



**INTEGRATED APPROACH FOR SPATIO-TEMPORAL VARIABILITY
ANALYSIS OF WETLANDS: A CASE OF WETLANDS OF ABAYA-
CHAMO LAKES; SOUTHERN ETHIOPIA**

Abaya

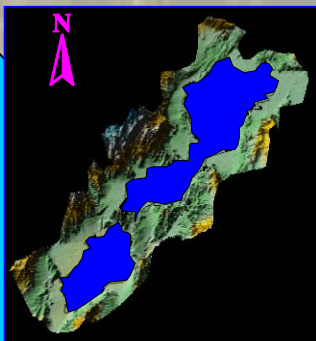
**A thesis submitted in partial fulfillment of the requirements for
the Degree of Master of Science In Remote Sensing and
Geographic Information Systems (GIS) in the department of
Earth Sciences**

Addis Ababa University; Ethiopia

Chamo

**Advisors: Dr. Dagnachew Legesse
Prof. Zerihun Woldu**

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March 2007

ADDIS ABABA UNIVERSITY
FACULTY OF SCIENCES
DEPARTMENT OF EARTH SCIENCES

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LISTS OF ABBREVIATIONS

ETM	=Enhanced Thematic Mapper
EPA	= Environmental Protection Authority
FAO	= Food and Agriculture Organization
FCC	= False Color Composite
GCP	= Ground Control Points
GPS	= Global Positioning System
LU/LC	= Land use and Land Cover
m.a.s.l	= Mean Above Sea level
MCE	= Multi Criteria Evaluation
MoA,	= Ministry of Agriculture
MSS	= Multi-scanning System
NDVI	= Normalized Difference Vegetation Index
RGB	= Red- Green_ Blue
SCRP	= Soil Conservation Research program
SNNP	= South Nations Nationalities of People
TCT	= Tasseled Cap Transformation
TCC	= True color Composite
TM	=Thematic Mapper
UNDP	= United Nations Development Program
WI	= Wetland Inventory

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ABSTRACT

Starting with the intensification of irrigation activities in the beginning of 1980s in Abaya and Chamo lakes area, the decreasing water inflow to the lakes caused relatively denudation of the wetlands of Abaya and Chamo. The ecological situation in the lake region changed significantly during last four decades. This research is geared with major objectives to map and assess the spatial and temporal variability of these changes with respect to the driving forces. It also aimed to determine wetlands priority area for conservation based on the direction and magnitude of denudation using RS and GIS techniques. To accomplish the objectives data were collected and analyzed utilizing field observations, satellite image analysis, hydro-meteorological data analysis and interviews. Five basic methods of wetlands variability analysis were used namely; Satellite image analyses and change detection, Lakes morphometric property analysis, Lake level fluctuation analysis, water balance analysis and sediment load analysis. Wetland and non-wet areas were identified and mapped using criteria and satellite images. Based on the TCT and classified images the temporal and spatial variability of the wetlands have been analyzed from the digital image.

The change detection showed that permanent wetland portions from 1973 to 1986 have been reduced by 12.9 km² in both lakes Abaya and Chamo. The change is from permanent wetland to other seasonal wetlands ecosystems. But from 1986 to 2000 a significant decrement has been observed but lesser than the previous decades (6.4 km²). The reason behind this change is that the free settlement and shoreline cultivation of the wetlands and uplands, land use land cover changes that fasten the soil erosion and eventually adds the sediment to the permanent wetlands. However the greater lion share of this temporal and spatial variability of the lakes comes from extreme wasteful utilization of the water from the rivers entering to the lakes and onshore cultivation. The time series analysis and water balance of the permanent lake in this research result shows that the wetlands are in danger and the outlook is bad. To safeguard wetland degradation or loss, a possible solution could be awareness creation to change the attitudes of the resident communities by linking the economic and social benefits of wetlands to its conservation for its protection.

Key Words: Wetlands, Spatial and temporal variability, GIS/RS, LU/LC change, lakes Abaya and Chamo

1 INTRODUCTION

1.1 General Background

Wetland is an ecosystem of which its formation process and characteristics are determined by water. Wetlands occur where the water table is at or near the surface of the land, or where the land is covered by shallow water. According to Ramsar Convention (1971) wetlands are defined as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Dugan, 1993).

According to Finlayson and Moser, 1991 globally, wetlands occupy about 6 percent of the land surface of the world, or approximately 890 million ha (approximately 2.2 billion acres) but an estimate of over 50% of world's wetlands may have been altered or lost in the last 50 years (Dugan, 1993). However, wetlands conservation requires an overview on their distribution and status, but in most cases not all wetlands are easily accessible and many countries lack or have insufficient (financial and technical) capacity to assess them (Ehrenfeld, 2000).

Wetlands provide a variety of goods and services, which constitute considerable ecological, social and economic values (Dixon and Wood, 2003). Wetlands play a crucial role in the environmental balance. They provide important wildlife habitat, can prevent flooding, and actually help to clean contaminated water through natural filtering processes (Ehrenfeld, 2000). Specifically, the ecological functions include flood control, water table maintenance, and habitat provision for some plants and animals (Gren et al., 1995).

While wetlands may be the most productive ecosystems on earth, they are also the most threatened. However, with the increasing population and subsequent demand for more wetland resources to sustain their livelihood, wetlands are now in danger of conversion and drainage. Globally, the increasing demand for products and services of wetlands has resulted in rising pressure on wetlands. This pressure has led to modification ranging from degradation to loss including change in vegetation composition and their conditions (Dugan, 1993). Wetland destruction and alteration has been and is still seen as an advanced mode of development, even at the government level.

Wetlands and their value remain little understood and their loss is increasingly becoming an environmental disaster. Even as rates of wetland loss are documented for the developed world, the limited study of these ecosystems in countries such as Ethiopia leaves us with little to say. Wetland loss is evident wherever major developments like dams; irrigation schemes and conversion projects are present in the developing world. While most of the threats that wetlands face result from their misuse, many are also related to unsustainable resource extraction. Another important reason for their vulnerability is the fact that they are dynamic systems undergoing continual change (Whigham, 1999). As a result, many wetlands are temporary features that disappear, reappear and re-create themselves over time.

The study area, wetlands of lakes Abaya and Chamo are located in the rift valley of Ethiopia. Lakes Abaya and Chamo are the major lakes of Ethiopia, with 1097 and 322 km² respectively. Starting with the intensification of irrigation activities in the beginning of 1980s in Abaya and Chamo lakes, the decreasing water inflow to the lakes caused the rapid areal and volumetric decrement of the Lakes, which would result a progressive desiccation, and denudation of the lakes. The ecological situation in the lake region changed dramatically during last decades. The hydrological systems (natural, semi-natural and man-made) are in a state of dynamic dis-equilibrium as they adjust to the rapid and intense internal and external forces (Seleshi, 2000).

The human settlements resulting exploitation of land are also the chief factors for the degradation of wetlands around the lakes, particularly Lake Abaya. The anthropogenic pressures in the catchments itself has resulted in degradation of the catchments area due to deforestation, extensive agricultural use and consequent erosion and increased silt flows, which have affected the quantity and quality of water stored in the lakes. Infrastructure development, housing pressure and encroachments have resulted in converting all wetlands to non-wetlands.

1.2 Problem statement and justification of the study

Wetland degradation can be considered as devastating as complete wetland loss since degraded wetlands could lose their ability to perform their valuable wetland functions. Loss of even small wetlands would have great environmental impacts and it is critical that the few

remaining wetland resources of Ethiopia shall be protected and conserved. However, the impacts of environmental changes on wetland ecosystems (from both natural and human causes) are poorly understood due to our limited knowledge of wetland ecology. The first step in interpret the intricate ecological processes of wetlands systems is to locate or map these areas on the landscape (Whigham, 1999).

The stud area, wetlands around Arbaminch, are playing major role in different ways. But unfortunately, they are degrading progressively due to different natural processes and human activities; as a result there is a tremendous influence on the quantity and quality of the lake, biodiversity and environment. The accelerated deterioration of the wetland resources and their functions, therefore, calls for an urgent institutionalization of management plan, which can create harmony among wetland users and ecological functions and values of the wetland.

In order to develop viable wetland conservation and management plan in the area a great deal of effort has to put in understanding the causes and effects at desired spatial and temporal scales. The problem is how to make this very applicable. Seleshi, 2000 has studied the water resources potential of the area for various developments plans like Irrigation, Hydropower, and consumption use and for others. But he associated impacts on the existence of the wetlands was underestimated. Hence this research is intended that would contribute to wetland conservation by developing the different zones for protection of wetlands. Basically to alleviate all the problems associated with the wetland lose it has been found that first to map and locate them in a landscape and know the actual causes, threats, rates and degrees of the wetland lose. In this regard remote sensing and GIS have great role to assist to develop management plans for the conservation and sustainable utilization of wetlands. Keeping the importance of wetlands around the lake, an attempt were made to assess and evaluate the spatial and temporal variability of wetland ecosystem around the lakes Abaya and Chamo, Arbaminch, Ethiopia. The desired outcome of the research is to see the rate of wetland denudation, which helps for the development of priorities through wetland zoning for both restoration and conservation of wetlands surrounding lakes Abaya and Chamo. Special interests were placed on the spatial distribution and the rate and intensity of changes.

1.3 Objectives

General objective:

- To assess the spatial and temporal variability of wetlands ecosystems and their properties. Finally to develop a zone of protection map based on the direction and magnitude of change of the wetlands.

Specific objectives:

1. To produce land use/land cover and wetlands map of different times of the study area using landsat images.
2. To analyze the changes on both the LU/LC and wetlands of Abaya and Chamo and to assess the causes of denudation.
3. To estimate the spatial and temporal variability of morphometric properties of the lakes (Abaya and Chamo) with respect to the associated factors and finally to suggest possible measures to protect wetland ecosystem.
4. To develop information system that supports hydro-meteorological and related environmental systems of the wetlands.
5. To map the extent and status of wetlands particularly lakes, detect physical trends pertaining to these lakes, and identify high disturbance areas for these wetlands denudation.

1.4 Assumptions, Limitations and future research gaps:

- Wetlands are different in type and nature (e.g. permanent wetlands like lakes, seasonal wetlands like flooded and swampy areas, flowing wetlands like riverin wetlands etc). However, in this study, 38% of the wetlands are lake, almost all the analysis concentrate on the lakes.
- In this study wetlands change refers the area and volumetric property of the lakes wetlands; but the quality of the lakes and very small wetland ecosystems are ignored.
- Moreover characterizing and change analysis of wetlands based on flora and fauna is not the major issue of this research while it is very crucial for wetlands change analysis these could be future research gaps.

1.5 Research questions

- How RS/GIS applied for wetlands identification and change detection?
- How and to what extent and direction wetlands change?
- What is the fate of the wetlands under human and natural processes?

2 LITERATURE REVIEW

2.1 General Overview of Wetlands

2.1.1 Definitions of Wetlands

The term "wetland" was not commonly used until quite recently. It appears to have been adopted as euphemistic substitute for the term "swamp" (Cowardin et al. 1979) Nineteenth-century scientists used terms such as mire, bog, and fen to describe the lands that are now called wetlands, and these terms are still used by scientists to describe specific kinds of wetland (Mitsch and Gosselink, 1986; Dennison and Berry, 1993).

Scientists have not agreed on a single commonly used definition of wetland in the past because they have had no scientific motivation to do so. Now, however, they are being asked to help interpret regulatory definitions of wetlands. The application of scientific principles to the definition of wetlands and to the determination of wetland boundaries could help stabilize and rationalize the application of regulations, but it does not ensure that any resultant definition will be precise in its ability to distinguish wetlands from all other kinds of ecosystems, or in its ability to specify the exact boundary of a wetland (Mitsch and Gosselink, 1986; Dennison and Berry, 1993).

"Wetland" is a general term used to describe areas, which are neither fully terrestrial nor fully aquatic. "A wetland is an area that has water at or near the surface of the ground during the growing season (wetland hydrology). It may support or is capable of supporting plants that are adapted to wet habitats (hydrophytic vegetation) and has soils that have developed under wet conditions (hydric soils). Often, the wetlands are described as "*ecotones*" as a result of the transition zone between terrestrial and aquatic systems. These distinctive factors have a crucial role in the complex ecosystem. The US Army Corp of Engineers Wetlands Delineation manual (1987) defines wetlands as "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions". The Corps definition utilizes the "three-parameter test" for permitting and planning purposes. These three parameters are hydrophytic vegetation, hydric soils, and wetland hydrology. Under this definition an area is considered a wetland only if all three conditions are present (U.S. EPA, 2003).

2.1.2 Global Overview of Wetlands

Wetland environments have existed throughout human history, forming part of the development and sustenance of many cultures in the world and are considered one of the most important ecosystems on earth. Wetlands comprise only three to six percent of the earth's land surface area, but they provide human populations with a host of goods and services, including water quality maintenance, agricultural production, fisheries, and recreation (Acreman & Hollis, 1996). In spite of their valuable benefits and functions, the rates of disappearance of this unique ecosystem are alarming at the global extent as a result of human influence (Mitsch and Gosselink, 2000). Human population growth, expansion of the cities, and demand for resources all generated the necessity to intervene in the landscape of wetlands through time.

The scientific community has appreciated the relevancies of the wetlands as expressed in different studies (e.g. identify the properties, their influence, classification, inventory and research of these ecosystems). There are many international organizations such as Ramsar Convention that works in the conservation and management of the wetlands. The convention was established in 1971 as an international treaty for the conservation and wise use of the wetlands and their resources in the world, using local, regional and national actions and international cooperation (Ramsar, 2002). Since governments understand the enormous ecological and economic benefits that wetlands provide, they have formulated policy to protect, restore and manage these ecosystems.

2.1.3 Overview of Ethiopian Wetlands

Using the directory of African Wetlands, Ethiopia wetlands are classified in to the following major groups, namely Lake Tana and Associated wetlands; the Ashenge and Hyak Lakes; Wetlands of Bale mountains; Wetlands of the Western Highlands; Lakes of Bishoftu; Lakes and associated wetlands of the southwest rift valley; lakes and swamps of awash river system; lakes of afar depression; the upper awash Valley-Dillu-meda, Aba Samuel; Western river floodplains; and Artificial Impoundments and Micro dams(EPA, 2006). All forms of wetlands, except marine habitats, including alpine formations, riverian lacustrine, palustrine and floodplain wetlands represented in Ethiopia. Ethiopia wetlands can be grouped into four

major categories based on the biomes in which they are found Group I – the Afro-tropical Wetland system; Group II – Somali-Masai wetland system; Group II-Sudano-Guinean wetland system; Group IV – Sahelian transition wetland system (EPA, 2006).

2.2 Classification of Wetlands

Cowardin (1979) recognizes the following five major wetland classifications: marine, estuarine, lacustrine, riverine, and palustrine. Marine and estuarine wetlands are associated with the ocean and include coastal wetlands, such as tidal marshes. Lacustrine wetlands are associated with lakes, while riverine wetlands are found along rivers and streams. Palustrine wetlands may be isolated or connected wet areas and include marshes, swamps, and bogs.

Wetlands can be also classified into three general categories: *marshes, swamps, and peat* lands. Within each of these categories, wetlands can vary widely. Because wetlands depend on water sources, their boundaries can change. The characteristics that describe each category include vegetation, soil type, water supply, and water chemistry.

2.3 Wetlands zoning for management purpose

The terrestrial habitat adjacent to and surrounding wetlands are critical for the management of natural resources. Most conservationists and land managers understand that this land and water interface protects adjoining aquatic resources by filtering chemical pollutants, moderating temperature, and ameliorating sedimentation and other pollution caused by human activities such as timber harvesting, road building, agriculture, and urbanization. Further more, scientists and other generally agree that patches or strips of terrestrial habitat ranging from 30 to 60 m wide can function as essential barrier around core aquatic habitats to protect them from surrounding land use practice. These up land “buffer zones “(also called buffer strips and riparian buffets) receives much attention for their value in protecting aquatic resources (Whigham, 1999).

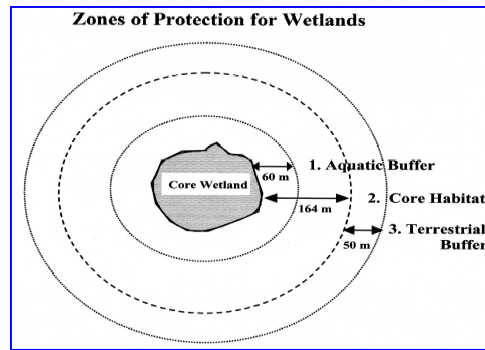


Fig 2.1 Protection Zones of Wetlands

The term "buffer zone" refers to the area of land adjacent to a wetland or water body. A buffer zone is generally thought of as a buffer against human generated disturbance in areas adjacent to the wetland. In terms of the regulations the buffer zone extends horizontally greater than 100 ft. from the wetland edge. The upland adjacent to the wetland is critical to the survival of wetland dependent wildlife, and its importance for wildlife extends well beyond 100 ft. This adjacent upland provides the habitat critical for activities including nesting, feeding, cover, and over-wintering. Without providing protection to the adjacent upland a wetland is unable to support the same biodiversity. Therefore the adjacent land is really a “life zone” not just a buffer protecting these species from adjacent human activities (Whigham, 1999).

2.3.1 Can one Size fit all conditions?

Buffer zones- in traditional senses of the term-continue to be a valuable concept, and they are still needed. Buffer zones should surround the upland portion of the core habitat to protect the terrestrial and aquatic habitats from surrounding land use practices that could damage these areas. While core habitat for maintaining viable population of species is not the same as a buffer zone for protecting water resources, some may ask whether core habitat for maintaining biodiversity also can be used to protect water resources. The answer is yes, but if the criteria for the size and use of the terrestrial habitat fully satisfies the needs of both functions. Ideally, one could develop a single universal size for core, buffer and transition zone of wetlands, which would simplify adoption of regulations and, management strategies. It is unlikely; however, that one value can be used for all wetlands, because of local differences in size topography, climate, and surrounding land use practices (Whigham, 1999).

2.4 Application of Remote Sensing for Wetlands management

Numerous studies have discussed the positive benefits and opportunities presented by the technology as well as the barriers and limitations of various remotely sensed data (Narumalani, (1997). Traditionally, wetlands are delineated using ground surveys. However, the surveys are difficult and time-consuming (Lyon, 1993). Remote sensing is one of the technologies that can provide cost and time-effective solutions to mitigate these problems. Over the years, remote sensing has been used as a tool to map large areas of wetlands. In addition, remote sensing technologies can supply the following information: (1) extent of wetlands, (2) identify the wetland resource as a type, (3) characterize the general wetland land cover type, (4) identify submerging and emergent wetlands, and (5) supply details about the resource using multiple spectral analysis of remote sensor data (Lyon & McCarthy, 1995). 5) Changes in surface environmental conditions can therefore be monitored using space-borne digital imageries (Lyon, 1993).

