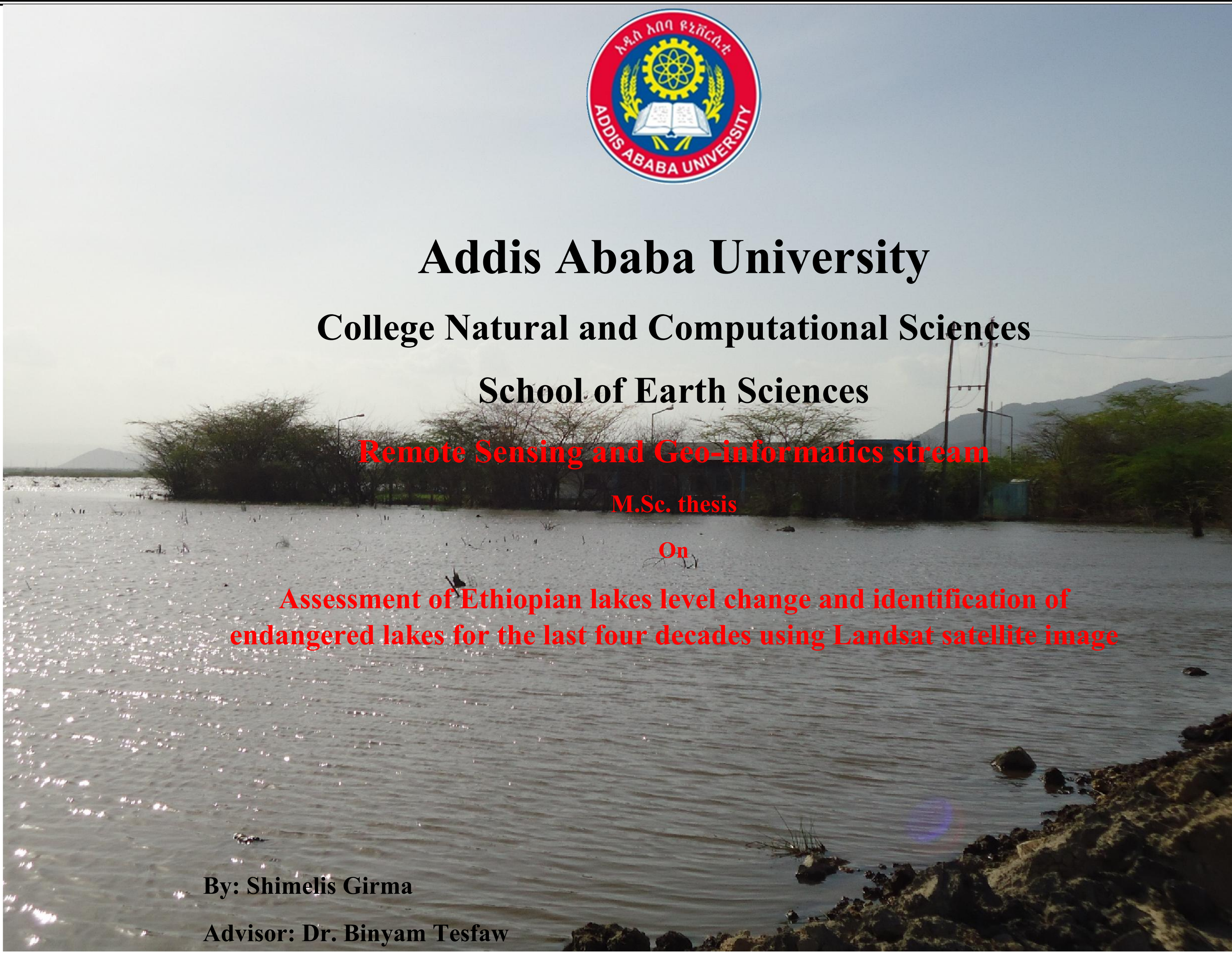


Addis Ababa University

College Natural and Computational Sciences

School of Earth Sciences

Remote Sensing and Geo-informatics stream

M.Sc. thesis

On

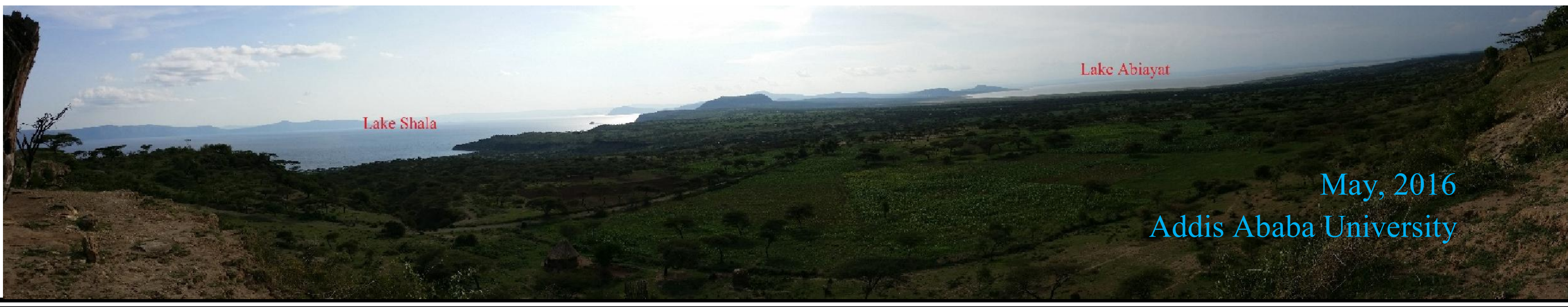
Assessment of Ethiopian lakes level change and identification of endangered lakes for the last four decades using Landsat satellite image

By: Shimelis Girma

Advisor: Dr. Binyam Tesfaw

Co-Advisor: Prof. Tenalem Ayenew

A Thesis submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote Sensing and Geo-informatics



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List of acronyms

a.m.s.l.	above mean sea level
ArcSDE	Spatial Data Engine
CSA	Central Statistics Authority
DBMS	Database Management System
DEM	Digital Elevation Model
DN	Digital Number
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization of United Nations
GPS	Global Positioning System
GIS	Geographic Information System
ha	hectare
km	Kilometer
LULC	Land Use Land Cover
MoWIE	Ministry of Water, Irrigation and Electricity
MoWR	Ministry of Water Resource
MER	Main Ethiopian Rift System
MSS	Multi Spectral Scanner
OLI	Operational Land Imager
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UNEP	United Nations Environmental Program
USGS	United State Geological Survey
UTM	Universal Transverse Mercator

Abstract

Lake level change is fluctuation of water level within the lakes that resulted from the shifting of water balance from its static state. At national scale, the Ethiopian lakes level change was not studied yet using remote sensing method and there was no well-organized geodatabase that shows their spatial variation with specified time interval. Therefore, this was the biggest challenge in order to identify whether the lakes are in dynamic or in steady state. This study aims to solve the above mentioned problem through assessing the Ethiopian lakes level change by developing well-organized geodatabase and identifying the endangered lakes for the last four decades using Landsat satellite images (Landsat MSS, TM, ETM+ and OLI sensors). The result shows that there are 108 natural and man-lakes and from these lakes endangered lakes were identified with ranking their spatial extent fluctuation. Accordingly, Lake Abiyata, Chamo, Chelelek and Haromaya, ranked top three declining lakes, and Lake Beseka, top one rising lake, was identified as endangered lakes. Furthermore, Lake Abiyata and Chamo were shrunk by 33.59% (66.64 km^2) and 8.98% (29.43 km^2) respectively and Lake Beseke was drastically raised by above 900% compared to their 1970's spatial extent. However, Lake Chelelek and Haromya were desiccated before 2010's due to anthropogenic factors. The main factors considered in this study was the Land use land cover of the lakes surrounding and over consumption of the lakes water. Moreover, the verification for identified endangered lakes were done using the field collected coordinates of the lakes edge and the trend of water level of the lakes measured by Ministry of Water, Irrigation and Energy. Due to the drastic decline, Lake Abiyata needs special rehabilitation practice and Lake Beseka also needs proper treatment. Furthermore, the final result of this study used as a benchmark for the coming researches.

Key words: Landsat image, lakes level change, endangered lakes, Ethiopia, geodatabase

Chapter I

1. Introduction

1.1. Background of the study

A lake is defined as a large body of water, usually fresh water, which is land locked and commonly formed when natural depressions or basins in the land surface become filled with water over time (UNEP, 2006). Lakes can also be defined as inland bodies of water that has no direct exchange with ocean and may contain fresh or saline water with varies depth (Hairston and Fussmann, 2002). Lakes can range from small ponds to water-bodies stretching hundreds of kilometers and containing vast quantities of water in terms of size. Beside their existence lakes can provide water for human survival, economic development and important for aquatic ecosystems (Chidammodzi, 2015).

Due to different reasons, such as over consumption of lakes and environmental factors (Brook Lemma, 2011; Megersa Olumana, 2012a), water with in the lakes may vary and causes fluctuation of the lake level. Lake level change is the change of level of water in the lake and this change is resulted from the shifting of water balance from its static state (Tenalem Ayenew, 2002). The change in water level of the lakes or the level change of the lakes are caused by climate change and other many natural and anthropogenic factors (Heine, 1969; Lavalle and Lakhan, 2000; Tenalem Ayenew, 2002; Xuchun *et al.,* 2014). Moreover, the change in water level of the lakes varied seasonally and fluctuates annually due to the difference of seasonal or annual precipitation and evaporation (Nakao, 1974). These changes are either increasing or decreasing in water level (area extent of the lakes). For instance, Lake Beseka is rapidly increasing in water level/area (Goerner *et al.,* 2008; Megersa Olumana, 2012a) and Lake Abiyata, chamo, Abaya, Lake Van (in Eastern Anatolia, Turkey) has a significant decreasing change in water level of the lake (Tenalem Ayenew, 2002; Azeb Belete, 2009; Kassaye Bewketu, 2010; Aksoy *et al.,* 2013).

Based on the nature of lakes, there are two categories of lakes. Namely, natural Lakes and man-made Lake (UNEP, 2006). According to Ryanzhin (2004) cited in UNEP (2006), there are approximately 50,000 natural Lakes and 7,500 human made Lakes in the world. For example, Lake Victoria is the natural lake that is the largest of all African Lakes and the second largest lake containing freshwater in the world, with a surface area of about 67,000 km^2 (Sutcliffe and Petersen, 2007). From those Lakes, our continent, Africa contributes about 677 lakes and Ethiopia has a share of 46 lakes which is 6.80% of African Lakes in terms of number (UNEP, 2006). According to World Fact Book (2015), Ethiopia is the world's 27th largest country, having an area of 1,126,829 km^2. From this area, the majority is covered with land and around 7500 km^2 is covered with natural and manmade lakes (Assefa Mitike, 2014; Dagnachew Melaku and Abate Shiferaw, 2014). For instance, Lake Tana that is the largest natural lake in Ethiopia and Lake Koka, which is a man made and formed by constructing dam in the Awash River in 1961 (Lautze *et al.,* 2007).

These lakes have great importance on the development of economic, environmental and social aspects for Ethiopia beside their existence. Apart from these, the lakes have an immense role on the economic growth of the country and for the survival of the surrounding communities (Seifemichael Abebe *et al.,* 2014). For instance, the majority of fish product in the country is from Lake Tana, Abaya, chamo, Hawasa and Ziway covered and used for the surrounding community as source of food as well as an economic income (Elizabeth Kebede *et al.,* 1994; Jacobus *et al.,* 2012). Besides, some lakes are used for the production of salt that have significant role on Ethiopian economy like Lakes of Ogaden, crater lakes of Dillo and Sogida (Tsegaye Berhe, 2009). The lakes are also source of income through ecotourism and source of water for irrigation farming like Lake Chamo, which is part of rift valley lakes, is one of the tourist attraction site with its huge Nile Crocodile and hippo (Wondersofethiopia, 2015).

According to many researches such as, Heine (1969); Lavalle and Lakhan (2000); Sutcliffe and Petersen (2007); Wilcox *et al.* (2007); Aksoy *et al.* (2013); Xuchun *et al.* (2014), some of the worlds' as well as Africans' lakes are vulnerable with fluctuation of water level due to human and natural impacts. Ethiopian lakes also incorporated in the changes of water level of lakes and numbers of researchers made their research on different lakes (Tenalem Ayenew, 2002; Seifu Kebede *et al.,* 2006; Berihu Abadi, 2007; Azeb Belete, 2009). For instance, the Main Ethiopian rift valley lakes such as Lake Abaya, Chamo, Abiyata, Hawasa, Ziway, Beseka and Langano were under the changes of water level of the lakes (Tenalem Ayenew, 2002; Berihu Abadi, 2007; Azeb Belete, 2009; Kassaye Bewketu, 2010; Megersa Olumana, 2012a). Moreover, the Lake Hayq water balance fluctuation or lake level also studied (Dagnachew Melaku and Abate Shiferaw, 2014); the Lake Tana level change also had been studied (Seifu Kebede *et al.,* 2006).

These previously studied researches were focused only on few of Ethiopian lakes showing the level change with different assessment methods. However, there about 46 lakes in Ethiopia (UNEP, 2006) and the majority of those lakes level change was not studied yet. Therefore, this research focused mainly on the development of the geodatabase that shows clearly the changes in water level of the lakes and the spatial variability with ten year interval for the last four decades using Landsat satellite images. Moreover, endangered lakes were identified and their major causes were studied for the management of the lake environment.

1.2. Statement of the problem

According to UNEP (2006), there are 46 lakes in Ethiopia. These lakes have great importance to Ethiopian Economy and essential for the livelihood of the community. However, the water level of the lakes varies due to climate change and other many natural and anthropogenic factors (Tenalem Ayenew, 2002). For instance, Lake Haramaya has been shrinking and totally desiccated since 2005 due to population increase and overconsumption. According to Brook Lemma (2011), the surface area of Lake Haramaya was 4.72 km^2 before 1987 and became 2.17 km^2 in 2000 then totally converted from aquatic to terrestrial. For few of Ethiopian lakes, the water balance/ level change were done by different researchers with different methods and the status of majority of the lakes are not studied yet. Moreover, these lakes have no well-organized Geodatabase that shows their change in terms of area within specified time interval. Therefore, this was the biggest challenge in order to identify whether the lakes are in dynamics (change) or in static (Steady) state. This research focuses on the analysis of the dynamics or changes of the lakes of the Ethiopia for the last four decades by developing well organized geodatabase. Then, addressing the causes for the changes of those endangered lakes.

1.3. Objectives

1.3.1. General objective

The general objective of this research is development of geospatial database for the whole Ethiopian lakes based on the Landsat satellite images acquired from the past 40 years and identifying the endangered lakes of Ethiopia.

1.3.2. Specific objectives

- Mapping of lakes from decadal interval multi temporal Landsat satellite images starting from 1970's to 2010’s and identifying endangered lakes.
- Identifying the major causes for the endangered lakes
- Verifying the extracted the endangered lakes

1.4. Significance of the study

The outcome of this study could give full information about the lake level change of Ethiopia within the last four decades. Besides, it can be a reference or initial step for the coming researches based on the development of geospatial database for the whole lakes of Ethiopia and identifying the endangered once in detail.

- Providing well organized geospatial database of lakes of Ethiopia could benefit the future researchers in these lakes.
- Clarifying the spatial variation of lakes level change for the last four decades could be important for mitigation and decision making especially environmental impacts on lakes in Ethiopia.
- Listing of the endangered and identifying the major causes for the level change of lakes have great significance for a better management of the lakes environment.

1.5. Scope of the study

This study mainly focus on the development of geodatabase for the Ethiopian lakes level change and identification of endangered lakes by ranking their fluctuation. Furthermore, the study considers land use land cover and over consumption of water are the major causative or contributing factors for endangered lakes. Accordingly, the lakes level change were attained with remote sensing data source and does not consider the water balance (inflow and out flow) and other hydrological parameters. Finally the verification was performed using field collected Global Positioning System (GPS) points and trend of the hydrological data of the lakes.

1.6. Limitation of the study

In this study Landsat satellite imagery was used for the extraction of the Ethiopian lakes level and then identification of endangered lakes. Since the Landsat image was taken from synoptic view or vertically from the top, it has a limitation on detecting the lakes with cliff edge clearly as those lakes with flat edge. The water level data for gauged lakes gained from Ministry of Water, Irrigation and Energy was time limited (due to data restriction) and some lakes have null data. Furthermore, the propagation of inflow-out flow (Water balance) during summer or rainy season were considered as the level of dry season or propagation was neglected.

Chapter II

2. Literature review

2.1. Lake level change

The lake level change is defined as changes water level of a lake seasonally and fluctuates annually due to the difference of seasonal or yearly precipitation and evaporation (Nakao, 1974). Similarly; the lake level change also described as it is the change of level of water in the lake and this change is resulted from the shifting of water balance from its static state and this is caused by climate change and other many natural and anthropogenic factors (Heine, 1969; Lavalle and Lakhan, 2000; Tenalem Ayenew, 2002; Xuchun et al., 2014). Moreover the level change of the lake is determined either by increasing or by decreasing in water level/ area extent of the lakes.

2.2.Previous researches

Previously, researches in relation with the lake level change were done by different researchers in few of Ethiopian lakes. For example, Kassaye Bewketu (2010) studied the Hydrodynamics of Selected Ethiopian Rift Lakes in which the study includes the central and southern (partly) main Ethiopian rift valley lakes. The study mainly focus on the significant factors that contribute to the water level fluctuations beginning from 1986 to 2010 and also quantify the fluctuations and identifies the lakes that need special attention. Finally, the results show that much of the fluctuations in water levels of the lakes were caused by human activities and recommends to the concerned body to protect Lakes Abiyata, Chamo, Ziway and Langano which are declining.

Tenalem Ayenew (2002) studied the recent change in the level of Lake Abiyata. The study focused on the spatial and temporal variations in the level of Lake Abiyata and controlling natural and manmade factors. The study has been made by combining evidence from hydro-meteorological and lake level records, water budget analyses, aerial photograph and satellite imagery interpretations, and numerical ground water flow modelling. Moreover, the study elaborates the most important components of the water balance of the lake; such as precipitation, river in flow and evaporation. Finally, the study argues that the climatic changes, abstraction of water for irrigation and soda ash production have a great contribution for the drastic change of the lake in both the lake level decrement and its hydrochemistry.

Azeb Belet (2009) studied the Climate Change Impact on Lake Abaya Water Level. The study was aimed to assess and analyze the impact of climate change on Abaya Lake level fluctuation by using hydrographic, socio-economy, climate and satellite data. Based on the Ministry of Water, Irrigation and Energy of Ethiopia, the study elaborates the previous level change of the lake that; from 1987 - 1998 the lake was raised by 3.35m, from 1998 - 2006 declined by 3.12 m and from 2006-2007 raised by 0.91m. The study analyzes different hydro-meteorological data the lake level fluctuation model was developed and the model forecasts in the near future (2015–2022) lake level increases even though future climatic conditions are not deterministic in nature. Moreover, the models showed the lake level fluctuate is mostly due to climatic factors (precipitation and evaporation causes the major changes) and human factors such as deforestation and agricultural expansion in the catchment.

Tenalem Ayenew (2004) studied the environmental implications of changes on the levels of lakes in the Ethiopian Rift since 1970. This study aims to address the lake level changes and their environmental consequences, based on evidence from hydro-meteorological records, hydrogeological field mapping supported by aerial photography and satellite imagery interpretations, water balance estimation, and hydrological modeling. The results reveal that the major changes in the rift valley are mainly related to anthropogenic factors and the changes appear to have grave environmental consequences for the fragile rift ecosystem. Finally, the author recommends that there should be an urgent implementation of integrated basin water management practice and there must be a legal body responsible for protecting the fragile rift environment.

Habtom G.Michael (2007) studied Lake Hawasa level fluctuation with research title of ‘Modeling and Forecasting Awassa Lake level fluctuation’. The study aims to develop model for the forecasted water balance of Lake Hawasa and defining the causes of lake level rise. The authors used runoff, precipitation, evaporation, groundwater and storage changes, and their annual changes over the 1981-2003 period data and analyze them to formulate the Lake level forecast model. Finally, the study conclude that the role of groundwater out flow is significant in the water balance of the lake and needs better attention during water balance computation and Lake Hawasa level is currently rising up.

Megersa Olumana (2012a) studied the extent (size and shape) of Lake Basaka expansion using remote sensing and GIS. The aim of the study was to assess the expansion extent (size, shape) of the lake from time series of Landsat images and ancillary data and estimate the spatio-temporal expansion extent of Lake Basaka with the prediction of possible future expansion of the lake by assuming that past trends. The result of the study indicates that the lake exhibit a remarkable and drastic expansion over the past five decades and there is a small rise in lake level has resulted in the inundation of a greater surface area. The lake water level rise by 7.6 m over the past half-century (1960–2010) and generally resulted in flooding of about 45.8 km^2 of surrounding areas and, an incremental lake volume of about 280 Mm^3.

Dagnachew Melaku and Abate Shiferaw (2014) studied the water level change detection of Lake Hayq using GIS and Remote sensing based analysis. The aim of the study was to show the water level change of Lake Hayq and the management practices for the change attained from 1972 to 2012. The analysis of the water level change was mainly focus on examining the precipitation, runoff from the watershed area, evaporation and surface outflow from the lake. The result of the study concludes the water balance of the Lake show that annually 0.9×10^6 m^3 of water misplaced from the lake and the fluctuations in the area and the level of the lake was imposed by both natural and anthropogenic forces. From those factors some of them are the natural factors like drought, topography of the watershed, erodibility of the soil, and variability of the rainfall were listed. The anthropogenic factors are over consumption of the lake water for irrigation, inappropriate use of wetland, LULC change and deforestation were described. Finally, the study recommends to keep the natural balance of the area wetland management there should be buffering zone, proper or study based use of lake water for irrigation, afforestation practice, and soil conservation program.

2.3. Nature of Ethiopian Lakes

According to UNEP (2006), there are about 46 lakes in Ethiopia. The majority of these lakes are located in Main Ethiopian Rift System (MER) and Afar depression. These lakes are categorized into two based on their nature; natural lakes and Man-made lakes. The natural lakes are those lakes created naturally or due to tectonism, volcanism and mass movement occurred in the previous eras/periods (Tenalem Ayenew, 2009). Man-made lakes are formed due various reasons of human activities for achieving different purpose. Beside their existence, the lakes have a great significance to the surrounding community as well as for the country. For instance, for the survival surrounding society, generating economic income, source of water for farming activity and important for aquatic ecosystems (Chidammodzi, 2015).

