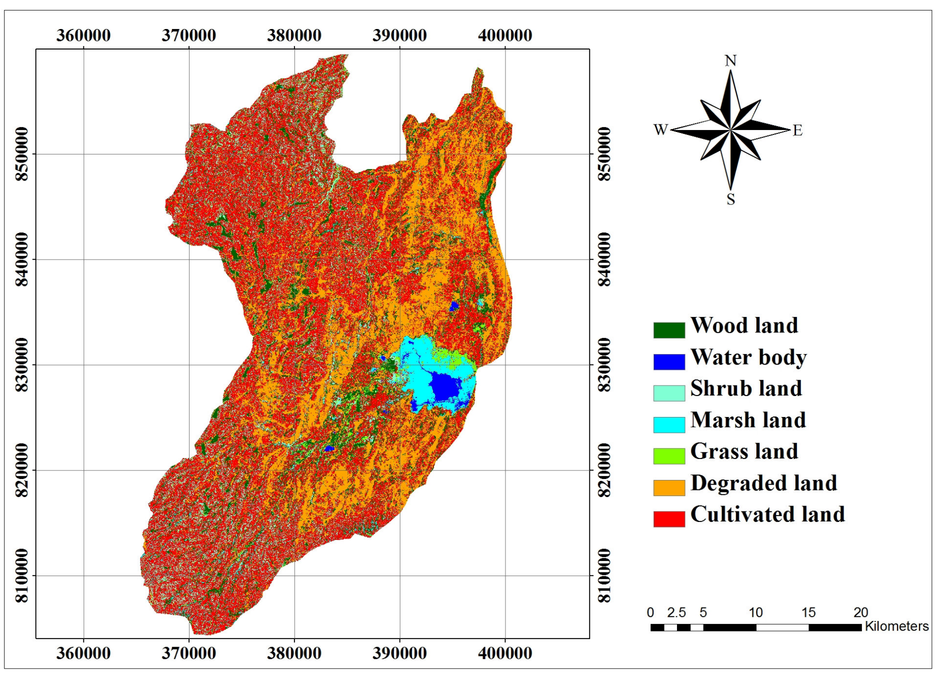


Figure 14. LULC map of the study area.

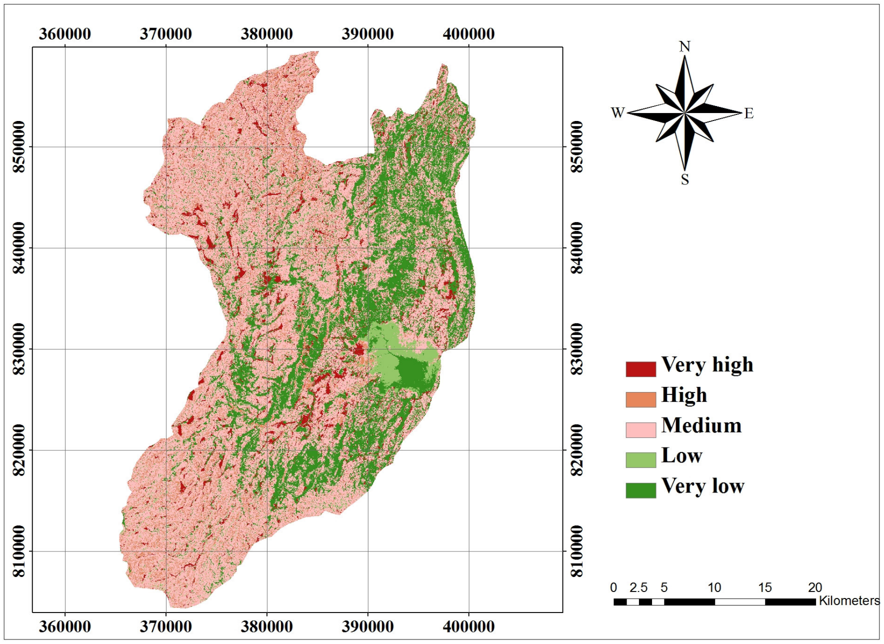


Figure 15. Reclassified land use map of the study area.

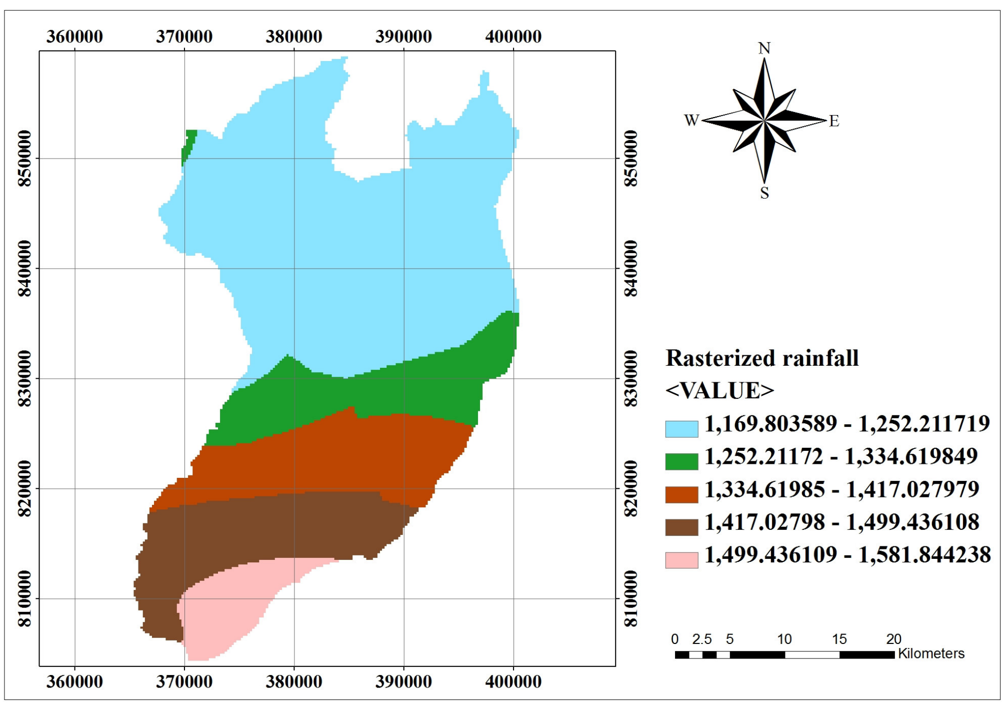


Figure 16. Rasterized rainfall map of the study area.

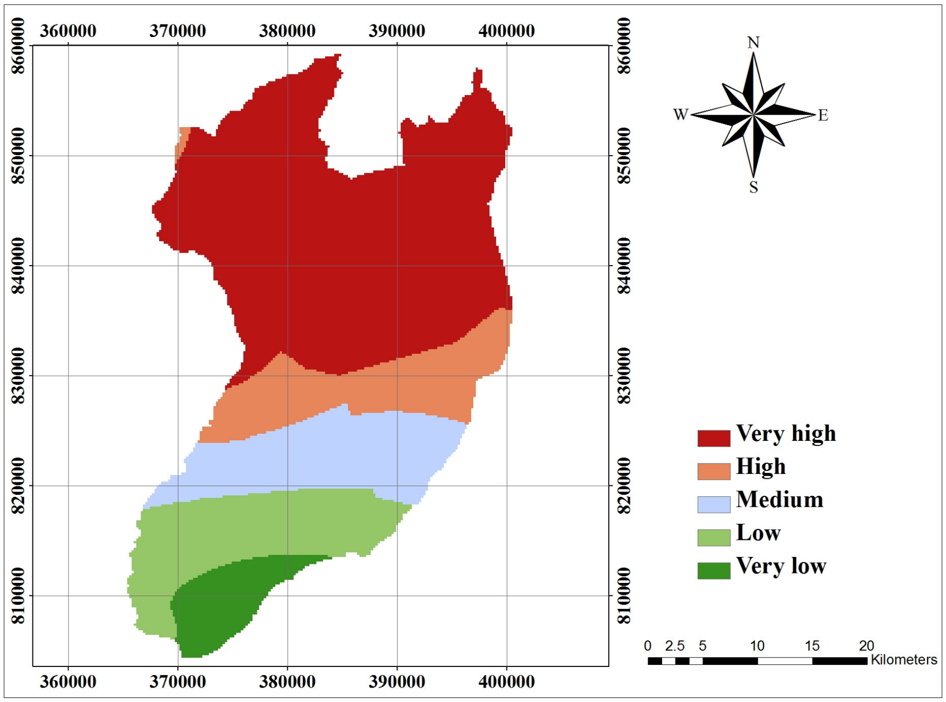


Figure 17. Reclassified rainfall map of the study area.