With launch of remote sensing satellites like the Landsat series with Multispectral Scanner (MSS) and later Thematic Mapper (TM), it has become cost effective and convenient to acquire multi-date digital images over a greater array of spatial and temporal scales than was possible with aerial photography (Lyon, 1993). Landsat-MSS Yet, its use is very limited for studies of different aspects (e.g., vegetation species identification, discrimination, etc.) of all types of wetlands, specifically, inland wetlands which usually have smaller areal extent and complex mixture of vegetation species. Basic constraints of using Landsat-MSS data for wetland mapping inventory in early studies were geometric inaccuracy and the poor spatial, spectral, and radiometric resolutions of data (Carter, 1982). Availability of Landsat-TM data solved this problem of coarse resolutions to some extent. With a spatial resolution of 28.5 meters, it becomes possible to study relatively smaller areas (Johnston, & Barson, 1993).

2.4.1 Ancillary data for mapping wetlands

The potential of a site to retain surface or soil moisture is largely determined by topographic and soil characteristics. Locating such specific site conditions using a combination of spectral data and ancillary environmental data has provided improved classification accuracies over classifications using only spectral data. These data provided ancillary information regarding the vegetative or hydrologic conditions on the landscape (Houhoulis & Michener, 2000).

2.4.2 Image processing for wetlands and non-wetlands mapping

2.4.2.1 Image enhancement (Transformations) for wetland mapping

The Tasseled Cap (TC) transformation was originally developed for crop development studies (Thomas, et.al, 1976) but has seen more widespread use as a predictable method for compressing scene characteristics into three orthogonal spectral bands. Unlike principle components analysis (PCA), TC transformations produce reliable spectral bands that can be directly associated with physical scene characteristics (Crist & Cicone, 1984; Collins & Woodcock, 1994). TC-Component 1 is a measure of brightness, TC-Component 2 is a measure of greenness, and TC-Component 3 is a measure of wetness. The coefficients used to derive these components were collected through samples of water, vegetation, soil, and impervious surface extracted from 10 Landsat scenes (Crist & Cicone, 1984; Huang et al., 2002a). Through widespread application and detailed development of current TC procedures, this transformation has proven to be efficient and highly effective. The brightness, greenness, and wetness components generally account for over 97% of spectral variability present in a given scene and have been widely used for quantifying spectral changes. The invariant nature of TC transformations allows direct comparisons of TC bands for multiple Land-sat scenes (Crist & Cicone, 1984).

2.4.3 Image classification

As far as classification of images is concerned, there are two common classification types (Lillesand & Kiefer, 1994).

2.4.3.1 Unsupervised Techniques

The variation of spectral responses provided by different wetland types creates a challenge for image analysts. This challenge is frequently addressed through the use of unsupervised clustering algorithms. Unsupervised classification algorithms, such as ISODATA and K-means in ENVI software, are statistical clustering algorithms that classify pixels based on a selected number of spectral clusters and are refined iteratively to reduce the spectral variation within each cluster. Land cover classes with highly variable spectral responses, such as wetlands, have been effectively classified using the ISODATA clustering algorithm (Thomas et al., 2002). ISODATA can split or combine clusters to develop numerous “wetland” clusters that capture a range of spectral responses within the wetland class (Evans, 2004).

ISODATA based wetland classifications using SPOT and Land sat data with ancillary data yielded overall accuracies of 84% to 86%, respectively (Thomas et al., 2002).

However, several inherent problems with unsupervised classification algorithms limit the accuracy and efficiency of this classification procedure. Adaptive clustering programs (i.e., ISODATA) can create hundreds of clusters, just to identify wetland classes (Henderson et al., 1998). Assigning each cluster to a land cover class is a time consuming process that requires the analyst to decipher inter-cluster spectral confusion. Unsupervised grouping algorithms are also sensitive to the range and variability of spectral values used to develop the initial clusters (Thomas et al., 2002).

2.4.3.2 Supervised Techniques

Supervised classification procedures are employed when a priori knowledge of specific land cover characteristics is available. This knowledge is then used to select training sites that sample the variability existing within each land cover class. Numerical grouping algorithms are used to statistically place each pixel into one of the predetermined land cover classes (Lillesand & Kiefer, 1994). The accuracy of supervised classifications strongly depends on how well the designated training sites represent the variability within each land cover type. Additionally, selection of the proper classification technique depends on the nature of the expert knowledge resources available and the distinctiveness of each land cover type.

2.4.4 Change Detection Techniques

The synoptic nature of remote imaging provides a complete sample of the variability present in diverse ecosystems, thus allowing many types of wetlands areas to be distinguished from the surrounding landscape features. Once an effective and reproducible detection method has been established, wetland areas can be monitored using multiple years of remotely sensed imagery. Periodic monitoring can then be used to analyze wetland distribution and evaluate the impacts of land management decisions on these important ecosystems (Muller, 1997).

The variety of image data sources and classification techniques has led to the development of numerous change-detection techniques, ranging from simple image comparisons to spectral vector measurements. Post classification comparison is a basic image comparison technique that provides readily interpretable results of changes between land-cover classes between

multiple classified images. This technique has been applied to wetland studies to determine the total area of wetland change and identify specific locations of such ecosystem changes (Choung & Ulliman, 1992; Ramsey & Laine, 1997; Munyati, 2000). More mathematically dependent methods use the differencing of individual standardized spectral bands or transformations of spectral data. Although differencing non-transformed Land-sat bands is an intuitive process, this method often provides spurious results due to influence of data noise and variable sensitivity of individual sensors (Nielsen et al., 1998). Simple differencing of more basic vegetation indices (e.g. Normalized Difference Vegetation Index) is less susceptible to noise interference, but is heavily dependent on the resolution of very few Land-sat bands (Hayes & Sader, 2001; Stefanov et al., 2001). Orthogonal transformations like TCT have proven to be an effective technique for detecting changes of diverse ecosystems using differencing techniques (Nielsen et al., 1998; Oetter et al., 2001; Parmenter et al., 2003).

2.5 Previous researches in the area

There are various researches which have been done in the area related with the two lakes. But majority of the studies were concentrated on the lakes and related water potentials for various development activities. To mention some Seleshi, 2000, Fekadue, 2003 and both of them highly focused on the water resources potential of the area but none of them did Wetland and upland dynamics analysis using GIS and remote sensing techniques.

However, Sileshi's, 2000 study has some similarities with this study with great difference in methodology. Sileshi had done much important information, which are fundamental for this thesis work to mention some, the bathymetry survey, lake water balance, lake level fluctuation and sedimentation Scenario analysis. All his information were not to mean incorrect but this research updates and uses GIS and remote sensing techniques (using satellite images) to get various information more scientific and up-to-date. For example Seleshi has used 1979 lakes area from Topographic map of the area to model the lakes water balance and sedimentation effect and volume and other analysis. Since wetlands are very dynamic and this study utilizes the recent available satellite image to calculate various morphometric properties of the lakes. The over all of his study were very much concentrated on the water resource but this study gave more attention on the dynamics of wetlands ecosystems giving more emphasis to lakes.

3 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study area is found in the South Nations and Nationalities of People region near the town called Arbaminch. It is far (about 505 km) away from Addis Ababa in the way from Addis Ababa to Konso. The study area includes the Abaya and Chamo sub basin and embraces the wetlands around Lakes Abaya covers (1,087 km²) and Chamo covers (317 km²) in area. These two lakes also have large drainage areas, 14,487 km² for Abaya and 18,753 km² for Lake Chamo. But the study area only covers a small watershed including water bodies, which is 3,783 km².

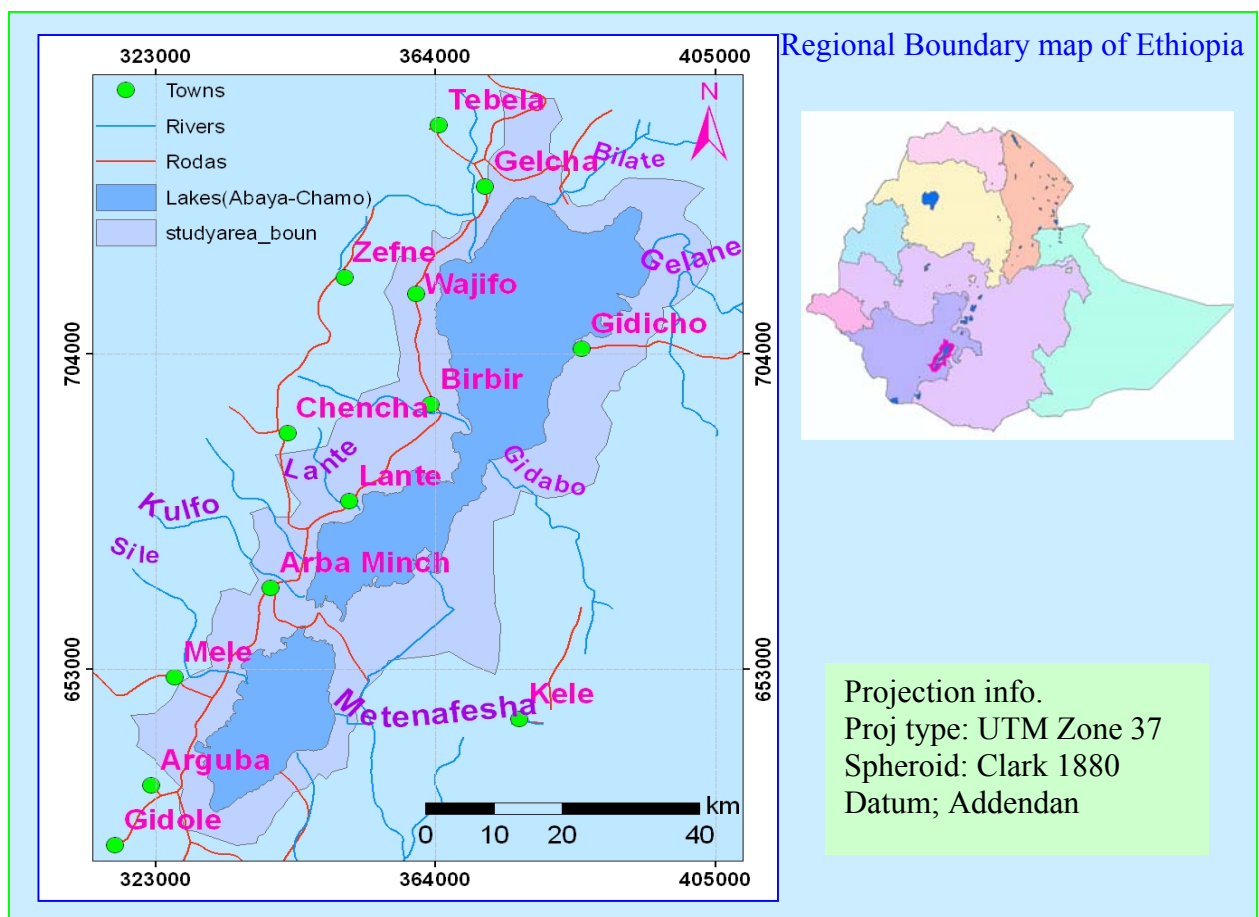


Fig 3.1 Location of the study area

3.1.2 Physiography of the study area

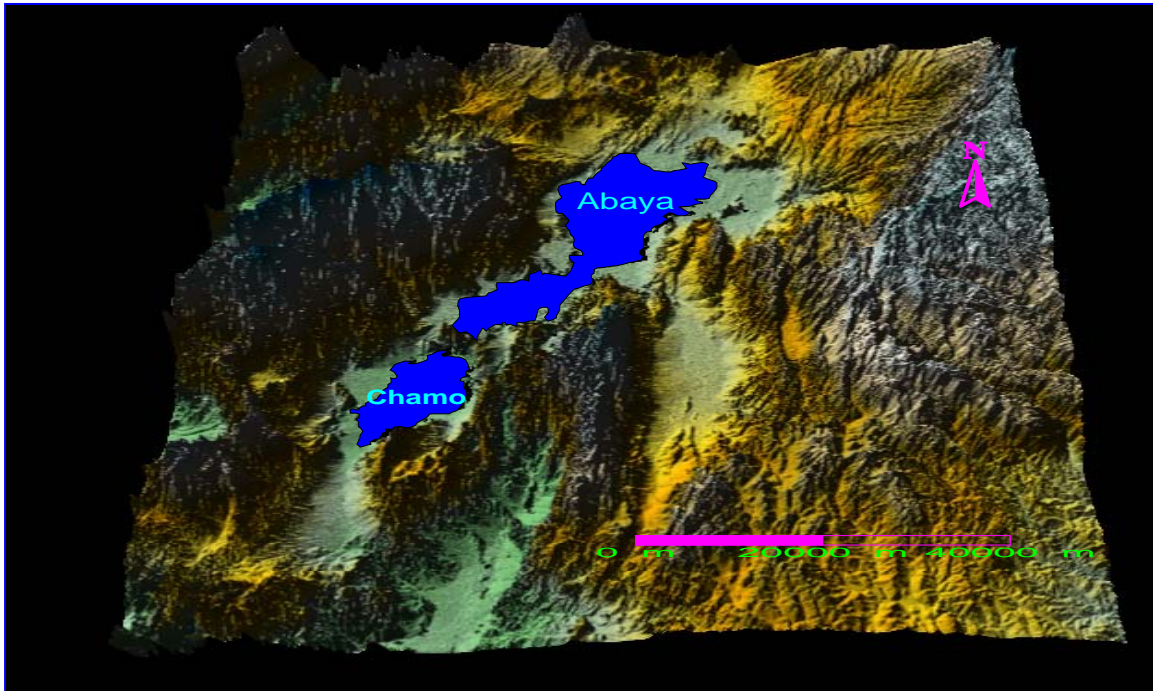


Fig. 3.2 DEM of the study area

The figure above in combination with figure 3.1 clearly show the drainage outlet Point and inlet points of Abaya and Chamo Lakes system, topographic condition (relief), and inter-linkage of various rivers. The major rivers, Bilate, Gidabo, Gelane are interconnected in Abaya Lake. Whereas Chamo together with Sile and Kulfo and other tributaries outflow at the outlet point named locally ‘Metenafesha’ and end up joining Segen River. The elevation of the basin varies from 3,560 m.a.s.l in the surrounding Gamo and 1171 m.a.s.l at Arbaminch town.

3.1.3 Climate

According to Ethiopian climatic classification, the area is characterized with hot semi-arid and warm temperature of tropical climate. Average annual rainfall ranges from 664mm at Bilate to 1239 mm at Chenchä with average maximum temperature (31.2 °C) at Arba Minch and minimum in Chenchä (13.9 °C). There is a distinct bimodality of rainfall and the peaks are between October and November and between March and April. The Bimodality of the rainfall in Alaba approaches that of the central plateau although there is still some tricking similarity to the stations in the south (EPA, 2006).

3.1.4 Biodiversity and eco-tourism of the wetlands

The water of the lake supports different species of phytoplankton, freshwater invertebrates, bacterio-plankton, and different fish species of which are commercially important. Different species of waterfowl, hippopotamus and reptiles also reside in, and are supported by the lake. Lakes Abaya and Chamo provide all the necessary amenities for Eco-Tourism including scenic beauty comparable to any where in Ethiopia, rich wildlife resource in Nechisar National Park, rich bird fauna, sport fishing for Nile Perch and Tiger Fish, the ‘*Azogebeya*’ (Crocodile Market). The ‘*forty springs*’ that gave rise to the name ‘Arba Minch’ provide special attraction to tourists. The conservation of these cultural and natural attractions warrants eco-tourism activities for conservation and sustainable use and generates income to the community (EPA, 2006).

3.1.5 Geology and Hydrology of the area

The Ethiopian Rift Valley is part of the great East African Rift Valley, which was formed as a result of Tertiary-Quaternary tectonic movements. In the Rift Valley lakes basins, including that of Abaya and Chamo, basalts, ignimbrites, pyroclasts and lacustrine sediments overlie the ancient basement rock. Quaternary basalt flows (recent Basalts) are found near Arba minch town and the hill separating the two lakes ‘*God’s Bridge*’. The rift valley floor near lakes Abaya and Cahmo is filled with alluvial sediments. Many perennial and intermittent rivers drain into the two lakes. Lake Abaya receives high runoff all the year round except for two months. Lake Cahmo receives Runoff from River Sille originated from areas receiving rainfall following the climatic pattern of the southern parts of Ethiopia. This indicates that it receives runoff only once a year, unlike Lake Abaya. Further more Lake Abaya receives runoff from four river basins, while Lake Chamo receives runoff from only two river basins. This partly explains why Lake Chamo is more sensitive to climatic fluctuation than Lake Abaya (EPA, 2006).

3.1.6 Land use

The area, lakes Abaya and Chamo, are surrounded by several land use types; moderately cultivated, rain fed peasant cultivation and sedentary peasant livestock grazing and fallow. The Eastern side of Lake Abaya, which is inaccessible, is characterized as riparian woodland and bush land dense scrubland. The land use type surrounding Lake Chamo on the southern

boarder of Lake Abaya is characterized as ground water forest and dense shrub land (EPA, 2006).

3.1.7 Soil of the area

Soil types in the rift valley are closely related to soil parent materials: Basalt ignimberite, lava, gnesis, volcanic ash and pumice, riverine, and lacustine alluvium. Cracking clays occur locally at lower elevations on colluvial fans-characteristic feature of Abaya and Camo basin. The fans, deltas and flood plains around lakes Abaya and Chamo are built-up from materials recently deposited by rivers and lakes. Soil fertility, structure and drainage are generally favorable for agriculture provided that there is enough moisture (EPA, 2006). The basic soil groups identified in the area according to FAO/UNDP classification are: Vertisols, Nitosols (Alfisols), and Lithosols, Andosols, Cambisols, Fluvisols and Sols. The soil type of the hills West of Lake Abaya is Orthic acrisols and dystic nitosols with textural classification of clay to sandy clay loam-clay to clay loam. The soil types on the wetern and southern plains around Lake Camo are chromic verticals and eutric nitosol with textural classification ranging between clay to clay-loam. The soil types along the eastern shore of lakes Abaya and chamo are vertisols, luvisols and nitosols with textural classification of clay to clay –loam (EPA, 2006).

3.1.8 Socio-economic information

The economic bases of the community in the province to the wetland are Farming, fishing, and Service (Hotels and tour operators) and petty trade. When considering the economic activities in the Arbaninch town, fishing farming in the outskirts of the town followed by the service sector seemed to dominate all other livelihood activities. Fishing is an important economic activity in Abaya and Chamo wetlands. Most of the commercial fishing is done in the south and southwestern part of lake Abaya, because of a relatively easier access to the landings sites, while fishing is carried out through out the lakes in lake Chamo (EPA, 2006). Tourism development is inadequate even although the natural tourism resources of the Abaya and Chamo wetlands are abundant and diverse, and could probably rank among the best touristically rich areas in Ethiopia (EPA, 2006).