2.3.1. Natural lakes of Ethiopia

Majority of the Ethiopian lakes are natural and few of them are man-made that uses for different purpose. The natural lakes are commonly created due to the instability of the earth system. For instance, tectonic activities in and near the rift valley of Ethiopia in the previous period was the cause for the formation of the rift valley lakes (Seleshi Bekele, 2006). Based on the nature of formation of the lakes, there are different names. Namely, Crater lakes, endorheic lakes, oxbow lakes, seasonal lakes, former lakes and others (NRSC and ISRO, 2013 cited in Jawak *et al.,* 2015). The Crater Lake is a lake formed in a volcanic crater after the volcano has been inactive for some time and lake water may be fresh or highly acidic and may contain various dissolved minerals. Endorheic Lake is a lake that has no significant outflow, either through rivers or underground diffusion like Lake Shala (Tenalem Ayenew, 2002). Oxbow lake is characterized by a distinctive curved shape, it is formed when a wide travel from a stream or a river is cut off. The Seasonal lakes are lakes that exists as a body of water during only part of the year. Former lakes are the prehistoric lakes and those that have permanently dried up through evaporation or human intervention. Majority of the lakes (in most of the rift lakes) were formed during the pluvial period with associated deposition of lacustrine sands, clay and diatomite (MoWR, 2008) and some of them are formed during the Quaternary basalt flow damming such as Lake Tana (Chorowicz *et al.,* 1998). For instance, the rift lakes (the central MER), from present day Lake Ziway to Lake Awassa, were occupied by a single huge lake during a late Pleistocene wet climatic period (pluvial) and then the lake dried to a degree more severe than at the present day (Mohr, 1960 cited in MoWR, 2008).

2.3.2. Man-made lakes of Ethiopian

The man-made lakes are constructed for various purposes; such as hydroelectric power generation, industrial use, irrigation farm (agricultural use) or domestic water supply (Jawak *et al.,* 2015). For instance, Lake Koka is a man-made lake which was initially constructed for the purpose hydroelectric power generation in 1961 from river Awash (Lautze *et al.,* 2007). Beside the use of generation of hydropower it also used for irrigation farm for the surrounding community and fish farming or fisheries.

2.4.GIS data type

The data type in GIS broadly categorized into two: spatial data and non-spatial data. The spatial data is data that has location value or the geography with locational value and that non-spatial data (attribute data) is data which describe more the spatial data in the form of table (usually). The spatial data usually represented in three geospatial data models: point, line and polygon. The point represents zero dimensional value objects like man-hole, GPS points and others which cannot be represented by polygon or line due to their size/area relative to the scale. Line represents feature like river, road, irrigation canals, power lines and others. Polygon usually represents the feature, which has an area. The spatial data further classified as vector data model and raster data model. The vector data model is a representation of the spatial features using points, lines, and polygons and useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets. The raster data models is a representation of the spatial features as a surface divided into a regular grid of cells and useful for storing data that varies continuously, as in an aerial photograph and a satellite image. The source for those GIS data types are mainly from hardcopy maps, remotely sensed imageries, aerial photographs, existing digital data files and point data sampled from different sources such as Global Positioning System GPS point and coordinate points from topo sheets.

2.5.Geodatabase

The concept of geodatabase mainly dependent on the concept of database. According to Harvey (2008), a database is defined as a collection of data stored in a structured format using a computer and can be thought of as a table, but the distinction is that the table is just one way (of many) to represent the database. Moreover, Konecny (2003) defined the database as a self-contained, long-term organization of data for flexible and secure use. It consists of the data and of a database management system (DBMS), the software to manage the data. A database permits a strict separation between data and an application. Based on the structure of development, database has three structures namely: hierarchical, network type and relational database Konecny (2003). Hierarchical databases are based on a tree structure, and they are inflexible with regard to changes. It is the oldest database type and supports one–n relationships well, but lead to redundant storage for n–m relationships. Network databases have been available since the 1970s, when the Conference on Data System Languages (CODASYL) introduced the first commercially available database of this type. It supports one–m and n–m relationships without redundancy. The other type database structure is relational database structure. The relational database is currently the most common database model and it is based on relational tables. Relationships between different entity types are expressed by tables which can be related to other tables in the database by common fields (Konecny, 2003; Harvey, 2008). The unique access/ key field to an individual entity or object is made possible by a segment having a one-one or n-one relation to other segments. Since the organization of each table is independent of other tables and can be accessed, combined and changed by simple operations.

According to Harvey (2008), the relational database has several advantages for geographic representation and cartographic representation. From these:

- Conceptual model of the database is distinct from the physical model

- Separate tables help maintain the integrity of the potential meaning of database elements. Most relational databases now use structured query language (SQL) for constructing queries involving tables of a single database, or with tables in other databases, even on other computers.
- The clarity of the relationships aids people using the database with previous experiences of the database. Reliable processing is critical for queries of geographic information and online maps.
- It is possible to define multiple views of the same data in different database tables for instance listing entries by street address or alphabetically by name.

However, Konecny (2003) describes the disadvantage of relational databases. Relational databases are the database that designed for simple data that means for 2D topological and for 3D spatial queries they become slow for interactive work. For these reason there should be an extensions in Geographic Information Systems which can accelerate the management of interactive sessions.

The database's role for storing geographic information makes it central to the process of communication, also for maps produced from geographic information. However Geodatabase is defined as a collection of geographic datasets of various types held in a common file system folder, a Microsoft Access database, or a multiuser relational DBMS (such as Oracle, Microsoft SQL Server, PostgreSQL, Informix, or IBM DB2). Geodatabases come in many sizes, have varying numbers of users and can scale from small, single-user databases built on files up to larger workgroup, department, and enterprise geodatabases accessed by many users.

Based on the data storage capacity the geodatabase has three types of geodatabase; namely: Personal geodatabase, File geodatabase and ArcSDE (Spatial Data Engine). Personal geodatabase stores all datasets within a Microsoft Access data file and limited in data size up to 2 GB. The file geodatabase store as folders in a file system and each dataset is held as a file that can scale up to 1 TB in size. The file geodatabase is usually recommended over personal geodatabases. Moreover personal geodatabases are designed to be edited by a single user while with a file geodatabase, it is possible to have more than one editor at the same time provided they are editing in different feature datasets, stand-alone feature classes, or tables. The other type ArcSDE, also known as multiuser geodatabases, store in a relational database using Oracle, Microsoft SQL Server, IBM DB2, IBM Informix, or PostgreSQL and can be unlimited in data size and numbers of users.

2.6. Remote sensing

Remote sensing is the acquisition and analysis of data about an object or area acquired from a device that is not in contact with the object or area and most of the remote sensor devices are placed in earth-observing satellites and both high and low flying aircraft (Fischer and Getis, 2010). Remote sensing is the ability to gather information without being in direct contact with it. The information is gathered by instruments at the natural level by our eyes, or by cameras or radiometers (which measure radiation). The instruments can be mounted on various platforms. The platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere (Levin, 1999). The ground borne sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. Sensors on the platform of aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time. The other one is sensors on board of satellites which have been launched into orbit to observe and monitor the Earth and its environment. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis.

2.6.1. Electromagnetic Spectrum and Bands

In remote sensing the information recorded on the sensor is measurements of electromagnetic radiation. The electromagnetic spectrum is a continuum of energy from short wave high frequency cosmic waves to longer wavelength low frequency radio waves. Within the visible spectrum our eyes can see the different colors which are variations in the wavelengths. The shortest wavelength end includes X-rays and the band to which our eyes are sensitive, called then ’visible’, which lies between 0.39 and 0.76 micrometers or ’microns (millionths of a meters). Within this band there is a relation between wavelength and the color of light such that the shortest is violet light (0.390 to 0.455 microns) and the longest is red light (0.620 to 0.760 microns). These ends of the visible spectrum act to define wavelengths shorter than violet as the ’ultraviolet’ and those longer than red as the ’infrared’. In fact very much longer wavelengths are not termed infrared but fall into the category of microwaves (millimeter wavelengths) and radio waves (many tens of meters). Some sensors detect reflected radiation and others emitted radiation. Incoming sunlight (solar radiation) is reflected, absorbed or transmitted by the earth’s surface and atmosphere. The reflected energy is measured by the optical sensors. As a result of the scattering and absorption of this reflected radiation by the atmosphere, satellite remote sensing can only use certain ‘windows’ in the spectrum.

2.6.2. Earth observation satellites

Earth observation satellites are satellites specifically designed for Earth observation from orbit intended for non-military uses such as environmental monitoring, meteorology, map making to monitor disasters to explore resources and others. Most Earth observation satellites carry instruments that should be operated at a relatively low altitude and most them are in sun-synchronous orbits except meteorological satellites. From those Earth observing satellites some of them are: Landsat (Land Satellite) from 1972 to still with sensors: Operational Land Imager (OLI), Enhanced Thematic Mapper Plus (ETM+), Thematic Mapper(TM), Multispectral Scanner (MSS)); JERS-1 (Japanese Earth Resources Satellite-1) from 1992 to 1998 (sensors: Synthetic Aperture Radar (SAR), Optical Sensor (OPS)) and others.

Landsat MSS

The Multispectral Scanner (MSS) sensor that launched on-board Landsat 1–5 starting from July 1972 to January 1999 (Levin, 1999). The MSS provides four bands of Earth surface reflectance in range of visible and near infrared regions of spectrum. One scene of this sensor covers 170 km north-south and 185 km east-west and the spatial resolution 60 m (processed). Most of the scenes are processed with Standard Terrain Correction (Level 1T) and the revisiting date of this sensor is 18 days (Gyanesh et al., 2009).

Landsat TM

The Landsat Thematic Mapper (TM) sensor was carried onboard Landsat 4 and 5 from July 1982 to May 2012 with a 16 day repeat cycle. According to Gyanesh et al. (2009), Landsat 4–5 TM image data files consist of seven spectral bands. The spatial resolution is 30 m for multispectral bands or from band 1–7 and the Thermal infrared band 6 was collected at 120 m. The approximate scene size is 170 km north-south by 183 km east-west which is taken from an altitude of 705 km. Most Landsat 45 TM scenes are processed through the Level 1 Product Generation System (LPGS). The image product from this sensor has projection of UTM_WGS 84 which is taken with repeating cycle of 16 days.

Landsat ETM+

Enhanced Thematic Mapper Plus (ETM+) was built by SBRS (Santa Barbara Remote Sensing) and mounted on Landsat 6 and 7. Landsat 7's ETM+ is a derivative of the Thematic Mapper (TM) engineered for Landsat 4 and 5. The primary performance related changes of the ETM+ over the TM's are the addition of the panchromatic band and two gain ranges (added for Landsat

6), the improved spatial resolution for the thermal band, and the addition of two solar calibrators. The ETM+ design provides eight-band; multispectral bands, Thermal bands and panchromatic bands with spatial resolution of 30 m, 60 m and 15 m respectively (Gyanesh et al., 2009). The ETM+ is planned to collect, filter and detect radiation from the Earth in a swath 185 km wide as it passes overhead and provides the necessary cross-track scanning motion while the spacecraft orbital motion provides an along-track scan.

Landsat OLI (Operational Land Imager)

LANDSAT 8 satellite sensor is part of the Landsat Data Continuity Mission was successfully launched on February 11, 2013. The satellite has two main sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) (Nischal et al., 2014). OLI will collect images using nine spectral bands in different wavelengths of visible, near-infrared, and shortwave light to observe a 185 km swath width of the Earth. This sensor gives image data having spatial resolution 15-30 meter covering wide areas of the Earth's landscape. TIRS was added to the satellite mission when it became clear that state water resource managers rely on the highly accurate measurements of Earth's thermal energy (Nischal et al., 2014).

2.6.3. Hydrological application of satellite images

Satellite based remote sensing has various advantages and applications because of it can track land surface information in real-time macroscopically, multi-temporally, multi-spectrally, dynamically, and repetitively (Jawak *et al.,* 2015). In terms of the water related application, the satellite images have an important role for lakes management in both quality of the water and the spatio-temporal variation of the lakes size and shape. Moreover remote sensing has a variety applications in water resources investigations. From these surface water supply reservoir (lakes and reservoirs) mapping and monitoring, water quality mapping and modeling, runoff forecast modeling, drainage network mapping, hydrologic research, watershed characterization, and surface and ground water pollution all rely on satellite images (Khorram *et al.,* 2012). The lakes/water bodies have been mapped using optical and radar imagery in several ways. From these classification (supervised and unsupervised), visual interpretation and other methods are used (Hui et al., 2008). The accurate assessment of the change of water bodies and their catchments, in terms of distribution and variation, from remotely sensed imagery is important for the evaluation and monitoring of those resources (Ouma and Tateishi, 2007). However the accuracy of the detected change can be influenced by the satellite image used and the method adopted for the analysis (Gudina Feyisa *et al.,* 2014).

Chapter III

3. Materials and Methods

3.1. Study area description

Ethiopia is a landlocked country found in the horn of Africa, bounded to the north by Eritrea, to the west by Sudan and south Sudan, to the south by Kenya and to the east by Somalia and Djibouti. Ethiopia is located within the tropical region between 3°24′ to 14°53′ N; and 32°42′ to 48°12′ E and has an area of around 1,126,829 km^2 which is the 27th world's largest country (World Fact Book 2015). From this total area the country, the majority is covered with land and around 7500 km^2 is covered with natural and manmade lakes (Assefa Mitike, 2014; Dagnachew Melaku and Abate Shiferaw, 2014). For instance Lake Tana is the natural lake which has an area of 3060km^2 (Abeyou Wale, 2008) and Lake Koka which is man-made water reservoir initially constructed for the purpose of electric power generation in 1961 from Awash river (Lautze *et al.,* 2007).

Since the location of Ethiopia is the eastern part of Africa, the east African rift system cross the country into two parts. These are Ethiopian and Somalia plateau with a wide region of different high topography comprising the East African and southern African Plateaus and called African Superswell (Corti, 2009). However the Ethiopian Rift valley, which bisects Ethiopia land, can be divided into two main physiographic segments, namely southern Afar and the Main Ethiopian Rift (Corti, 2009). Moreover, Main Ethiopian Rift (MER) divided geographically into three sectors: Northern MER, Central MER, and Southern MER (Giday Woldegabriel *et al.,* 1990; Bonini *et al.,* 2005; Corti, 2009). With these varying physiographic features the lakes are evenly distributed to all over the country.

3.1.1. Topography

Ethiopia contains a variety of distinct topographical zones. It is a country of geographical contrasts, varying from as much as 116 m below sea level in the Danakil depression to more than 4,600 m above in the mountainous regions (Alemayehu Mengistu, 2006). Ras Dashen, with an altitude of 4,620 m, is the fourth highest peak in Africa. The most distinctive feature is the northern part of the Great Rift Valley, which runs through the entire length of the country in a northeast-southwest direction with an elevation varies from 1,500 to 3,000 m. From the west of the Great Rift Valley there is High Plateau region having rugged tableland is marked by mountain ranges. Towards the East of the Great Rift Valley, the Somali Plateau which is arid and rocky semi-desert, extending to the Ogaden, covers the entire southeastern region of the country (FAO, 1984a). In the northern Great Rift Valley, the Danakil desert reaches to the

Red Sea and the coastal slopes of Eritrea. The western boundary of Ethiopia follows roughly the western escarpment of the High Plateau, although in some regions the Sudan plains extend into Ethiopian territory.

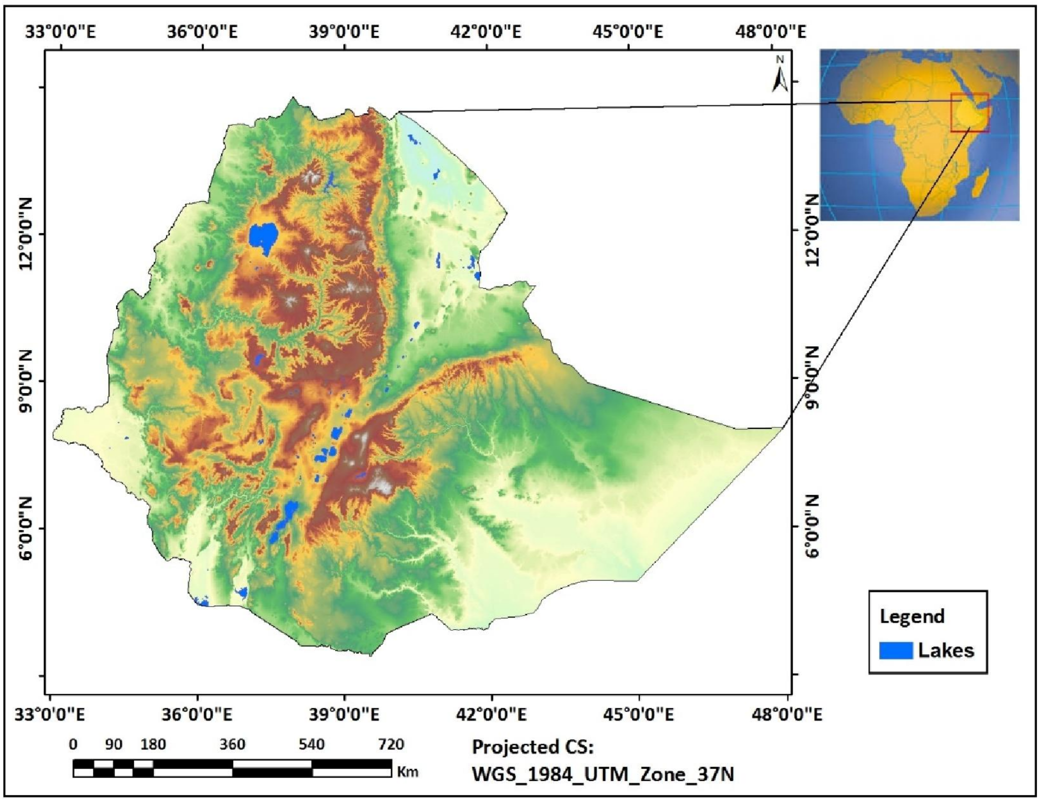


Figure 1: Study area

3.1.2. Soil

According to FAO (1984b); there are about 43 soil types or unit in Ethiopia. The soil type is extremely varying due to the land use type, parent material and topographic and climatic factors (FAO, 1984b). From these soil units, the largest part of the country's landmass is covered by Lithosols, Nitosols, Regosols, Cambisols and Vertisols (Alemayehu Mengistu, 2006).

3.1.3. Climate

Since the location of Ethiopia is the tropical region of the earth and crossed by East African Great Rift Valley system, the climate ranges from equatorial desert to hot and cool steppe, and from tropical savannah and rain forest to warm temperate, from hot lowland to cool highlands (Tamiru Alemayehu, 2006). The climate of south-eastern and north-eastern lowland regions are typically tropical and much cooler in the central highland regions of the country which west of the rift and also the some places to East of the rift. Mean annual temperature of Ethiopia is around 15-20˚C in the high altitude regions, while 25-30˚C in the lowlands. The climatic conditions of the rift valley is mainly characterized by semi-arid to arid with mean annual rainfall varying from 300 mm to 800 mm (Tenalem Ayenew, 2004; Tamiru Alemayehu, 2006).

The climate of Ethiopia is mainly influenced by altitude and the main climatic regions are Dega (cool to cold temperature), Weina Dega (warm to cool climate), Kolla (warm to hot climate) and Bereha (Hot and arid climate). The climatic region names with Kolla has the climate of hot lowlands and the average temperature is between 20°C to 30°C with the altitude ranges from 500 to 1,500m a.m.s.l. The other region is Bereha climatic region which covers an area of the desert lowlands below 500m a.m.s.l. and the average annual temperature is over 30°C. The region of Weina Dega has an average annual temperature ranges between 16°C and 20°C and comprises much of the highlands between 1,500 to 2,500 m a.m.s.l. Dega climatic region is typical of the cool highlands where average temperature falls between 10°C and 16°C and the altitude range is above 2500m a.m.s.l. Generally the largest part of the country is cold tropics (FAO, 1984a)

3.1.4. Geology of Ethiopia

Ethiopia has a complex geological history that began millions of years ago and continues, emphasizes on the roughness of the surface; a highland complex of mountains and bisected plateau characterizes the landscape (Seleshi Bekele *et al.,* 2007). According to FAO (1984a), much of the Ethiopian topography lies above 2,000 m altitude and comprises wide areas of structurally horizontal table-land. The flat lying nature of the pene-plained formed during Precambrian era basement rocks underlying, during Mesozoic era marine sediments and during Tertiary flood basalts which followed the great swell (Mohr, 1971 cited in FAO, 1984a). Dominantly or on a large scale, the Ethiopian physiography is formed due to tectonics and also denudation, deposition and volcanic processes have their own limited significant role in shaping the surface of the country (FAO, 1984a).

3.1.5. River basins

According to MoWR (2001), there are twelve river basins in Ethiopia, namely Abbay, Baro-Akobo, Tekeze. Omo-Ghibe, Rift valley, Awash, Wabi-Shebelle, Genale-Dawa, Ogaden, Danakil, Aysha and Mereb, in which ten of them have run-off excluding the Rift valley and Omo Ghibe river basins. From those river basins Wabi-Shebelle river basin covers the largest area, about 200,214 Km^2, and Abbay river basin has a maximum annual flow, which is about 52.62 billion m^3.