4.2.1.6 Geomorphology Factor

The genesis of the geomorphologic units in the study area is strongly related to volcanic and tectonic processes. The different geomorphologic units were delineated by onscreen digitization of the Landsat ETM+ image of the study area. As mentioned in section 2.3 there were five geomorphic units in the study area, viz., Boyo plain, highly rugged terrain, ridges, and the plateau. Based on the potential of flooding it was reclassified into five classes (Fig 18). The reclassification of geomorphology is shown in Table 13.

Table 12. Reclassification of geomorphic factor

Geomorphology	Rank	Level of Hazard
Mountainous	1	Very low
Highly rugged terrain	2	Low
Ridges	3	Moderate
Plateau	4	High
Boyo plain	5	Very high

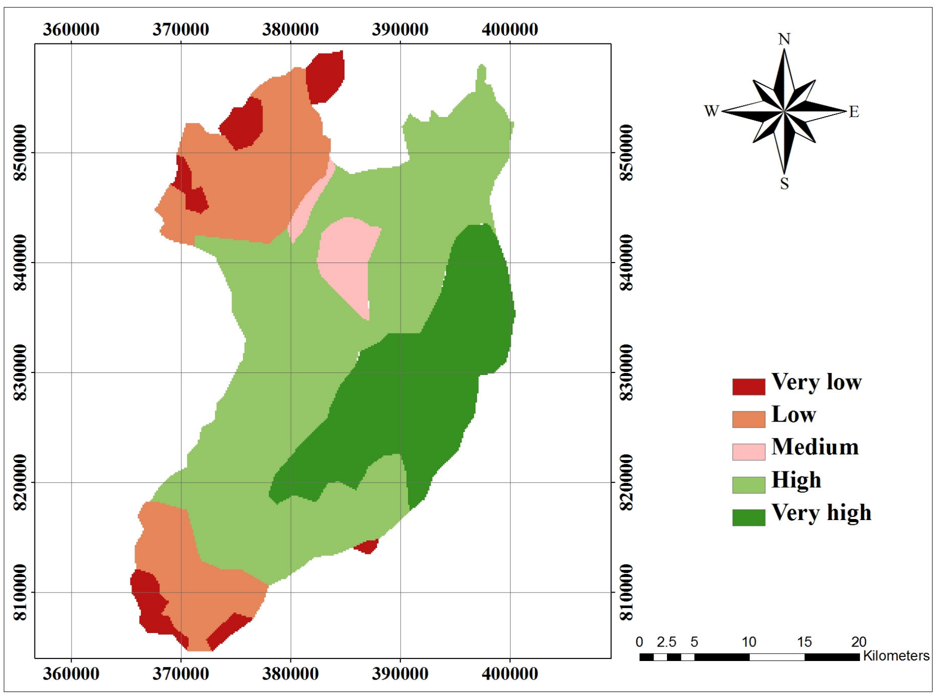


Figure 18. Reclassified geomorphologic map of the area.

4.2.2 Flood Hazard Analysis

At this stage, all the factor layers are ready to be combined in order to assess the flood hazard zones in the study area. If all datasets were equally important, it could be possible to combine them simply. However, from the principal eigenvector calculation, the relative importance of each parameter was determined. Therefore, the higher the weight, the more influence a particular factor will have in the flood generation. Accordingly, the factor layers were combined by applying the following formula in the raster calculator of spatial analyst extension in ArcGIS environment. It was done systematically using ArcGIS model builder (Fig 19).

[Drainage Density] * 0.3827 + [Elevation] * 0.2308 + [Geomorphology] * 0.1827 + [Land Cover] * 0.1022 + [Rainfall] * 0.0617 + [Slope] *0.0399 = Flood Hazard Zone.

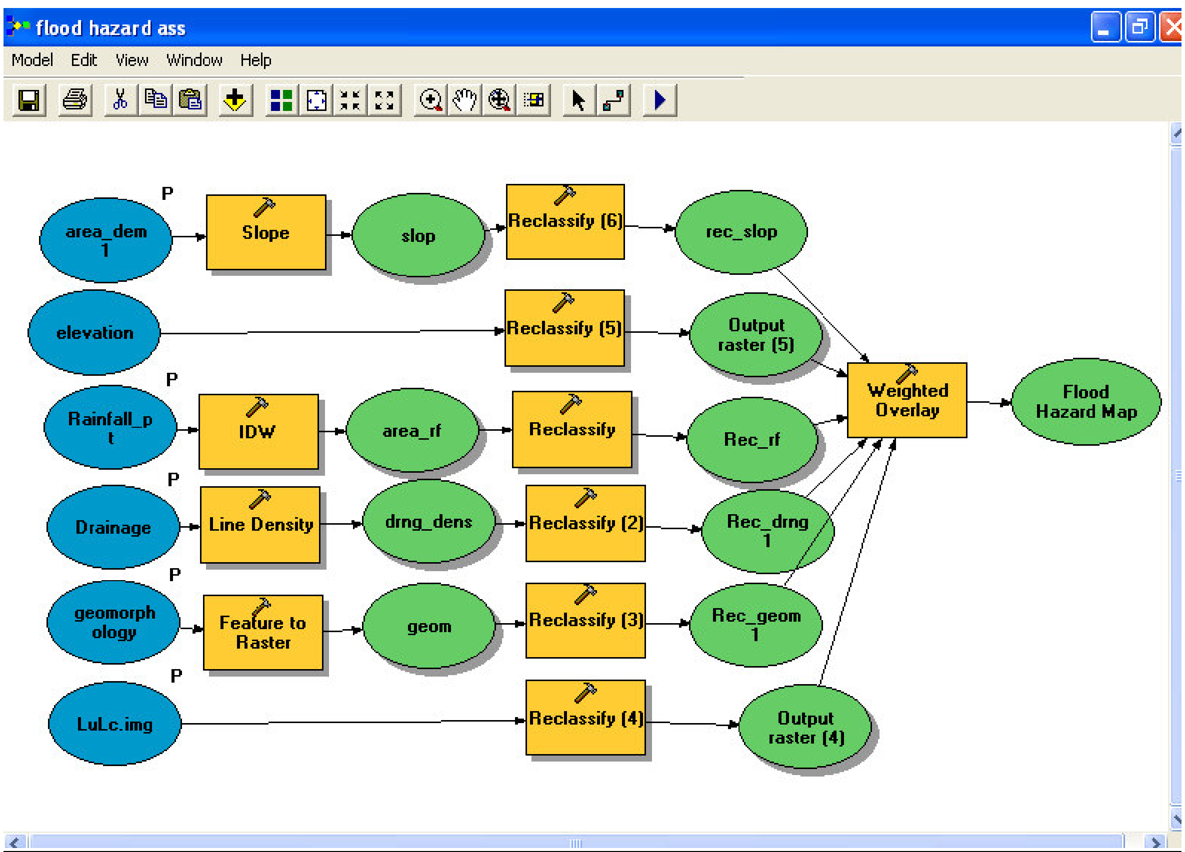


Figure 19. Flood hazard analysis model builder dialog box.

4.2.3 Flood Risk Analysis

As the flood hazard result has revealed, 100 % of the very high and 92.7% of high flood hazard areas of the catchment fall in Shashogo W0reda. So it is found important to do flood risk for this Woreda. The general risk equation according to Baker, (1998) is

Risk = (Elements at risk)* (Hazard* Vulnerability) ………………(Equation 1) .

The flood risk of the Shashogo Woreda was analyzed using the above equation by considering the two elements at risk: population density and land use by assuming vulnerability to be 1. The three factors, flood hazard, population density and land use of the Shashogo Woreda remained to be equally important in the weighted overlay process and again it was done systematically using ArcGIS model builder (Fig 20). The land use of the Woreda was reclassified based on their sensitivity to flooding. Accordingly, agriculture and grass land were given more weight which was equal to 5, marshland was given weight 4, wood land was given weight 3, shrub land was given weight of 2 and degraded land was given weight 1.