3.2 Methodology

3.2.1 Data and materials used

Table 3.1 Material and Satellite images Used

S/N	Types	Names and description	
1	Software and program	Global-Mapper, Surfer, Arc View 3.3, Arc GIS 9.1, ENVI 4.2, ERDAS 8.6, ILWIS 3.2, IDRISI Microsoft Spread sheet	
2	Topo-sheet	(1:50,000 scale) From EMA	
3	Materials	GPS Magellan	
4	Other Data	Digital soil map, Digital land use map	
5		SRTM image 30 m resolution	
Satellite images used			
Landsat Types	Path and Row	Date of Acquisition	Spatial Resolution (m)
Landsat-MSS	181_55 and 181_56	Jan.12, 1973	57 X 57
Landsat-TM	169_56, 169_55 168_55, 168_56	Jan.28 1986,	28.50 X 28.50
Landsat-ETM+	169_56, 169_55 168_55, 168_56	Jan.27, 2000	28.50 X 28.50
Panchromatic	169_56, 169_55 168_55, 168_56	Jan.27, 2000	15 x15

3.2.2 Data collection

The important data were collected with the help of various methods. The different methods that were employed during the study for data collection are described below.

A) Preliminary field survey or simple observation:

A preliminary field survey has been conducted to get a general view on the physical condition of the area such as the vegetation cover, land use type, topography of the study area. During this stage of the process, detailed investigations were carried out into past and present wetland uses, condition and management practices. Information was gathered using a number of research tools, such as taking GCP using GPS, informal interviews and focus group discussions. The objective of the investigation stage is to develop a clear

understanding of the wetland resources, who uses them, what they are used for, what the existing management rules are and what local capacity and opportunities for community management exist in addition what are the reasons that wetlands are being denudating

B) Reviewing the different literatures: It has been tried to get some valuable information from already done research papers, Internets, or other resources.

C) GPS Readings: To locate and know the different features in the study area GPS readings were taken to collect various futures in the study area.

D) Satellite images and top sheet: Along with the above-mentioned methods of data gathering the very great concern of this research almost all data were extracted from the Satellite images relevant for the study and from the top sheet. Appropriate satellite images and classification routines are selected depending on the individual site features and targets of the studies.

3.2.3 Data analysis

3.2.3.1 Sample site Selection for fieldwork and data collection

Since it was difficult to identify all the land cover classes only by interpreting satellite images, ground truth data collection through fieldwork were need to be conducted. Since wetland ecosystems are very complex and difficult to interpret by only satellite images, sample data collection during the fieldwork were done by selecting sites that are identified to be representative to those wetland ecosystems and land cover classes with in the boundary (See Appendix 1-2).

3.2.3.2 Band Selection

In this research band selection were made through the analyses of: Reflectance properties of objects or features, Correlation matrix of the image, Spectral reflectance curve of the different wetlands types of the area; and the histogram behavior of the bands. For the purpose of calculating the correlation matrix, spectral profile and the histogram of the Land-sat images the image processing software ENVI 4.2 and ERDAS IMAGIN 8.6 were used.

A) Application of Bands for features identification

The basic premise of remote sensing (satellite images) is that different objects do have different reflectance properties at different EMS (electromagnetic spectrum) interacting with them since all objects vary with internal structure, morphology, and chemical composition.

The figure below clearly shows which bands are more sensitive with which features. During the study the spectral behavior of different objects has been primarily referenced with this table and band selection has been performed. For this particular study where the wetlands or moisture of the area is major focus infrared bands (particularly near and mid infrared) were found the most crucial bands in discriminating wet terrain with that of non-wet terrain.

Table 3.2 Application of bands for different feature identification

Band	Band name	Application
0.45-0.56	Blue	-Soil and vegetation discrimination -Bathymetry and coastal mapping -Cultural/ urban features
0.52-0.66	Green	-Green vegetation mapping and cultural/urban features
0.63-0.69	Red	-Vegetated and non vegetated mapping -Cultural/urban features
0.76-0.90	NIR	-Delineation of water body -Soil moisture discrimination
1.55-1.75	MIR	-Vegetation moisture discrimination -Soil moisture discrimination -Differentiation of snow and ice
10.4-12.5	TIR	-Vegetation and soil moisture analysis -Thermal mapping
2.08-2.35	NIR	-Discrimination of minerals and rocks -Vegetation moisture analysis

B) Analyses of the Correlation Matrix

Satellite data often show a degree of correlation, meaning that when the spectral values in one band are high the values in another band are expected to be high as well. The correlation matrix of the spectral bands contains useful information about the redundancy of information and selection of optimal band combination for interpretation purpose. If the bands show strong correlation (value near to 1.000) this indicates that the bands usually contain similar information. When those bands are visualized the minimum interpretability among different feature would be noticed. Below, Table 3.3 represents the correlation matrix of the sub scene that was clipped by the study area boundary.

From this table it can be observed that there exists high correlation among visible (band 1-3) and mid-infrared bands. It means that there is a high redundancy of Information within those bands in the wetlands and non-wetlands so it makes more sense to select the bands, which contain minimum redundancy.

Therefore, one band from the visible region, the near infrared and one from mid-infrared can be selected for the best separability in the wetland areas using Landsat TM and ETM image. Infrared bands 4 and 7 are sensitive to wetlands and commonly to use band 3 from the visible bands in this study has also decided to do so. Therefore, bands 7, 4 and 3 (or else 2) were finally selected for the interpretation purpose as TCC image but others FCC were also used.

Table3.3 Correlation matrix of Landsat image of 1986

Band	1	2	3	4	5	7
1	1.000	0.999	0.899	0.879	0.769	0.678
2	0.999	1.000	0.945	0.894	0.912	0.845
3	0.899	0.945	1.000	0.912	0.899	0.8999
4	0.879	0.894	0.912	1.000	0.762	0.654
5	0.769	0.912	0.899	0.762	1.000	0.899
7	0.678	0.845	0.934	0.654	0.899	1.000

According to the histogram behavior (refer to Figure 3.3) the bands 5 and 7 showed a normal distribution curve but band 7 has high amplitude than band 5 and gives the representative radiance range and this means more information can be extracted from band 7 other than band 5.

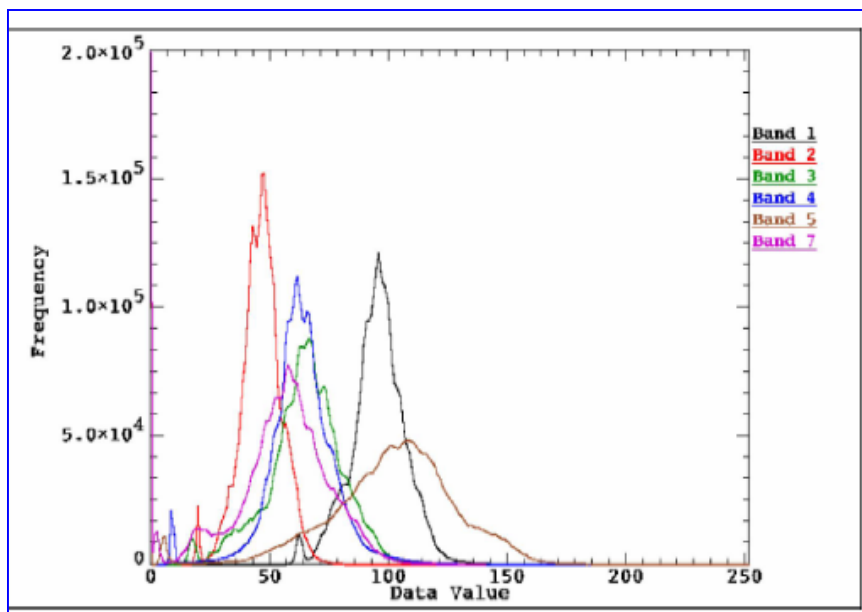


Fig 3.3 Histogram of different bands using 2000 land-sat Image

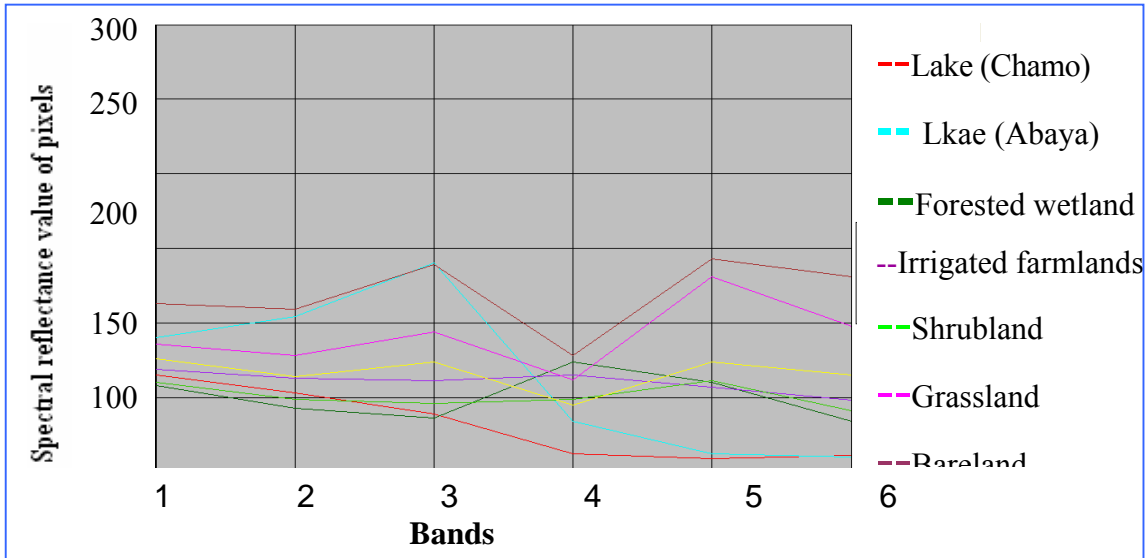


Fig.3. 4 Spectral reflectance profile of the various LU/LC and wetland ecosystems (2000)

As band 7 and 2 show a high variability among the feature classes they are also useful for image interpretation. All the spectral lines in Figure 3.4 band 5 and 6 (note: 6 in the figure represent 7 in the image) did not cross each other. However, as band 7 and 4 are more sensitive to wetlands than band 5 thus it is found to be more useful than band 5 for wetlands identification in the area. But for other LU classes different FCCs were also used.

3.2.3.3 True and False Color Composite Image Preparation

To enhance the visualization of the vegetation and to prepare the image for the future classification various false color composite were made. In this research three TCC and FCC (for all of the Land-sat MSS, TM & ETM images) were found to be more useful for the process of identifying the different land cover classes in the study area. The different True and FCC band combinations used in this research are. FCC-1, FCC-2, FCC-3 of Land-sat, MSS 4-2-1, 4-3-1 & 3-2-1 and Land-sat TM & ETM+ 7-4-3, 7-4--2 & 7-4-1. The best image combination used for wetland identification and LU/LC mapping were the TCC prepared using bands 7, 4 ,3 and 7,4,2 (RGB) respectively for ETM and TM sensors satellite imageries i.e. for the year 1986 and 2000 images (see Figure 3.6). The inclusion of TCT as another channel in this classification has offered considerable benefit for extracting the maximum information especially wetlands. The visual interpretations of all classes were also aided by the topographic maps and the LU/LC map of the study area prepared by FAO.

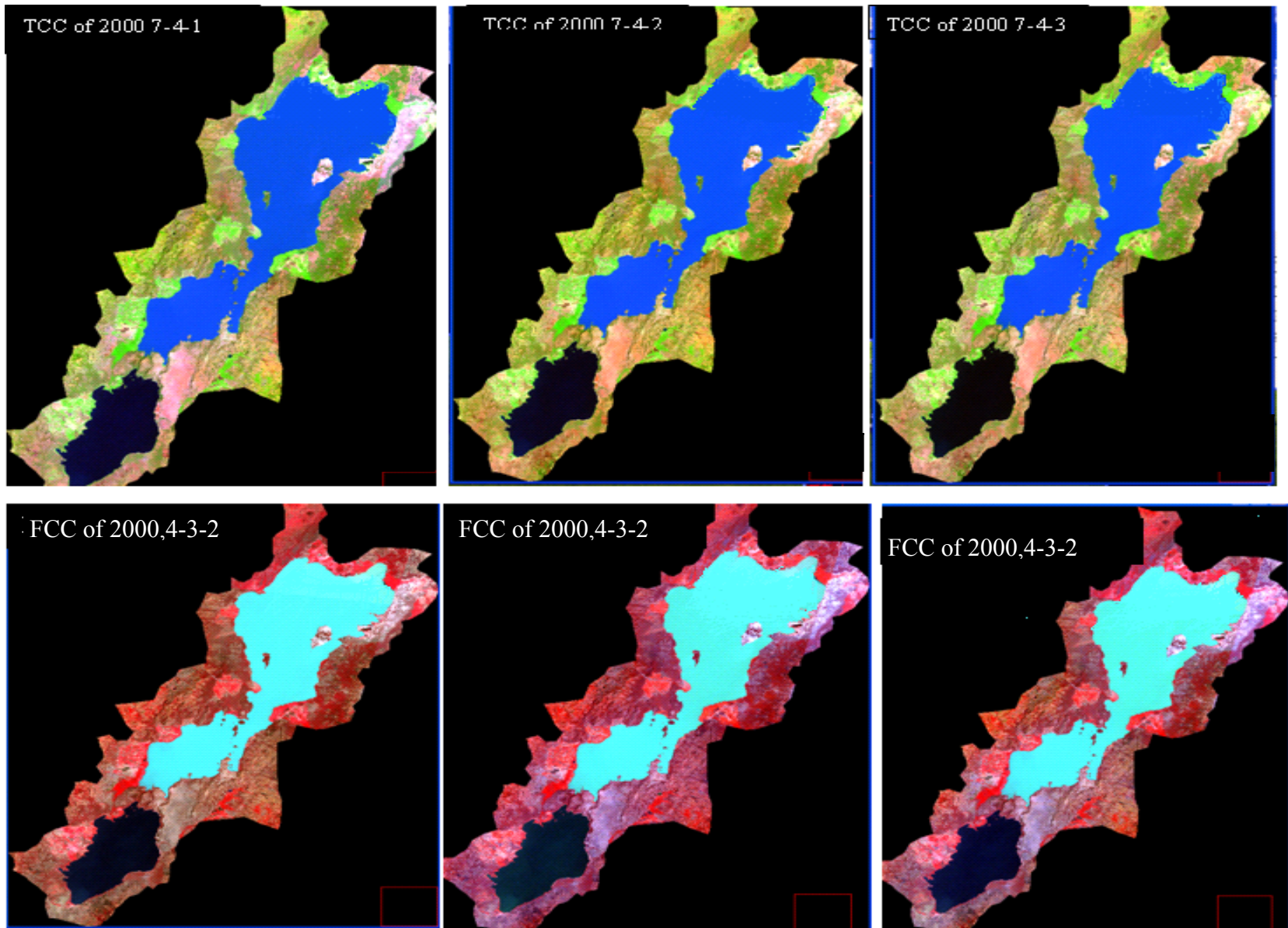


Fig. 3. True and false color composite prepared for image interpretation

3.2.4 Color balancing

By chance the study area boundary has been laid down with four path and row images of landsat scene. These entire Landsat scenes have not been acquired with the same illumination as a result the color of the images was different. Therefore it was found that balancing the color is paramount important. ENVI 4.2 moasicing tool uses Color Balancing to match the statistics from one image to another (or many others) to balance the data range between different images. Similar analysis for all data of the satellite images were applied the color balancing process using ENVI 4.2 software. The figure 3.6 below shows the effect and result of color-balancing process.

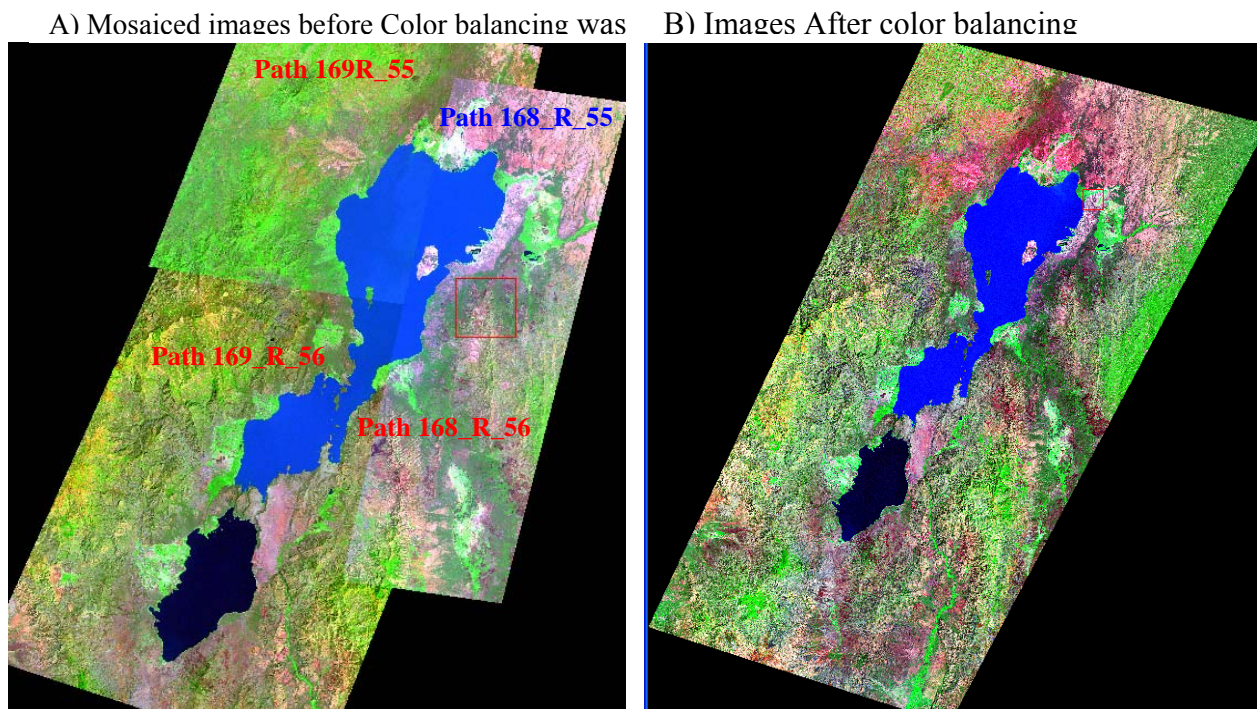


Fig. 3.6 Color Balancing of Satellite images

Fig.3.5 (A) depicts mosaic landsat 2000 image with out application of color balancing. In this image the different path and rows of the image have different colors. If all these images were classified with out color balancing the LU/LC classification of would be error, hence figure 3.5 (B) was color-balanced image used for classification. For all date images color balancing has been done before classification.