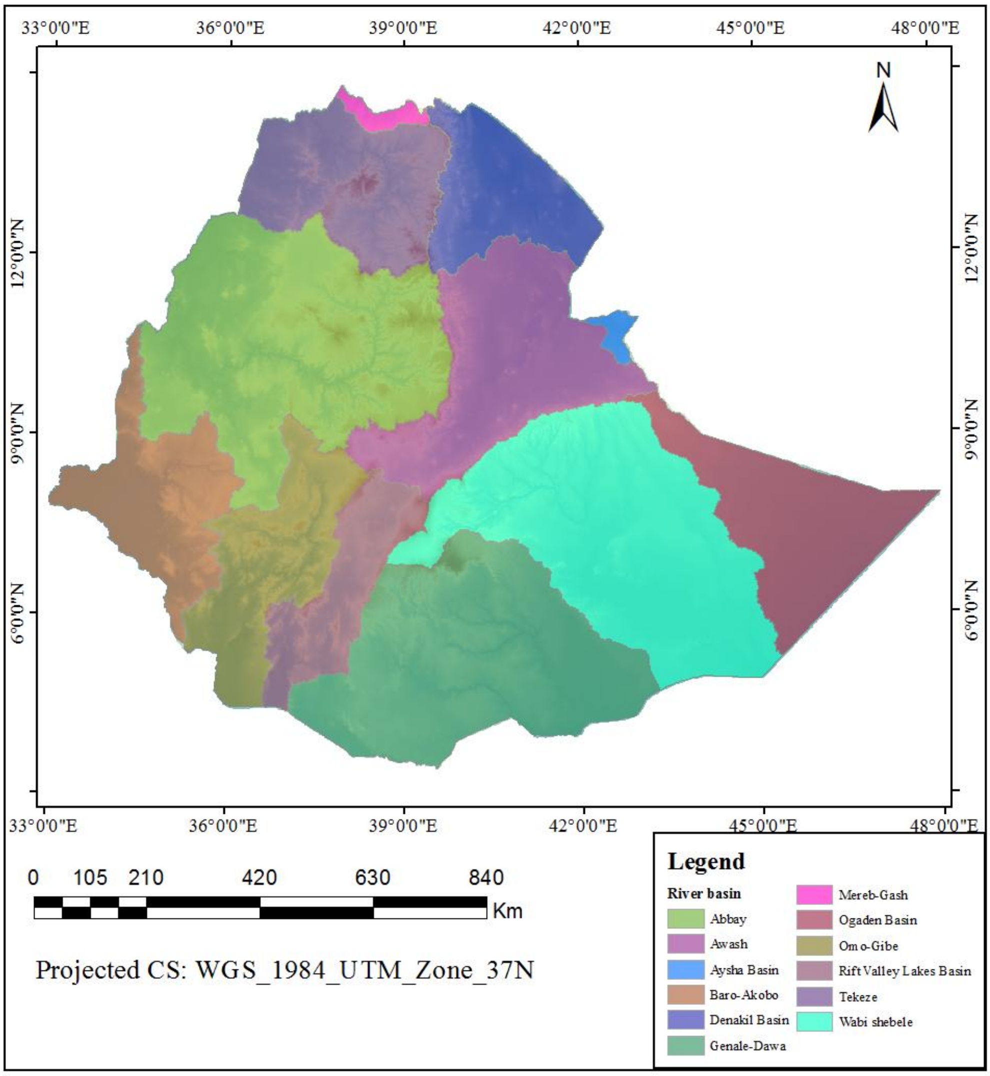


Figure 2: Ethiopia river basins (Source: MoWIE)

3.1.6. Agro-ecological zones (AEZ)

The Agro-Ecological Zones (AEZ) approach is based on principles of land evaluation used by FAO. Accordingly, agro-ecological zones (AEZs) are geographical areas exhibiting similar climatic conditions that determine their ability to support rained agriculture (HarvestChoice, 2010). At a regional scale, AEZs are influenced by latitude, elevation, and temperature, as well as seasonality, and rainfall amounts and distribution during the growing season. The resulting AEZ classifications for Africa have three dimensions: major climate zone (tropics or subtropics), moisture zones (water availability) and highland/lowland (warm or cool based on elevation) (HarvestChoice, 2010). The agro-ecological zone of Ethiopia mainly falls in climate zone which includes tropic and subtropics as shown in figure 3 below.

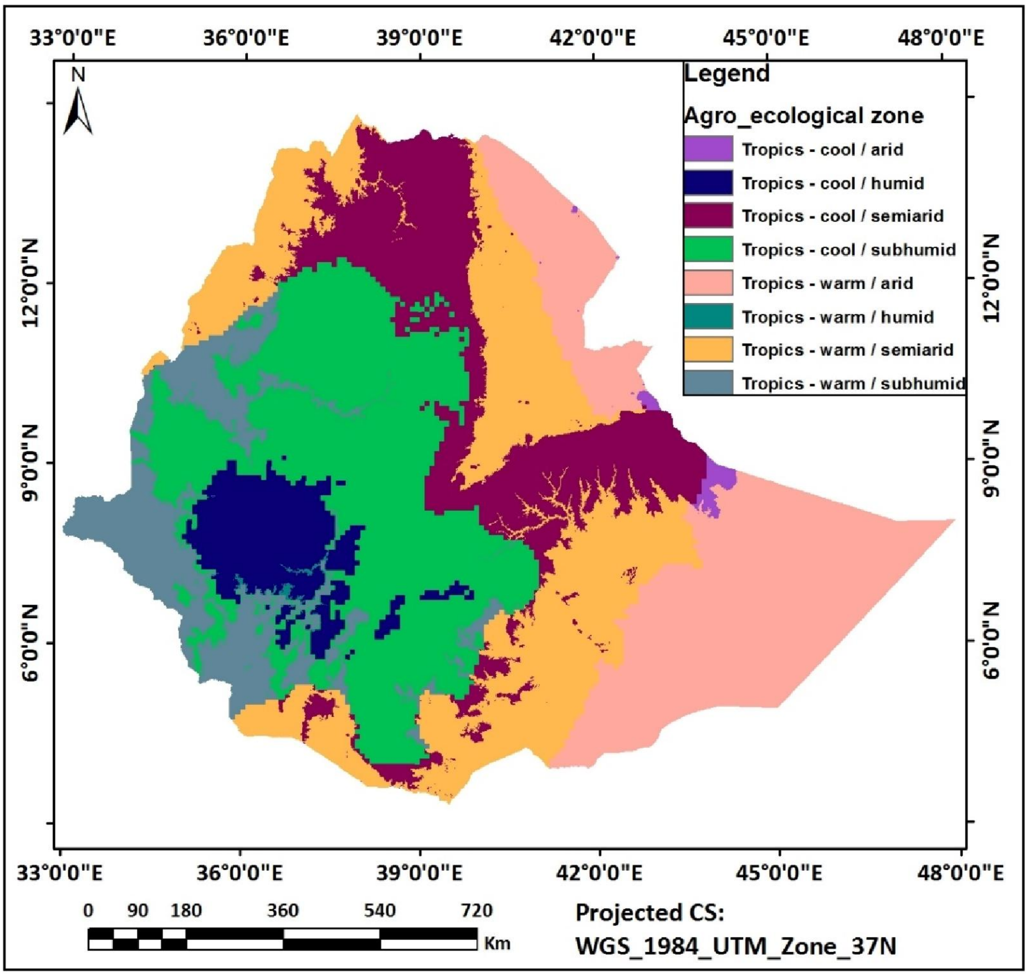


Figure 3: Agro-ecological zones (AEZs) of Ethiopia (Source: HarvestChoice, 2015).

3.1.7. Significance of Ethiopian lakes

The significance of those lakes for the surrounding community and also for the country is become crucial. Those lakes are majorly used for fisheries, tourism and recreation, irrigation farming and biodiversity conservation are some of them. For instance Lake Tana, has a fishery potential of 10,000ton/year and Lake Chamo has 4500 ton/year by leading Lake Ziway, Abiyata and Koka (Assefa Mitike, 2014).

Fish farming /fisheries

According to Assefa Mitike (2014), fish farming or fisheries in Ethiopia have great contribution to the economy in providing employment, food and income. For instance in the main Ethiopian rift valley lakes over 3,000 families depend on fishing activities in commercial such that in processing, distribution and marketing centers (Yilma Abebe and Geheb, 2003). Even though majority of the production was supplied to the market it also used as the source of food for the surrounding community (Assefa Mitike, 2014). The potential and production of fishery is differs from Lake to Lake. For example Lake Tana leads the fishery potential of the lakes by

10,000 ton/year and Lake Chamo (4500 ton/yea) and Ziway (2,941 ton/year) follows. Even though Lake Tana has a great potential, it has the third rank in production 1,454 ton/year following Lake Ziway (2,454 ton/year) and Lake Chamo (4,359 ton/year) (Assefa Mitike, 2014). Beside these over 60% of Ethiopia's fish supply originates from the main Ethiopian rift valley lakes (Elizabeth Kebede *et al.,* 1994; Yilma Abebe and Geheb, 2003). However some of lakes (like Lakes Chamo, Hawassa Abiyata and Ziway) are threatened by exploitation of over-fishing and other lakes are under-exploited (Assefa Mitike, 2014).

Tourism and Recreation values

According to Tesfaye Zeleke (2015), Lakes are some of the natural tourist attraction sites in Ethiopia. Current tourism also used as income generating beside the survival of the surrounding community. For instance Lake Hawassa is the mover or engine of the socio-economy of Hawassa city, both in the past and present (Tesfaye Zeleke, 2015). Moreover the rift valley lakes ecosystem incorporates about a total of 538 species of birds and more than 65% of the country's total species are recorded from these ecosystem (Yilma Abebe and Geheb, 2003). Because of geographical location, climate, nature, topography, beautiful lakes and a variety of wildlife, Ethiopian is currently become a major tourist and recreational site in east Africa. For instance Lake Chamo, which is located in southern part of main Ethiopian rift valley, is one of the tourist attraction site with its huge Nile Crocodile and hippo (Wondersofethiopia, 2015). Lake Abiyata and Shala are also another tourist and recreational site by their variety of resident bird species and migratory birds (Elizabeth Kebede *et al.,* 1994).

Irrigation farm

Irrigated agriculture is a priority of the agricultural transformation and food security strategy of the Ethiopian Government. Increased availability of irrigation and less dependency on rainfed agriculture is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country. The Ethiopian lake, both natural and man-made lakes, have their own contribution to the irrigation farm. For instance Lake Tana shore irrigation covers about 37,000 ha, Lake Koka feeds Wonji-Shew sugarcane 5,925 ha irrigation farm and Fincha reservoir (Abay Chomen) 8,060 ha farm land (Seleshi Bekele *et al.,* 2007). However some of the lakes are threatened by over consumption the water. For example a large scale withdrawals of water from the main Ethiopian Rift lakes are mainly used for irrigation farming and soda ash or trona extraction (Dagnachew Legesse and Tenalem Ayenew, 2006).

Biodiversity conservation

Ethiopia is culturally and biologically diverse, among the four most diverse countries in Africa for endemic vertebrates; 15% of the estimated 7,000 vascular plants are thought to be endemic (Alemayehu Mengistu, 2006). Some of the important ecological values of the Ethiopia is to be derived from its large variety of habitats. Lakes of various sizes and of fresh and alkaline waters are home to a large diversity of animal species, especially birds. From these the two neighboring lakes located in the rift valley, Lakes Abiyata and Shala, special importance to wildlife in providing feeding and breeding grounds for a rich bird fauna of over 360 species of resident and migratory birds and currently the two lakes have been enclosed in a national park since 1970 (Elizabeth Kebede *et al.,* 1994). These park ecosystems provide ecological functions which maintain and protect nature and human systems.

3.2. Materials and data description

3.2.1. Remote Sensing data

The data used for the assessment of level change of the Ethiopian lakes was Landsat images which were downloaded from USGS site named with LandsatLook viewer (http://landsatlook.usgs.gov/viewer.html). The Landsat satellites have been collecting multispectral images of Earth from space since 1972, each image contains multiple bands of spectral information which may require significant user time, system resources, and technical expertise to obtain a visual result. The LandsatLook image product option was created to provide Landsat imagery in a simple user-friendly and viewer-ready format, based on specific bands that have been selected and arranged to simulate natural color. This type of product allows easy visualization of natural color of the archived Landsat image.

The LandsatLook Viewer displays the LandsatLook natural color image product of all Landsat series (Landsat 1 to 8) images in the USGS archive and which was designed primarily for visualization purposes. The images are full resolution files derived from Landsat Level 1 data products, in which the geometric and radiometric correction were done. The natural color image is a composite of three bands are to show a natural looking (false color) image. Reflectance values were calculated from the calibrated scaled digital number (DN) of the source image data. The band combination for the natural color or false color composite is differ on the Landsat series based on the band arrangement and combination.

The Landsat program is the longest-running enterprise for acquisition of satellite imagery of Earth (USGS, 2015). On July 23, 1972 the Earth Resources Technology Satellite was launched.

Eventually Earth resource satellite renamed to Landsat. The Landsat series currently attain at the eight series which is most recent, named as Landsat 8, was launched on February 11, 2013. The instruments on the Landsat satellites have acquired millions of images. The images, archived in the United States and at Landsat receiving stations around the world, are a unique resource for global change research and applications in agriculture, cartography, geology, forestry, regional planning, surveillance and education, and can be viewed through the USGS 'EarthExplorer' website. Landsat image band combination of natural color were depends on the sensors type and the description of bands also varied as shown on table below.

Table 1: Landsat image band combination and description

	Landsat 8 OLI	**Landsat 7 ETM+**	**Landsat 4–5 TM**	**Landsat 4–5 MSS**	**Landsat 1–3 MSS**
Band combination	6, 5, 4	5, 4, 3	5, 4, 3	2, 4, 1	7, 5, 4
Band description	Band 6 – *SWIR 1 (Short-wave Infrared)*, Band 5 – *NIR (Near Infrared),* Band 4 – *Red*	band 5 *SWIR – l (Short-wave Infrared)*, band 4 – *NIR (Near Infrared),* band 3 – *Red*	band 5 *SWIR – l (Short-wave Infrared),* band 4 – *NIR (Near Infrared)*, band 3 – *Red*	band 2 – *Red,* band 4 – *Near Infrared,* band 1 – *Green;*	band 7 – *NIR (Near Infrared),* band 5 – *Red,* band 4 – *Green*

3.2.2. Ancillary data

The secondary data used in the study includes the Central Statistics Agency (CSA) spatial data released in 2007, Google Earth and Wikimapia. The CSA spatial data contains only natural lakes data for some of the regional states of Ethiopia. The other data used in this research was the Digital Elevation Model data (DEM) (30 m spatial resolution from USGS) of Ethiopia to determine the altitude of the lakes. These data were used for the identification of the lakes name and location.

3.2.3. Field data

The field data used in this research was for the land use land cover classification and validating the classification using accuracy assessment of the supervised classification. Moreover, after the endangered lakes were identified from the analysis and extraction of water bodies from the Landsat image it was used validating the lakes level change. The data type collected from the field for this research was mainly location based land use types and the changes of the lakes level edge using hand held Global Positioning System (GPS) and photo camera.

3.2.4. Software

The software used in this study were mainly ArcGIS 10.3 for the extraction of the lakes level data, producing the out puts layout and displaying and analyzing the tabular data. The other software used ERDAS imagine 2014 and Global mapper with different versions.

3.3. Methods

The methodology used in this research for achieving the objectives of the research was began with acquisition of Landsat imagery from the Landsat look viewer starting from 1970's to 2010's. The imagery acquired was at the dry season of the years in which the month ranges from October to March of three years, before half of the decade, of the each decade. After the successful data acquisition the lakes was mapped carefully by digitizing them from the Landsat imageries. Those extracted lakes was properly stored in well-organized Geodatabase for the further analysis. Finally the endangered lakes were identified as shown the figure 2 below.

3.3.1. Image data acquisition

The Landsat image with the spatial resolution of 30m were downloaded from the official web site of LandsatLook, through LandsatLook viewer, based on customized area of interest or used base area of interest. An area of interest extracted and downloaded as a simple graphic file directly through the viewer, and the original full image tile is also available. This downloaded LandsatLook image product were a georeferenced file GeoTiff (.tif) format. The image used in this research were downloaded during the dry season of years ranges from 1972 to 1975 represents 1970's decadal data, 1982 to 1985 represents 1980's decadal data and similarly continues as table 2 shown below.

Table 2: Decadal data representation

Data acquired years	Decade represented
1972-1975	1970's
1982-1985	1980's
1992-1995	1990's
2002-2005	2000's
2012-2015	2010's

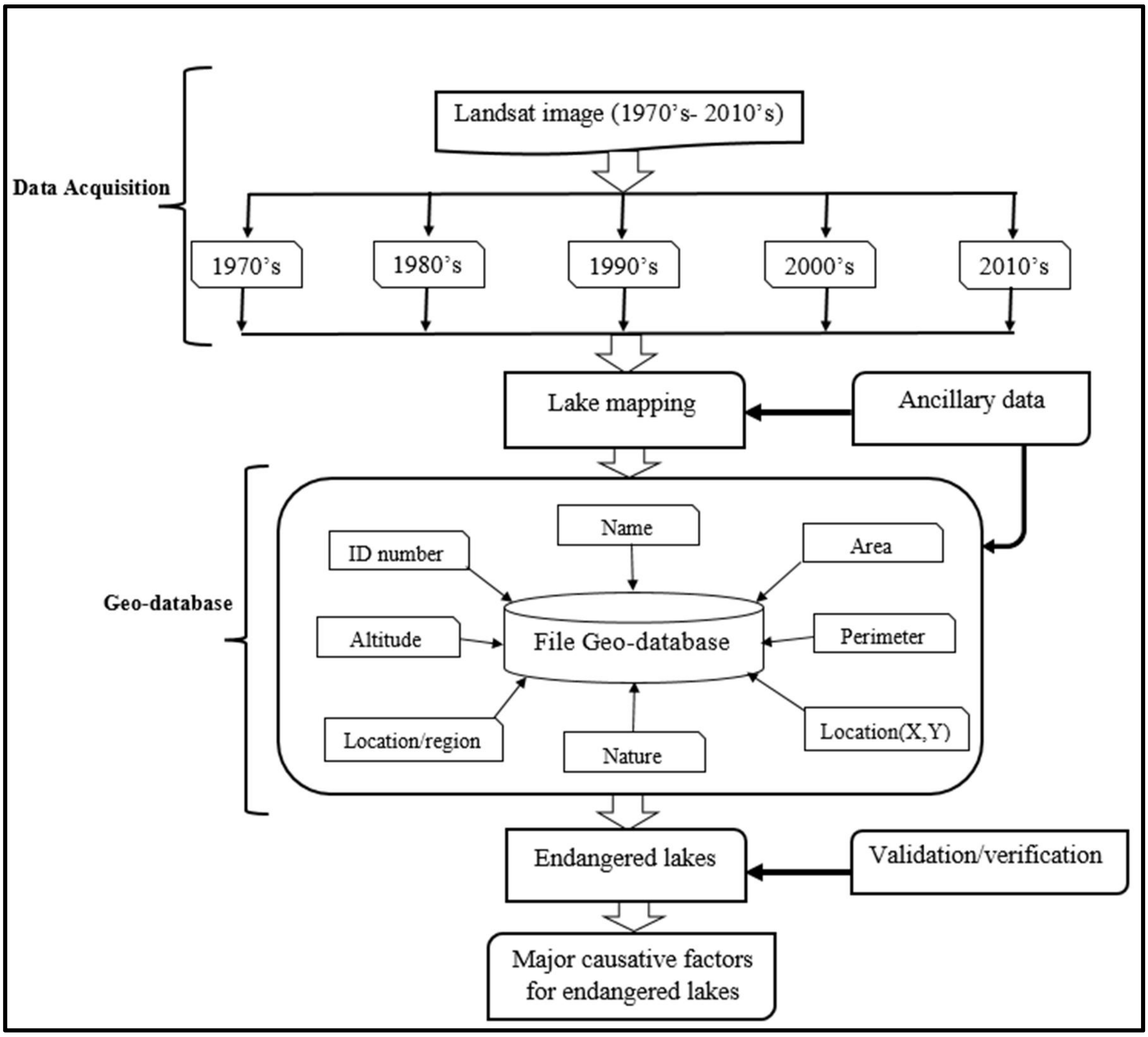


Figure 4: Work flow

3.3.2. Mapping lakes

The lakes were mapped by digitizing each lakes feature from the acquired decadal intervals Landsat imagery. Digitizing is the process of converting features into a digital format and it is one way of generating digital data. There are several ways to digitize new features, these includes digitizing on-screen or heads up over an image, digitizing a hard copy of a map on a digitizing board, or using automated digitization. From these, digitizing on-screen or heads-up digitization, is one of the most common methods used in this research. In digitizing on-screen method, an aerial photograph, satellite image, or ortho-photograph display on-screen as a base map, then features or lakes are draw on top of it.

3.3.3. Development of geospatial database

A spatial database or geodatabase designed here was the file geodatabase type which has the capacity of storing spatial data up to one Terra Byte (1TB). This geodatabase stored datasets named with decadal interval, in which each dataset has a maximum of yearly existing lakes feature class and datasets named with each lakes name, every datasets having a maximum of five lakes feature classes. The feature classes, are homogeneous collections of geographic features with a common spatial representation, typically a point, line, or polygon, and set of attributes stored in a database. The feature dataset is a collection of related feature classes that share a common coordinate system and used to integrate spatially or thematically related feature classes. Since the vector data (geographic objects with vector geometry) are versatile and frequently used for representing features with discrete boundaries geographic data types, such as streets, states, and parcels, the lakes are also represented with vector data type.

3.3.4. Identification of endangered lakes

The identification of endangered lakes were evaluated from the change of their spatial extent or area during the last four decades from the geodatabase. The change in their area were ranked and the top three from declining lakes, extinct lakes and top one from raising lakes identified as endangered or threatened lakes in this study. Therefore, the word 'endangered' represents both the drastically declining lakes (including desiccated lakes) and drastically raising lakes in Ethiopia.

3.3.5. Major causes considered for the endangered lakes

The lakes level change was mainly due to the combined effect of natural process and anthropogenic effects. From these, the land use land cover (LULC) of lakes surrounding and over consumption of lakes water were considered for endangered lakes. The LULC of the lakes surrounding was classified using supervised classification method with the field data for training area and accuracy assessment. Furthermore, abstraction of lakes water for irrigation and other purpose also considered as other factor for endangered lakes.

3.3.6. Field verification or Validation of the endangered lakes

The endangered lakes identified from the extracted Landsat satellite imagery was verified using GPS points collected from the lakes surrounding and hydrological data (for gauged lakes) of lakes collected by Ministry of Water, Irrigation and Electricity (MoWIE). The GPS points collected from accessible lakes edge that shows the current status or position of the lakes edge which was used for verifying the extracted lakes edge. Furthermore, the hydrological data from the MoWIE was used for comparing the trend of water level of endangered lakes with extracted lakes level or spatial extent changes.

Chapter IV

4. Results and discussion

4.1. Results

The Landsat series product image was used to extract the lake level change of each lake for the last four decades. The extracted lakes are populated in well-organized geo-database in decadal interval and lakes name datasets. Accordingly, there are about 108 lakes which are 93 natural lakes and 15 man-made lakes were extracted from the satellite image with the help of ancillary data as shown figure 5 below. However, the number of lakes in Ethiopia enumerated by UNEP (2006), was 46 lake and this contradicts with the result of this study. The number of the lakes varies in decadal interval because of some lakes are extinct due to different reasons and some of them are becoming in exist or created. For instance, in 1970's most of the reservoirs were not exist when compared to 2010's, and Lake Chelelek and Haromaya are extinct before 2010's. Man-made lakes (reservoirs) are majorly used for hydro-electric power generation, irrigation farm, for drinking water and related purpose. From natural lakes, Lake Tana is take the leading in spatial extent or surface area and Lake Lay Bahir is the smallest lake, area: 0.0188 km^2, in Ethiopia. The location of these lakes are shown figure 5 below with polygon representation and table 2 shows the description of the representation.