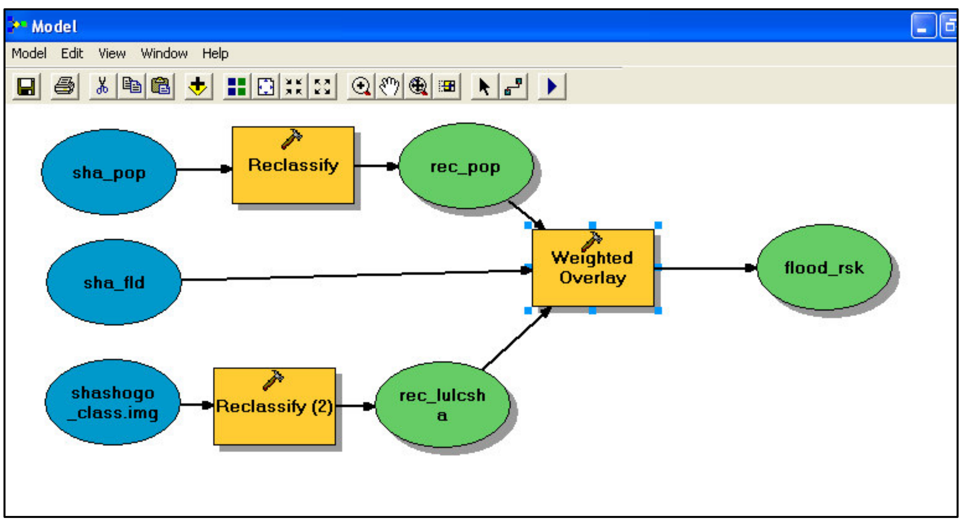


Figure 20. Flood risk analysis model builder dialog box.

4.2.4 Flood related with seasonal expansion of Lake Boyo

As mentioned in section 2.10, Lake Boyo was one source of flood in Shashogo Woreda. Based on the four Landsat imageries acquired on similar months of different years, seasonal expansion of Lake Boyo was interpreted.

The imageries used to interpret the seasonal expansion of Lake Boyo were, Landsat MSS acquired on 21/11/1973, Landsat TM acquired on 23/11/1984 and 31/11/1995 and Landsat ETM+ acquired on 18/11/2005. These images were classified (Fig 22) and the area of the lake was easily calculated using ArcGIS 9.2 software. The Lake surface area in 1973, 1984, 1995 and 2005 was 0.64, 1.45, 5.45 and 9.85km^2 respectively. This indicates the expansion of water body at the expense of other land use classes.

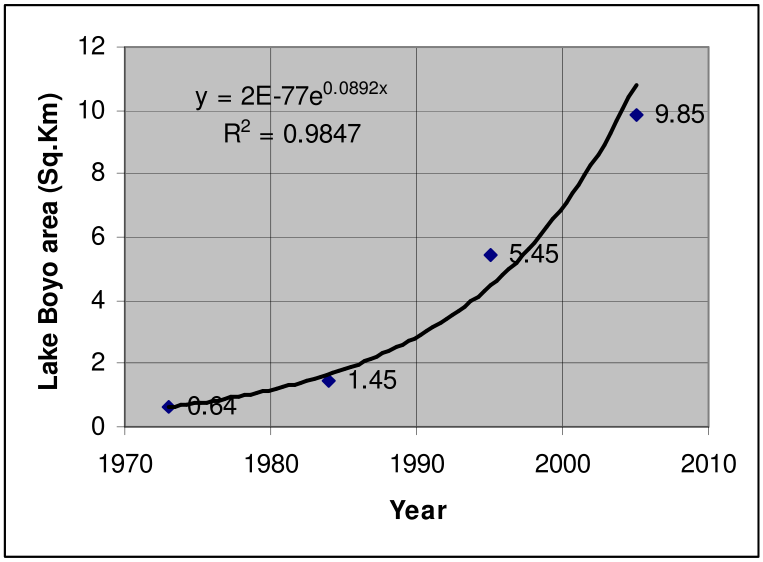


Figure 21. Inundation of Lake Boyo in different years (Source: Landsat imageries of the year 1973, 1984, 1995 and 2005).

Using the above equation (Fig 21), flood associated with Lake Boyo was projected for the years 2010,2020,2030,2040 and 2050 (Table 14) and the inundated area of the Shashogo Woreda as a result were done. The inundated area was computed using the Surface area of Lake Boyo in 1974 as an initial state.

Table 13. Projected seasonal expansion of Lake Boyo and area to be inundated as a result.

Year	Area of Lake (Km^2)	Area to be inundated (Km^2)
2010	12.255	11.615
2020	15.418	14.778
2030	18.581	17.94
2040	21.744	21.1
2050	24.907	24.27

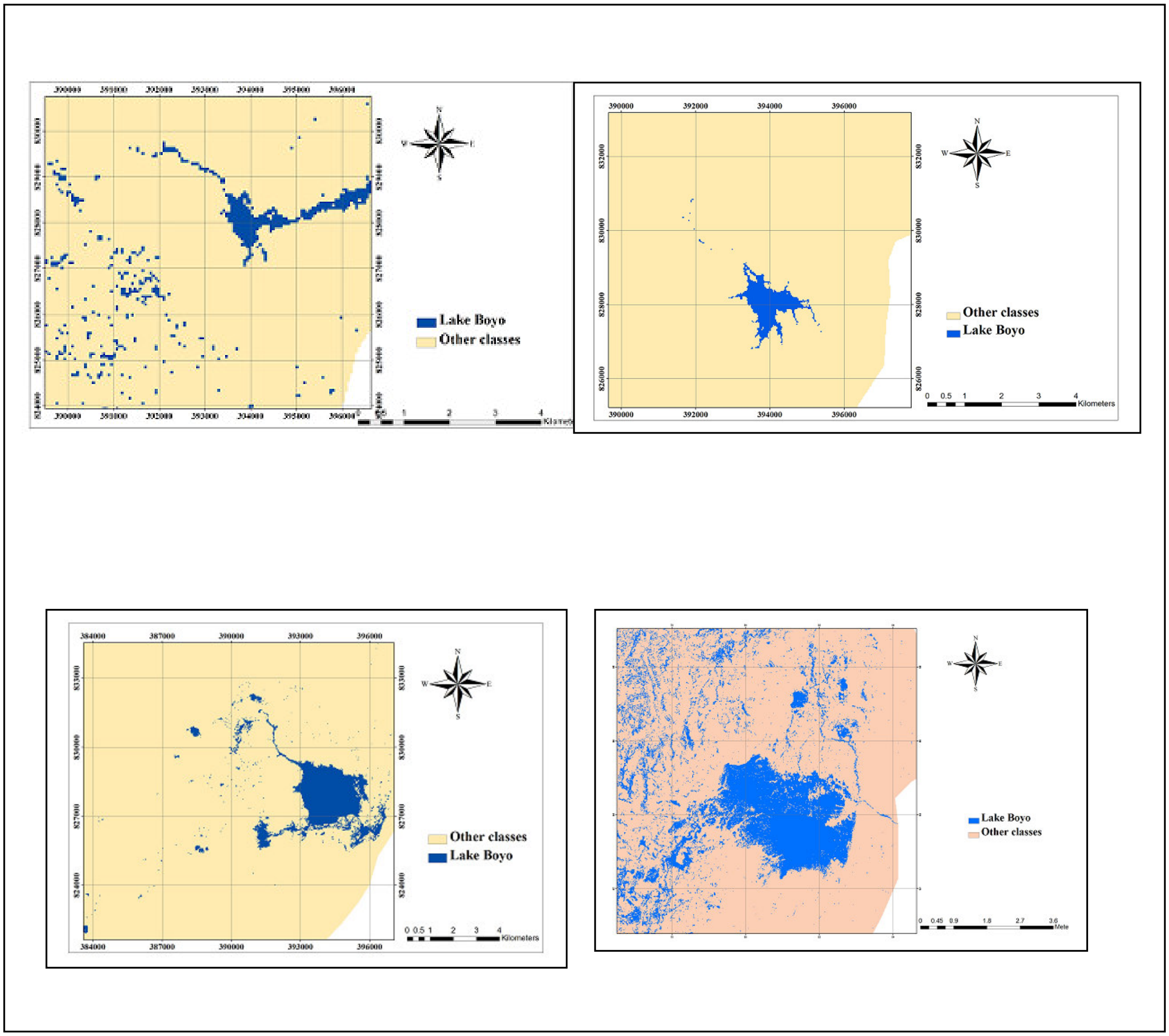


Figure 22. Seasonal expansion of Lake Boyo at the years , 1973 (top left), 1984 (top right), 1995 (bottom left) and 2005 (bottom right).