3.2.5 Image transformation and Classification

In order to enhance the images for visual identification; image transformation were applied on each of the FCC images. To aid the discrimination of the different land cover classes especially the wetland area from that of the non-wetland areas one of the most commonly used is the Tasseled Cap transformation. Supervised image classification was done on each of the satellite images using the image processing software ENVI 4.2. The maximum likelihood classification were applied for the image classification after selecting 14, 13 and 15 training areas on the 1973, 1986 & 2000 Landsat images respectively. The selection of training areas were made based on the information obtained from field data, TCT & others; inter band comparison, ancillary maps (LU/LC maps), and that of the image interpretation of the different FCC and TCC images.

3.5.5.1 Post Classification (Smoothing)

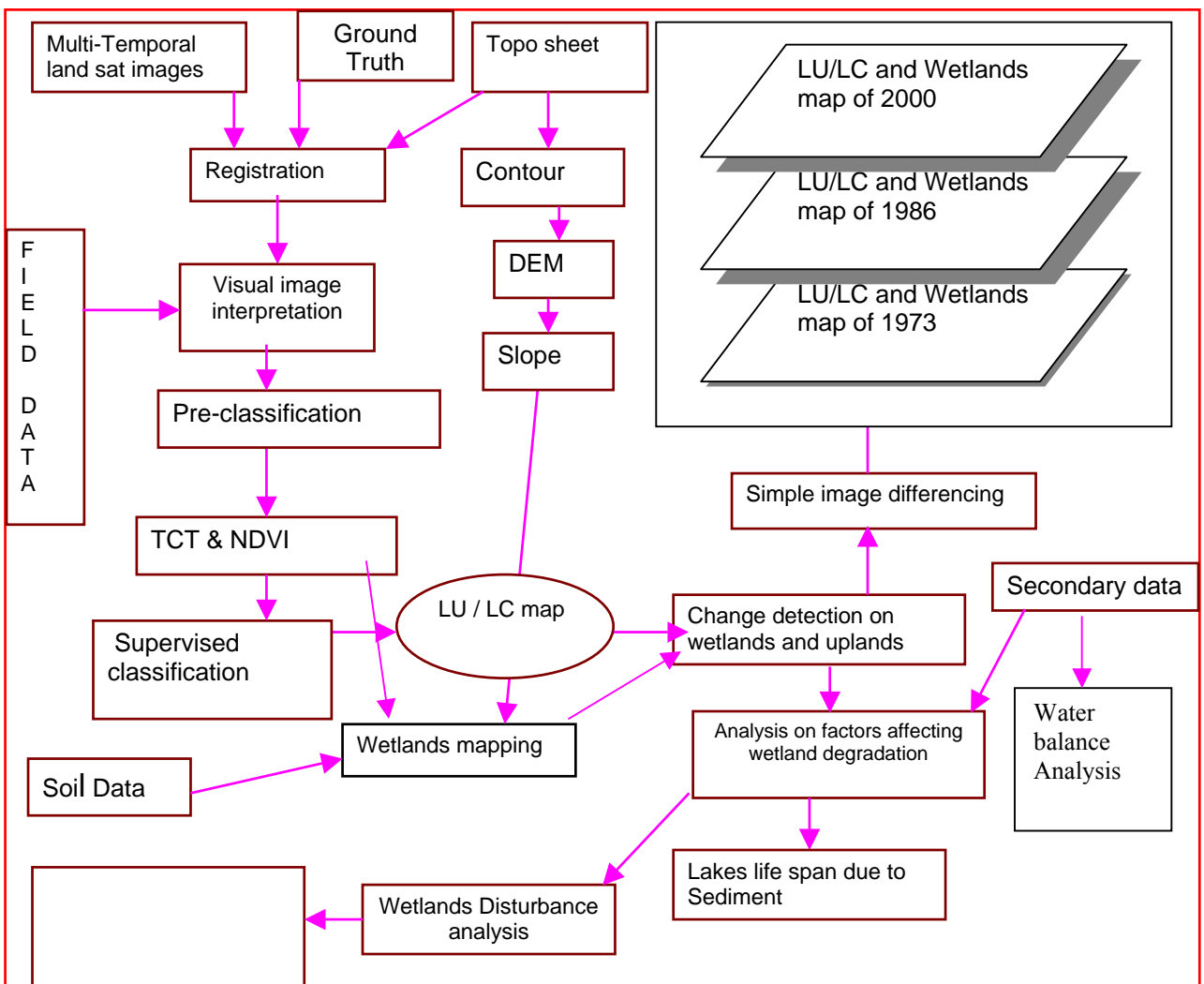
Classified data often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classifier (Lillesand & Kiefer, 1994) and it is often desirable to smooth the classified output to show only the dominant (presumably the correct) classification. Moreover, classified images often suffer from a lack of spatial coherency (speckle or holes in classified areas). Low pass filtering could be used to smooth these images, but the class information would be contaminated by adjacent class codes (ENVI, 2001). To overcome this problem *majority filter analyses* were applied using a kernel size of 5X5 pixels in ENVI 4.2. During the classification process all the images to be classified were masked under the study area boundary, which was digitized during the pre fieldwork stage from the 1: 50,000, topo-sheet.

The digital classification and interpretation of multi-year remote sensing data were carried out using supervised classification technique to locate LU/LC and wetland areas around Lakes Abaya and Chamo at various time series. And eventually the different time series maps of the LU/LC and wetland were subjected to change detection analysis to estimate the rate and direction of change on each class. The changes that occurred from time to time have been studied by change detection studies of the digital satellite data-using Image differencing algorithm in ENVI 4.2 software.

In addition with the mapping and spatial variability analysis of the different LU/LC of the study area the lakes main wetland portions of the study area have been well analyzed of their morphometric properties using hydrological and meteorological data analysis.

Lastly, Geographical spatial database using GIS technology was developed and the existing wetland area was subjected to zonation for protection purpose. The zonation process was carried out by GIS techniques in such a way that a certain portion of the adjacent wetland areas would be buffered. The respective Buffer, Core and Transition zones were delineated. For simplified description of the research structure the following flow chart is important. All the others subsequent sections deal with the results and discussion.

Chart 3.1 Schematic view of the methodology



4 MAPPING OF UP LANDS AND WETLANDS

4.1 Mapping of uplands LU/LC

In this research mapping of land use land covers of the area comprises two major categories namely: *uplands* (which are non-wetlands) and *lowlands* (Which are wetlands). Classification and change detection of uplands as the main focus of this study, it is necessary to map and briefly describe the LU/LC classifications because it is believed that land use land cover changes are the main factors in wetlands changes. It is a general classification that includes the Water body; Bare land, Shrub land, Forest, Grassland, Cultivation (irrigated and seasonal) and wetlands. The LU/LC map of the area has been developed from the satellite images following the different principles and procedures of image classification that was discussed previously.

4.1.2 Discussion on each upland LU/LC identified from images and their accuracy

A) Water body: This land cover includes the lakes, ponds and reservoirs found in the study area. Image classification of the various time series results the water body has been classified with an over all accuracy of 100, 99.91 and 100 percent for the year 1973, 1986 and 2003 respectively. This Land Cover class of all others has been classified with very high accuracy.

B) Bare land: This land Cover class represents areas that are covered by either rock outcrop or bare-soil or rocky and rugged topography areas. The bare land class have been classified with an over all accuracy of 93.25, 95 and 98.48 for the year 1973, 1986 and 2000 respectively. Relatively the classification accuracy of this category is very high.

C) Shrub land: This land cover includes short tress and bushes, which have an opened canopy. Image classification of the various time series results the Shrub lands have been classified with an over all accuracy of 95.59, 92.39 and 91.84 percent for the years 1973, 1986 and 2000 respectively.

D) Forest: This land cover includes big tress, which have closed canopy of both natural and artificial forests. Image classification of the various time series results the Forests have been classified with an over all accuracy of 90.17, 95.59 and 70.38 percent for the year 1973, 1986 and 2000 respectively.

F) Grass land: This land cover includes areas; pasture lands, grazing areas dominantly covered with grasses. There might have also sparse vegetation with it. Grasslands have been classified with an over all accuracy of 84.31, 97.45 and 69.9 percent for the year 1973, 1986 and 2000 respectively. Relatively the 2000 image classification results poor classification of grasslands.

G) Irrigated (perennial) farmlands: This land cover includes areas, which are continuously cultivated using irrigation schemes. They are always covered by crops and appear green in the image. This land use is very common following wetlands around the periphery of the lakes and rivers. These land uses have been classified with an over all accuracy of 78.97, 89.65, and 76.36 percent for the year 1973, 1986 and 2000 respectively.

H) Wetlands: This land cover includes areas seasonally or permanently wet or flooded and may be also have some vegetation cover (often short and tall grass, and tress) even surrounding of irrigation sites not used for crop production. These land covers have been classified with an over all accuracy of 57.72, 83.12 and 87.68 percent for the year 1973, 1986 and 2000 respectively. Of all LU/LC categories wetlands were classified poorly because wetlands are very dynamic and have different character. This confirms that wetland mapping using supervised technique results poor map. For this poor classification the next section has a solution to apply in further classifying and mapping wetlands in detail.

I) Seasonal croplands: The seasonal croplands are those areas, which are seasonally covered by crops, and are commonly cultivated by farmers. The LU/LC classification of the images results an over all accuracy of 94.5, 92.1 and 89.3 percent for the year 1973, 1986 and 2000.

Generally, the accuracy assessment for all LU/LC mapping was 85.9 %, 95.8% and 91.2 % for the year 1973, 1986 and 2000 respectively. In principle it is clear that the number of LU/LC classes for all period should not be the same and equal since there is a change, new classes may be created and old ones may be disappeared. But for change detection purpose those new classes and old classes would be merged during the change detection analysis and therefore only those permanent ones are presented here in the analysis of this research.

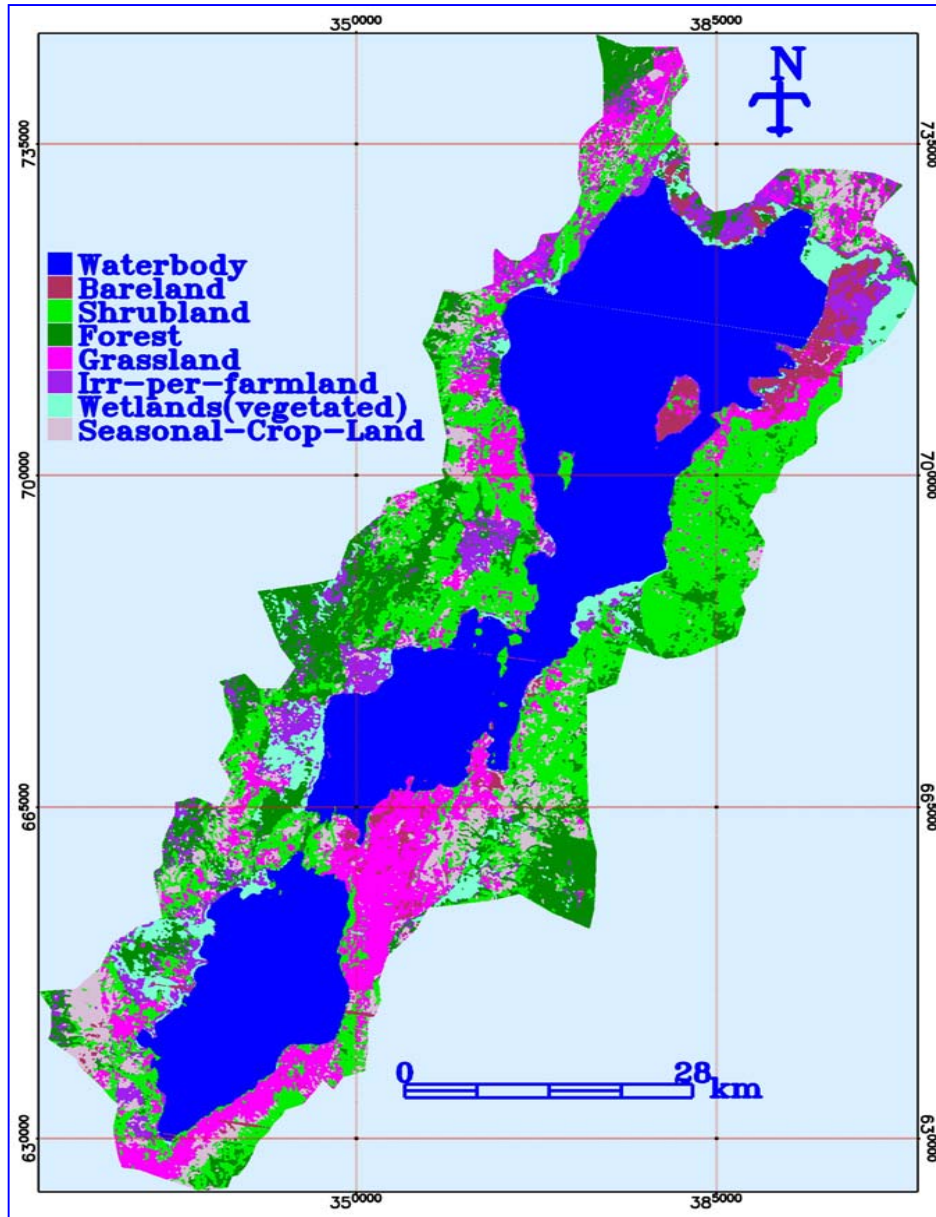


Fig 4.1 LU/LC map of Abaya and Chamo Sub-basin (1973)

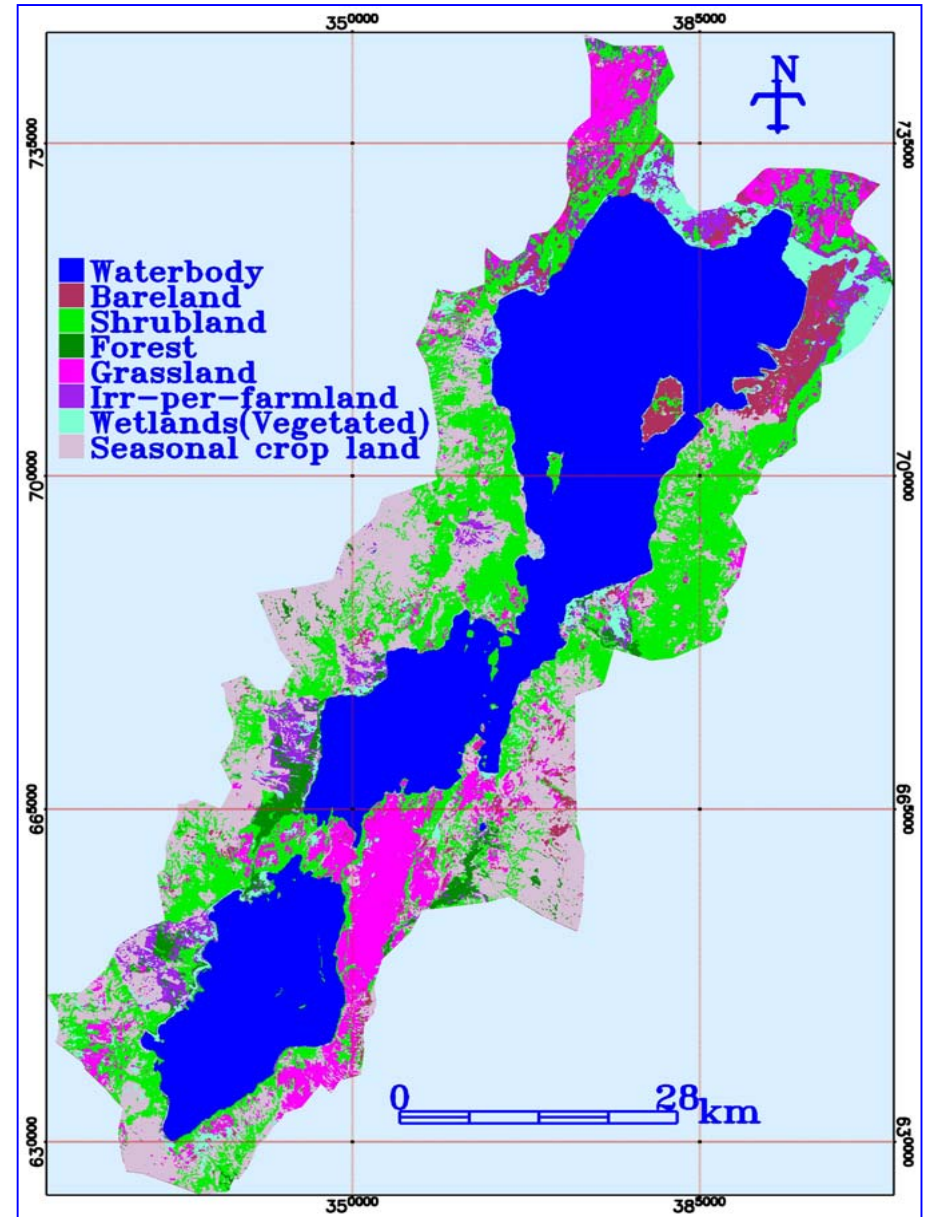


Fig 4.2.LU/LC map of Abaya and Chamo Sub-basin (1986)