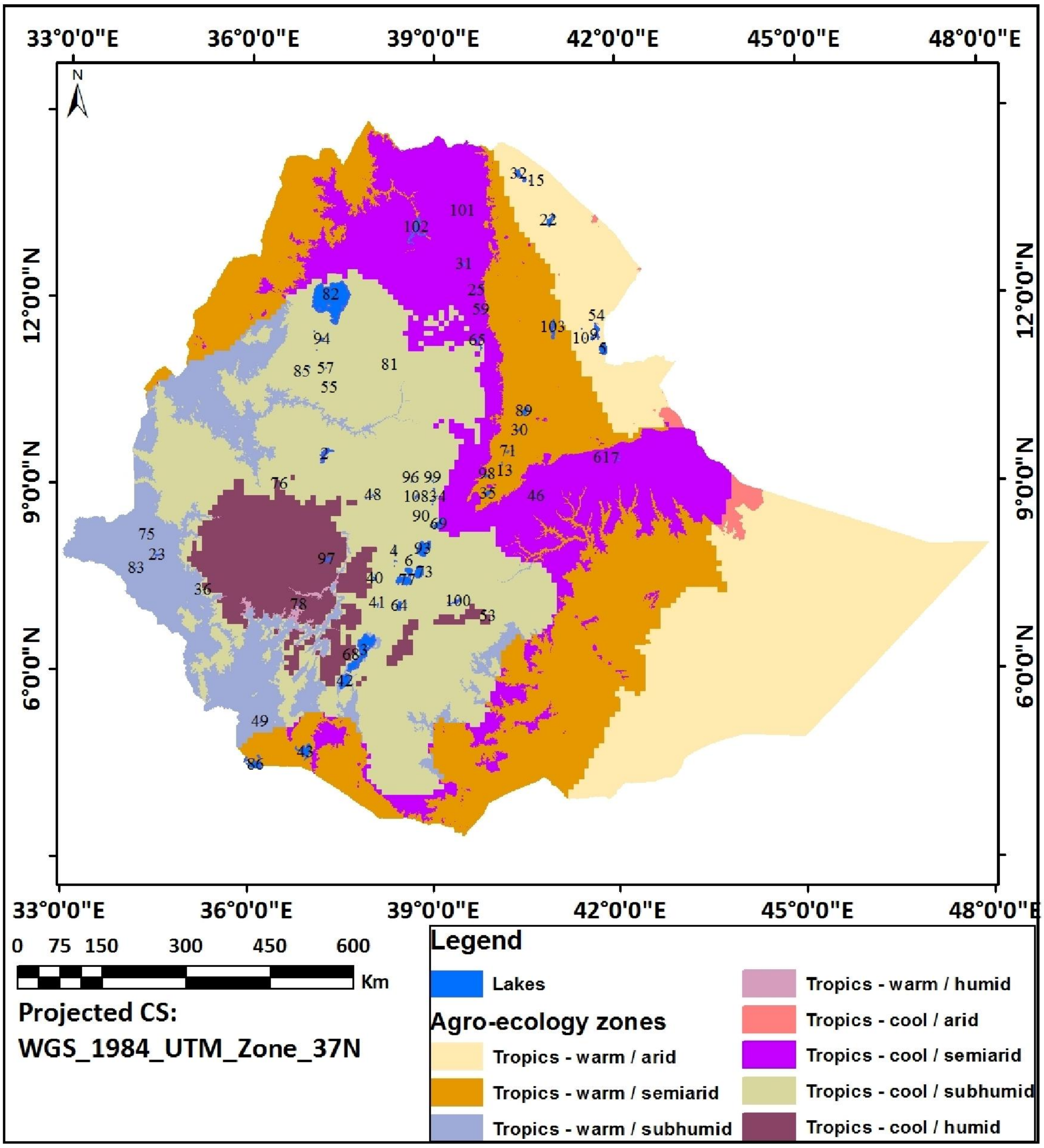


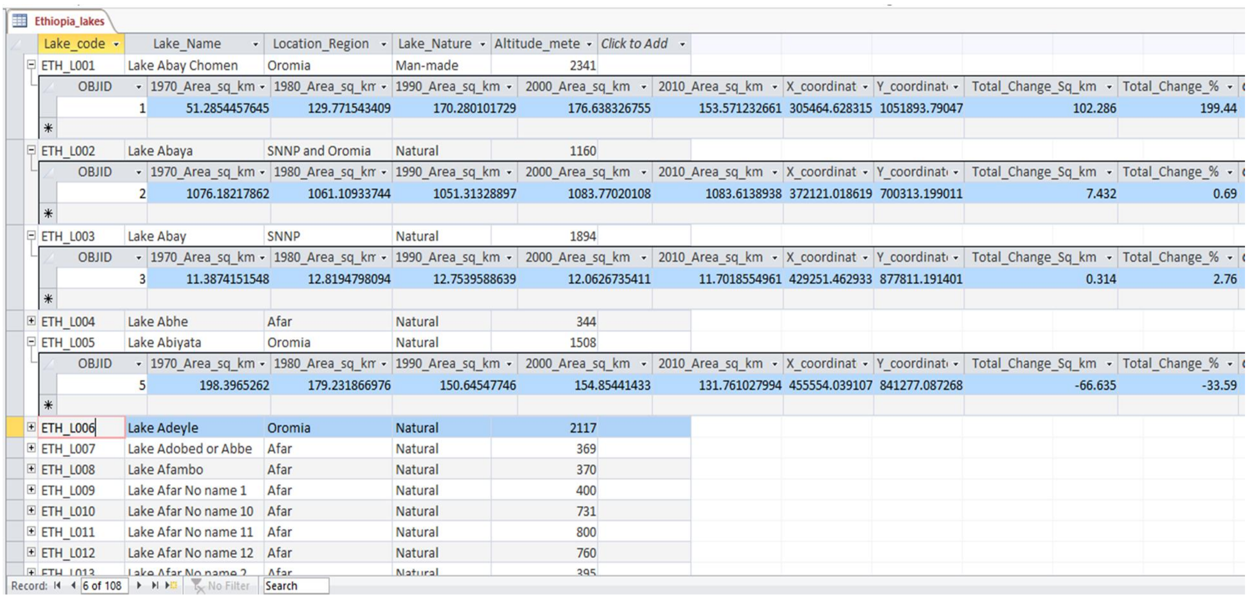
Figure 5: Ethiopian Lakes

Table 3: Ethiopian lakes description

ID	Lake_Name	Altitude (m)	ID	Lake_Name	Altitude (m)	ID	Lake_Name	Altitude (m)
1	Lake Ara Shitan	2185	37	Lake Bishoftu	1949	73	Lake Langano	1507
2	Lake Abay Chomen	2341	38	Lake Bishoftu Guda	1924	74	Lake Lay Bahir	3203
3	Lake Abaya	1160	39	Lake Bode Ameda	1544	75	Lake Nidamulo	541
4	Lake Abay	1894	40	Lake Boyo	1893	76	Lake Chancho	2193
5	Lake Abhe	344	41	Lake Budamada	1623	77	Laka Shala	1517
6	Lake Abiyata	1508	42	Lake Chamo	1150	78	Lake Shisha Womba	1336
7	Lake Adeyle	2117	43	Lake Chew Bahir	491	79	Lake Shoshma	967
8	Lake_Adobed_or_Abbe	369	44	Lake Chefre	1395	80	Lake Sorga	2007
9	Lake Afambo	370	45	Lake Chelekleka	1935	81	Lake Tach Bahir	3269
10	Lake Afar no name 1	400	46	Lake Chercher	1744	82	Lake Tana	1721
11	Lake Afar No name 10	731	47	Lake Chuche	1840	83	Lake Tata	532
12	Lake Afar No name 11	800	48	Lake Dandi	2943	84	Lake Tido	1593
13	Lake Afar No name 12	760	49	Lake Dipa	393	85	Lake Tirba	2227
14	Lake Afar No name 2	395	50	Lake Dono Womba	1949	86	Lake Turkana	328
15	Lake Afar No name 3	-69	51	Lake Elen	1597	87	Lake Wanchi	1872
16	Lake Afar No name 4	711	52	Lake Finkile	2144	88	Lake Wenchi	2944
17	Lake Afar No name 5	712	53	Lake Garba Guracha	3933	89	Lake Yardi Gaddabasa	571
18	Lake Afar No name 6	713	54	Lake Gemeri	369	90	Lake Zekuwala	2843
19	Lake Afar No name 7	708	55	Lake Geray	1800	91	Lake Zengena	2538
20	Lake Afar No name 8	702	56	Lake Gololisha	1941	92	Lake Zigna	1161
21	Lake Afar No name 9	705	57	Lake Gudera	2319	93	Lake Ziway	1620
22	Lake Afdera	-66	58	Lake Hadiya	2142	94	Reservr Koga	2042
23	Lake Aliwaro	539	59	Lake Hara	1519	95	Reservr Dire	2535
24	Lake Amha No name 1	1519	60	Lake Hardibo	2029	96	Reservr Gefersa	2564
25	Lake Amha No name 2	1632	61	Lake Hara Yabela	1987	97	Reservr Gilgelgibe I	1644
26	Lake Amha No name 3	2064	62	Lake Haro Kilole	2003	98	Reservr Kesem	897
27	Lake Amha No name 4	2092	63	Lake Haromaya	2092	99	Reservr Legedadi	2386
28	Lake Amha No name 5	1873	64	Lake Hawasa	1800	100	Reservr Melka Wakena	2268
29	Lake Archema	1873	65	Lake Hayk	1926	101	Reservr Tigr No name	2122
30	Lake Artaele	588	66	Lake Hora	1924	102	Reservr Tekeze	1067
31	Lake Ashenge	2479	67	Lake Hora Oda	1955	103	Reservr Tendaho	506
32	Lake Assale	-113	68	Lake Ila Abaya	2003	104	Reservr Wedecha	2400
33	Lake Bancili	-117	69	Lake Koka	1588	105	Lake Chitu	1558
34	Lake Belbela	1981	70	Lake Kuriftu	1913	106	Lake Chelelek	1786
35	Lake Beseka	931	71	Lake Laido	733	107	Lake Helbera	1899
36	Lake Bishan Waka	1404	72	Lake Laki	4143	108	Reservior Aba Samuel	2054

4.1.1. Lakes geo-database

The lakes geo-database (file geodatabase) developed in this study contains two types of datasets organized in terms of year or decade and lakes name. The datasets named with year or decade are five, each dataset contains number of lakes ranges from 84 to 105 feature classes. However, datasets named with each lakes name holds one to five feature classes depending on the existence of the lakes during each decade. Furthermore, for the presentation decadal change level change of the lakes, the relational database in Microsoft Access were developed. This relational database shows the variability of the spatial extent of lakes throughout the four decades clearly and easily. Moreover the database also shows the overall lakes level change both in square kilometer and percent as shown figure 6 below.



Ethiopia_lakes

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_mete	Click to Add
ETH_L001	Lake Abay Chomen	Oromia	Man-made	2341	

OBJID	1970_Area_sq_km	1980_Area_sq_km	1990_Area_sq_km	2000_Area_sq_km	2010_Area_sq_km	X_coordinat	Y_coordinat	Total_Change_Sq_km	Total_Change_%
1	51.2854457645	129.771543409	170.280101729	176.638326755	153.571232661	305464.628315	1051893.79047	102.286	199.44

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_mete
ETH_L002	Lake Abaya	SNNP and Oromia	Natural	1160

OBJID	1970_Area_sq_km	1980_Area_sq_km	1990_Area_sq_km	2000_Area_sq_km	2010_Area_sq_km	X_coordinat	Y_coordinat	Total_Change_Sq_km	Total_Change_%
2	1076.18217862	1061.10933744	1051.31328897	1083.77020108	1083.6138938	372121.018619	700313.199011	7.432	0.69

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_mete
ETH_L003	Lake Abay	SNNP	Natural	1894

OBJID	1970_Area_sq_km	1980_Area_sq_km	1990_Area_sq_km	2000_Area_sq_km	2010_Area_sq_km	X_coordinat	Y_coordinat	Total_Change_Sq_km	Total_Change_%
3	11.3874151548	12.8194798094	12.7539588639	12.0626735411	11.7018554961	429251.462933	877811.191401	0.314	2.76

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_mete
ETH_L004	Lake Abhe	Afar	Natural	344
ETH_L005	Lake Abiyata	Oromia	Natural	1508

OBJID	1970_Area_sq_km	1980_Area_sq_km	1990_Area_sq_km	2000_Area_sq_km	2010_Area_sq_km	X_coordinat	Y_coordinat	Total_Change_Sq_km	Total_Change_%
5	198.3965262	179.231866976	150.64547746	154.85441433	131.761027994	455554.039107	841277.087268	-66.635	-33.59

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_mete
ETH_L006	Lake Adeyle	Oromia	Natural	2117
ETH_L007	Lake Adobed or Abbe	Afar	Natural	369
ETH_L008	Lake Afambo	Afar	Natural	370
ETH_L009	Lake Afar No name 1	Afar	Natural	400
ETH_L010	Lake Afar No name 10	Afar	Natural	731
ETH_L011	Lake Afar No name 11	Afar	Natural	800
ETH_L012	Lake Afar No name 12	Afar	Natural	760
ETH_L013	Lake Afar No name 2	Afar	Natural	395

Record: 6 of 108 No Filter Search

Figure 6: Ethiopian lakes level change database sample

4.1.2. Extracted lakes and their distribution

The extracted lakes from the Landsat image was categorized as natural and man-made lakes or reservoirs based on their nature. Accordingly, the natural lakes which are created due to volcanic activity or creator lakes level change (for some of them) in rate of change were describe on table 4 below. Furthermore, the man-made lakes or reservoirs are also extracted which exist during the last four decades that are established at different time for different purposes. Those reservoirs show the level change from their establishment to 2010's as shown table 5 below.

Table 4: Natural lakes (Creator Lakes)

S.no	Lake Name	Coordinate		1970's Area	1980's	1990's	2000's	2010's
		X_center	Y_center	sq.km	%	%	%	%
1	Lake Bishoftu	498081.21	966295.78	0.881	12.872	12.283	12.347	6.474
2	Lake Bishoftu Guda	499278.30	971322.66	0.597	26.538	25.568	29.318	23.346
3	Lake Haro Kilole	509181.16	973103.20	0.716	18.320	118.313	26.446	33.200
4	Lake Hora	499067.67	968685.44	0.919	15.263	21.767	26.759	21.475
5	Lake Hora Oda	497397.28	961186.82	0.439	-5.043	28.349	27.220	27.889
6	Lake Kuriftu	500052.26	970402.93	0.168	16.809	-9.038	7.374	9.978
7	Lake Zekuwala	484058.32	944238.30	0.201	6.512	-4.340	-12.515	-25.808
8	Lake Zengena	277787.80	1207163.05	0.377	32.876	31.680	31.845	33.482

Table 5: man-made lakes or reservoirs rate of level change

S.no	Reservoirs name	Coordinate X-center	Y-center	1970's area in km^2	1980's %	1990's %	2000's %	2010's %
1	Abay Chomen	305464.6	1051893.8	51.29	153.04	232.02	244.42	199.44
2	Aliwaro	666426.9	869119.36			15.11 km^2	-6.67	-4.07
3	Koka	509157.7	927418.83	149.30	-4.05	6.73	-11.63	-7.21
4	Aba Samuel	468280.2	974980.18	11.63	-11.98	-100.00	-100.00	-100.00
5	Koga	300154.7	1256350.9					
6	Dire	492946.8	1012014.8				1.17 km^2	25.34
7	Gefersa	459596.1	1002379.9	1.07	8.80	-2.77	8.73	35.90
8	Gilgelgibe I	310876.6	863245.8				15.66 km^2	151.67
9	Kesem	594290.9	1011769.3					
10	Legedadi	497744.6	1002591	4.07	2.66	-10.23	-4.89	4.66
11	Melka Wakena	540635.7	788137.13			61.68 km^2	-31.20	-12.92
12	Tekeze	468550.9	1454368					
13	Tendaho	712451.5	1274525.4					
14	Tigr No name	551617.7	1486596				0.135 km^2	18.59
15	Wedecha	500209.2	989088.22		2.48 km^2	-11.19	105.63	-6.33

The distribution of the lakes in Ethiopia were evenly distributed throughout the country. The distribution of the lakes geomorphological set up of the country (both the natural lakes and man-made lakes) were in the rift valley, escarpments and highlands. From these the natural lakes found in the rift valley, Lake Abaya, Ziway, Shalla, Abiyata, Chamo, Langano and Beseka are some of them and shows the level change during the last four decades as shown table 6 below. Furthermore, the Ethiopian lakes also distributed in the highlands topographically. For instance, Lake Tana, Hayk, Ardibo, Ashenge, Wanchi, Dandi, Tirba, Lay Bahir, Tach Bahir and Garba Guracha are some of the highland lakes. Those highland lakes was also incorporated in the lakes level change during the last four decades as shown on tables 7 below.

Table 6: Rift valley lakes

S.no	Lake Name	Coordinate X_center	Y_center	1970's Area sq.km	1980's %	1990's %	2000's %	2010's %
1	Lake Abaya	372121.02	700313.20	1076.182	-1.401	-2.311	0.705	0.691
2	Lake Abiyata	455554.04	841277.09	198.397	-9.660	-24.068	-21.947	-33.587
3	Lake Adobed	783028.30	1258780.56	27.225	13.190	-38.228	-13.744	-3.492
4	Lake Afambo	791378.16	1264368.25	38.216	-0.701	-5.910	5.359	18.935
5	Lake Afdera	707765.13	1469267.19	110.240	2.225	2.225	4.589	4.390
6	Lake Assale	651159.77	1552947.78	41.861	3.564	33.044	9.259	86.463
7	Lake Beseka	595576.26	980556.21	4.338	571.243	647.526	806.369	998.747
8	Lake Chamo	340398.71	645359.12	327.840	-1.587	-5.666	-8.559	-8.978

9	Lake Chitu	436069.23	818444.38	0.733	6.675	3.121	5.933	-5.275
10	Lake Hawasa	437920.65	779808.21	83.981	4.016	7.636	9.393	6.489
11	Lake Shalla	446295.66	825346.92	306.636	0.012	-0.820	-0.805	-1.628
12	Lake Ziway	481402.14	882822.25	409.174	0.904	-0.202	0.726	1.154

Table 7: Highland lakes

S.no	Lake Name	Coordinate		1970's Area	1980's	1990's	2000's	2010's
		X_center	Y_center	sq.km	%	%	%	%
1	Lake Adeyle	824160.53	1043396.87	2.844	-2.975	-22.053	-23.560	6.669
2	Lake Ashenge	554478.67	1390731.32	14.587	-10.119	-16.434	-3.148	-1.024
3	Lake Dandi	391319.09	977549.86	6.550	10.717	11.732	10.255	13.123
4	Lake Dono Womba	261008.46	788508.99	0.652	-6.121	-4.138	-8.134	-8.846
5	Lake Garba Guracha	596256.75	760810.67	0.098	-17.598	25.728	28.822	25.592
6	Lake Hardibo	583519.32	1242411.76	15.029	0.337	-2.556	1.346	-0.290
7	Lake Hayk	577418.60	1254407.68	21.354	2.353	0.290	2.409	1.065
8	Lake Lay Bahir	420887.07	1212137.87	0.009	85.702	115.079	181.596	105.908
9	Lake Shisha Womba	258522.71	782083.92	3.116	1.335	1.927	-1.155	-2.703
10	Lake Shoshma	250762.60	762479.57	0.497	3.742	-4.613	-6.027	-0.304
11	Lake Tach Bahir	420774.29	1211429.32	0.046	-31.936	47.426	29.114	33.717
12	Lake Tirba	264746.47	1197950.83	0.468	25.076	22.402	25.285	25.252
13	Lake Wanchi	433209.01	859882.88	0.234	103.211	60.585	101.048	166.343

4.1.3. Identified endangered lakes result

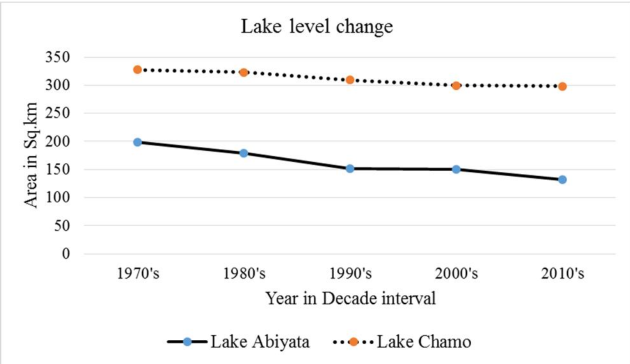
The geodatabase shows the decadal lake level variation clearly in terms of the spatial extent of the whole Ethiopian lakes. As discussed on section 3.3.4, the term endangered here represents both the lakes which has been coming to extinct and enlarging rapidly. Based on these the endangered lakes were identified based on the rank of their declining and raising of lakes during the last four decades as shown on table 8 shown below. However, the top three lakes, Lake Abiyata, Chamo and Chelelek, from declining lakes and top one from raising lakes, Lake Beseka, were identified as endangered. Moreover, due the extinction, Lake Haromaya was also included in endangered lakes as shown on table 9 below.