5 Results and Discussion

5.1 Flood Hazard

In this study, the flood hazard zone of the study area was delineated by considering the six parameters. The final combined resulting map obtained after the weighted overlay analysis was flood hazard map of the study area (Fig 23). From this map, the different levels of flood hazard in the study area was calculated and given in Table 12. The result has revealed that, 0.4 % of the catchment was characterized by very high flood hazard level and 21% of the catcment was characterized by high flood hazard level. Out of 21% of the Lake Boyo catchment that is characterized by high flood hazard level, 92.7% was located in Shashogo Woreda (Table 13). On the basis of historical information, Shashogo Woereda was commonly inundated area due to its geomorphic settings as it comprises of topographically flat lands.

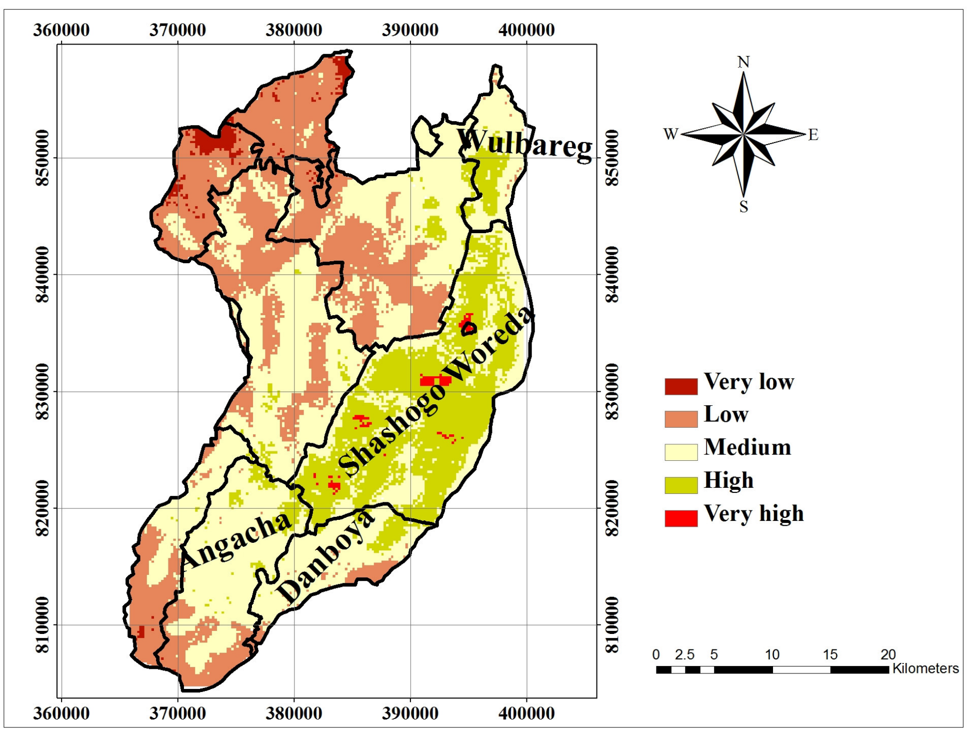


Figure 23. Flood hazard map of Lake Boyo catchment.

Areas of different Woredas found in the catchment that are subjected to different flood hazard levels were also calculated. The result has revealed that, 100% of very high level of hazard and 92.7 % of high flood hazard level zones are found in Shashogo Woreda, which is composed of 31 PAs out of which only 25 PAs are located within Boyo catchment. The lower feet of Wulbareg (4.35%), Danboya (1.61%), Angacha (1.53%), and Demboya also experience less of the floods and more of water logging and inundation for some times during and after the rainy season.

Table 14. Area comparison of the catchment and Shashogo Woreda by flood hazard level.

Flood hazard level	Lake Boyo catchment	Shashogo Woreda	% Shashogo Woreda
	Area Km2		
Very high	4.5	4.5	100
High	218.16	201.2	92.7
Medium	553.4	86.4	15.6
Low	332.4	0.31	0.09
Very low	11.7	0	o

The flood hazard area of the Woreda was calculated and the result has revealed that, Mololicho, Shemo and Biramora PAs were subjected to very high flood hazard, while small portion of Bidika Pa was subjected to low hazard level (Fig 24). Each land use classes were cross tabulated with the flood hazard of the Woreda, the result is shown in Table 16.

Table 15. Cross tabulated area of land use and flood hazard of the catchment.

Land cover type	Flood Hazard (Area in Ha.)					Total
	Very high	High	Moderate	Low	Very low	
Shrub land	4.6	671.4	3949.2	4145.7	222.2	8993.1
Grass land	28.9	762.3	766.6	717.5	50.9	2326.2
Wood land	55.7	3558.1	8129.6	4213.3	149.4	16106.1
Marsh land	171.4	2494.9	1056.5	971.8	34.03	4728.6
Cultivated land	61.1	6615.4	24393.1	19900.9	680.5	51651
Degraded land	93.7	6758.6	17015.4	3197.0	24.53	27089.2
Total	415.4	20860.7	55310.4	33146.2	1161.56	

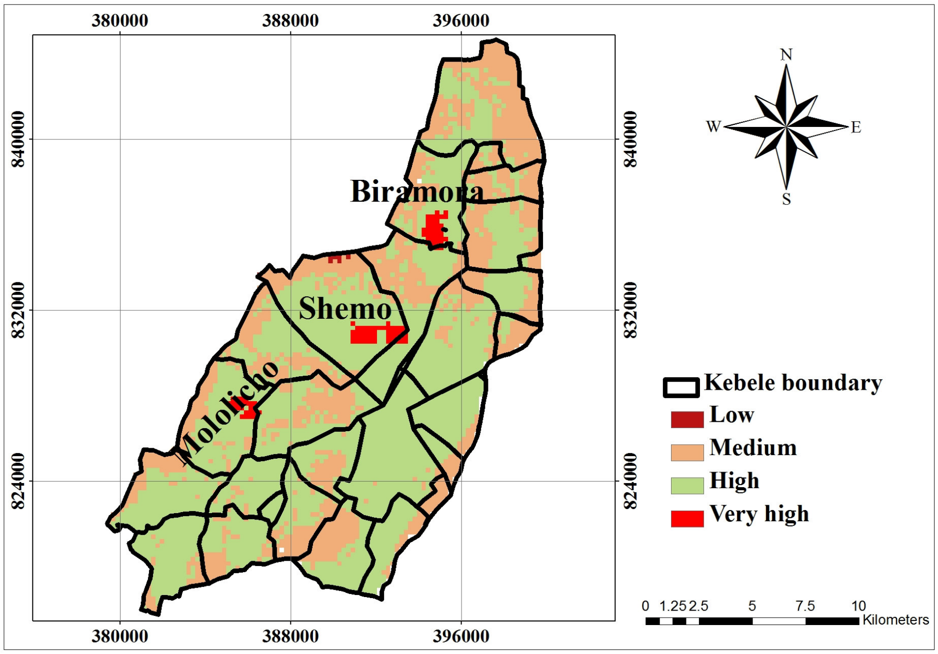


Figure 24. Flood hazard map of Shashogo Woreda.

5.2 Flood Risk

As it was already mentioned, 100% of very high flood hazard and 92.7% of high flood hazard zones were found in Shashego Woreda. As a result, flood risk analysis was done by considering only the Woreda's population, land use and flood hazard level. According to the flood risk map of the Shashogo Woreda, it was estimated that 1735.19, 13647.4, 8986.8, 1337.1 hectare areas were subjected to very high, high, medium and low flood risk, respectively (Table 18)**.** Out of twenty five PAs under study, seven PAs were subjected to very high flood risk, these are Kemetcho Borara, Bira Mora, Suta, Mololicho, Musagesa, and Urbecha Antata (Fig 25), and 23 PAs were subjected to high flood risk . Each land use classes were cross tabulated with the flood risk of the Woreda, the result is shown in Table 17.