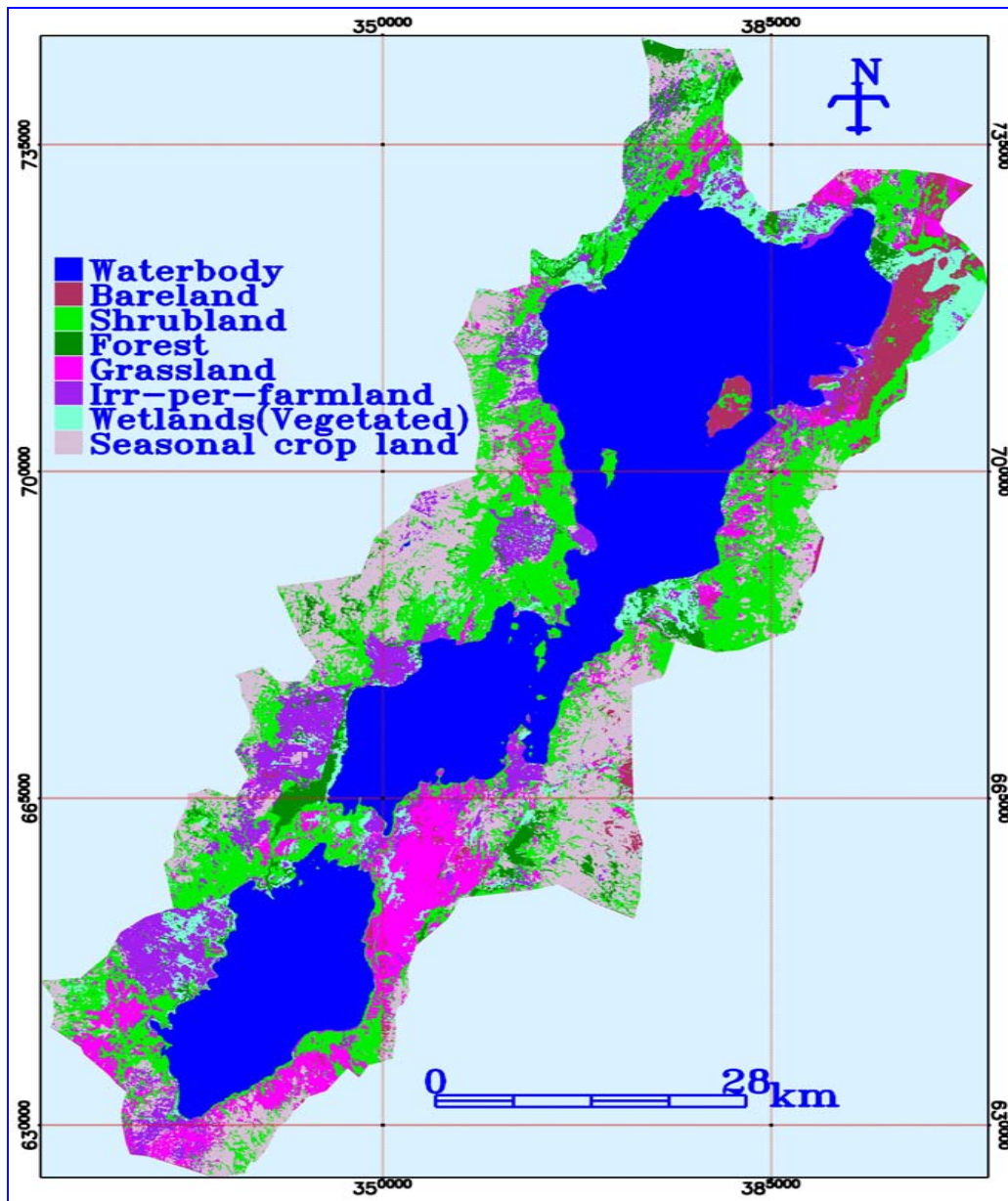
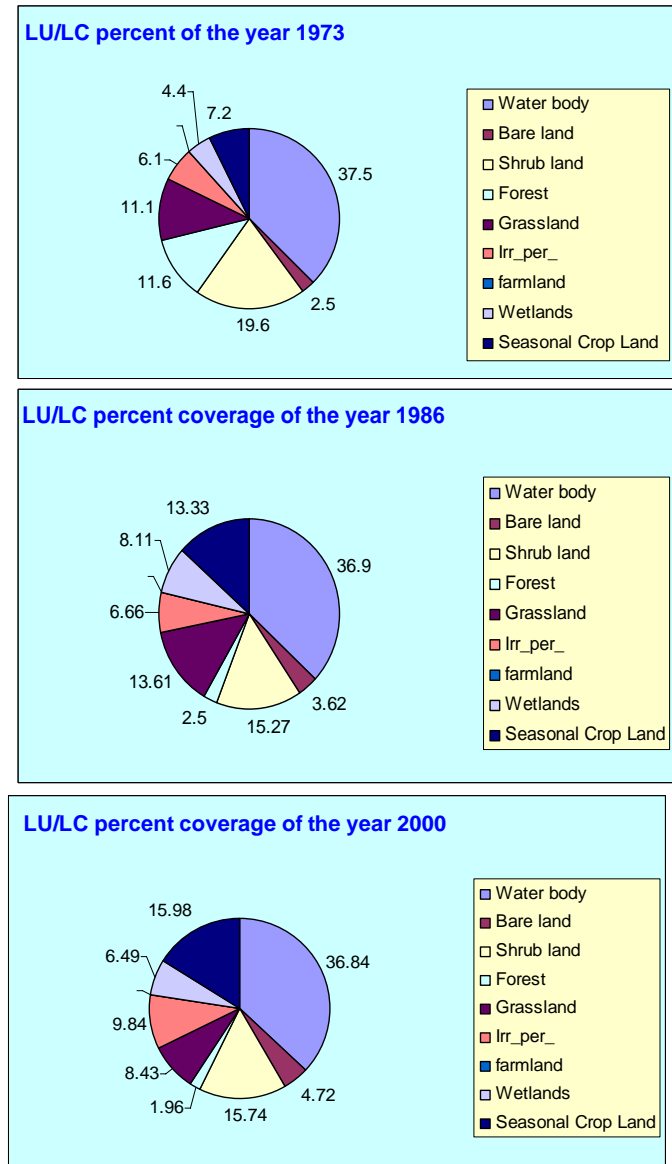


Fig 4.3 LU/LC map of Abaya and Chamo Sub-basin (2000)

Chart 4.1 LU/LC percent coverage of the area



4.2 Mapping of wetland boundaries, locations and types

One of the major objectives of this research is wetland mapping which ultimately is important to provide information for users about the location and types of wetlands for use in planning and overall management of wetlands. Accurate wetland mapping is an important tool to understand wetland function and monitor wetland response to natural and anthropogenic actions. Wetland mapping is used to evaluate land use decisions and monitor the effectiveness of mitigation efforts (Muller et al., 1993). Therefore, wetland maps are a prerequisite for wetland inventory and for wetland development planning, management, protection, and restoration. Delineation and mapping of wetlands in this study follows two major techniques (methods); the first is based on the criteria of wetlands and the second is using the satellite images. On the subject of the first method of mapping of wetlands, the criteria of wetlands is based on the definition of wetlands as presented in Section-two i.e. literature review part of the paper.

Regarding on the first technique, often four criteria are used, for wetland delineation and mappings are Wetland inventory (hydrophytic vegetation), hydric soils, slope and hydrologic state. Therefore, Wetland mapping utilize combinations of available geographic data mentioned above, and satellite imagery (most powerful that can perform all the others) as of the second technique. Based on the description stated above all necessary input layers were created and put in a suitable format as follow so as to accomplish the goal of wetlands mapping in the study area.

4.2.1 Creating criterion layers for wetland mapping

In this study GIS analysis has been used to map the wetlands; it requires digital information in GIS format. The four primary digital data layers selected for use were the hydric (waterlogged) soil layer, Slope (elevation), and hydro-geomorphologic and the wetland inventory data verified with field data collected during the study. It has to be clear here that the method chosen was an overlay analysis. Before the overlay analysis, several steps were taken to prepare the data for the mapping procedure. In this portion the procedures to create each layer would be described in detail one by one.

A) Creating Hydric (waterlogged) soil map layer: In principle and from the definition of the wetlands areas with frequently wet or permanently logged or flooded areas are hydric soil in nature. To locate these areas it was paramount important to do a detail soil survey. But doing detail soil survey for wetlands mapping was found to be too expensive and is very difficult to accomplish with in six months of time. However in this paper the soil survey done by FAO (2001) in digital format was adopted since it has a very detailed soil classification system. Therefore the soil map of FAO has been used and reclassified in to a major class called hydric and non-hydric soils.

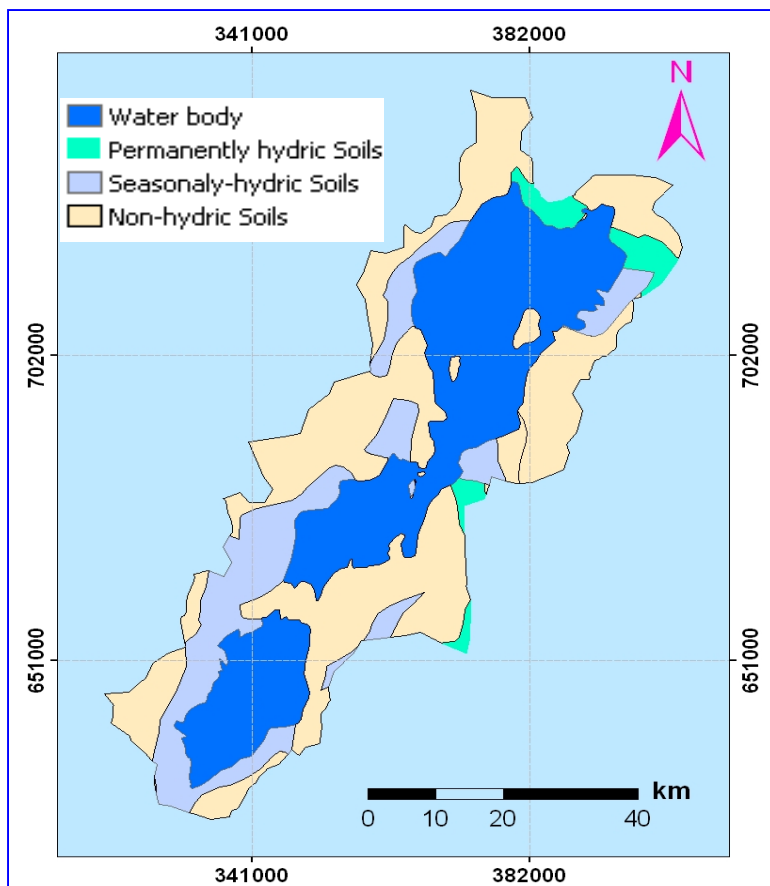


Fig 4.4 Hydric soil map

B) Creating Slope layer: Basically wetlands are commonly found in low lands or flat (flood plain areas). In this case the slope of the area is an indicator of the location of the wetlands. Therefore it is possible to delineate the location of different wet areas based on slope. Having this basic principle the slope of the area was generated from the digitized contour map of the areas. Then finally the slope map is reclassified in to two major slope classes that describe class one wet areas and class two is non-wet areas.

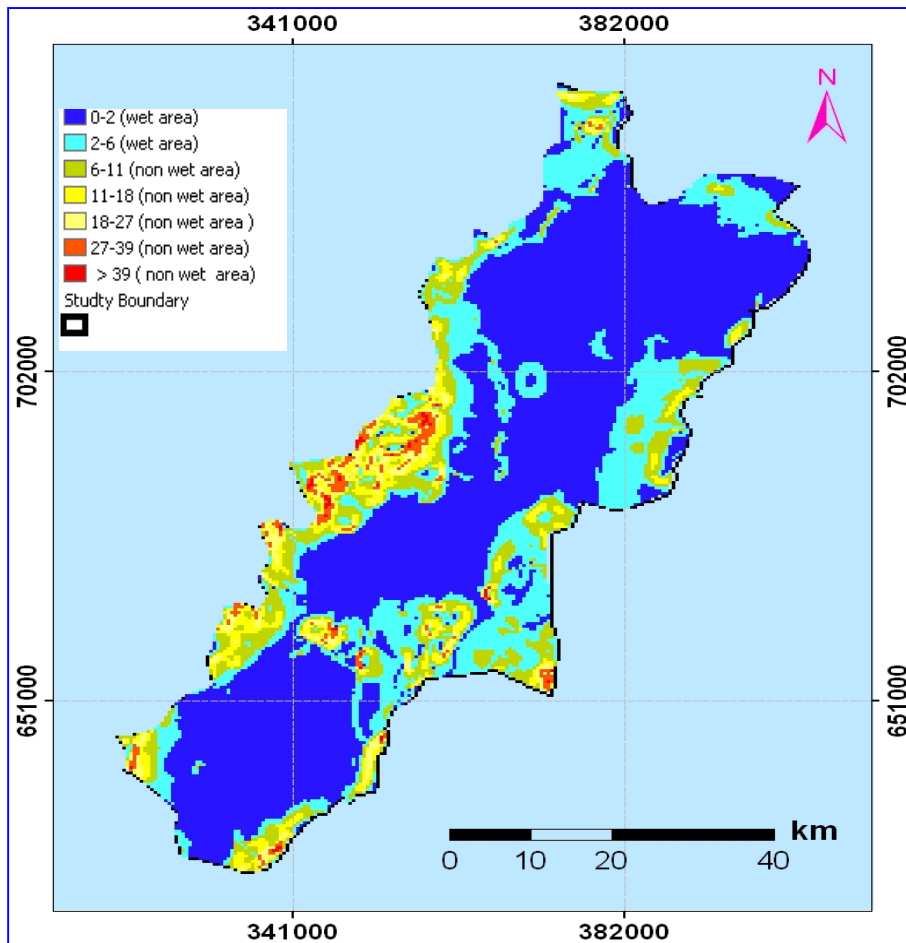


Fig. 4.5 Wetness and Non-wetness classification based on slope (percent)

C) Creating Hydro-geomorphologic layer: The hydro-geomorphology of a wetland is unique in defining the wetland's function (see Finlayson, 1995). Thus the morphology and hydrological state of the area can be used for wetland identification from other uplands. In this study the geomorphology and hydrological state of the area has been prepared from the secondary data obtained from FAO and EPA. These maps have various wetlands of Ethiopia including lakes, rivers, marsh areas and other inundated areas, which were done by FAO and surveyed by EPA supported with field works, were utilized for wetland mapping. Fig 4.6 shows a map prepared from the combination of various layers, Lakes, rivers, inundated areas, and geomorphologic maps. In principle lakes and rivers represent wet areas at some distance from their actual location. To locate these areas the main location of the rivers and lakes were buffered at some distance, which supposed to be part of wetlands. In this regard buffering has been applied to lakes (1000m) and rivers (300m) from their original place.

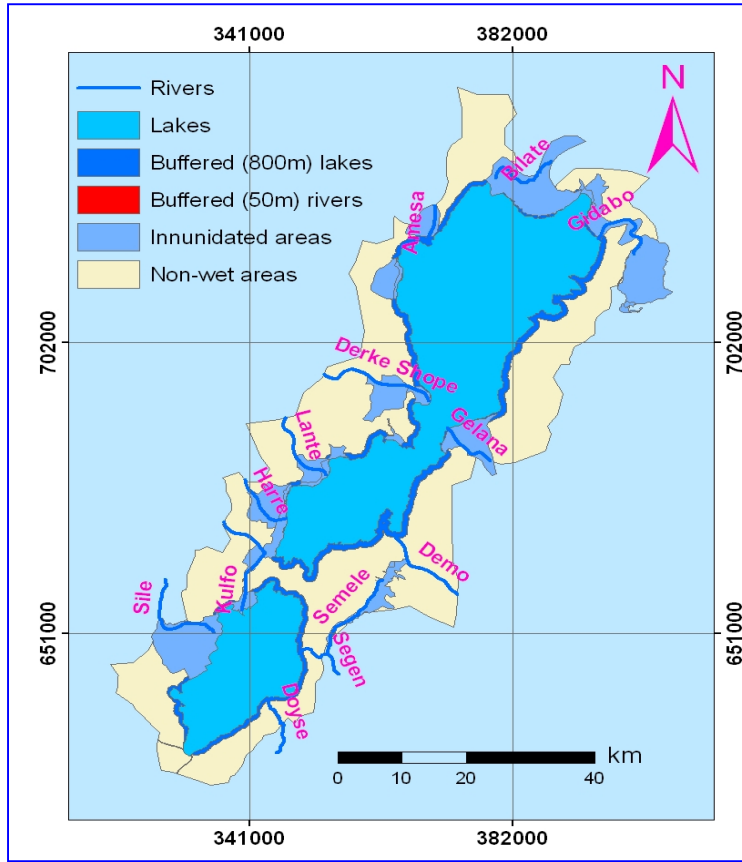


Fig. 4.6 Hydro-Geomorphic based Wetlands map

D) Organizing the Wetland inventory; Wetland inventory data of EPA verified with field data collected during the study was helpful in mapping wetlands. Wetlands are not characterized by nonliving components like soil and slope and water rather they harbor unique flora and fauna species that make them distinguishable from other ecosystems. The living components are important for wetlands mapping along with soils properties as wetlands have unique soils properties (soil moisture surplus) and slope, etc all the ecosystems having the above features are included in a wetland systems. Therefore, it is somehow unreasonable to name wetlands only in terms of slope and soil unless field verified surveys are incorporated with these criteria. Hence in order to supplement the wetland delineation and mapping in the study area wetland inventory, which comprises specially the living components of the wetlands (Hydrophytic vegetation and some faunas) have been included in the mapping procedure in this study which strengthen the mapping process. (The field survey data for the above with description and type's wetland inventory is listed in Appendix 1.2).

4.2.2 Analysis of Satellite imageries for wetlands mapping

Wetlands can also be delineated and mapped from satellite imageries. Not only mapping them but their spatial and temporal variability is best studied using the synergetic property of wetlands at different time series. Due to the fact that was described above and other benefits of satellite imageries studying the spatial and temporal variability of wetlands will be more meaningful and effective in using satellite imageries. For the convenience of further analysis of the other sections of this paper here it is better to give more space and time to describe in detail about the application of satellite imageries for wetland studies.

Satellite imageries are acquired with several bands at a time. These several bands help to distinguish one object from the other. In understanding and mapping of wetlands selection of bands and their combination is paramount important. The approach was to try which combinations judged to be good candidates for discriminating wetlands from uplands and in this regard the previous studies were adopted for band combination and selection to map wetlands. However below the best band combination were selected, as there was great reflectance variation between them. For this case band 7, 4, 2 for TM and ETM and 4, 3, 2 for MSS sensors since these bands are more sensitive to moisture. For more information on band selection see the previous section.

According to Lillesand, & Kiefer, 1994, to discriminate features or objects from an image there are various techniques applied to increase the interpretability of the image. To mention some: 1) Band transformations included orthogonal spectral transformation (a) tasseled-cap, (b) principal component, and (2) INDICES like normalized difference vegetation index (NDVI), and (3) Image enhancement includes: Spectral and spatial enhancements etc.

4.2.2.1 Image transformation for wetland mapping

Orthogonal spectral data transformations compress spectral data into a few spectral components that can accurately detect diverse ecosystems (Collins & Woodcock, 1994; Nielsen et al., 1998; Oetter et al., 2001; Dymond et al., 2002; Parmenter et al., 2003). Principle component analysis (PCA) and Tasseled Cap Transformation (TCT) are two commonly applied orthogonal data transformations. PCA maximizes the spectral variability

detected by decreasing the redundancy of information contained in multiple spectral bands (Armenakis et al., 2003). PCA components are based on statistical relationships that are difficult to interpret and are variable between different landscapes (Collins & Woodcock, 1994). Whereas TCT components are based on the physical characteristics present in an image and are therefore ecologically interpretable and comparable between image dates (Collins & Woodcock, 1994). TCT rotate Landsat spectral data onto brightness, greenness, and wetness axes that correspond to the physical characteristics of features (Parmenter et al., 2003). TCT Component 1 is a measure of image brightness derived from the responses of all but the thermal (Band 6) Landsat bands (Armenakis et al., 2003). TCT Component 2 is a measure of greenness calculated through differencing near infrared with visible bands. TCT Component 3 is a measure of wetness determined by comparing visible and near infrared responses with short-wave infrared response. The invariant nature of TCT allows direct comparisons of TCT bands for multiple Land-sat scenes (Crist & Cicone, 1984).