Table 8: Rank order of lakes change during four decades

Rank order	Declining lakes		Raising lakes		Relatively stable	
	Lake name	∆ Km^2	Lake name	∆ Km^2	Lake Name	∆ Km^2
1	Lake Abiyata	-66.635	Lake Beseka	43.325	Lake Chitu	-0.0387
2	Lake Chamo	-29.433	Lake Tana	36.966	Lake Shoshma	-0.0015
3	Lake Chelelek	-10.300	Lake Assale	36.194	Lake Lay Bahir	0.0097
4	Lake Yardi	-8.321	Lake Boyo	16.739	Lake Wenchi	0.0143

Table 9: Identified endangered lakes

	Year in decade interval										
	1970's	1980's	Decedal change in	1990's	Decedal change in	2000's	Decedal change in	2010's	Decedal change in	Total lake level change in sq.km and in %	
Lake Name	Area in sq.km	Area in sq.km	sq.km	Area in sq.km	sq.km	Area in sq.km	sq.km	Area in sq.km	sq.km		
Lake Abiyata	198.3965	179.2319	-19.1647	151.2402	-27.9917	150.9078	-0.3324	131.7610	-19.1468	-66.635	-33.59
Lake Chamo	327.8403	322.6389	-5.2014	309.2663	-13.3726	299.7817	-9.4846	298.4071	-1.3746	-29.433	-8.98
Lake Cheleleka	10.3004	6.6760	-3.6244	4.6615	-2.0145	0.1655	-4.4960	0.0000	-0.1655	-10.300	-100.00
Lake Haromaya	4.1030	4.2037	0.1006	3.0440	-1.1596	2.0773	-0.9667	0.0000	-2.0773	-4.103	-100.00
Lake Beseka	4.3380	29.1184	24.7804	32.4275	3.3091	39.3181	6.8906	47.6634	8.3453	43.325	998.75



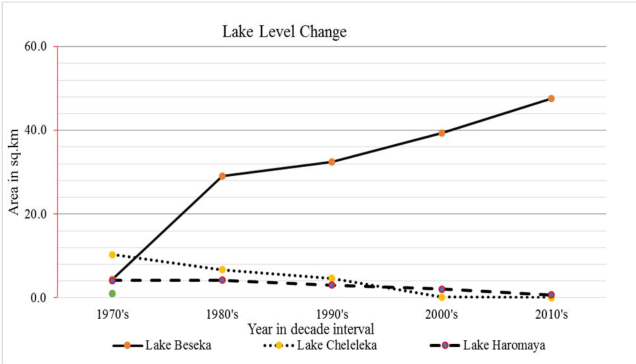
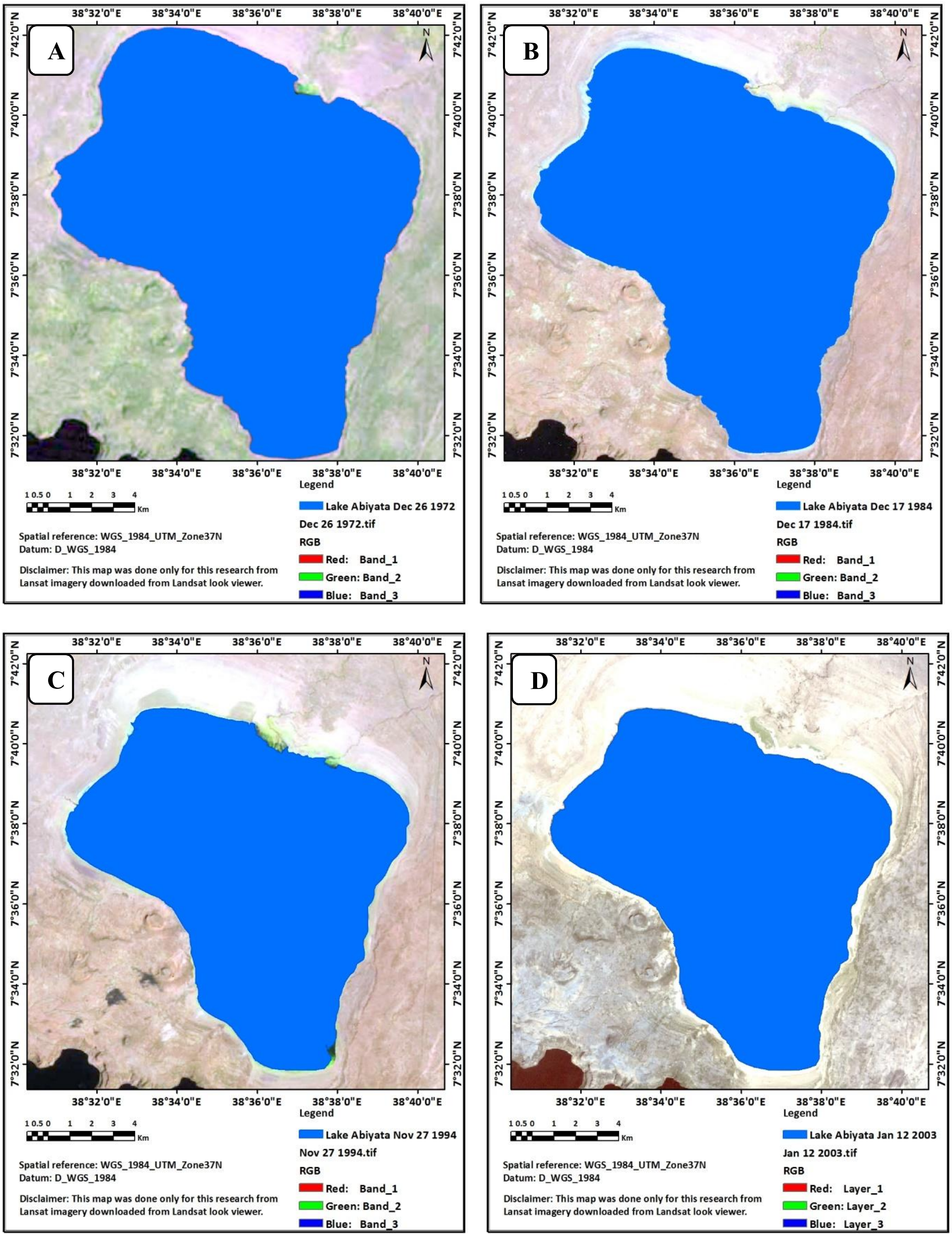


Figure 7: Endangered lakes

Lake Abiyata

Lake Abiyata is one of drastically shrinking or decreasing lake of the rift valley lakes and also Oromia region lakes compared to its initial state. Initially, in 1970's, Lake Abiyata has spatial extent or an area of 198.397 km^2 and declined on the first two decades by 19.16 km^2 and 28.59 km^2. Then on the third decades relatively the lake was decline slightly by 0.33 km^2 and on the fourth decades it comes to the decline by 23.09 km^2. Generally the Lake Abiyata was decline by 33.59 km^2 in the last four decades and currently (up to Jan 28, 2015) the lake level status is 131.76 km^2. Moreover the direction of decline of the lake is mainly on the north western direction shrunk by a distance of 3.64 km and in the south eastern direction the lake level shifted to center by 1.267 km through the last four decades as shown figures below.


A
38°32'0"E
38°34'0"E
38°36'0"E
38°38'0"E
38°40'0"E
7°42'0"N
7°40'0"N
7°38'0"N
7°36'0"N
7°34'0"N
7°32'0"N
N
1 0.5 0 1 2 3 4
Km
Spatial reference: WGS_1984_UTM_Zone37N
Datum: D_WGS_1984
Disclaimer: This map was done only for this research from Lansat imagery downloaded from Landsat look viewer.
Legend
Lake Abiyata Dec 26 1972
Dec 26 1972.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
B
Legend
Lake Abiyata Dec 17 1984
Dec 17 1984.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
C
Legend
Lake Abiyata Nov 27 1994
Nov 27 1994.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
D
Legend
Lake Abiyata Jan 12 2003
Jan 12 2003.tif
RGB
Red: Layer_1
Green: Layer_2
Blue: Layer_3

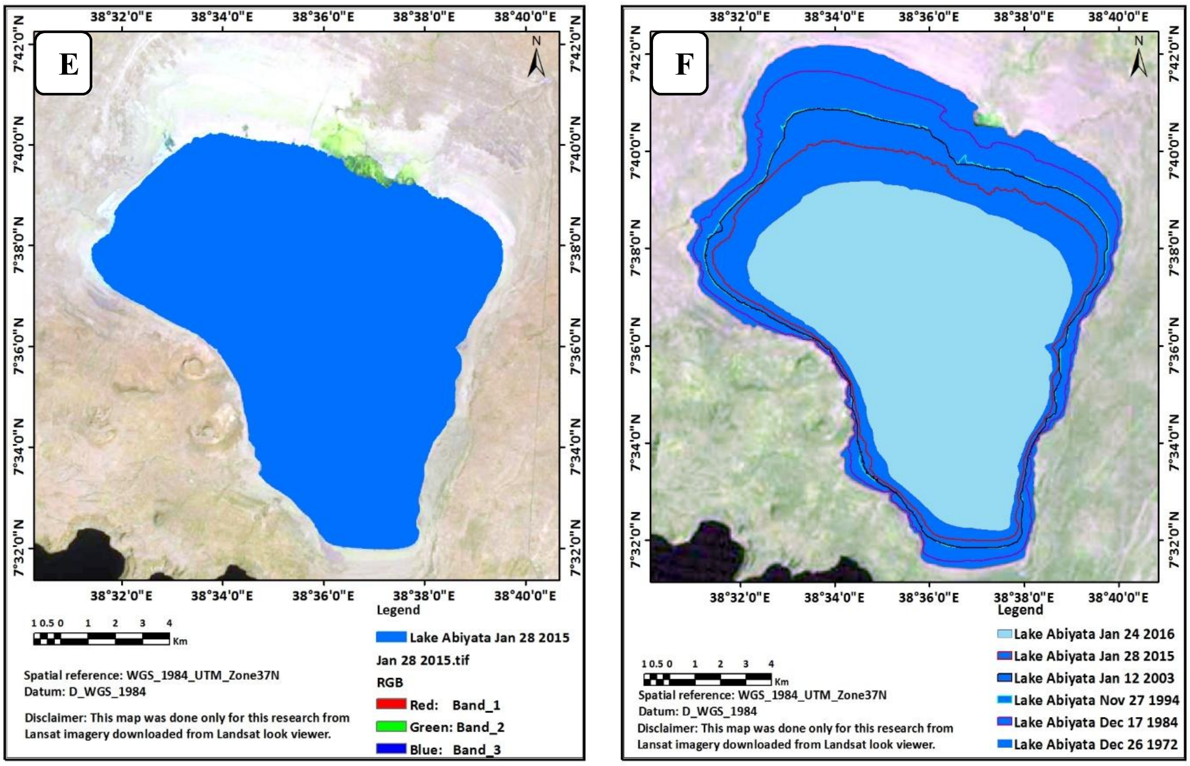
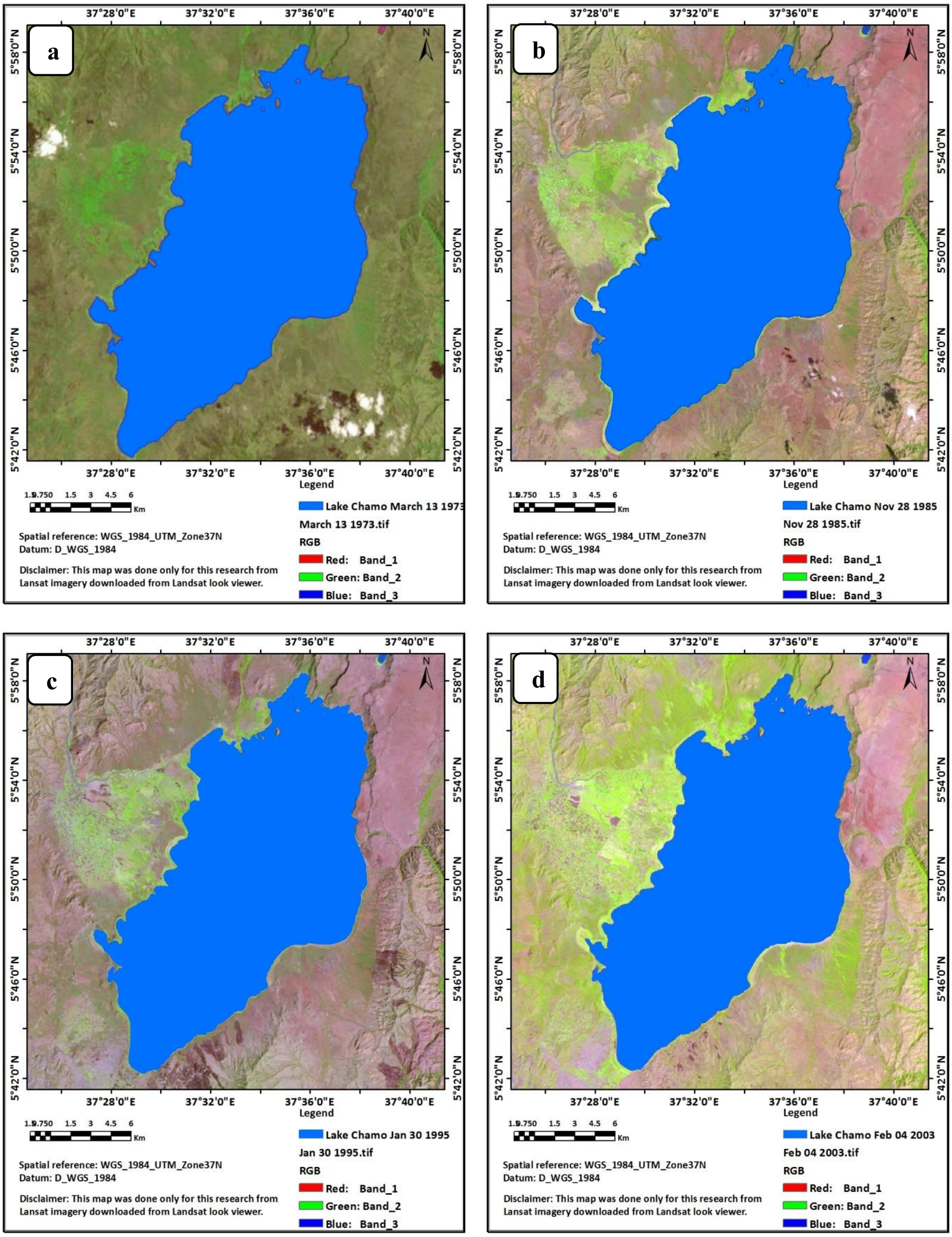


Figure 8: Lake Abiyata level change

Lake Chamo

Lake Chamo is one of the southern main rift valley lake located at the south of Lake Abaya in SNNP regional state. Lake Chamo is one of the major lake which has a great significance for fish supply in the country as well as limited irrigation farm for the surrounding society. However, the lake was decline continuously with in the four decades a total area of 29.43 km^2. Initially the lake had an area of 327.84 km^2 in 1970's and decline by an area of 5.20 km^2, 13.37km^2, 9.48 km^2 and 1.37 km^2 with respective of the decades. The direction of the declining of the lakes was in the south western and western margin of the lake and no change at the north eastern edge as shown the figures below.


a
b
c
d
37°28'0"E
37°32'0"E
37°36'0"E
37°40'0"E
5°58'0"N
5°54'0"N
5°50'0"N
5°46'0"N
5°42'0"N
N
1.5 0.750 1.5 3 4.5 6
Km
Legend
Lake Chamo March 13 1973
March 13 1973.tif
Lake Chamo Nov 28 1985
Nov 28 1985.tif
Lake Chamo Jan 30 1995
Jan 30 1995.tif
Lake Chamo Feb 04 2003
Feb 04 2003.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
Spatial reference: WGS_1984_UTM_Zone37N
Datum: D_WGS_1984
Disclaimer: This map was done only for this research from Lansat imagery downloaded from Landsat look viewer.

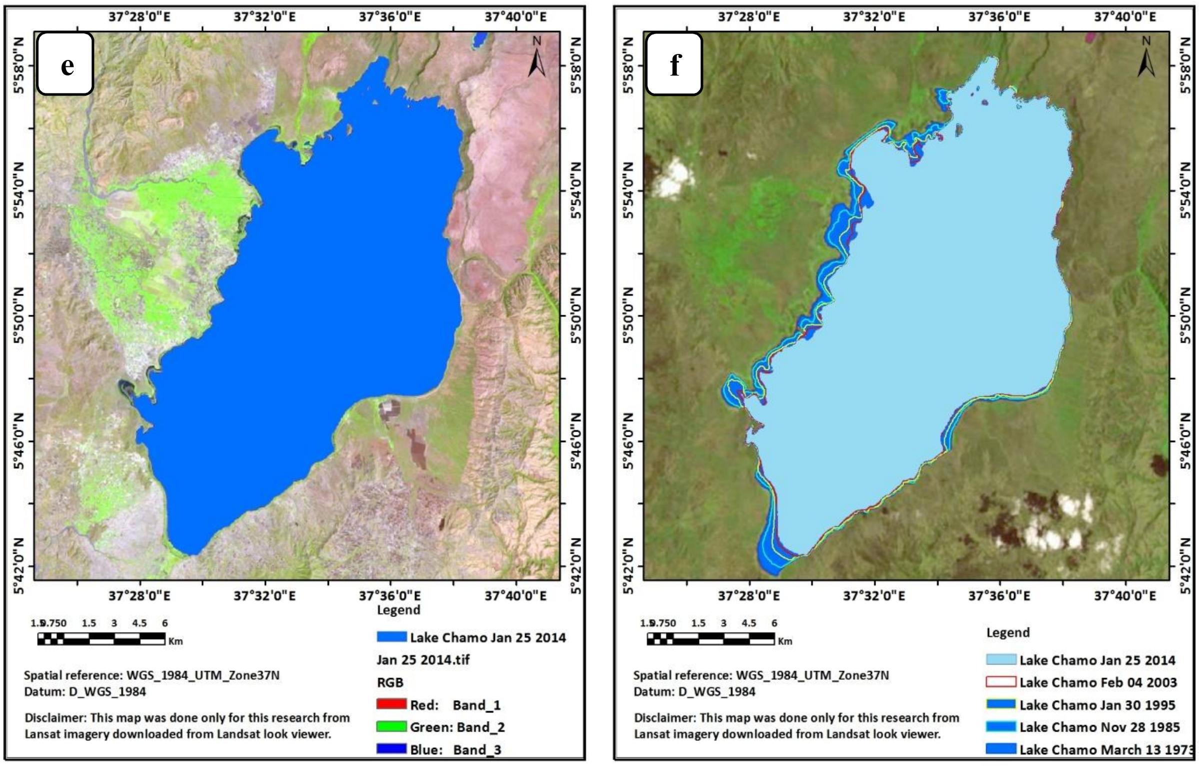


Figure 9: Lake Chamo level change

Lake Chelelek

Lake Chelelek (Lake Shalo) was one of the rift valley lakes which is located to the north east of Lake Hawasa and it was existence or before 2000's. During 1970's, the lake had an area of 10.30 km^2 and eventually it becomes disappeared after 2000's. The lake were decline with an area of 3.62 km^2 in 1980's, 2.01 km^2 in 1990's, 4.496 km^2 in 2000's and then totally desiccated as shown on the figures below.

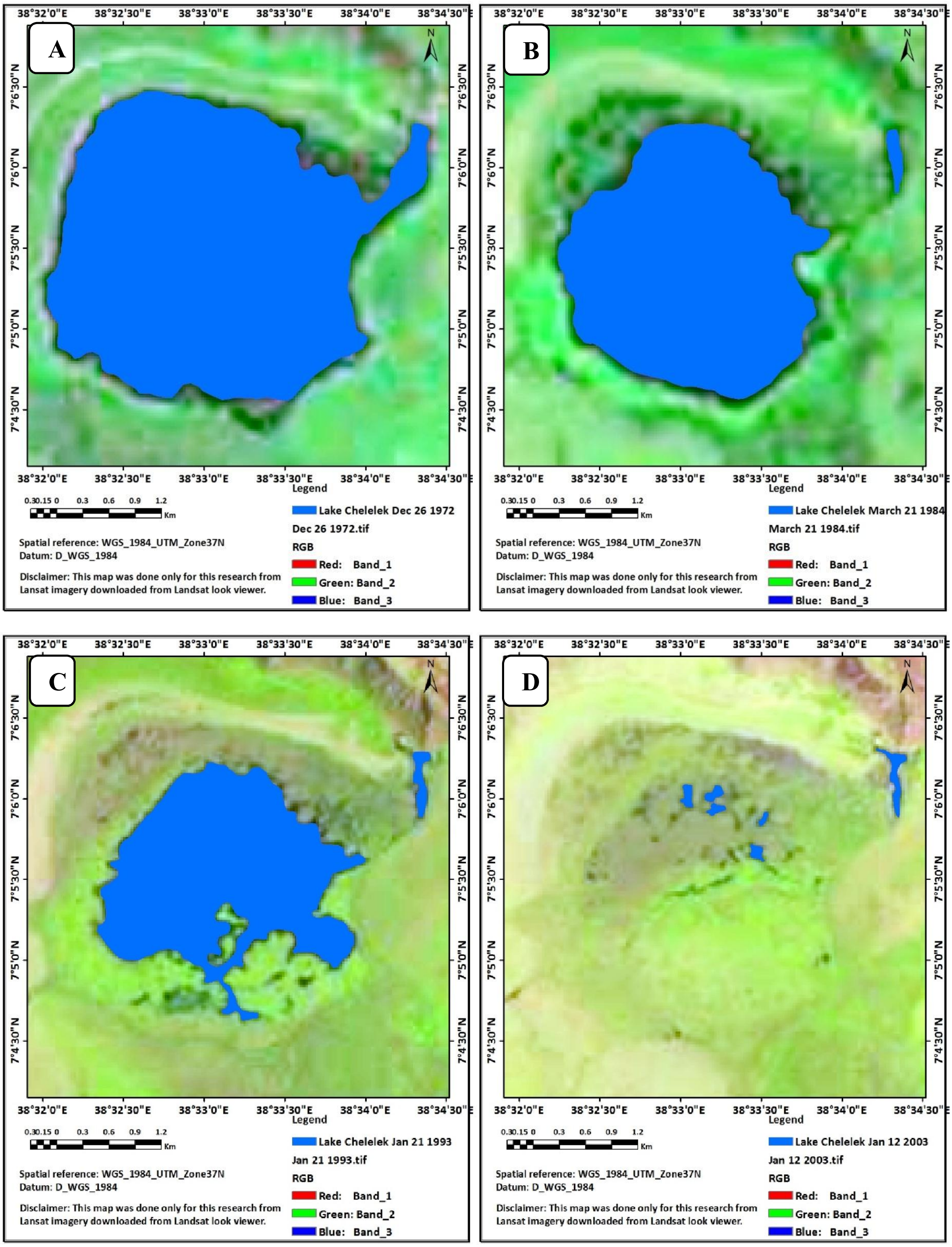


Figure 10: Lake Chelelek level change

Lake Haromaya

Lake Haromaya, which was located in eastern part of the country and west of Harar city, was one of the desiccated or dried lake during the third decades of this study or in 2000's. The lake level in 1970's of Haromaya Lake had an area of 4.103 km^2, in 2000's 2.077 km^2 and finally in 2010's it becomes null or dried.