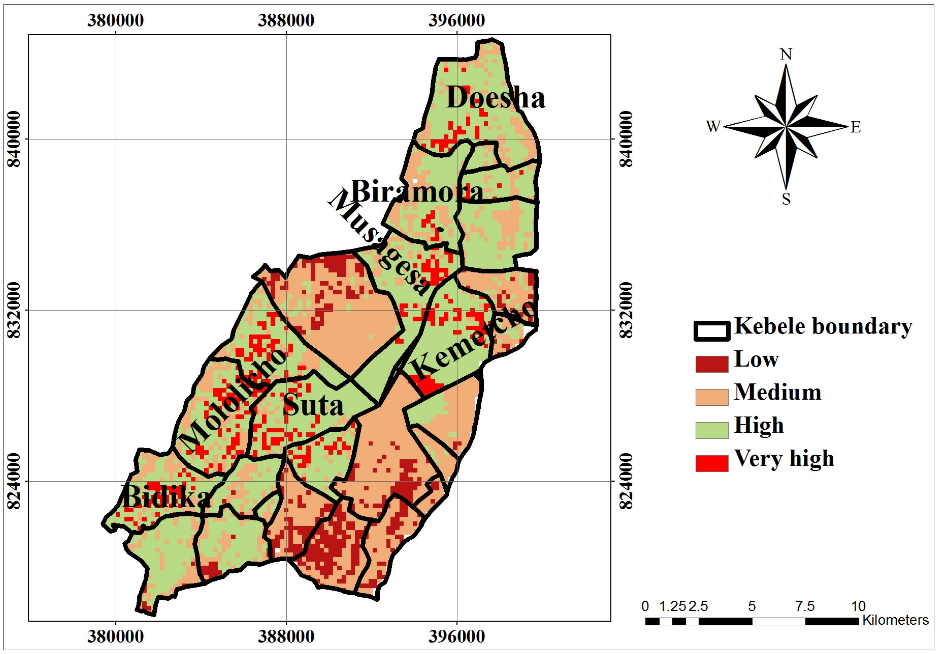


Figure 25. Flood risk map of Shashogo Woreda

Table 16. Cross-tabulated areas of land use and level of flood risk.

Land cover type	Flood risk (Area in Ha.)					Total
	Very high	High	Moderate	Low	Very low	
Shrub land	7.82	347.84	267.97	335.7	-	8993.1
Grass land	10.10	550.83	543.66	555.5	-	2326.2
Wood land	17	469.15	819.69	4213.3	-	16106.1
Marsh land	26.84	248.92	156.56	426.86	-	4728.6
Cultivated Land	96.54	5005.40	2897.1	1234.95	-	51651
Bare land	32.45	6758.68	705.4	978.0	-	27089.2
Total	190.75	13380.82	5390.38	7744.31	-	110,894.2

A total of 190.75 hectare land use classes were subjected to very high flood risk, while a total of 7744.31 hectare land use classes were subjected to low flood risk.

5.2.1 Land use/Land cover Change and Flood Hazard/Flood Risk

With the depletion of vegetation in most areas of the catchment, the fragility of topsoil triggered rapid erosion occurrences spread over wider ranges of the catchment. Increased erosion, therefore, meant increased movement of storm floods rich of sediments carried down to Lake Boyo.

As a result of such situation, Lake Boyo is extending, and it can be clearly seen from the Landsat imageries of the area. Fofo River was used as the discharge of Lake Boyo, however; blocked by the rising level of sand deposits, it is disappeared. As a result, the flood waters of Lake Boyo spills back by engulfing sizeable extent of crop and pasture lands and displacing large number of peoples from their homes in the vicinity.

Blocked by the rising level of sand deposits at Fofo, the flood waters spill back by engulfing sizeable extent of crop and pasture lands and displacing large number of people from their homes in the vicinity.

5.3 LULC in 1984

As mentioned earlier, there were seven major land cover units identified to exist in 1984, viz., cultivated land, water body, marshland, degraded land, wood land, shrub land and grass land.

In that year, nearly 31.0 percent of Lake Boyo catchment was under crop cultivation. Interpretation and analysis of the land cover data of that year revealed that the area occupied by vegetation cover, including grasslands was estimated at 58,008 hectare, which accounted for 36.54 percent of the overall land cover in the area. The water body occupied 240 hectare and other land use classes occupied 51075.12 hectare. Figure 26 shows graphic display of area coverage of each land use type of 1984.

Figure 26. Graph depicting area coverage of each land use type in 1984.

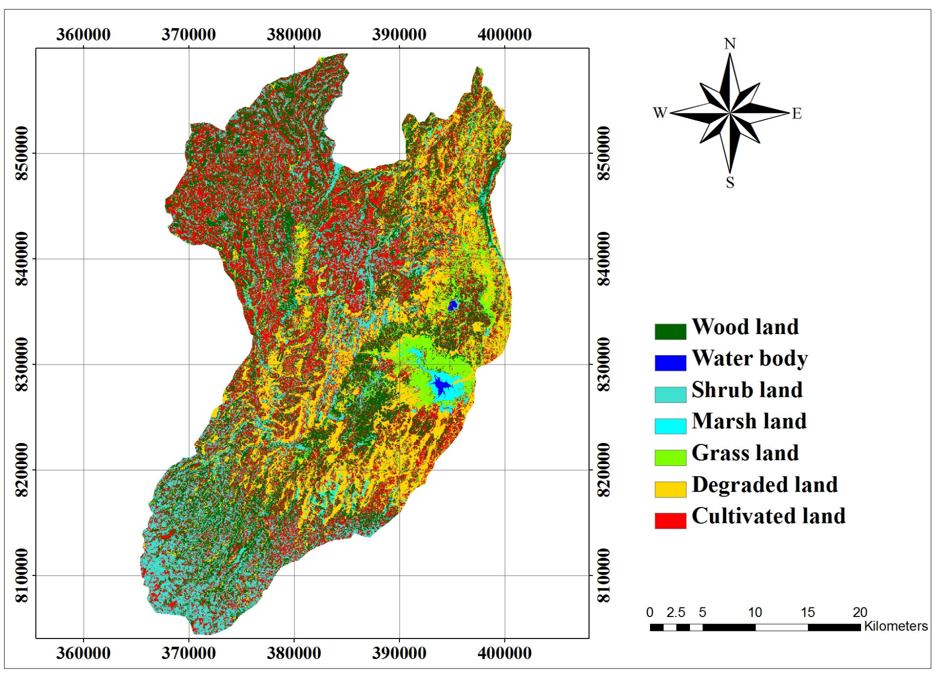


Figure 27 . Land use map of Boyo Lake catchment in 1984.

5.4 LULC in 2005

The pattern of land cover distribution around 2005 reflected the expansion of cropland at the expense of diminishing in the coverage of general vegetation in wider part of the catchment. Broadly, the proportion of cultivated land, which was about 31.0 percent in 1984, grew to 51.64 percent in 2005. Such increase led to the devastation of about 31,067 hectares of natural and man-made vegetation existed around 1984. As it can be seen in Figure 27 the area occupied by vegetation cover, including grasslands was estimated to be 32,903.8 hectare and the area occupied by water body is 2450.46 hectare while other classes occupy 51585.5 hectare.

Among other things, areas surrounding the lake showed a gradual shift from vegetation land to cultivation activities with the corresponding area of the Lake's water body, marshland units and tall grasses grown on marshy and wet land units by pushing the formerly vegetation land which in 2005 were almost entirely converted to cropland under potential risk of flooding. As flood would significantly contribute to the surface increase of the lake's water, the seasonal size of Boyo Lake was expected to have been stretched further in the years after 2005. Consequently, the extent of invasion on crop and grassland covers could be wider.

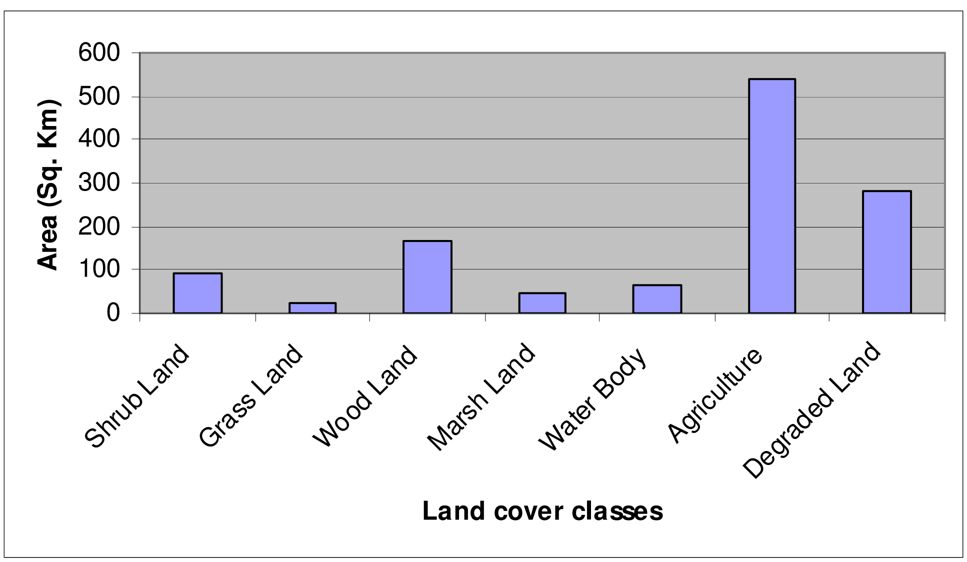


Figure 28: Graph depicting area coverage of each land use type of 2005.