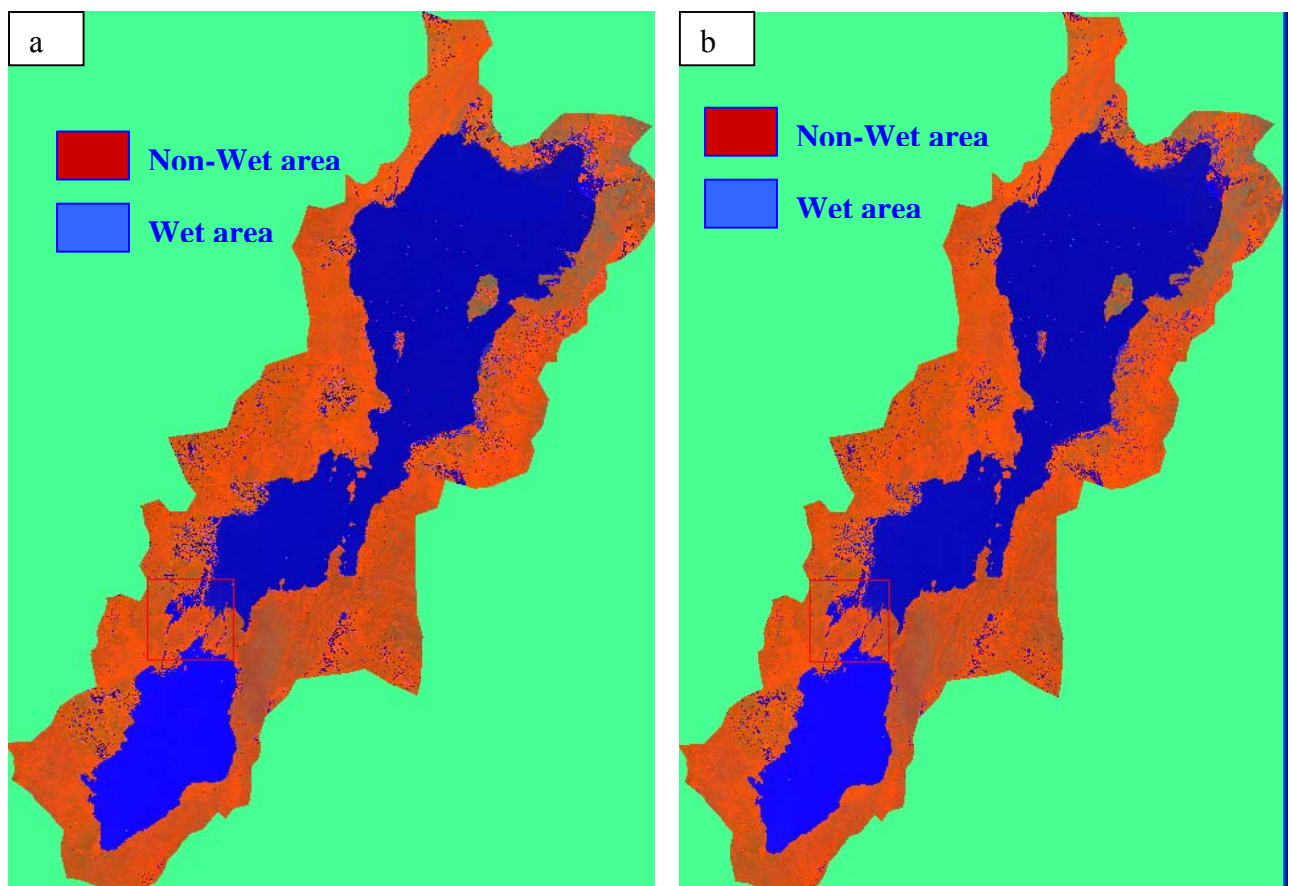


Fig. 4.7 Wetness component of TCT image of land-sat 1986 (a) And 2000 (b) years respectively developed using ENVI 4.2 software)

The wetness component contrasts the sum of the visible and near infrared bands with the longer infrared bands to determine the amount of moisture being held by the vegetation or soil. The brightness, greenness, and wetness components generally account for over 97% of spectral variability present in a given scene and have been widely used for quantifying spectral changes (Collins & Woodcock, et. al. 2002). TCT have effectively isolated wet sites on a landscape (Dymond et al., 2002) and improved distinctions between moist and senescent vegetation (Crist et al., 1986). The longer infrared bands are the most sensitive to soil and plant moisture; therefore, the contrast of visible and near infrared bands with the longer infrared bands highlights moisture levels within a scene (Crist and Cicone, 1984). TCT can be calculated using two methods, DN value based (Crist and Cicone 1984) and Reflectance value based which is atmospheric effect free and the second is widely applicable (Crist 1985), In this study the TCT image indices were found using ERDAS 8.6 Model builder applying the following formulas to each bands as follows. The coefficients are the indices values taken from table 4.1

$$\text{Brightness} = 0.3037(TM1) + 0.2793(TM2) + .4743(TM3) + 0.5585(TM4) + 0.5082(TM5) + 0.1863(TM7)$$

$$\text{Greenness} = -0.2848(TM1) - 0.2435(TM2) - 0.5436(TM3) + 0.7243(TM4) + 0.0840(TM5) - 0.1800(TM7)$$

$$\text{Wetness} = 0.1509(TM1) + 0.1973(TM2) + 0.3279(TM3) + 0.3406(TM4) - 0.7112(TM5) - 0.4572(TM7)$$

Table 4.1 Indices values of TCT images for TM and ETM (1986 and 2000 images)

Weights for Tasseled Cap Transformation of TM and ETM data						
Component	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 7
Brightness	0.3037	0.2793	0.4343	0.5585	0.5082	0.1863
Greenness	-0.2848	-0.2435	-0.5436	0.7243	0.0840	-0.1800
Wetness	0.1509	0.1793	0.3299	0.3406	-0.7112	- 0.4572

All these image processing were done prior to classification to increase the interpretability of the image. In this study all the above-mentioned pre-classification techniques were applied and their power to distinguish wetlands from up lands has been tested. Finally the best one was chosen, i.e. TCT. After all these techniques have been applied the next step is to classify the more interpretable image. The calculation of TCT, which is a complex procedure

involving the linear combination of all the bands of an image. The iteration technique during the analysis of the different time series of the satellite imageries confirmed, for the study area, that a combination of first three TCT bands provided a best result for separating vegetation, soil and water. The three transformed bands (synthetic channels) were then used to classify the image subset for the study area into two general classes (Wet areas and non wet areas as shown in figure 4.7 a and b).

4.2.2.2 Image Classification with inclusion of TCT image as one band

Based on the transformed images using TCT techniques including the wetness component as a band in the image the satellite imageries are now easily interpretable and can be classified visually or else using other techniques like supervised and unsupervised classification. However supervised classification with the help of filed survey data as a training set was used to classify the enhanced images of the different time series (January 1986,2000) were used for identification and mapping of the wetlands. The field data collected was divided into training and testing sample (Appendix 1- 2). A supervised classification was done by using the training sample set with the help of maximum likelihood classifier as decision rule. The reason for this choice was that it has high ability to segregate the spectral signatures of every pixel in the spectral space and gives a better result in general as well for highly variable ecosystems like wetlands (Richards, 1993).

4.3 Mapping Wetland types from the classified images and ancillary data

During supervised classification the area has been subjected to a major classification in to wetlands and non-wetlands (uplands). The classification system of the wetlands is adopted from Ramsar wetlands classification as presented in appendix 1-1. The sub systems for each main system are also described in detail in the GIS database since it is very difficult to represent all small areas in a map. The “wetland” class was reclassified to primarily wetland system, which comprises A) Palestrin wetlands, B) Lacustrian wetlands main systems C) Riverin wetlands main system, D) Man mad wetlands. For more clarification of these wetland ecosystems see appendix 1.1-3. In general both techniques described above, criteria based and satellite based mapping, yields the wetland map of the area.

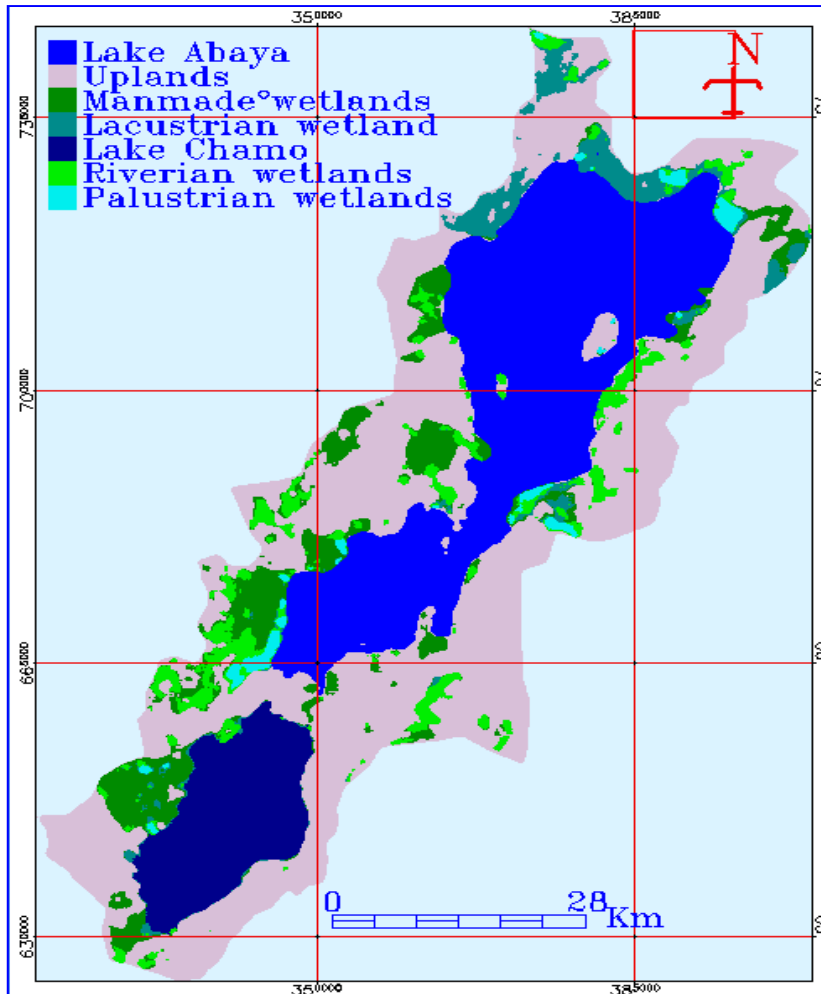


Chart 4.2 Wetlands Ecosystems

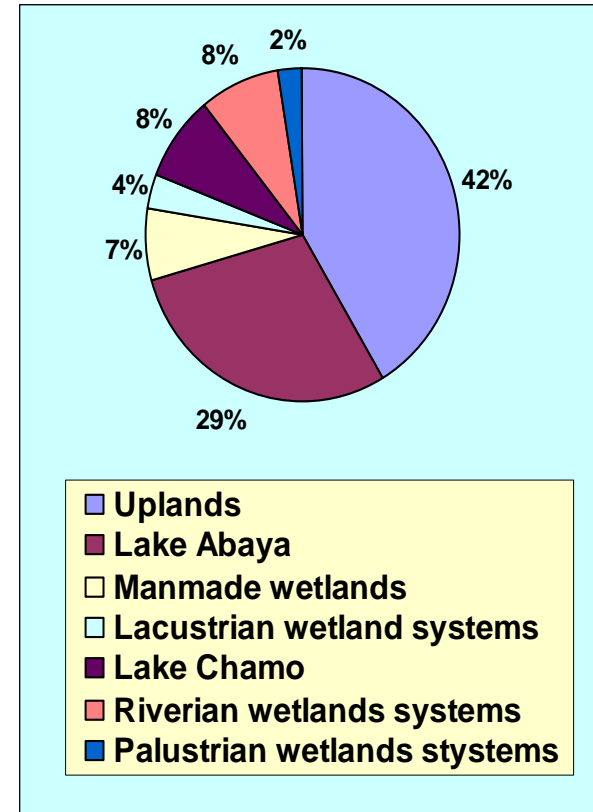


Fig.4.8 Wetland ecosystems of Abaya and Chamo developed using Satellite images analysis

4.4 Overlay Analysis for final wetland mapping

In the above sections two independent methods were applied to map wetlands. To have a final wetlands ecosystems map it is crucial to apply a certain procedure on both maps. Finally wetland type mapping procedure was based on an overlay analysis of GIS data. The Landsat LU/LC data, field data, and digital soil, slope, hydro morphological data were “unioned” to begin the final wetland mapping process. Only 2000 ETM satellite image LU/LC cover data were used for this purpose. The first seven LU/LC classes were collapsed into the “non-wet” class that was used for the remainder of the analysis. The WI data and the soil data were used to eliminate some polygons from the Dataset since Polygons classified as temporarily wet area that are not on hydric soils are not likely to meet the definition of a wetland and were, therefore, eliminated as wetland sites. Other areas considered uplands by field data on the land cover imagery and occurring on hydric soil were mapped as man made wetlands. This part of the procedure is complex to describe here.

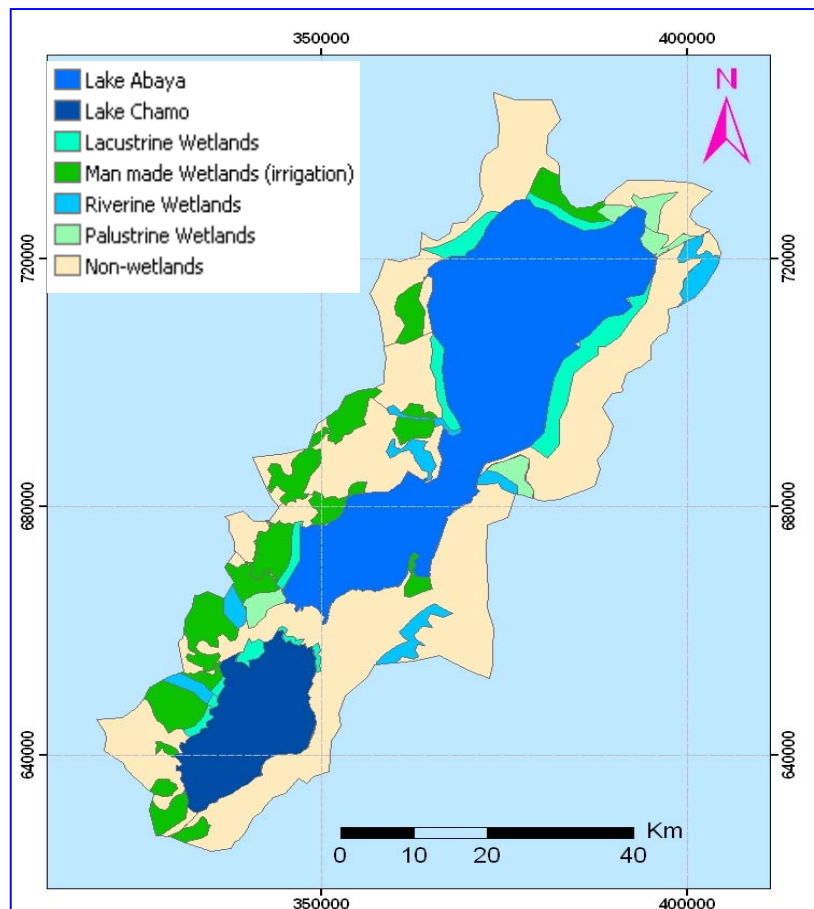


Fig. 4.9 Final Wetland Map resulted from Overlay analysis

4.5 Field verification and accuracy assessment

Wetland types generated during the study have to be verified in the field hence an accuracy assessment of the wetland type data has been done. Sample sites for each wetland type were chosen using a stratified random sampling technique. Over 35 sites were sampled to determine the accuracy of the data. Accuracy Assessment of Wetland Mapping in the area especially automated image classification describes the analyses in detail. The assessment showed that the mapping procedure for wetland locations results h a great deal of accuracy value of 85.23%. The assessment calculated the probability that if a user visits a wetland polygon one of this study result wetland types maps that he would find a jurisdictional wetland of the probability was 85% overall and varied by wetland type. Lakes, ponds, swamps and rivers were mapped with the greatest accuracy (90% or higher), while peat, hardwood flats and managed vegetated wetlands were less accurate (between 65% and 75%). The assessment detected some errors of exclusion where sites that really were wetlands were not included on maps. It was determined that much of this error resulted from errors in the field data and from changes that had occurred in the area.

Table 4.2 Identified Wetlands during field visit

Watershed (Rivers)	Local names of the wetlands	Area (km ²)	Condition	Locations
	Hot Spring	5.0	Always	388365 E & 730891 N
	Gefo	14.0	Seasonally	380491 E & 731918N
Gidabo	Alame, Gola and Dure	78.0	Seasonally	395867 E & 724694N
Gelane	Jirme and Daka	10.0	Seasonally	378095 E & 681595 N
	Jelo and Shamole	83.0	Seasonally	394329E & 722730 N

In the Abaya and Chamo region, partially in the Abaya drainage, there are considerable marshy/swampy or inundated plain areas. These included in the above table Bilate state farm (gefo) marsh or inundated area of Bilate river and around the hot springs; Dure, Gola and Alame marsh areas of Gidabo river; Jelo and Shamole marsh and inundated areas of Gelana river. But the marsh area related to Chamo Lake is insignificant.

5. CHANGE DETECTION ANALYSIS ON BOTH WETLANDS AND UPLANDS

5.1 Background

Besides natural processes like flooding, climate change etc, activities such as agriculture, road construction, building, and urbanization often cause indirect damage to wetland systems. The hydrological alterations associated with these activities affect water supply and drainage patterns of surface and subsurface moisture, reducing the size and distribution of ecosystems dependent on these water sources (Ehrenfeld, 2000; Winter et al., 2001). Monitoring these changing ecosystems helps to determine the tolerance of wetlands ecosystems to human activities (Ghermay et al., 2000). Among the best remote sensing instruments for monitoring this type of changes are the Landsat instruments. Landsat is the best suited satellite sensor for change detection because it covers the longest retrospective period of any satellite program, extending from the early 1970s to the recent years,

In the strategic approach to conservation and management of wetlands, the monitoring process is an important phase to identify the potential change, detect that change has occurred and its direction and tendency (Hellawell, 1991). Therefore, the study as one of its major objectives, tried to analyze and detect change of the land use and wetland systems. To detect the change various arrays of techniques are available to see wetland change from multi-temporal remote sensing data sets (Jensen, 1996; Coppin and Bauer, 1996). The goal of change detection is to discern those areas on digital images that depict change features of interest between two or more image dates. One method, change detection algorithm using ENVI software applies image *differencing*, is simply the subtraction of the pixel digital values of an image recorded at one date from the corresponding pixel values of the second date.

This method has been documented widely in change detection research (Singh, 1986; et.al. 1998). Many researchers favor this method for its accuracy, simplicity in computation, and ease in interpretation. Similarly, this study completely focused on this method for change detection. Simple differencing of classified images; TCT images and vegetation indices

(e.g., Normalized Difference Vegetation Index) are less susceptible to noise interference (Hayes & Sader, 2001). Index differencing is more spectrally dynamic than simple differencing of pixel, although these techniques are also heavily dependent on the resolution of only two spectral bands (Stefanov et al., 2001; Dymond et al., 2002).