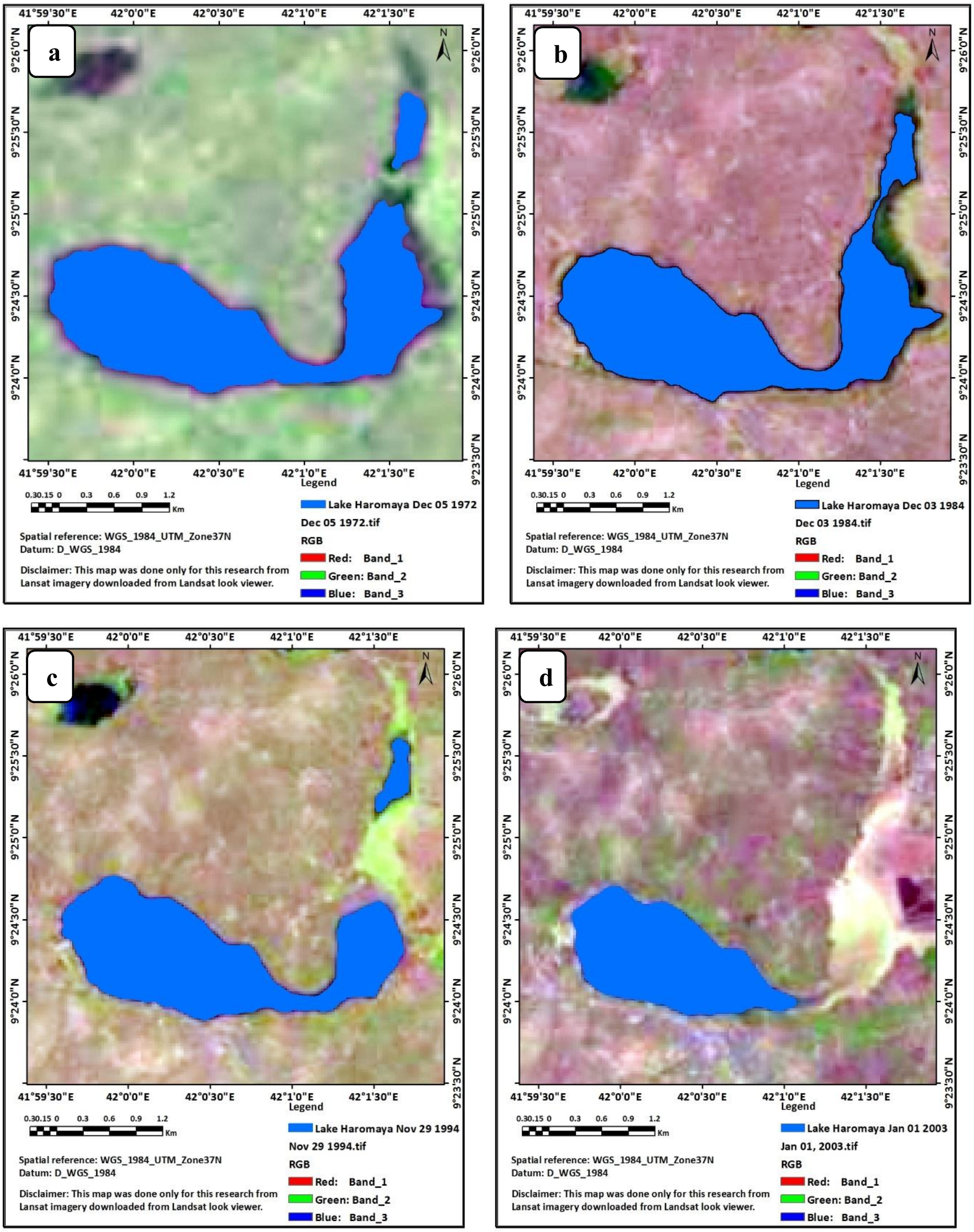
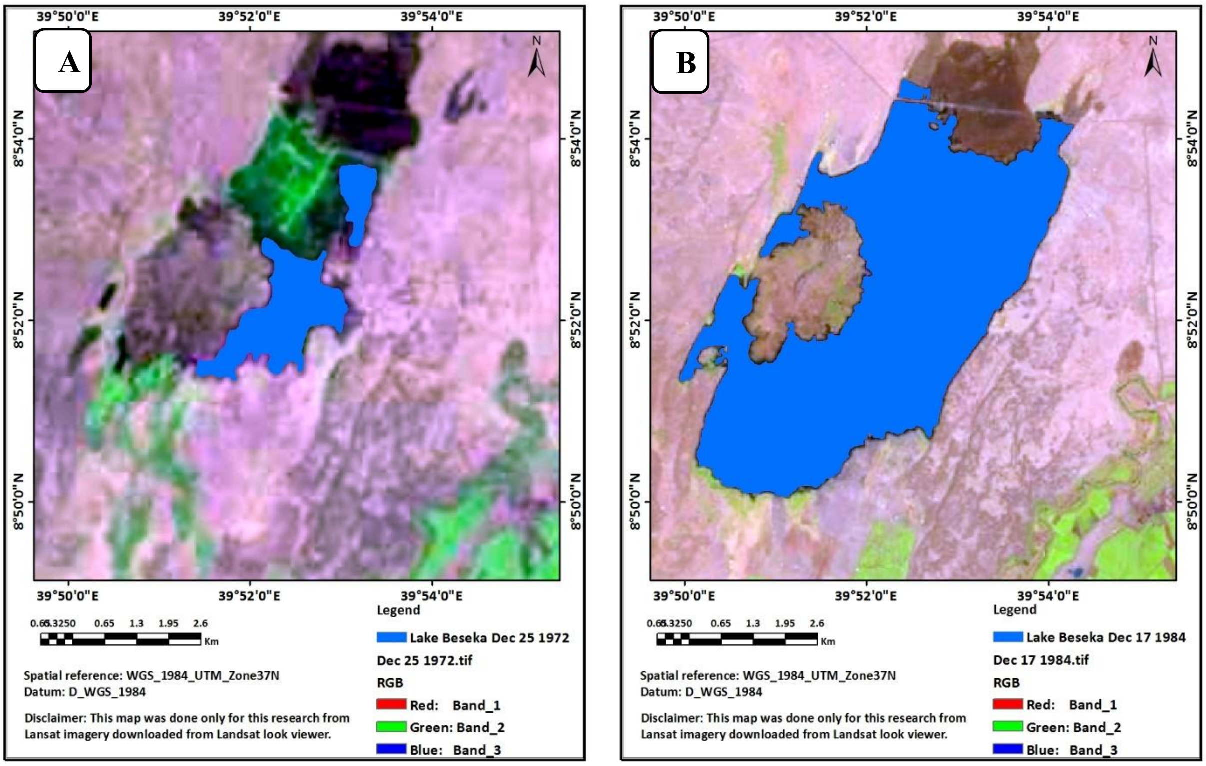


Figure 11: Lake Haromaya level change

Lake Beseka

Lake Beseka, which is located in the northern main Ethiopian rift valley region, is one of drastically rising or expanding lake in Ethiopia. In 1970's the lake level was insignificant compared to current status, which rises about a total area of 43.33 km^2 during the four decades and now the lake level covers an area of 47.66 km^2. During the 1970's the lake level covers only surface area of 4.338 km^2 and then in the next decade it was elevated by 24.78 km^2. Move over the level of the lake was also significantly increased by 3.31 km^2, 6.89 km^2, and 8.35 km^2 in 1990's, 2000's and 2010's respectively. On the other point of view, the lake level was raised from its initial level (during 1970's) in percent were about 998.75 % as shown figures below. The rise of the lake level during the last four decade was in all directions of the lake level extracted in 1970's; particularly to north and south direction the lake expands about 3.88 km and 3.66 km respectively in distance. Moreover in the west and east part of the lake there is significant expansion even if it was not equivalent to other direction. The north east and east direction the lake were expanding rapidly towards south of Metehara town is currently became endangered by flooding part of the town and road from Metehara to Addis ketema or Sugar factory as shown on figure 13 below. Furthermore, due to raise of the lake level, the lakes water were drained to Awash River and this may affect the downstream users the river because saline of the lake.



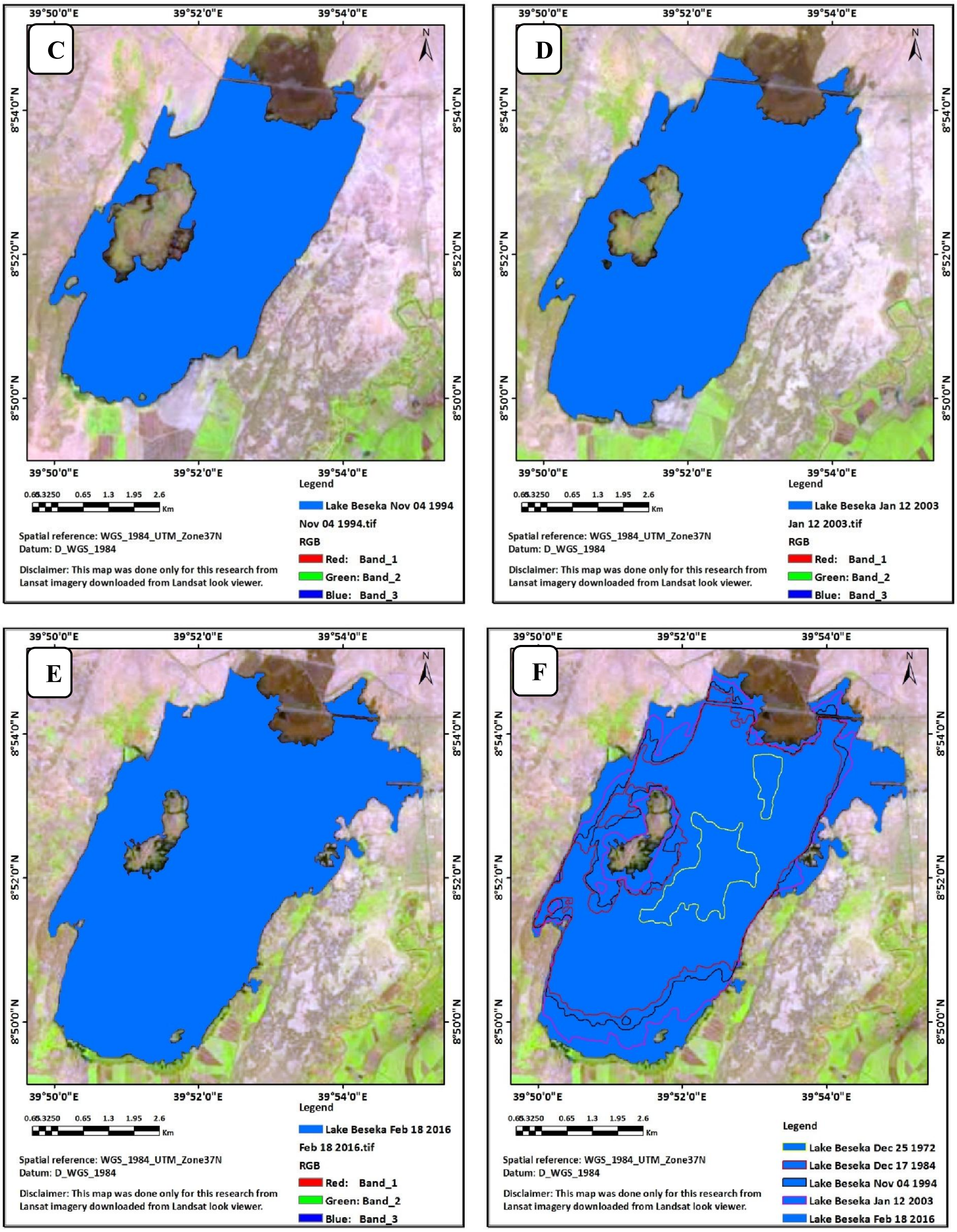


Figure 12: Lake Beseka level Change

Plate 1: Lake Beseka effects on the surrounding environment

4.1.4. Major causes considered for identified endangered lakes

The main causes for the lakes level decline or raise was different based on the location and nature of the lakes. The major causes identified were Land use land cover change and over consumption of lakes water for irrigation and other purpose. For instance, Lake Beseka and Abiyata, that are the alkaline lake, were not used for irrigation farm by the surrounding communities and Lake Haromaya were totally desiccated due to over consumption of the lakes water. Currently (during field work) Haromaya Lake was totally dried and surrounding farmers were using the previous the lake bed for cultivation as shown on plate 2 below.

The land use land cover of the Chamo, Abiyata and Beseka lakes were considered as a factor for the decline and raise of the lakes. For instance, the land use type of Lake Chamo surrounding during 1985 and 2015 shows that, the land use type were gradually converted as shown figure 14 below. Mainly the forest were decreasing and cultivation and farm lands are expanding as shown. The cultivation and farm land of the lakes surrounding were using slightly by pumping the lakes water and majorly by exploring the ground water near to lake and tributary rivers flow to lake. Furthermore, Abiyata and Beseka lakes water were not totally used for irrigation purpose by the surrounding community. The land use type of Lake Abiyata edging or surrounding were a dry sand that is represented as bare land on the map and considered as one of the driving or facilitating factor for the declining of the lake as shown figure 15. However, Lake Besekas' edge were covered by sparsely located shrub land and sugarcane irrigation farm of Metahara sugar factory as shown on figure 16. The ground water flow from irrigation farm was also expected as one factor for the raise of the lakes. Accordingly, the land use land cover of the lakes surrounding affects directly the lakes by exploiting the lakes water and by controlling the lakes surrounding temperature. For instance, the northern part of the Chamo Lake were covered by forest during 1985 and decreased in 2015. Moreover, the absence of forest and vegetation to the lakes surrounding and expansion of bare land area (mainly near to Abiyata and Beseka Lakes) promotes the evaporation of the lakes water.

Furthermore, the decline of Lake Abiyata were associated with the establishment of soda ash factory and used by an industry since 1985. However, abstraction of the lake water for soda ash factory was not the only factor for the decline of the lake. Because the lake was also shrunk by 1.0837 km in the north, 241.46 m in the west and 269.69 min south direction or shrunk by total of 19.165 km^2) before the establishment of soda ash factory as shown figure 13 below.

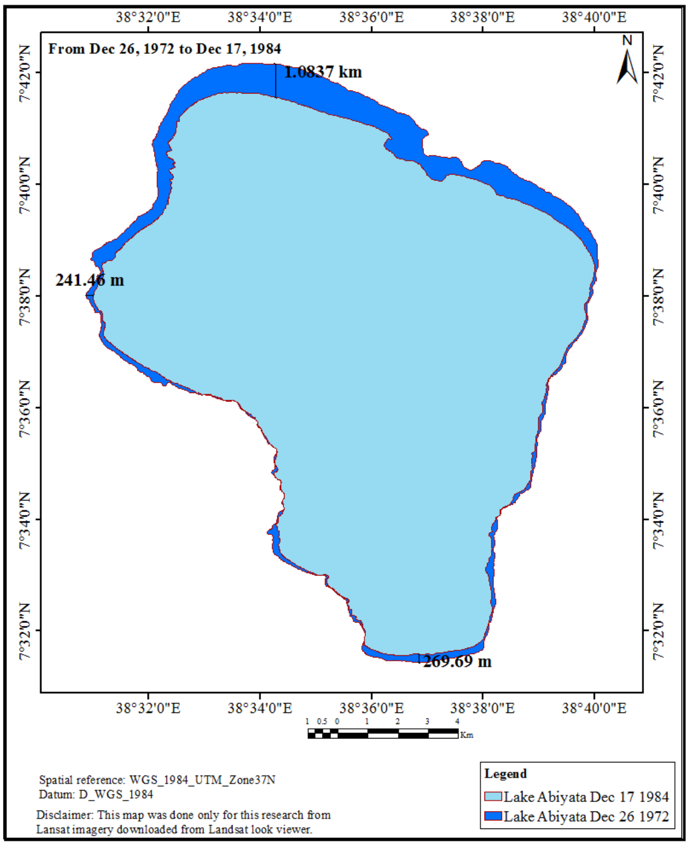


Figure 13: Lake Abiyata level change between 1970's and 1980's

Plate 2: Over consumption of Lake Haromaya consequence

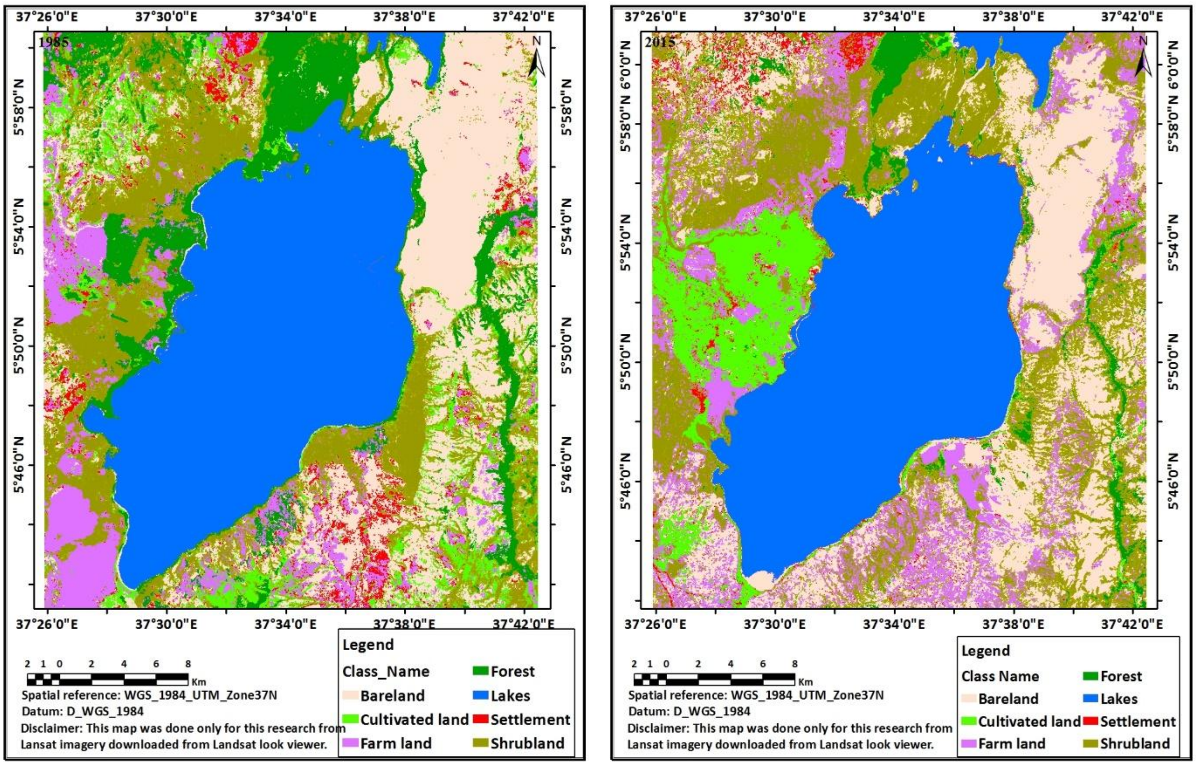


Figure 14: LULC variability of Lake Chamo surrounding

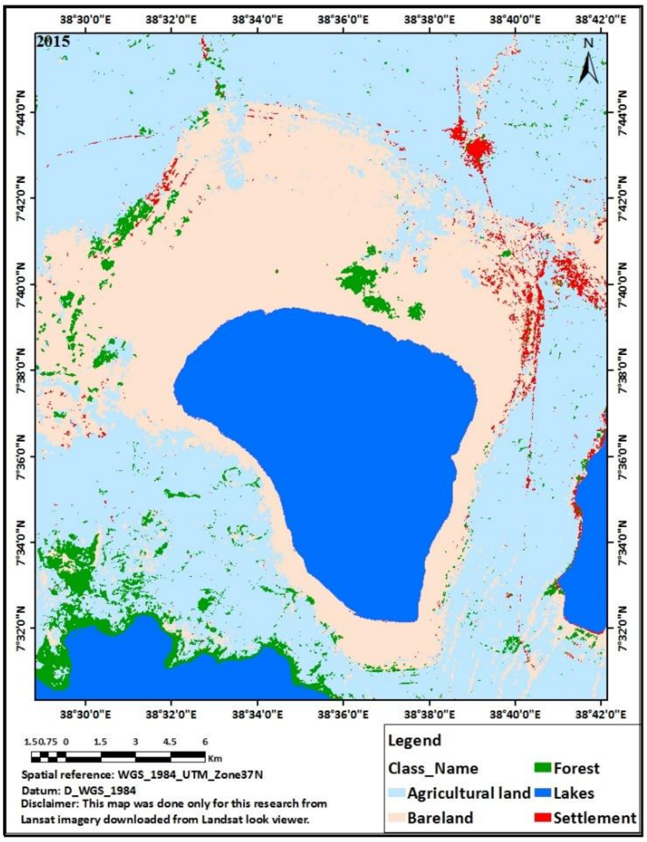


Figure 15: LULC of Lake Abiyata surrounding

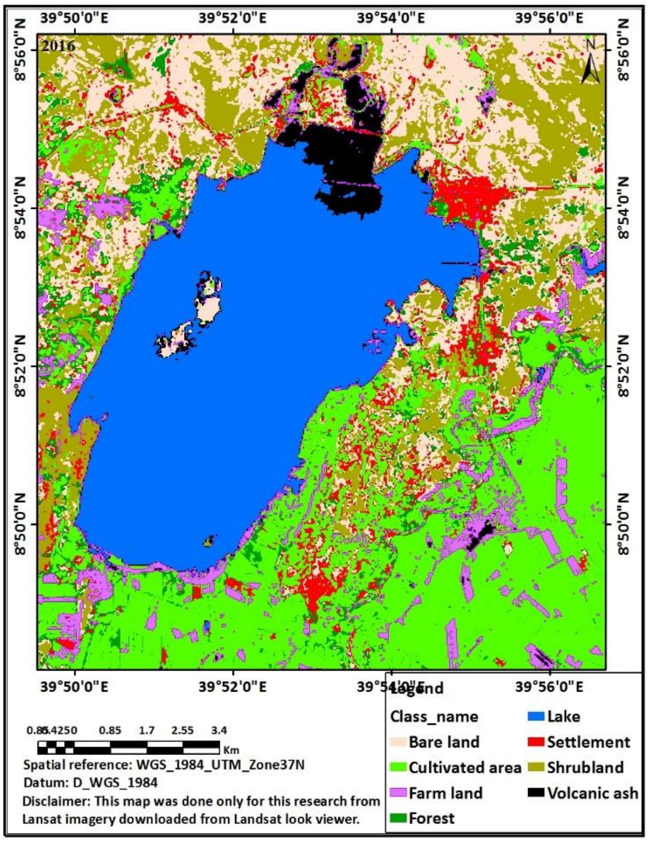


Figure 16: LULC of Lake Beseka surrounding

4.1.5. Verification of the result for endangered lakes.

The lake level change attained in this research were from Landsat imagery acquired at dry season of the last four decades. Since the extracted feature classes in the geodatabase shows the spatial extent of each lake, the endangered lakes was verified or validated. Endangered lakes were validated using field collected GPS point and hydrological data of the gauged lakes form Ministry of Water, Irrigation and Energy.

Field collected GPS data

The GPS data collected from selected lakes surrounding shows the current status of respective lakes edge. The data were used in validating the lakes level change extracted from the Landsat satellite imagery. For instance, the GPS reading taken at the southern tip of Lake Abiyata current edge on March 2016 was far from edge of 1972 (south eastern reading point) was about 1.267 km as shown on figure 17. Moreover, the GPS reading taken from the edge of Lake Haromaya (late) was about 29.74 m far from the edge of 1980's extracted lake level as shown on figure 18 below and similarly done for Lake Chamo and Beseka as shown on figure 19 and 20 below.

Generally, the GPS data collected from identified endangered lakes edge in this research validates that the lakes level change that extracted from Landsat satellite imagery were real and shows the correct status of the lakes level.