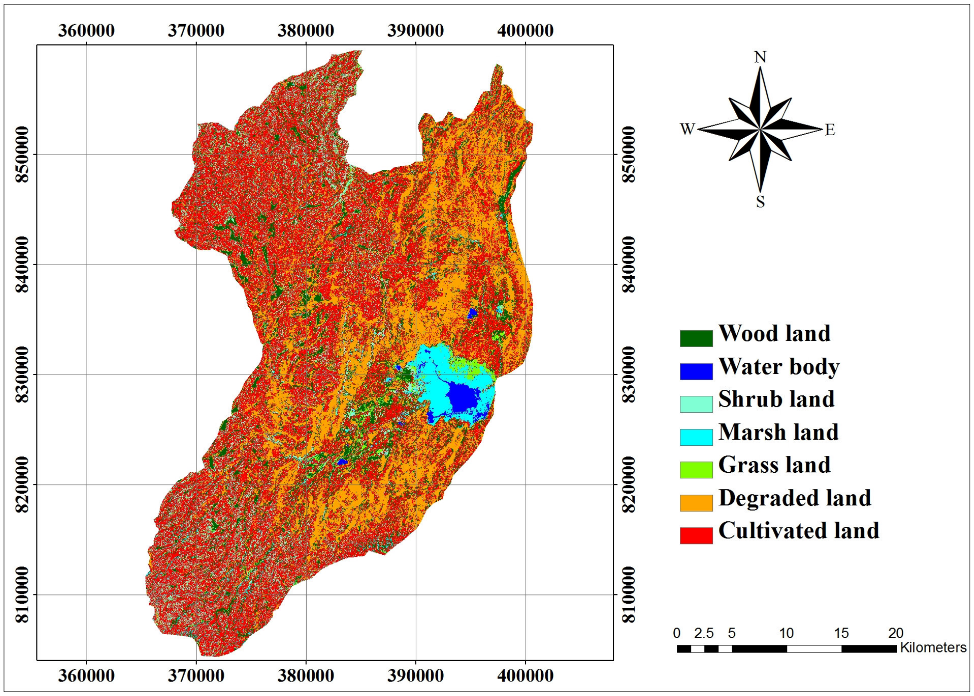


Figure 29. Land use map of Boyo Lake catchment in 2005.

5.5 Change Detection

The period between 1984 and 2005 witnessed the greatest change in the composition of land cover in Boyo catchment. In 2005, cultivated land alone covered about 48.64 percent of the area. Broadly, the proportion of cultivated land, which was about 31.0 percent in 1984, grew to 48.64 percent in 2005 (table 17). Such increase led to the devastation of about 31,067.4 hectares of natural and man-made vegetation existed around 1984.

The change detection statistics of the area coverage of different land use land cover in Lake Boyo catchment was cross tabulated using ENVI 4.3 software package.

The change detection statistics display the analysis result in three forms as number of pixel, percentage and area. It was done by referring the 1984 Landsat TM classified image as initial state and the 2005 Landsat ETM+ classified image as final state image. The result shows the change of each land use classes listed as follows; (-46.42%) shrub land, (-73.96%) grass land, (-48.4%) wood land, (56.74%) marshland, (98.9%) water body, (58.69%) cultivated land.

Table 17. The land use/land cover of Lake Boyo catchment change detection statistical summary in percentage

		From initial State (1984)						
		Shrub Land	Grass Land	Wood Land	Marsh Land	Water Body	Agriculture	Degraded Land
To final State (2005)	Unclassified	0	0	0	0	0	0	0
	Shrub Land	24.1	2.64	6.57	0.25	0.2	7.71	1.03
	Grass Land	2.52	3.52	2.95	0.105	0	1.3	1.45
	Wood Land	9.39	14.56	22.03	11.801	0.51	10.45	13.31
	Marsh Land	4.96	18.61	2.5	9.4	0.21	2.28	1.6
	Water Body	0.056	1.26	0.12	16.05	98.82	0.16	0.52
	Cultivation	56.34	34.68	51.7	11.46	0.7	59.34	17.21
	Degraded Land	2.62	24.73	14.1	50.83	1.44	18.69	64.88
	Class Total	100	100	100	100	100	100	100
	Class Change	75.9	96.48	77.97	90.51	1.18	40.66	35.11
	Image Difference	-46.42	-73.96	-48.4	56.74	98.9	58.9	42.35

6 Conclusion and Recommendation

6.1 Conclusion

Pair wise comparison method of flood hazard map generation is a better approach to deduce a sound decision for a forthcoming flood disaster, provided the required data are standardized to a common scale in personal geodatabase. This research confirmed the method used was capable to integrate all the flood hazard causative factors and the components of flood risk as well in a GIS environment. Using this method, composite maps were generated to assess flood hazard and risk of Boyo catchment.

One of the Multi Criteria Evaluation technique which is known as Weighted Overlay in GIS environment was shown to be useful for delineating areas at different rating in terms of flood hazard and flood risk. Moreover, factor weight computation in Weight module, that is developed by providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated, has generated valuable information. This could be useful for disaster studies in the future.

Therefore, it has been shown that MCE–GIS based model combination has potentiality to provide reasonable and non-biased approach in making decisions in disaster studies. Satellite images were shown to be very important for Land use/ Land cover change studies. The change statistics of land use / land cover of Boyo catchment showed that the depletion of vegetation triggered erosion occurrences spread over the catchment which inturn increases movemebt of storm floods rich of sediments carried down to Lake boyo.

6.2 Recommendation

This investigation provides information on flood hazard at a catchment and Woreda level and flood risk at a Woreda level that could be used by the pertinent decision makers to act upon the current land use policy for reducing vulnerability to flood disaster in Shashogo Woreda in particular and that of the Boyo Catchment at large. Thus the responsible bodies of the Woreda as well as the Region should incorporate the flood hazard and flood risk assessment studies in their development strategies. Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in the study area.

Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in Shashogo Woreda. So in order to mitigate persistent flood risks in Shashogo Woreda the following measures are recommended to be functional;

1. Reforestation of hill slopes in the catchment;
2. Planting woods densly in gullies;
3. Blocking artificial drains which interfere natural flow of rivers and streams;
4. Opening artificial channels to facilitate discharges of Lake Boyo to Bilate River

7 Reference

AG consulting Hydrogeologist and Engineeres Plc., 2007. *Water Resources Potential Assessment of two neighboring river basin namely Omo-Gibe and Bilate River Basin*. Unpublished Report.

Alessandro, G., Colombo, J., Javier. H., Ana, L and Vetre, A., 2002. *Guidelines on Flash Flood Prevention and Mitigation*. Institute for the Protection and Security of the Citizen Technological and Economic Risk Management Natural Risk Sector I-21020 Ispra (VA), Italy.

Al-Sabhan, W., Mulligan, M. and Blackburn, G. A., 2003. *A real-time hydrological model for flood prediction using GIS and Remote sensing*. Environmental Management , 9-32.

Asrat, A., Barbey, P, Gleizes, G., 2001. *The Precambrian Geology of Ethiopia*, Rock Review Ltd. African Geosciences Review 8, 271-288.

Ayenew, T., Demlie, M., Wohnlich, S., 2008. Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. Journals of African Earth Sciences,52, 97 – 113.

Baker, V.R., Kochel, R.C., Paton, P.C., 1988. *Flood Geomorphology*. Natural Hazards Review 7, 111-124.

Barton, I. and Bathols, J., 1989. *Monitoring Floods with AVHRR*. International Journal of Remote Sensing 10, 1873-1892.