The dynamic nature of wetland ecosystems requires an equally dynamic change detection procedure. These ecosystems can exhibit a variety of vegetative or hydrologic changes (Whigham, 1999; Mitsch & Gosselink, 2000) that might not be detected when using one or two spectral bands. There are several digital change detection algorithms or techniques which have been developed and used over the years to estimate changes using remote sensing (in most cases satellite) data. These techniques are based on various mathematical and/or statistical relationships, principles and assumptions. The use of one specific change detection technique or method over another can calculate a significantly different estimate of the change for the same area. Therefore, it is important to use the most appropriate technique to study a particular area and environment.

Four change detection methods were compared both for non-wetland and wetland areas are: NDVI image, PCA image, and TCT image and of classified images. Each method was evaluated and compared with the other methods on its ability to classify temporal and spatial states of wetlands over the three time periods. The methods were evaluated and contrasted on the basis of classification accuracy (Congalton, 1991), efficiency in computation and processing, and ease in interpretation. Finally the TCT image differencing has been found the best and more accurate in wetland change detection whereas the classified image differencing for non- wetlands change detection has been used.

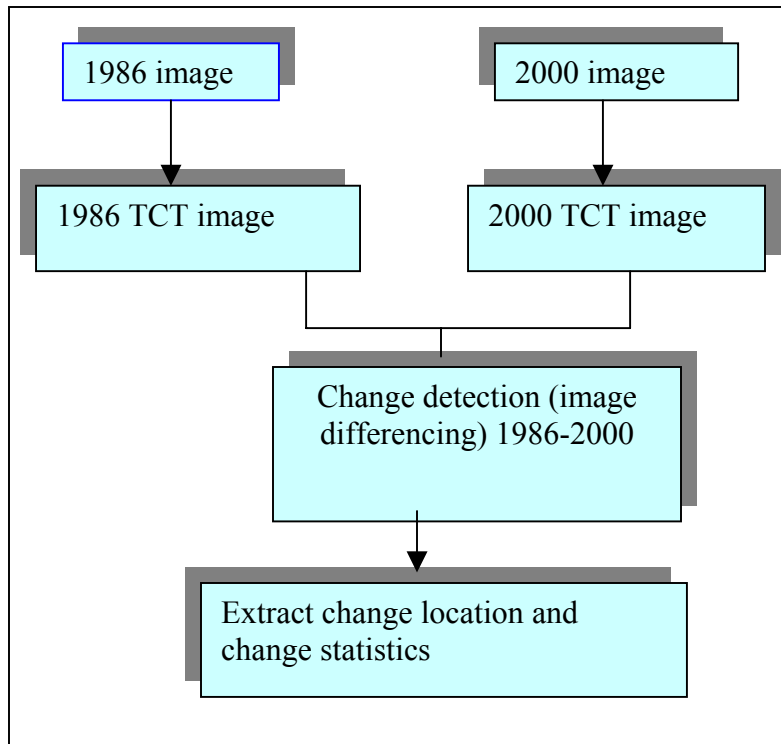
5. 2 Wetland Change detection analysis using satellite images

The overall aim of this study was to detect and map changes in the area extent of standing water and wetlands over time, several standard, commonly used image-analysis techniques were considered. Out of all the techniques discussed above the Tasseled Cap Transformed (TCT) image of the wetness component was selected to use for the study of change detection analysis of the wetlands.

5.2.1 Change Detection Procedures

A conceptual model of the change detection process is used to illustrate the image processing steps required to perform the Image differencing change detection analysis (Figure 5.1). The image-differencing algorithm in ENVI 4.2 was then used to calculate the magnitude of spectral change between two wetness TCT components of January 1986 and 2000.

Chart 5.1 Conceptual model for Change detection procedure using image differencing



5.2.2 Mapping and Classifying the TCT Change Images

Based on the above principles and methods the TCT images which were done and presented in figure 4.7 a and b have been subjected to image differencing. It has to be clear that for wetlands mapping and changes detection purpose the 1973 image was ignored for convenience of mapping and change detection. This is why MSS sensors images when applied by TCT do not yield Wetness component as like of the TM and ETM images. The “wetness” component from the TCT image was utilized as a means of detecting change from multi-temporal satellite scenes.

The figure(5.1) map shows the TCT image difference between 1986 and 2000, the image difference doesn't clearly show where the change of wetlands occur since these areas are too small to be visualized in such a small scale map. However the change statistics of the same image helps to understand whether there is a change in wetlands or not and are presented in the next table 5.1. To support this change specifically Lakes water body the conventional method also presented below in table 5.2.

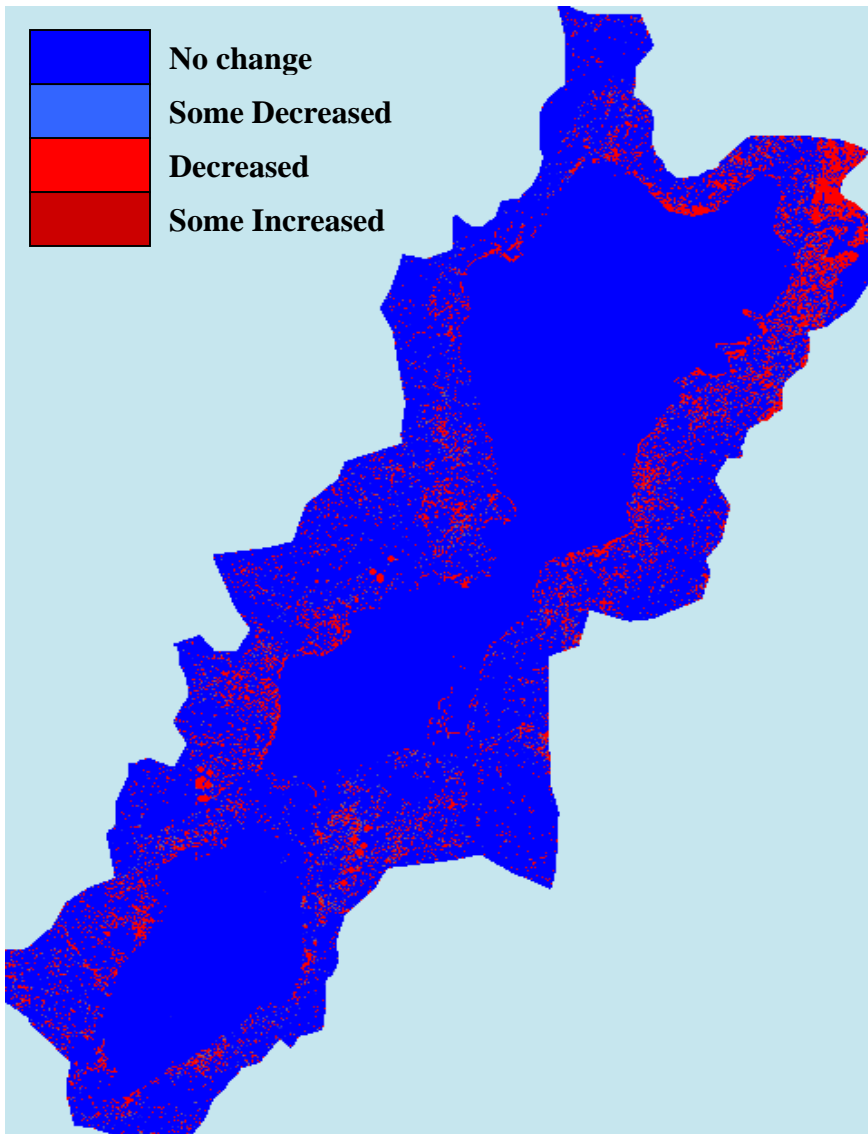


Fig. 5.1 Tasseled cap change image of 1986 and 2000

Table 5.1 TCT images based Change detection of 1986 and 2003

Components	PositiveChangeKm ²	NegativeChangeKm ²	NochangeKm ²	Difference
Brightness	471.85	50.78	15.34	421.07
Greenness	121.862	161.998	29.705	-40.138
Wetness	15.07	93.43	1423.41	-78.46

TCT (Crist and Cicone, 1984) on the TM and ETM images to convert the land cover information included in seven bands into three indicators: brightness, greenness and wetness, which respectively means the land bareness, vegetation vigor and soil moisture. Tasseled cap results and changes in tasseled cap values between images can be used to assess changes to the environment. These changes are compared and contrasted to changes in normal classification results.

5.2.3 Greenness Tasseled Cap Indicator

The results of the Greenness TCT change between 1986 and 2000 presented in table 5.1. The results showed that highest greenness positive change (vegetation increase). The overall greenness net change is about -40.138 km² for the total area of vegetation. The result is exaggerated as compared with the classification value for forests because the TCT image includes all kinds of vegetation i.e. scrublands and grasslands. The greenness positive change value was for the period (1986-2000) is real forest changing of the area, which practically mach with the classification results of similar period i.e. both expresses negative change.

5.2.4 Wetness Tasseled Cap Indicator

The results showed that 1423.41 km² of wetness are un-changed which also includes the lakes water body. However there is a significant negative change of the wetness accounts 93.43 km² which was resulted from the lakes periphery loss and draining of wetlands for agricultural activities. However there is also a positive change of wetness value of TCT image change accounts about 15.07 km² which is due to new wetlands are created by anthropogenic factors like building of dams, irrigation and the like. The overall net wetness change is negative and is about -78.46 km².

5.3 Conventional method for lakes change detection

Another method to see the change of wetlands is to digitize features after classification and computing their area conventionally (manually). For this purpose the TCT image has been subjected to digitization to extract lakes surface area. In this regard the interest is only the lakes boundary since other types of wetlands are very difficult to determine their area manually. Comparison of lakes spatial variability from the digitized and classified images is presented in the table below. The comparison shows that with both methods the wetlands spatial variability is similar i.e. decreasing in aerial extent.

Table 5.2 Spatial variation comparison of lakes in different methods

Time	1973		1986		2000	
Unit	Km ²	ha	Km ²	ha	Km ²	ha
Chamo(classified)	325.13	325,136.2	305.76	305,763.3	300.76	300,761.78
Abaya(classified)	1101.78	110,178.4	1093.78	109,378.4	1089.78	108,987.6
Total Lake area (classified image)	1,426.74	140,644.3	1,399.5	139,353.6	1,389.54	138,854.1
Chamo (digitized)	338.59	338,594.2	329.86	329,864.28	308.9	308,914.7
Abaya (digitized)	1108.703	110,870.3	1100.27	110,027.8	1095.45	109,545.25
Total Lake Area (Digitized)	1447.299	144, 729	1430.14	143,014.12	1,403.321	140,332.12

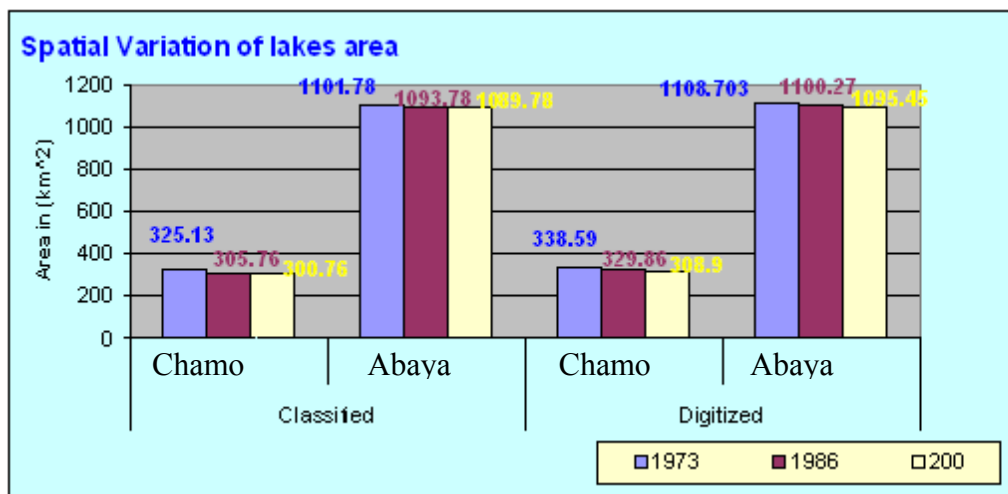


Fig 5.2 Spatial variability of lakes

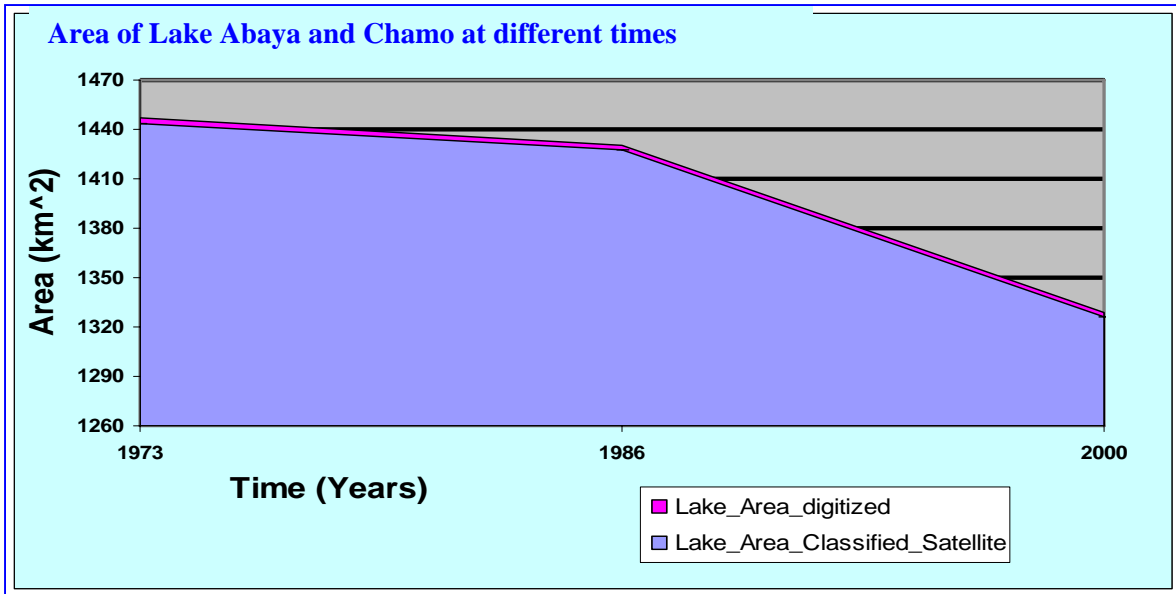
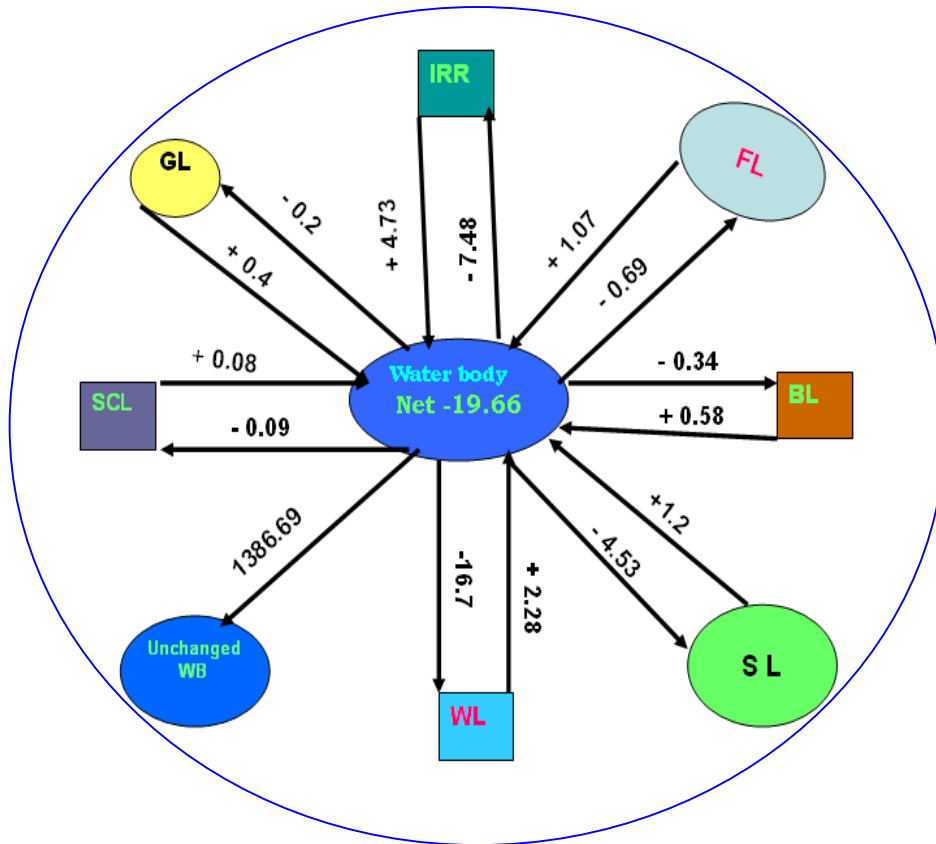


Fig 5.3 Sum total spatial variability of lakes area

As shown by the above timeline figures 5.3 permanent wetlands (lakes) have decreased in the past three decades. According to this study on the contrary temporary and seasonally flooded wetlands are being increased due to the permanent ones are replaced by temporary marsh areas. The continuous decline of the surface area of the lakes has increased the vulnerability of the wetlands resulting due to changes of land use pattern, such as grazing and cultivation of perennial and annual crops, tree planting e.g. planting of *Eucalyptus camandulensis*.

In general in the previous sections (5.2 and 5.3) it has been tried to use two method of change analysis of wetlands. From the results it was possible to analyze very small wetland areas using the first method (satellite image) but conventional method (digitization) was very difficult to analyze small wetlands. However both methods were treated in this paper and yields useful result. Nevertheless as the research result indicates satellite based change detection analysis is more powerful than the conventional ones. Manual change detection result of the study showed that Wetlands surrounding the Lake area undergo a decrement of nearly 13 km² and 30 km² for Abaya and Chamo respectively and but automated one resulted totally about 25 km² area lake Chamo and 10 km² of lake Abaya have been lost in the past three decades.



Where;
 WB Corresponds to Lake water body
 IRR= Irrigated perennial farmland
 FL= Forest land
 BL = Bare land
 SL = Shrub land
 WL = Wetlands
 SCL= Seasonal Crop Lands
 GL = Grass Lands
 (All Values are in km²)

Fig. 5.4 Wetlands dynamics of the period 1973 and 2000 Using Automated change detection method

The two methods actually result some disparity in value of change detection. This is perhaps due to natural variation in the hydrological cycle, agricultural practices, or image bias and even error during digitization. While the acreage amount is not as such very big, wetlands can be restored to provide functions that have been lost however; wetlands restoration is less effective when they currently occupy more than 35 percent of the study area.