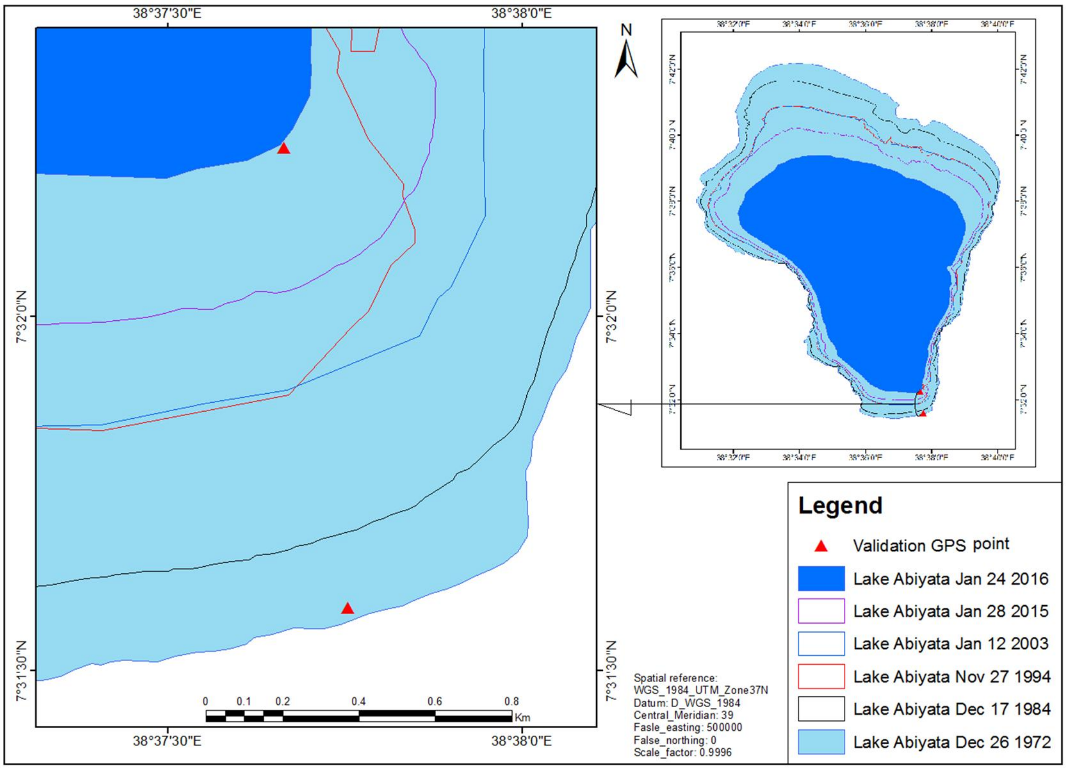


Figure 17: Lake Abiyata and GPS validation data

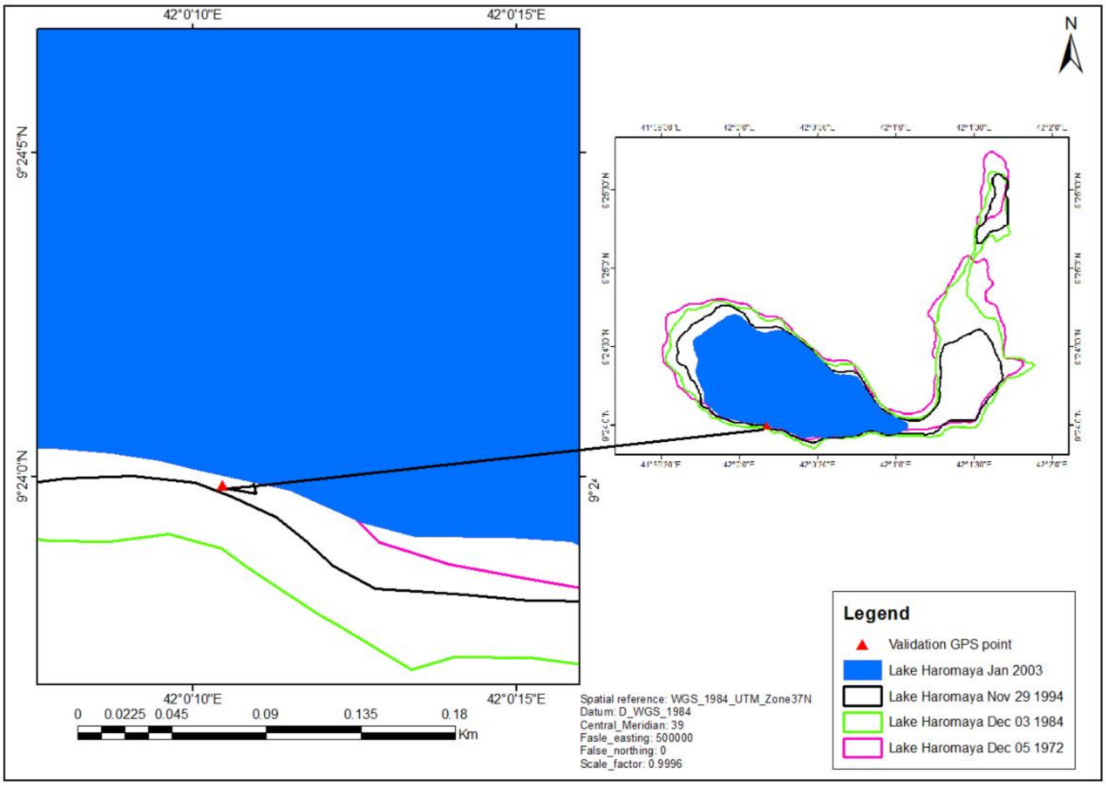


Figure 18: Lake Haromaya and GPS validation data

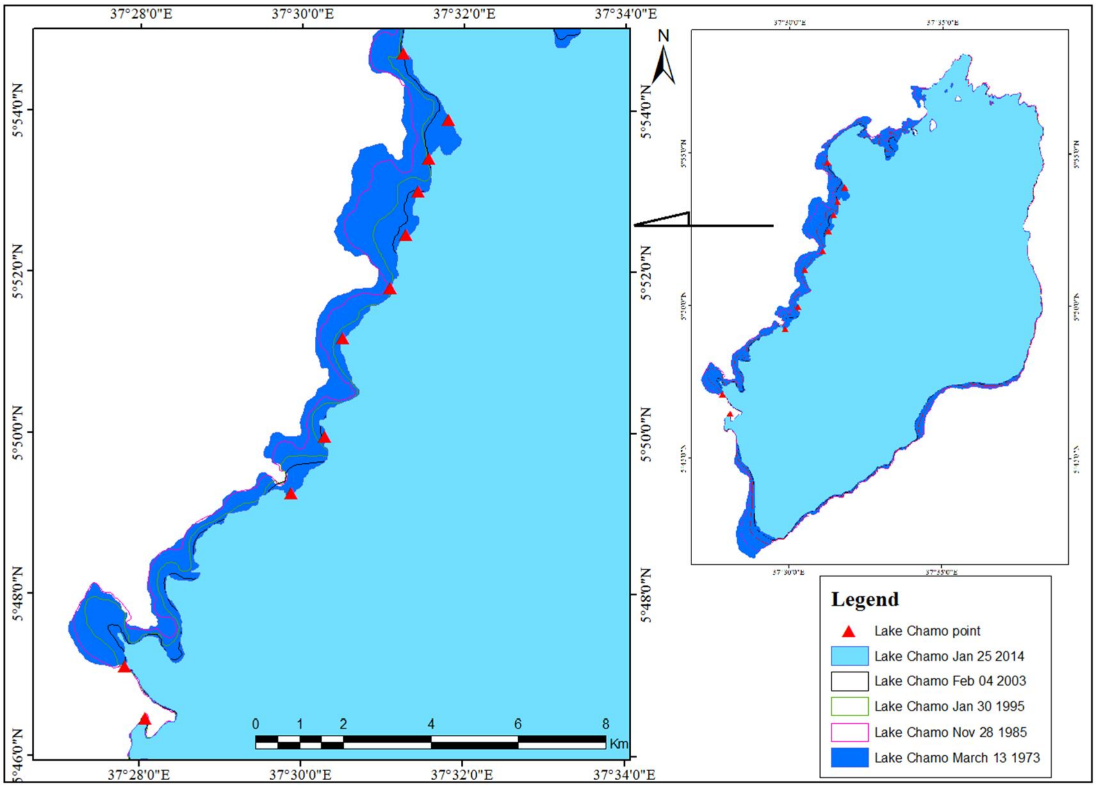


Figure 19: Lake Chamo and GPS validation data

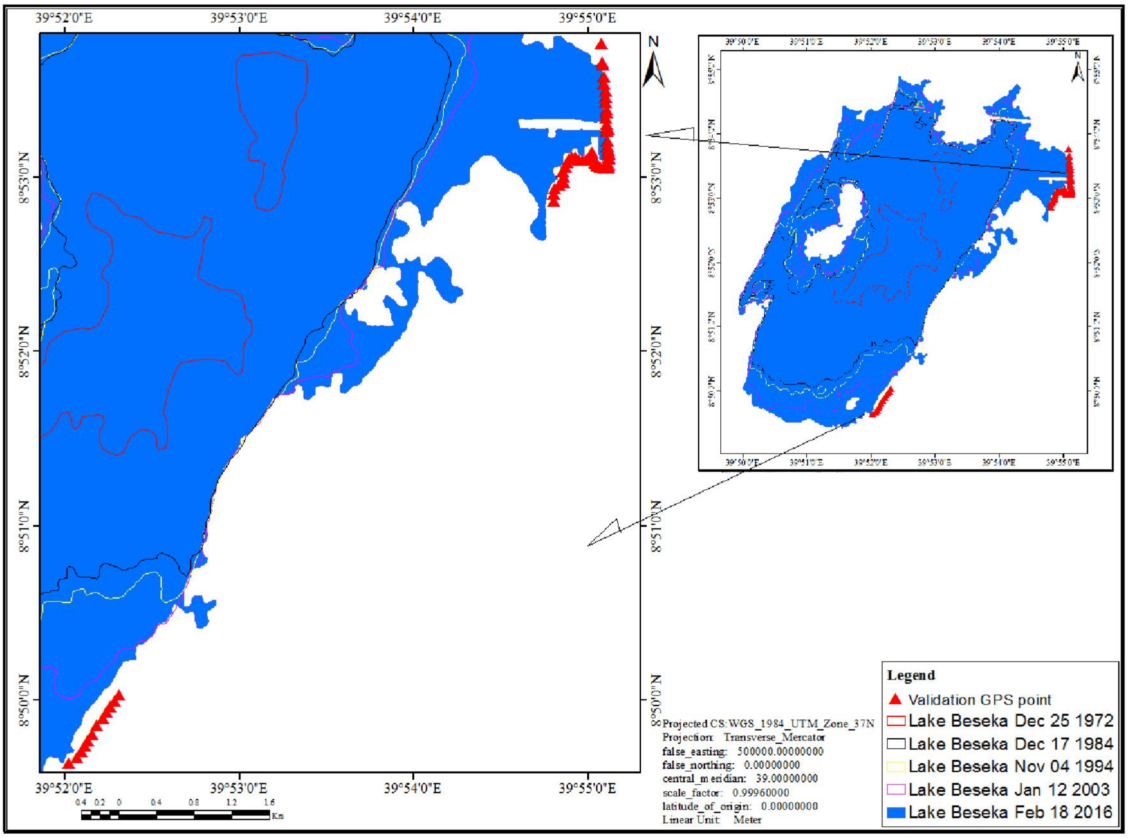


Figure 20: Lake Beseka and GPS validation data

Hydrological data

The hydrological data for sample gauged lakes were gained from Ministry of Water, Irrigation and Energy department of hydrology as shown below. The measured data shows that the decline and raise trend of Haromaya, Abiyata and Beseka Lakes. The water level trend for Haromaya and Abiyata Lakes were generally in declining way as shown in figure 21. The data gained from MoWIE starts from 1990 to 2013 shows the varying trend in each year interval. However, the overall trend of Abiyata and Haromaya Lakes shows the decline in their water level and Lake Beseka trend shows the raise of water level.

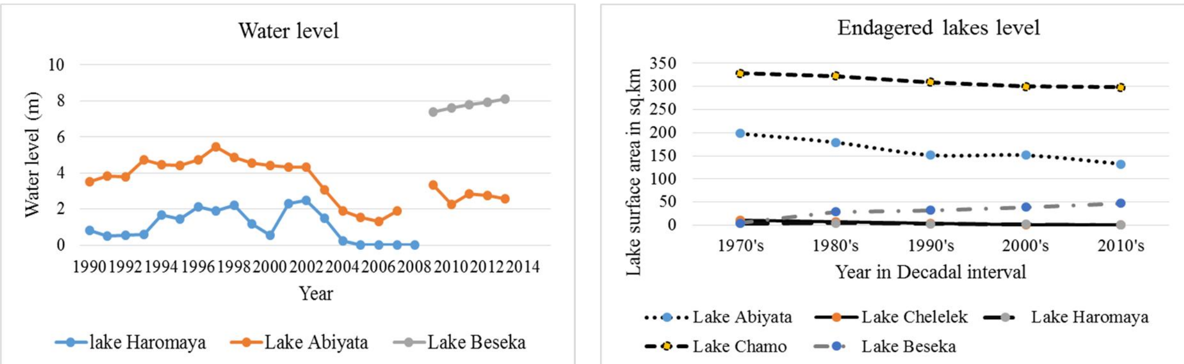


Figure 21: Annual and dry seasonal data

4.2.Discussion

The Landsat satellite image also used by different researchers as an essential input data alone and also by integrating with other relevant data for the assessment of lakes level change for some of Ethiopian lakes. For example, Tenalem Ayenew (2002), used the Landsat satellite imagery with other data to study the lake level change of Lake Abiyata, Kassaye Bewketu (2010), used Landsat image with the integration of Hydro-meteorological data to study the Hydrodynamics of Selected Ethiopian Rift Lakes and also Demeke Teklu and Alemu Lema (2014) also enumerates the level of lake Chamo using Landsat image and aerial photograph. This research also used Landsat image as a major input data for the assessment of the Ethiopian lakes level change.

Accordingly, the image data used here was since 1970's or from the beginning of the Landsat satellite image acquisition. Each lake was mapped from Landsat image in decadal interval using digitizing method then after populated in file geodatabase which developed in ArcGIS10.3 software. The geodatabase developed here contains datasets equivalent with number of lakes existing during the lakes four decades. Accordingly, there are about 108 lakes (93 natural and 15 man-made) extracted in this study. However, Tesfaye (1990) cited in Hagos Gebresllassie *et al.* (2014) listed 58 major lakes and marshes and UNEP (2006) enumerates 46 lakes in Ethiopia. Furthermore, a brief database that represents the whole attribute table of the lakes were developed using Microsoft Access. This database shows the lakes level change in terms of their spatial extent during the last four decades using a relationship between tables.

The extracted lakes was both the natural lakes and man-made lakes which are distributed throughout the all geomorphological setup of the country. From the natural lakes, the lakes found around Bishoftu are creator lakes (Tenalem Ayenew, 2009). The natural lakes Ethiopia was distributed throughout the rift valley, escarpments and highlands of Ethiopia. Accordingly, Lake Abaya, Chamo, Shalla, Ziway, Langano and Beseka were among the rift valley lakes (Tenalem Ayenew, 2009). Furthermore, Lake Tana, Garba Guracha, Lay Bahir, Tach Bahir, Hayk and Hardibo were among the highland lakes of Ethiopia.

According to the result of this research, there are five lakes that are identified as an endangered lakes, both in decreasing and increasing in their level or spatial extent. Those are Lake Abiyata, Chamo, Haromaya and Chelelek are in shrinking (drying) aspect and Lake Beseka in rising level. However, Lake Chelelek and Haromaya were desiccated before a decade and few years respectively. Lake Abiyata was the most drastically declining in its level from Ethiopian lakes followed by Lake Chamo which is relatively slow when compared with. Moreover, Tenalem Ayenew (2002) and Kassaye Bewketu (2010) also argues with the decline of Lake Abiyata. Lake Abiyata area extent described by Kassaye Bewketu (2010) were 162 km^2, 164 km^2 and 117 km^2 during Jan 1986, Jan 2000 and Jan 2010 respectively. However the result of this study was 179.23 km^2 150.91 km^2 and 131.76 km^2 during Dec 17 1984, Jan 12 2003 and Jan 28 2015 respectively. Furhtermore, Derege Tsegaye *et al.* (2012) argues that Abiyata Lake will dry up by 2021 if current trends of land use land cover change, socioeconomic and climate conditions continues.

Similarly, this study shows that Lake Chamo also one of declining lakes in its level or spatial extent during the last four decades. Accordingly, Alemayehu HaileMicael and Solomon Raju (2014) discussed that the shrunk of Lake Chamo were by 14% which about 50.12 km^2 (in 45 years) from the extent of 1965. The authors enumerates the lake spatial extent with random years interval and some the results extracted in Jan 1965, Dec 1972, Dec 1984, Jan 1995 Feb 2003 and Jan 2010 and that has an area 347.57 km^2, 338.36 km^2, 333.22 km^2, 314.28 km^2, 304.44 km^2, 297.45 km^2 respectively. However, the result of this study extracted during March 1973, Nov 1985, Jan 1995, Feb 2003 and Jan 2014 and had spatial extent of 327.84 km^2, 322.64 km^2, 309.27 km^2, 299.78 km^2, 298.41 km^2 respectively.

Based on the result of this study, Lake Chelelek and Haromaya were desiccated before a decade and few years ago. During the 1970's, Lake Chelelek spatial extent were about 10.30 km^2 and gradually desiccated before 2010's. The observation of this study was further supported by Tenalem Ayenew and Yemane Gebreegziabher (2006), which describe the drastic decline of Lake Chelelek. Moreover the decline or desiccation of Lake Haromaya in this study was also strengthen by Brook Lemma (2011), that discusses the lake was disappeared before 2004.

Furthermore, some lakes were in drastic declining trend of their level during the last four decades. Accordingly, Lake Beseka were one the most drastically rising lakes in its level in Ethiopia. The result of this research shows that, the lake was expanding by about 43.325 km^2 during the four decades and this was supported by Megeresa Olumana (2012a; 2012b). Megersa Olumana (2012b), discussed the spatial extent of Lake Beseka during 1973, 1986, 2000, and 2008 were 753 ha (7.53km^2), 2943 (29.43 km^2), 4168 ha (41.68 km^2) and 4585 ha (45.85 km^2) respectively and totally the lake was raised by 38.32 km^2. Moreover, Megersa Olumana (2012a), enumerates the extent of the lakes as 2.7 km^2, 8.4 km^2, 10.2 km^2, 29.5 km^2, 41.5 km^2, 43.4 km^2 and 48.5 km^2 during 1960, 1973, 1975, 1986, 2000, 2007 and 2010 respectively and a total of 45.8 km^2 expansion. However, the lake level change attained by this study were 4.34 km^2, 29.12 km^2, 32.47 km^2, 39.32 km^2 and 47.66 km^2 during Dec 1972, Dec 1984, Nov 1994, Jan 2003 and Feb 2016 respectively. The lake spatial extent described by Megersa Olumana (2012b) and Megersa Olumana (2012a) in 1973 was varied as 7.53 km^2 and 8.4 km^2 respectively. For these variation there is no reason described.

From Ethiopian lakes some the lakes show that there is slight decline and also slight raising in their level when related the initial (1970's) spatial extent. For instance, Lake Tana was among the lakes that has a slight change of rising compared to its extent. Hence the lake was raised by 1.17 % when compared with the level or spatial extent extracted during 1970's. However, McCartney *et al.* (2010), faces the result of this study and argued with the average surface area of the lake was decreased by ~ 0.993 %. Furthermore, their study forecasts the reduction will be ~ 2.68 % within some years.

Majority of the lakes in Ethiopia were in dynamics in their level during the last four decades due to different reasons. The causes for the changes in lakes level may categorized as man-made factors and due to natural process. From the man-made factors, over consumption of the lakes water for irrigation farm and diverting tributary rivers of lakes are the major causes as observed during the field work.

Table 10: Relative change in lake level or spatial extent over the last four decades (1972 to 2015)

No	Lake name	Lake level change in %	Likely reason for level change
1	Lake Abiyata	-66.	Over extraction of lake water for soda ash factory and land use type
2	Lake Chamo	-8.98	In some extent irrigation farm of lake and largely tributary rivers
4	Lake Haromaya	-100	Over consumption of lake water and tributary rivers
5	Lake Chelelek	-100	Sediment deposition and land cover type
6	Lake Beseka	+998.79	Ground and direct flow from irrigation farm and other natural (tectonic) factors

Land use land cover of lakes surrounding area

The land use land cover of the lakes surrounding as shown on figure 14, 15 and 16, the land use type of the Lake has directly or indirectly affects the lakes level. Accordingly, Derege Tsegaye *et al.* (2012) the decline in the size of lakes found in central rift valley was the majorly resulted from Land use land cover (LULC) and land degradation, which is increased by 200% from 1973 to 2006. Moreover, the sediment yield was increasingly going from the surrounding steep slope catchments to the lake following the LULC and degradation which is also seriously affecting the life span of the lakes. Similarly, the land use type of Lake Chamo surrounding was in dynamic due anthropogenic factors. Accordingly cultivation was increased and forest were reversely decreasing. Furthermore, Tibebu Kassawar (2007) argues that, from 1973 to 2000 there was an expansion of farm land and irrigation per farm and relatively decreasing of wet land and lake area in Abaya - Chamo Lakes watershed.

The land use land cover of Lake Beseka surrounding, as figure 16 above shows, the south eastern part of the lake was majorly covered by cultivated area which is sugar cane irrigation farm. Accordingly, Ashenafi Burka (2008), discussed that water body, bare land and farm land were increased and grass land wood land were decreased during 1973 to 2002. Furthermore, Tenalem Ayenew and Yemane Gebreegziabher (2006) argues that the main factor for the dramatic decline (now dried) Lake Chelelek was due siltation.

Over consumption of lakes water for Irrigation farm and other

The lakes those have a change in their level were majorly caused by the surrounding communities. For instance, the late Haromaya Lake, including the rivers flows towards the lake, was used by the surrounding farmers for irrigation farm and extraction of the ground water for nearly found cities (Brook Lemma, 2011) in addition to these currently Harar brewery borehole were constructed. Currently the lake was dried fully and some of the surrounding farmers uses the early lake bed for farming as shown on plate 3 and appendix-plate 3 below. The irrigation farm practice also considered as one factor for the drastic rise Beseka Lake. For instance, according to Seleshi Bekele *et al.* (2007), the excess water loss from Metehara sugarcane irrigation and also a rise in groundwater inflows into the lake (Tenalem Ayenew, 2004) was believed to be the cause for ever growing of Lake Beseka.