Central Statistics Authority (CSA), 2007. *Statistical Abstract*. FDRE/CSA, Addis Ababa Ethiopia, 337pp.

Clark, M. J., 1998. *Putting Water in its Place: a Perspective on GIS in Hydrology and Water Management.* Hydrological Processes 12, 823-834.

Correia, F. N., Saraiva, M. D., Silva, F. N. and Ramos, I., 1999. *Floodplain Management in Urban Developing Areas: GIS-based flood analysis and urban growth modeling*. Water Resources Management 13, 23-37.

Debarati 2006. Disaster Data: *A Balanced Perspective disaster report.* Website: www.credcunch@ em-dat.net. Access Date: January, 2009.

Deutsch, M., Ruggles, F., Guss, P. and Yost, E., 1973. *Mapping the 1973 Mississippi Floods from the Earth Resource Technology Satellites*. Proceedings of International Symposium on Remote Sensing and Water Resource Management. American Water Resources Association, Burlington, VT.

Di Paola, G.M., 1972. *The Ethiopian Rift Valley (between $7^0$00' and $8^0$40' lat. North).* Bulletin Volcanology 36, 517 – 560.

DPPC, 2006. Joint Government and Humanitarian Partners: Flash appeal for the 2006 flood disaster in Ethiopia. Website: www.dppc.gov.et/downloadable/reports/appeal/2006/Flood%20Appeal%20II%20MASTER%20Final.pdf. Access Date: April, 2009.

Granger, K., 2002. *Community Risk Assessment in Mackay, a Multi-Hazard Risk Assessment*. Website: www.ga.gov.au/image_cache/GA4177.pdf . Access Date: November, 2008.

G.V. Bapalu, and R. Sinha., 2006., *GIS in Flood Hazard Mapping: A case study of Kosi River Basin, India*. Website: www.GISdevelopment. Access Date: March, 2009.

Islam, M. M. and Sadu, K., 2002., *Development of Priority Map Remote Sensing Data for Flood Counter Measures by Geographic Information system.* Journal of Hydrological Engineering 7, 346-355.

Jason, K. L., Gopalakrishnan. C and Lin.Z., 2005. *Advances in Decision Support Systems for Flood Disaster Management: Challenges and Opportunities*. Journal of Water Resources Development 21, 593-612.

Jayaseelan, A.T., 2001. *Droughts and Floods Assessement and Monitoring Using Remote Sensing and GIS: Satellite Remote Sensing and GIS Applications in Agricultural Meteorology*. Department of Space, Govt. of India, Hyderabad. 291-313.

Kazmin, V., 1980. *Transform faults in the East African Rift System*. In: Geodynamic Evolution of the Afro – Arabian Rift System. Accademia Nazionale dei Lincei, Rome, Atti dei Convegni Lincei, 47, 65 – 73.

Kefyalew A., 2003. *Integrated Flood Management Case Study Ethiopia: Integrated Flood Management*. World Meterological Organization.1-14.

Kite, G. W., 1988. *Frequency and Risk Analysis in Hydrology Water Resources Publications*. Littleton, CO.

Lambin, E. F., B.L. Turner, B. L., 2001. *The Causes of Land Use Land Cover Change: Moving Beyond the Myths*. Journal of Natural Resources 17, 150–156.

Leopold, K. and Hersh, R. (2002) Climate forecasts in flood planning: promise and ambiguity. *Journal of the American Water Resources Association* 38, pp. 1703-1713.

Malczewski, J., 1999. *GIS and Multicriteria Decision Analysis*, John Wiley and Sons, New York.

Mengesha, T., Chernet, T., Haro, W., 1996. *Explantion of the Geological Map of Ethiopia 1:2,000,000 scale*. Ethiopian Institute of Geological Survey, 79pp.

Morbedelli, L., Nicoletti, M., Petrucciani, C., Piccrillo E.M., 1975. *Ethioian South – Eastern Plateau and Related Escarpment. K – Ar ages the Main Volcanic Events (Main Ethiopian Rift from $8^0$10' to $9^0$00' lat. North).* In "Afar Depression of Ethiopia" eds. A. Pilger and A. Rosler. Schweizerbart, Stuttgart, 362 – 369.

Myers, M. F. and White, G. F., 1993. *The challenge of the Mississippi flood*. Environment 35, 6-35.

Mohr, P.A., 1967. *The Ethiopian Rift System*. Bulletin of Geophysics Observatory, Addis Ababa, 11, 1 – 65.

Nawaz, F and Shafique, M., 2006. *Data integration for flood risk analysis by using GIS and Remote Sensing as tools*. Website: www.GIS.development. Access date: March, 2009.

Ott, T. and Swiaczny, F., 2001. *Time-integrative Geographic Information Systems.* Springer, Berlin.

Smith, K and Ward, R., 1998. *Integrated Flood Risk Management in England and Wales*. Natural Hazards Review 4, 126-135.

Sanyal, J. and Lu, X., 2004. *Application of Remote Sensing in Flood Management with Special Reference to Monsoon Asia: a review*. Natural Hazards 33, 283-301.

Smith, L. C., 1997. *Satellite Remote Sensing of River Inundation Area, Stage and Discharge: a review*. Hydrological Processes 27, 1427-1439.

SOS Sahel/Ethiopia, 2008. *Land Cover Changes and Land Degradation Study at Boyo Lake Cathment*. Unpublished Report, Awassa, Ethiopia.

SWRDO, 2007. uhgÔ ¨[Ç u1999 ¯.U ¡[Uƒ ¨^ƒ ¾Å[c¨<” ¾Ô`õ ›ÅÒ ¾T>ÑMê ›ß` S[Í.

Stedinger, J. R., Vogel, R. M. and Maidment, D. R., 1993. *Frequency Analysis of Extreme Events*. Hand book of Hydrology McGraw-Hill, New York.

Tholey, N., Clandillon, S. and De Fraipont, P., 1997. *The Contribution of Space Borne SAR and Optical Data in Monitoring Flood Events: Examples in Northern and Southern France*. Hydrological Processes 11, 1427-1439.

Vermieren, J. C. and Watson, C. C., 2001. *New Technology for Improved Storm Risk Assessment in the Caribbean*. Disaster Management 6, 191-196.

Wang, Y., Colby, J. D. and Mulcahy, K. A., 2002. *An Efficient Method for Mapping Flood Extent in a Coastal Flood Plain Using Landsat TM and DEM data*. International Journal of Remote Sensing 23, 3681-3696.

Water Resources Development Assessement/Food and Agriculture Organization, 1986. Dam Site Feasibility Study of Bilate River. Unpublished Report, Addis Ababa, Ethiopia.

Wu, R. C., Guertin, D. P. and Heilman, P., 1989. *Information Technology in Watershed Management Decision Making*. Journal of the American Water Resources Association 40, 347-358.

APPENDIX

Appendix 1: Mean monthly rainfall of the study area

Appendix 2: Mean monthly temperature of the study area

Appendix 3: Cross-Tabulated area and flood hazard in different Woredas of the catchment.

Appendix 4: Cross tabulated areas and level of flood Hazards in Lake Boyo catchment.

Appendix 5: Sets of land use land cover classes collected during field work.

Appendix 1. Mean monthly rainfall of the study area.

Station	Monthly Rainfall (mm)												Annual Rainfall (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Alaba	31.9	49.0	90.4	159.3	117.6	96.3	118.7	111.0	114.9	76.8	30.1	9.1	1005.1
Angacha	35.6	47.3	131.7	224.1	179.4	168.5	202.2	205.6	218.7	120.4	74.7	43.4	1651.7
Fonko	22.4	74.0	126.1	158.6	144.9	137.4	170.1	193.6	155.2	112.0	16.9	16.0	1327.3
Hossaina	26.0	32.0	94.0	164.0	113.0	130.0	160.0	188.0	149.0	62.0	18.0	23.0	1159.0
Wulbareg	35.9	80.9	121.2	146.9	176.9	185.3	200.0	177.2	161.5	97.2	14.6	9.4	1406.9

Appendix 2. Mean monthly temperature of the study area.

station	**Monthly Mean Temperature (°C)**												**Annual mean Temp (°C)**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Alaba	20.7	21.6	21.4	21.1	20.5	19.5	18.5	18.9	19.4	19.3	19.4	20.0	20.0
Angacha	19.4	19.4	18.8	19.2	19.2	18.5	18.8	18.5	18.5	18.9	19.6	18.8	19.0
Wulbareg	18.0	18.4	17.8	18.6	17.4	18.2	17.7	17.4	17.3	17.3	17.2	16.9	17.7
Hossaina	16.4	17.8	18.6	17.6	16.8	16.0	15.7	15.5	16.0	15.9	16.5	16.6	16.6

Appendix 3. Cross-Tabulated area and flood hazard in different Woredas of the catchment.