Another way of consuming the lake water were observed around Lake Abiyata and Shalla for soda ash extraction. According to Tenalem Ayenew (2002), the soda ash industrial plant was investigated in 1984 and began 1985 large production process from the two lakes. The establishment of soda ash industry was mainly considered as the major cause for the rapid decline of Abiyata Lake (Elizabeth Kebede *et al.,* 1994; Tenalem Ayenew, 2002; Tenalem Ayenew, 2004; Tenalem Ayenew and Dagnachew Legesse, 2007; Kassaye Bewketu, 2010). However, the declining of Lake Abiyata was not began after the establishment of soda ash factory, there was a significant decline during the period between 1970' and 1980's as shown on the result of the study and figure 13 above. Therefore, the decline of Lake Abiyata was the combined effect of soda ash industry and other factors.

Plate 3: Lake Abiyata Current status

Meteorological variability

Temperature Variability

The variability of temperature in selected stations has not a significant change through the year range of lake data extracted as shown figure below. The temperature data taken for this research was the dry season of the respective years. As the figure below shows the temperature data has not much difference during the dry season of the selected year. However, some lakes are shrinking continuously in their level with almost constant temperature of surrounding stations

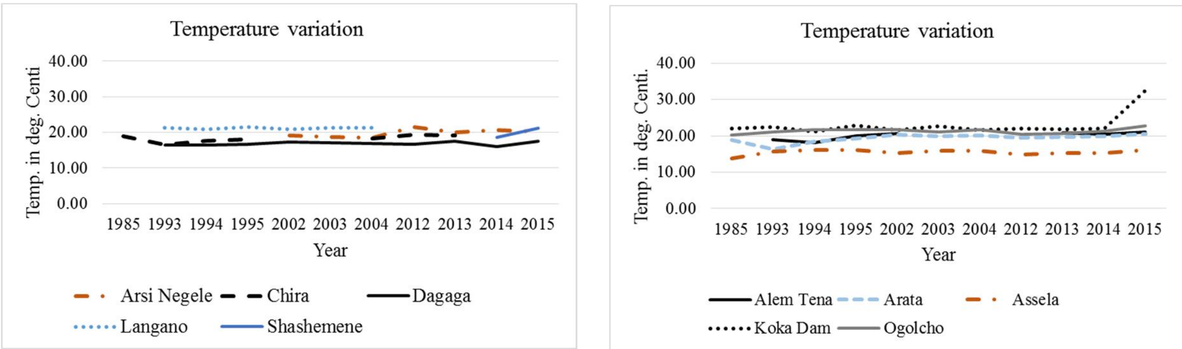


Figure 22: Selected area Temperature variation

Rainfall occurrence in dry season

The rainfall during the dry season of the years, in which the satellite imagery was taken, was not null as shown on figure below. For some stations the rainfall of selected years was not similar and also for few of them, the amount of rainfall has close value. However, the variation in amount of rainfall and the amount of rainfall recorded during the dry season of the respective years may not have a significant change on the lake level.

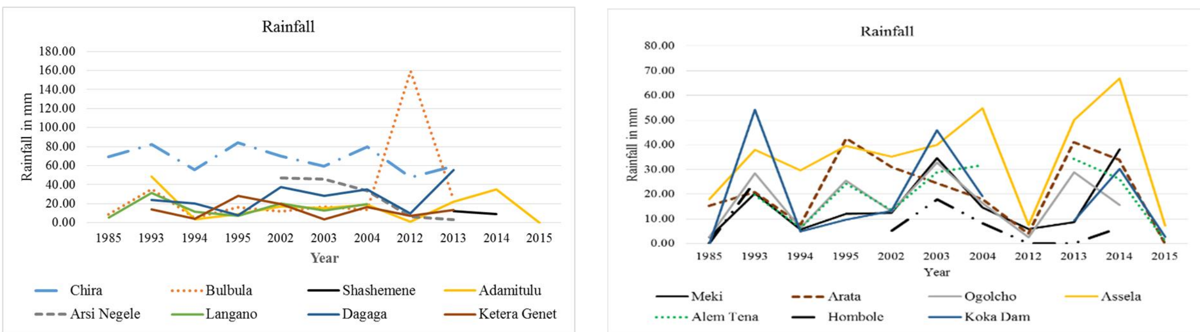


Figure 23: Selected area Rainfall variation

Chapter V

5. Conclusions and Recommendations

5.1.Conclusions

The Landsat satellite image used for different applications related to environmental management aspect. From these, here Landsat image was used for the assessment of Ethiopian lakes level change for the last four decades. Accordingly, in Ethiopia there are about 108 lakes (93 natural and 15 man-made lakes). Those lakes were stored in well-organized file geodatabase and additionally brief database were developed using Microsoft Access from the attribute tables. These databases show clearly the decadal lake level or spatial extent of the whole Ethiopian lakes starting from 1970's to 2010's. Furthermore, the database describes the distribution of those lakes with respect to the geomorphological setup, rift valley and highlands lakes and their locations with in the country.

The result of the study shows that much of the Ethiopian lakes are fluctuating in their level and lakes that has a radical declining (including dried) and drastically raising lakes were ranked and identified as an endangered lakes. The lakes that has top three rank in rapidly declining compared to their initial status (1970's) are Lake Abiyata, Chamo, Chelelek and Haromaya (desiccated) and Lake Beseka was the first rank in drastically raising. From the declining lakes, Lake Chelelek and Haromaya were desiccated before 2010's. Accordingly, Lake Abiyata was drastically decline by 66. 64 km^2 (33.59%) and Lake Chamo also decline by 29.41km^2 (8.98%) from their initial spatial extent (1970's) to 2010's. However, Lake Beseka raises extremely through the last four decades with a total spatial extent of 43.33 km^2 (>900%) and currently flooding Metehara town and surrounding. Moreover, the verification of the declining and raising lakes were done using GPS point collected from the respective lakes edge and the trend of their water balance for gauged lakes.

The major causes considered for endangered lakes in this study were the land use land cover change of the surrounding, over consumption of the lakes for irrigation farm and other purpose and finally the meteorological variability trends during the dry season. The land use land cover of Chamo, Abiyata and Beseka lakes surrounding were considered as one factor. For instance the land use type of Lake Chamo (mainly in south western direction) were converted to cultivation land by using the lake water (slight use), tributary rivers and the ground water. Furthermore the bare-land type of land use near Abiyata Lake may one of the driving factor for shrunk of the lake. The agricultural land (sugarcane farm) land use type near Beseka Lake were also considered as one factor for the raise of the lake.

Moreover, over consumption of the lakes water also the other considered factor of the decline (desiccation) of Lake Haromaya and Abiyata. The factor usually discussed or mentioned for the decline of Abiyata Lake were mainly the establishment of soda ash factory. However, the lake were declined or shrunk by 19.16 km^2 with in a decade before the establishment of the factory. Therefore, the abstraction of water for soda ash factory was not the only factor for the declining or shrinking of the Lake Abiyata. The meteorological variability trend were considered as causes for the fluctuation of the level of the lakes. However, the temperature and rainfall of selected stations shows (during the dry season and respective years) does not have a significant variation.

Generally, the majority of the Ethiopian lake were fluctuating in their level (spatial extent) due to different reasons. For example, Lake Abiyata, and Chamo are the top declining lakes and Lake Beseka was the top raising lake during the last four decades. However, Lake Chelelek and Haromaya were desiccated or dried during the last four decades due to different factors.

5.2. Recommendations

Since the result of this clarifies the fluctuation of the Ethiopian lakes level, the upcoming researches uses this data as an initial step for different purpose. From these:

- The output this study can be used as a benchmark for the upcoming researches concerning the lakes of Ethiopia.
- The next research can making it the geodatabase of this research web based.
- The concerned body should consider and take an action of rehabilitation for Abiyata, Chamo and Haromaya Lakes.
- Abstraction of water from Lake Abiyata should be minimized until the lake declining trend stop.
- Since the drastic raise of Lake Beseka was destructive the surrounding and also drained to Awash River, there should be a critical treatment for the lakes surrounding.

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Appendix

Lake_code	Lake_Name	Location_Region	Lake_Nature	Altitude_meter
ETH_L001	Lake Abay Chomen	Oromia	Man-made	2341
ETH_L002	Lake Abaya	SNNP and Oromia	Natural	1160
ETH_L003	Lake Abay	SNNP	Natural	1894
ETH_L004	Lake Abhe	Afar	Natural	344
ETH_L005	Lake Abiyata	Oromia	Natural	1508
ETH_L006	Lake Adeyle	Oromia	Natural	2117
ETH_L007	Lake Adobed or Abbe	Afar	Natural	369
ETH_L008	Lake Afambo	Afar	Natural	370
ETH_L009	Lake Afar No name 1	Afar	Natural	400
ETH_L010	Lake Afar No name 10	Afar	Natural	731
ETH_L011	Lake Afar No name 11	Afar	Natural	800
ETH_L012	Lake Afar No name 12	Afar	Natural	760
ETH_L013	Lake Afar No name 2	Afar	Natural	395
ETH_L014	Lake Afar No name 3	Afar	Natural	-69
ETH_L015	Lake Afar No name 4	Afar	Natural	711
ETH_L016	Lake Afar No name 5	Afar	Natural	712
ETH_L017	Lake Afar No name 6	Afar	Natural	713
ETH_L018	Lake Afar No name 7	Afar	Natural	708
ETH_L019	Lake Afar No name 8	Afar	Natural	702
ETH_L020	Lake Afar No name 9	Afar	Natural	705
ETH_L021	Lake Afdera	Afar	Natural	-66
ETH_L022	Lake Aliwaro	Gambella	Man-made	539
ETH_L023	Lake Amh No name 3	Amhara	Natural	2064
ETH_L024	Lake Amh No name 5	Amhara	Natural	1873
ETH_L025	Lake Amha No name 1	Amhara	Natural	1519
ETH_L026	Lake Amha No name 2	Amhara	Natural	1632
ETH_L027	Lake Amha No name 4	Amhara	Natural	2092
ETH_L028	Lake Ara Shitan	SNNP	Natural	2185
ETH_L029	Lake Archema	SNNP	Natural	1873
ETH_L030	Lake Artaele	Afar	Natural	588
ETH_L031	Lake Ashenge	Tigray	Natural	2479
ETH_L032	Lake Assale	Afar	Natural	-113
ETH_L033	Lake Bancili	Afar	Natural	-114
ETH_L034	Lake Belbela	Oromia	Natural	1981
ETH_L035	Lake Beseka	Oromia	Natural	931
ETH_L036	Lake Bishan Waka	Gambella	Natural	1404
ETH_L037	Lake Bishoftu	Oromia	Natural	1949
ETH_L038	Lake Bishoftu Guda	Oromia	Natural	1924
ETH_L039	Lake Bode Ameda	SNNP	Natural	1544
ETH_L040	Lake Boyo	SNNP	Natural	1893
ETH_L041	Lake Budamada	SNNP	Natural	1623
ETH_L042	Lake Chamo	SNNP	Natural	1150
ETH_L043	Lake Chancho	Oromia	Natural	2193
ETH_L044	Lake Chefre	SNNP	Natural	1395
ETH_L045	Lake Chelekleka	Oromia	Natural	1935
ETH_L046	Lake Chelelek	Oromia	Natural	1786
ETH_L047	Lake Chercher	Oromia	Natural	1744
ETH_L048	Lake Chew Bhir	SNNP	Natural	491
ETH_L049	Lake Chitu	Oromia	Natural	1558
ETH_L050	Lake Chuche	SNNP	Natural	1840
ETH_L051	Lake Dandi	Oromia	Natural	2943
ETH_L052	Lake Dipa	SNNP	Natural	393
ETH_L053	Lake Dono Womba	SNNP	Natural	1949
ETH_L054	Lake Elen	Oromia	Natural	1597
ETH_L055	Lake Finkile	Oromia	Natural	2144
ETH_L056	Lake Garba Guracha	Oromia	Natural	3933
ETH_L057	Lake Gemeri	Afar	Natural	369
ETH_L058	Lake Geray	Amhara	Natural	1800
ETH_L059	Lake Gololisha	SNNP	Natural	1941
ETH_L060	Lake Gudera	Amhara	Natural	2319

ETH_L061	Lake Hadiya	Oromia	Natural	2142
ETH_L062	Lake Hara	Amhara	Natural	1519
ETH_L063	Lake Hara Yabela	Oromia	Natural	1987
ETH_L064	Lake Hardibo	Amhara	Natural	2029
ETH_L065	Lake Haro Kilole	Oromia	Natural	2003
ETH_L066	Lake Haromaya	Oromia	Natural	2092
ETH_L067	Lake Hawasa	SNNP	Natural	1800
ETH_L068	Lake Hayk	Amhara	Natural	1926
ETH_L069	Lake Helbera	SNNP	Natural	1899
ETH_L070	Lake Hora	Oromia	Natural	1924
ETH_L071	Lake Hora Oda	Oromia	Natural	1955
ETH_L072	Lake Ila Abaya	SNNP	Natural	2003
ETH_L073	Lake Koka	Oromia	Man-made	1588
ETH_L074	Lake Kuriftu	Oromia	Natural	1913
ETH_L075	Lake Laido	Afar	Natural	733
ETH_L076	Lake Laki	Oromia	Natural	4143
ETH_L077	Lake Langano	Oromia	Natural	1507
ETH_L078	Lake Lay Bahir	Amhara	Natural	3203
ETH_L079	Lake Nidamulo	Gambella	Natural	541
ETH_L080	Lake Shala	Oromia	Natural	1517
ETH_L081	Lake Shisha Womba	SNNP	Natural	1336
ETH_L082	Lake Shoshma	SNNP	Natural	967
ETH_L083	Lake Sorga	Oromia	Natural	2007
ETH_L084	Lake Tach Bahir	Amhara	Natural	3269
ETH_L085	Lake Tana	Amhara	Natural	1721
ETH_L086	Lake Tata	Gambella	Natural	532
ETH_L087	Lake Tido	SNNP	Natural	1593
ETH_L088	Lake Tirba	Amhara	Natural	2227
ETH_L089	Lake Turkana	Partly SNNP	Natural	328
ETH_L090	Lake Wanchi	SNNP	Natural	1872
ETH_L091	Lake Wenchi	Oromia	Natural	2944
ETH_L092	Lake Yardi Gaddabasa	Afar	Natural	571
ETH_L093	Lake Zekuwala	Oromia	Natural	2843
ETH_L094	Lake Zengena	Amhara	Natural	2538
ETH_L095	Lake Zigna	SNNP	Natural	1161
ETH_L096	Lake Ziway	Oromia	Natural	1620
ETH_L097	Reservoir Aba Samuel	Oromia	Man-made	2054
ETH_L098	Reservoir Koga	Amhara	Man-made	2042
ETH_L099	Reservoir Dire	Oromia	Man-made	2535
ETH_L100	Reservoir Gefersa	Oromia	Man-made	2564
ETH_L101	Reservoir Gilgelgibe I	Oromia	Man-made	1644
ETH_L102	Reservoir Kesem	Afar	Man-made	897
ETH_L103	Reservoir Legedadi	Oromia	Man-made	2386
ETH_L104	Reservoir Melka Wakena	Oromia	Man-made	2268
ETH_L105	Reservoir Tekeze	Amhara and Tigray	Man-made	1067
ETH_L106	Reservoir Tendaho	Afar	Man-made	506
ETH_L107	Reservoir Tigr No name	Tigray	Man-made	2122
ETH_L108	Reservoir Wedecha	Oromia	Man-made	2400

Appendix I 1: Microsoft Access database; Ethiopian lakes list

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Cultivated land	6	5	4	66.67%	80.00%
Lakes	12	12	12	100.00%	100.00%
Settlement	3	2	1	33.33%	50.00%
Farm land	3	3	2	66.67%	66.67%
Shrubland	4	5	3	75.00%	60.00%
Bareland	10	11	8	80.00%	72.73%
Forest	2	2	2	100.00%	100.00%
Totals	40	40	32		

Overall Classification Accuracy = 80.00%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7494

Conditional Kappa for each Category.

Class Name	Kappa
Cultivated land	0.7647
Lakes	1.0000
Settlement	0.4595
Farm land	0.6396
Shrubland	0.5556
Bareland	0.6364
Forest	1.0000

----- End of Kappa Statistics -----

Appendix I 2: Accuracy Assessment of LULC classification of Lake Chamo surrounding 1985

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Lakes	7	7	7	100.00%	100.00%
Forest	7	7	5	71.43%	71.43%
Settlement	7	7	5	71.43%	71.43%
Bareland	7	7	6	85.71%	85.71%
Shrubland	8	7	6	75.00%	85.71%
Cultivated land	5	7	4	80.00%	57.14%
Farm Land	8	7	6	75.00%	85.71%
Totals	49	49	39		

Overall Classification Accuracy = 79.59%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7619

Conditional Kappa for each Category.

Class Name	Kappa
Lakes	1.0000
Forest	0.6667
Settlement	0.6667
Bareland	0.8333
Shrubland	0.8293
Cultivated land	0.5227
Farm Land	0.8293

----- End of Kappa Statistics -----

Appendix I 3: Accuracy Assessment of LULC classification of Lake Chamo surrounding 2015

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Settlement	9	9	7	77.78%	77.78%
Lakes	9	9	9	100.00%	100.00%
Bareland	9	9	6	66.67%	66.67%
Forest	8	9	7	87.50%	77.78%
Agricultural la	10	9	7	70.00%	77.78%
Totals	45	45	36		

Overall Classification Accuracy = 80.00%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7500

Conditional Kappa for each Category.

Class Name	Kappa
Settlement	0.7222
Lakes	1.0000
Bareland	0.5833
Forest	0.7297
Agricultural land	0.7143

----- End of Kappa Statistics -----

Appendix I 4: Accuracy Assessment of LULC classification of Lake Abiyata surrounding 2015

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Lakes	10	9	9	90.00%	100.00%
Volcanic ash	8	9	7	87.50%	77.78%
Farm land	9	9	7	77.78%	77.78%
Cultivated area	11	9	8	72.73%	88.89%
Forest	8	9	6	75.00%	66.67%
Settlement	7	9	5	71.43%	55.56%
Bare land	11	9	8	72.73%	88.89%
Shrubland	8	9	6	75.00%	66.67%
Totals	72	72	56		

Overall Classification Accuracy = 77.78%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7460

Conditional Kappa for each Category.

Class Name	Kappa
Lakes	1.0000
Volcanic ash	0.7500
Farm land	0.7460
Cultivated area	0.8689
Forest	0.6250
Settlement	0.5077
Bare land	0.8689
Shrubland	0.6250

----- End of Kappa Statistics -----

Appendix I 5: Accuracy Assessment of LULC classification of Lake Beseka surrounding 2016

Year	Meki	Arata	Ogolcho	Assela	Alem Tena	Hombole	Koka Dam
1985	2.58	15.33	2.74	17.95		0.00	0.00
1993	20.25	20.82	28.50	38.05	19.62	24.97	54.20
1994	5.70	7.77	6.32	29.58	6.47		4.87
1995	11.97	42.63	25.48	39.52	24.20		9.73
2002	12.48	30.85	13.03	35.08	13.45	5.20	13.28
2003	34.66	24.45	32.85	39.87	28.95	17.77	45.90
2004	14.63	17.78	16.37	54.68	31.80	8.18	19.17
2012	5.97	3.96	2.47	7.40		0.00	
2013	8.64	41.08	28.92	50.12	34.30	0.00	9.30
2014	38.08	33.83	15.55	66.80	26.18	6.32	30.27
2015		0.13		7.28	1.18		2.75

Year	Chira	Bulbula	Shashemene	Adamitulu	Arsi Negele	Langano	Dagaga	Ketera Genet
1985	69.47	8.55				5.26		
1993	82.42	35.22		48.57		31.25	24.07	13.83
1994	55.62	5.15		3.28		11.38	20.10	3.88
1995	84.10	15.98		8.80		7.33	7.76	28.15
2002	69.72	11.90		16.95	46.80	19.87	37.17	19.35
2003	59.22	16.93		15.05	46.07	12.45	28.30	3.65
2004	79.58	13.40		18.90	33.35	19.28	35.08	16.38
2012	47.55	159.37		1.05	6.06		9.60	7.23
2013	59.12	25.00	12.20	22.23	3.10		55.64	13.48
2014			9.08	34.78				
2015		1.06		0.00	1.42		20.13	

Appendix I 6: Rainfall data

Name	1985	1993	1994	1995	2002	2003	2004	2012	2013	2014	2015
Arsi Negele					19.12	18.80	18.45	21.57	20.10	20.68	20.17
Chira	18.83	16.58	17.71	18.07			18.37	19.33	19.19		
Dagaga		16.43	16.53	16.75	17.37	17.18	16.91	16.68	17.60	16.04	17.52
Langano		21.25	20.92	21.43	20.97	21.39	21.41				
Shashemene										18.67	21.19
Alem Tena		18.92	18.18	19.93	20.65		18.93		20.81	20.46	21.13
Arata	18.84	16.27	18.37	19.26	20.28	19.97	20.06	19.50	19.75	19.80	20.58
Assela	13.73	15.73	16.20	16.17	15.35	15.93	15.91	14.85	15.28	15.24	16.04
Koka Dam	22.10	22.52	21.19	22.78	21.60	22.64	21.64	21.98	21.74	21.98	32.44
Ogolcho	20.28	20.99	21.63	21.78	21.67	20.95	21.74	20.38	20.65	21.17	22.80

Appendix I 7: Temperature data

Appendix-plates

Appendix-plates 1: Lake Chamo surrounding current status

Appendix-plates 2: Lake Abiyata surrounding current status

Appendix-plates 3: Lake Haromaya surrounding current status

Appendix-plates 4: Lake Beseka surrounding current status

Declaration

I, the undersigned, declare that this thesis entitled "ASSESSMENT OF ETHIOPIAN LAKES LEVEL CHANGE AND IDENTIFICATION OF ENDANGERED LAKES FOR THE LAST FOUR DECADES USING LANDSAT SATELLITE IMAGE" is my original work and has not been presented for a degree in any other university and that all sources of materials used for this thesis have been interestingly acknowledged.

Shimelis Girma Degefe

Signature _________

Date ____________

Addis Ababa University

Addis Ababa

May, 2016

This thesis entitled "ASSESSMENT OF ETHIOPIAN LAKES LEVEL CHANGE AND IDENTIFICATION OF ENDANGERED LAKES FOR THE LAST FOUR DECADES USING LANDSAT SATELLITE IMAGE" is an original work of Shimelis Girma Degefe under my supervision.

Dr. Binyam Tesfaw	Prof. Tenalem Ayenew
Signature _________	Signature __________
Date ____________	Date ______________