Woreda	**Flood Hazard (Area in square kilometer)**					**Total**
	Very high	**High**	**Moderate**	**Low**	**Very low**	
Shashogo	4.5	169.8	86.4	0.31	0	261.01
Lemmo,	0	5.14	125.3	5.14	0.027	135.61
Damboya	0	9.35	60.45	5.86	0	75.66
Doyo Gena	0	0.57	33.9	32.8	0.49	67.76
Angacha,	0	12.1	97.5	29.03	0.1	138.73
AnaLemo,	0	8.4	103.1	84.8	0.1	196.4
Mierab Azerinet	0	0	1.14	54.5	2.9	58.54
Wilbareg	0	13.3	34.3	0.32	0	47.92
Misha	0	0	6.1	44.6	7.9	58.6
Total	4.5	218.66	548.19	257.36	11.52	**1040.23**

Appendix 4. Cross tabulated areas and level of flood Hazards in Lake Boyo catchment.

Level of Hazard	**Area (sq.km)**	**Area (%)**
Very High	4.5	0.4
High	218.16	21.0
Medium	553.4	49.41
Low	332.4	29.64
Very Low	11.7	1.04
Total	1120	99.95

Appendix 5. Cross-tabulated areas of PA's and flood risk.

No.	PA Name	Flood Risk area in hectare				Total
		Very High	High	Medium	Low	
1	Afto Aturancho	-	467.35	350.5	-	817.8
2	Alege Gimbichu	-	675.1	90.87	-	765.9
3	Amerkebo Shemo	-	726.9	610.15	-	1337.1
4	Bechagola	-	553.3	536.6	4.3	1089.9
5	Bidika	-	-	311.56	904.4	1216
6	Bira Mora	147.1	778.9	376.5	-	1306.9
7	Dadashashogo	-	155.8	95.2	-	251
8	Doesha Ambericho	-	761.6	1249.9	-	2011.5
9	Doesha hule	-	168.76	406.7	-	575.46
10	Doesha town	-	56.2	108.2	-	164.4
11	Golicho Boye	-	519.28	233.67	-	752.95
12	Hirko Fofo	-	597.1	250.9	-	848
13	Hoyawa	-	497.64	129.8	12.98	627.44
14	Hurbecha Antata	4.3	428.4	229.35		675.03
15	Hushe Gola	-	562.5	419.75	-	982.25
16	Jamaya	-	1726.62	69.2	-	1795.8
17	Jelo adancho	-	887.1	173.09	-	1060.2
18	Kemetcho Borara	1224.6	337.5	-	-	1562.1
19	Mololicho	99.5	1081.8	363.5	-	1544.8
20	Musagesa Hablera	39	1021.2	623.1	-	1683.3
21	Shayanbe Wanchikora	-	359.2	307.2	-	666.4
22	Shemsamsie	-	-	125.5	-	125.5
23	Shemo Ejaja	-	147.1	1774.2	415.4	2336.7
24	Suta	220.69	1068.85	116.8	-	1406.3
25	Tembule Gitoshe	-	69.24	34.6	-	103.8
Total		1735.2	13647	8986.8	1337.1	

Appendix 6. Sets of land use land cover classes collected during field work.

No.	X	Y	Cover type
1	374367	840316	Wood land
2	374368	840940	Wood land
3	373317	842615	Wood land
4	373313	843353	Wood land
5	372181	845396	Wood land
6	380497	815055	Degraded land
7	380980	816673	Degraded land
8	382655	818149	Degraded land
9	383478	819199	Degraded land
10	384499	819909	Degraded land
11	385975	818859	Degraded land
12	387224	818404	Degraded land
13	386997	822208	Degraded land
14	372494	816918	Wood land
15	371699	810173	Wood land
16	372806	821895	Wood land
17	371387	808669	Wood land
18	372011	806313	Wood land
19	374480	840473	Wood land
20	381690	837336	Cultivated land
21	377688	834441	Cultivated land
22	376126	830864	Cultivated land
23	394973	833618	Cultivated land
24	397357	830722	Cultivated land
25	395881	839181	Cultivated land
26	381576	837563	Cultivated land
27	375729	849455	Cultivated land
28	394377	848462	Cultivated land
29	387423	847128	Cultivated land
30	395625	854138	Cultivated land
31	387508	845595	Cultivated land
32	375729	849313	Cultivated land
33	374622	852123	Cultivated land
34	371131	844573	Cultivated land

35	369258	842672	Cultivated land
36	381746	841196	Cultivated land
37	371614	807761	Marsh land
38	394973	829985	Grass land
39	393781	831092	Grass land
40	393667	831148	Grass land
41	395200	831120	Grass land
42	395540	831091	Grass land
43	396988	829956	Grass land
44	397328	833447	Grass land
45	3976676	850505	Grass land
46	375758	849569	Grass land
47	372749	847071	Grass land
48	375218	852936	Grass land
49	393768	831290	Grass land
50	387111	815907	Marsh land
51	383506	813551	Marsh land
52	380923	812586	Marsh land
53	382002	823173	Marsh land
54	392929	820297	Marsh land
55	392106	828736	Marsh land
56	391652	829161	Marsh land
57	392134	827146	Marsh land
58	391368	828253	Marsh land
59	392163	826919	Marsh land
60	390656	831915	Marsh land
61	391254	830779	Marsh land
62	395171	830155	Grass land
63	395628	830439	Grass land
64	375672	849342	Cultivated land
65	387792	845680	Cultivated land
66	381860	842019	Cultivated land
67	381292	829559	Cultivated land
68	381775	827004	Cultivated land
69	388738	830439	Cultivated land
70	374906	829105	Cultivated land
71	375190	816418	Cultivated land

72	375218	815339	Cultivated land
73	382314	815197	Cultivated land
74	371018	818461	Cultivated land
75	367754	813381	Cultivated land
76	397896	848263	Wood land
77	398804	830013	Wood land
78	389239	825812	Wood land
79	386032	823088	Wood land
80	383733	825812	Wood land
81	386060	822917	Wood land
82	372437	821924	Wood land
83	371387	825557	Wood land
84	395881	839181	Cultivated land
85	381576	837563	Cultivated land
86	375729	849455	Cultivated land
87	394377	848462	Cultivated land
88	387423	847128	Cultivated land
89	395625	854138	Cultivated land
90	387508	845595	Cultivated land
91	382484	827600	Degraded land
92	382683	828452	Degraded land
93	384272	828537	Degraded land
94	377319	826124	Degraded land
95	383475	827686	Degraded land
96	382539	827742	Degraded land
97	393639	832301	Degraded land
98	372494	816918	Wood land
99	371699	810173	Wood land
100	372806	821895	Wood land
101	371387	808669	Wood land
102	372011	806313	Wood land
103	374480	840473	Wood land
104	380467	815055	Degraded land
105	380982	816673	Degraded land
106	382657	818149	Degraded land
107	383468	819199	Degraded land
108	384499	819909	Degraded land

109	385975	818859	Degraded land
110	395881	839181	Cultivated land
111	381566	837563	Cultivated land
112	375739	849455	Cultivated land
113	394367	848462	Cultivated land
114	387433	847128	Cultivated land
115	395635	854138	Cultivated land
116	395313	832670	Water Body
117	395058	835576	Water Body
118	391453	835746	Water Body
119	391254	825926	Water Body
120	396363	826522	Water Body
121	395739	826380	Water Body
122	385445	830694	Water Body
123	396987	829956	Grass land
124	396328	833447	Grass land
125	397676	850505	Grass land
126	375758	849569	Grass land
127	372749	847071	Grass land
128	375218	852936	Grass land
129	365636	859398	Grass land

Declaration

I, the undersigned declare that this thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for this thesis have been dully acknowledged.

Candidate: Destaye Gobena Derbe

Signature: ____________________

Date of Submission: ____________________

The thesis has been submitted for examination with my approval as university advisor.

Advisor: K.V. Suryabhagavan

Signature: ____________________

Date of Approval: ____________________