5.4 Analysis of Change Detection on non-wetlands

From one image, a map can be generated showing different land uses and land covers at the moment the image was captured. When generating such a map periodically a set of maps will be obtained which reveal the dynamics of the ecosystem and the spatial relationship between elements at different time scale. Changes and relationships between the elements can be explored and modeled (Toyra and Pietroniro, 2005). The land use and cover status was identified through the classification of land sat imagery acquired in January 1973, 1986 and 2000 in ENVI 4.1 software. The classification and mapping issues were discussed in detail in Section 4 here the change of these classes are analyzed.

Landsat images acquired on January 12, 1973 and January 28, 1986 were selected as the historical image and used for change detection against the January 27, 1986 and 2000 images respectively. When comparing two image scenes, steps must be taken to reduce exogenous errors such as pixel size differences, which lead to inaccurate detection of spectral change (Collins & Woodcock, 1994). Spatial resolution differences between Landsat MSS, TM and ETM sensors were standardized through Pixel resizing algorithm using ENVI 4.2 software. Their pixel sizes were standardized in to 1986 image (i.e. 28.5m) prior to change detection analysis.

In this study only two phase of change detection were done; one is on 1973 and 1986 and the other is on 1986 and 2000. The changes of land use and cover categories were assessed and change detection maps for each and every land use category were prepared in GIS. The generalized spatial distribution and change statistics of land use changes in the study area are presented in the following tables.

The change detection tables presented below are change matrices that depict what are changed to what. The column of the table represents the initial stage 1973 or 1986 and the row represents the final stage 1986 or 2000. The diagonal values of the table depict the unchanged values, which are found in both times images. Unlike the diagonal values the class change tells the total changed image areas of each LU/LC of the initial stages.

Where as the class total value of the column indicates the initial stage image total area of each LU/LC classes where as the row total represents the final stage area of LU/LC classes. The Image difference is the total net change of the two time images. The negative image difference indicates a certain LU/LC is in a state of decrement and the positive indicates increment.

Table 5.3 Area based (Km²) Change detection of 1973 and 1986 years images

		Initial stage image classes (1973)										
F I N A L S T A G E 1 9 8 6	Classes	Water body	Bare land	Shrub land	Forest	Grassland	Irr_per_farmland	Wetland	Seasonal cropland	Row total	Class total	
		Water body	1382.69	0.58	1.26	1.07	0.42	4.73	2.26	0.08	1393.08	1393.54
		Bare land	0.12	43.36	26.68	3.97	32.11	7.57	1.32	17.29	132.42	133.99
		Shrub land	4.53	1.55	354.76	124.99	39.12	13.9	6.11	27.74	572.69	574.29
		Forest	0.43	0.46	5.57	41.43	2.95	7.57	33.83	7.61	99.84	100.23
		Grassland	0.2	16.28	124.99	30.71	233.62	10.86	3.66	93.85	514.16	515.22
		Irr_peri_farmland	5.16	5.27	29.52	22.91	44.04	70.34	38.66	32.22	248.12	248.2
		Wetlands	13.23	24.65	28.1	33.9	43.63	75.96	60.1	17.87	297.45	298.79
		Seasonal crop land	0.09	1.47	167.87	178.63	23.43	40.09	18.05	71.42	501.07	502.86
		Class Total	1404.44	93.66	739.7	439.38	419.89	231.78	164.14	268.56		
	Class Change	23.76	50.30	384.95	397.85	186.27	161.43	104.04	197.14			
	Image Difference	-12.92	40.33	-165.41	-399.15	95.33	16.42	134.65	234.3			

In summery, the LU/LC changes in all the land use types are not static; there is a significant LU/LC change observed in the area. The automated digital LU/LC change between the time periods of 1973 and 1986 and 1986 and 2000 is presented in the tables respectively. The Major concerns of the study, ‘wetlands’, have gone though an immense change in the past three decades.

Table 5.4 Area Km² based Change detection 1986 and 2000 years images

		Initial stage image classes (1986)									
F I N A L S T A G E 2 0 0 0	Classes	Water body	Bare land	Shrub land	Forest	Grassland	Irr_per_farmland	Wetland	Seasonal cropland	Row total	Class total
	Water body	1382.69	0.28	1.26	1.03	0.67	4.59	10.66	0.04	1,386.7	1393.54
	Bare land	0.52	50.55	26.68	3.77	82.12	7.56	1.31	17.21	178.1	133.99
	Shrub land	1.23	1.57	190.31	13.61	39.22	13.3	6.82	27.78	593.1	574.29
	Forest	0.13	0.28	5.57	61.93	2.93	7.76	26.24	7.69	73.9	100.23
	Grassland	0.2	16.46	124.99	3.99	186.27	10.87	3.26	94.85	312.8	515.22
	Irr_peri_farmland	4.46	5.47	29.52	2.91	42.47	161.29	38.66	32.22	340.6	248.2
	Wetlands	10.23	24.66	28.1	3.4	13.43	15.97	204.04	17.87	231.4	298.79
	Seasonal crop land	0.09	1.25	167.87	8.97	53.05	27.3	8.08	271.42	599.9	502.86
	Class Total	1,393.5	133.98	574.3	100.2	515.2	248.2	298.8	502.9		
	Class Change	16.76	43.36	383.99	38.18	233.62	87.01	94.76	197.66		
	Image Difference	-6.04	44.12	18.8	-26.3	-202.4	92.4	-67.4	97.0		

The lakes have been changing negatively from 1973-1986 by -12.92 Km² area and from 1986-2000 by -6.04 Km² areas. This result directly indicates that almost 2% of the lake area has gone away in ten years gap and 31% of the grasslands and 14% of shrub lands are changed to bare lands. Where as, except the lake wetlands ecosystems other wetlands ecosystems have been increased. From the period 1973 to 1986, 159.90 Km² area has been changed to wet areas of Palustrian and Lacustrian ecosystems. This great change has been brought from due to Lake Periphery loss and inundation of other LU/LC as briefly described in the above tables and charts. The great change is observed on Shrub lands especially from 1973-1986 where 165.41 km² areas have been gone away. Forests also changed negatively 339.15 from 1973-1986 and 1986-2000 -26.3 Km²

Table 5.5 Summary of area based Change detection of 1973, 1986 and 2000 years images

LU/LC Types	1973		1973-1986	1986		1986-2000	2000	
	In %	Km ²	Km ²	In%	Km ²	Km ²	In %	Km ²
Water body	37.5	1,405.98	-12.97	36.9	1,393.01	-6.31	36.84	1,386.70
Bare land	2.5	93.7	-40.28	3.62	133.98	-44.12	4.72	178.1
Shrub land	19.6	739.7	-165.40	15.27	574.3	-18.80	15.74	593.1
Forest	11.6	439.4	-339.20	2.5	100.2	-26.30	1.96	73.9
Grassland	11.1	419.9	95.30	13.61	515.2	-202.40	8.43	312.8
Irr_per_Farmland	6.1	231.8	-16.40	6.66	248.2	92.40	9.84	340.6
Wetlands	4.4	164.1	134.70	8.11	298.8	-67.40	6.49	231.4
Seasonal Crop Land	7.2	268.6	234.30	13.33	502.9	97.00	15.98	599.9

Seasonal crop lands also under positive increment 234.3 from 1973-1986 and 97.8 from 1986-2000 in Km². Both bare land and grasslands were positively increased from 1973-1986 but Grasslands have been decreased from 1986-2000 periods. The other wetland portions of the area, lakes periphery or named as Lacustrian wetlands which are found in the lakes periphery and the Palustrian wetlands which are wet areas covered by vegetation are also under threat and converted to man made wetlands (artificial wetlands) of commonly irrigated cultivated areas. This portion of the change accounts 75 Km² areas of wetlands from 1973-1986 and 15 Km² areas of wetlands from 1986-2000 have been converted to artificial wet areas the so-called Irrigation farmlands. The study concluded that there was a significant change in land use and land cover in the lake catchment for the last four decades which can bring about change in the runoff generation and sedimentation of the lake which results reduction of the lakes dimension especially the Lake Abaya having big catchment with intensified cultivation.

6 ASSESSMENT OF POSSIBLE FACTORS ON WETLAND CHANGES

6.1 Background

In the previous sections mapping of land uses and wetlands along with their extent of change were discussed and analyzed in detail. In this section more emphasis and attention is given to wetlands specially the lakes to evaluate the factors associated with the changes of wetlands. Basically, the ability to understand upstream anthropogenic effects upon downstream wetland ecosystems is of great interest for wetland managers. However, it is difficult to single out with certainty a specific factor responsible for the sharp drop in water volume and wetland changes. There is little doubt that there are multiple forces of change that play here and the key driving variables are irrigation and drought, which may be related to a process of climate change in the region. Researchers do not yet know how much of the drying is due to the drought and how much is due to irrigation. There is also some speculation that the drought over the entire region may be due to climate change. International ongoing researches link the drought in all over the world with increased temperatures and changes in wind and rainfall over large areas of oceans. Such a correlation suggests the drought may be part of an overall climate change that coincides with a worldwide increase in higher surface temperatures. However, such theories must be treated with extreme caution and specific area analysis.

In understanding of the variability of wetlands in this study it is thought that three major factors are associated namely, Meteorological variables, hydrology and anthropogenic factors. From these different possible causes for the continuous wetlands dynamics were considered in this study. They are, land use/ land cover dynamics of the watershed, excess irrigation water use, changes in hydro meteorological phenomenon's in the area caused by natural or/and human factors. Therefore, integrated assessment of wetlands ecosystem is desirable to understand anthropogenic and/ or natural impacts upon wetland ecosystems.

It is obvious that wetlands ecosystems largely depend on the hydrological cycle, which includes the climatic and hydrologic condition of the area. Therefore for better understanding of the dynamics of wetlands the relation and trends of the various hydro-meteorological data are essentially to see.

Generally, it can be argued that, the wetlands of lakes Abaya and Chamo may be impacted due to the following major reasons.

- 1) Land use land covers changes over the lakes catchment
- 2) Siltation of the lakes due to erosion resulted from LU/LC change (deforestation)
- 3) Effect of natural condition: Decrease in rainfall and runoff and increasing evapo-transpiration, which is associated with climatic change
- 4) Over use of water resources for irrigation and consumptive purposes
- 5 Misuse of the water resources and pollution

6.2 Poor land use and agricultural systems

The result of land use land cover change says to many about the effect of these changes on the wetlands in general and the lakes in particular. In the analysis it is already said that upland forests and shrub lands are reducing and on the contrary the seasonal peasant crop lands area increasing which shows there is decrement in vegetation cover of the land that enhances erosion (see the figure below for comparative LU/LC dynamics). The removal of vegetation cover increases erosion and enhances sedimentation of the wetlands. Farming of the catchments contributes to enhanced nutrients and particular runoff where the grassland around the wetlands is overgrazed or fields are fertilized.

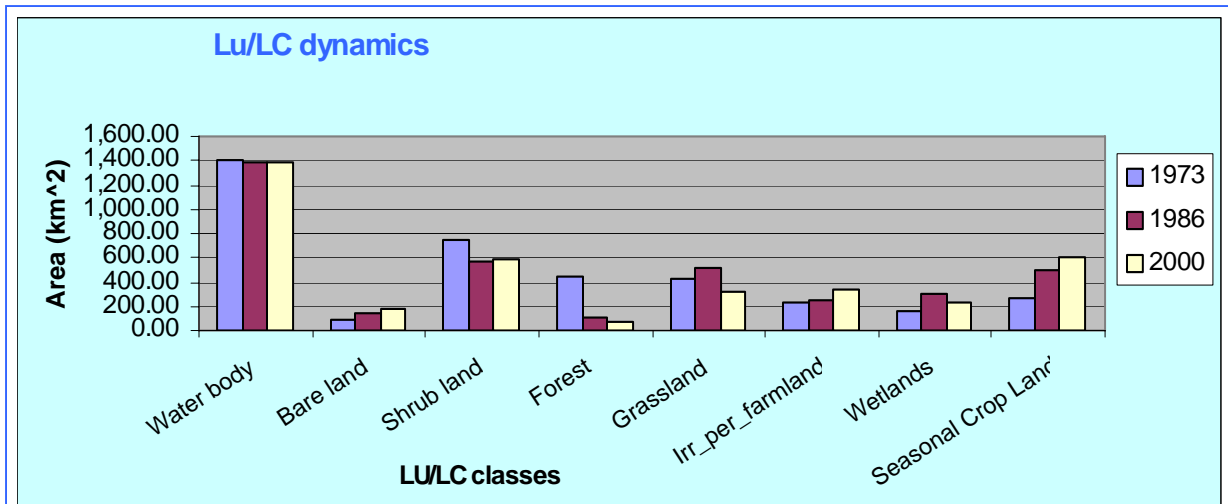


Fig. 6.1 LU/LC dynamics of the study area

The conversion of swamps to agricultural land with long-term drainage and cultivation reduces the diversity of the wetland habitats; wetland species are replaced by non-wetland species. As it was possible to conclude from change detection of LU/LC results presented above, some of the principal threats of the wetlands of Lake Abaya and Chamo emanate from

lakeshore (wetlands) farming for perennial and annual crops. Land use change has created a variety of impacts to wetland areas. These changes have many effects on a wetland in terms of climate, air and water quality, hydrological changes, and boundaries and fragmentation of flora and fauna. The land use /Landcover mapping and change detection dealt in the previous sections is a good substantiation for there is a misuse of land use in the area and results a great deal of change in the lakes hydrology. The quantity and quality of the lakes are highly affected by LU/LC change of their drainage basin. Even though quantification of their impact is very difficult and needs further study it is possible to describe their effect subjectively. The surrounding marsh areas of Abaya and Chamo lakes are now being in intensive perennial cultivation, which was not half a century before. But now almost 80% of perennial irrigation farmlands are found with in the vicinity of the lakes. This results reduction of water flowing to the lakes (quantity impact), intrusion of chemicals from the farmlands to the lakes (quality impact) and because of disturbed surface yields high soil lose sedimentation of the lakes will be increased. More over agricultural activities on wetland areas of perennial and annual crops are converting swamps to agricultural land with long-term drainage and cultivation reduces the diversity of the wetland habitat; wetland species and replaced by non-wetland species.

6.3 LU/LC change and its impact on lakes hydrological condition

It has been known for many decades that water in the hydrological cycle is in a continuum between the various parts of the cycle, and development or contamination of one component will impact on the other parts of the cycle. There is now increasing recognition of the potential for land use and particularly land use change to impact on parts of the water cycle of rivers and lakes. Land use change can have significant effects on runoff volume and consequently lakes levels and volume. The rate of land use change in recent centuries is much faster than that in the past. Much of the pre-settlement results development of irrigation schemes around the two Lakes region and wet areas of the lakes buffer zones have been converted to agricultural land uses. This has induced reduction of large volume of water entering to the lakes. It is therefore important to understand the impacts of historical land cover and land-use change, to put ongoing modifications into the proper context. Here this study summarized the trajectory of land cover and land use change (LU/LC) and the resulting impacts through a synthesis of results from studies encompassing a wide range of environments. Land cover has changed dramatically in the past 40 years in Abaya and

Chamo drainage basin due to both fast resettlements surrounding the lakes to get benefit out of the lakes. These changes have in turn affected the hydrological dynamics of the major rivers draining to the lakes.

6.4 Climatic Variables

The natural phenomena like Climate variables, soil, geology, and underground process have a great impact on change of lakes hydrology. Particularly, the increase in temperature over the years which results high evaporation and decrease in precipitation on the main watersheds have resulted in the decrease of volume of lakes and the surface area of surrounding wetlands. The shrinkage in the surface area of the lakes is more pronounced in Lake Chamo than Lake Abaya.

6.4.1 Precipitation

One of the inputs for wetlands in general lakes in particular is rainfall. The rainfall data has been recorded in the area for the last forty years. To know whether rainfall variation is linked with the variability of the lakes and wetlands dynamics about four decades monthly rainfall data has been analyzed and the trend is presented for both lakes. The trend result showed that there is a subtle decrement of rainfall data.

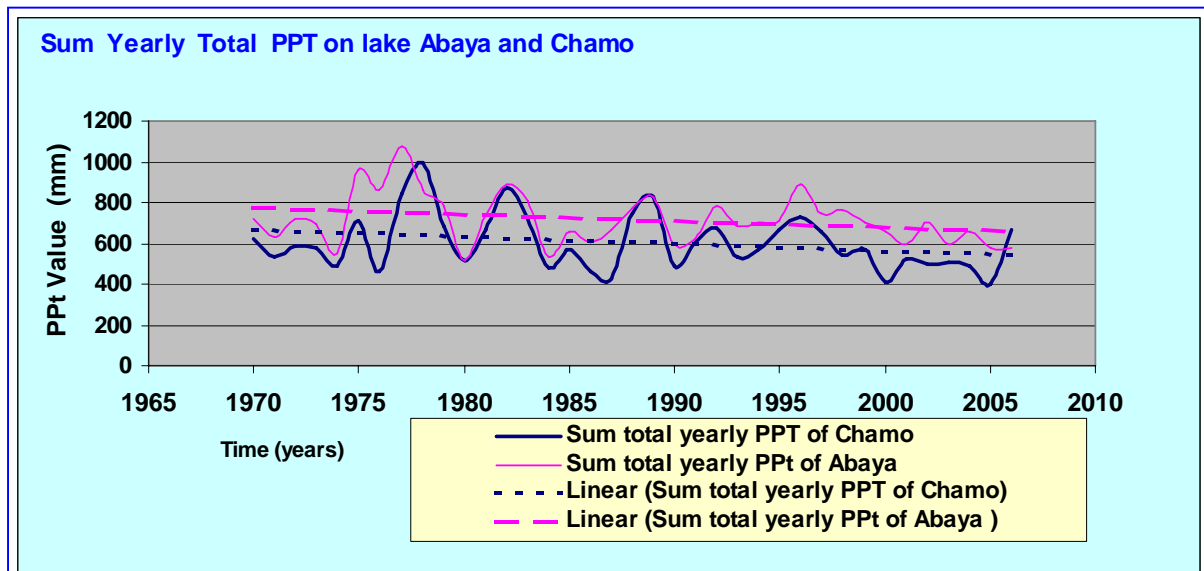


Fig. 6.2 Trend of Rain fall on Lakes Abaya and Chamo: Source Selesi, 2000

As it is possible to understand from the graph the area in general receives low rainfall since it is located in rift valley region where rainfall is very low. In addition with the problem of area

receiving low rainfall the trend of the rainfall in the area is under subtle decrement and this double crisis of the lakes makes the life of the lakes under question.

6.4.2 Evaporation

The other lake water reduction factor is evaporation. Four decades daily-recorded evaporation data of the area is very much enough to predict and understand the situation of the area. Evaporation in the study area showed that there is a significant increment in temperature in the area due to climate change brought by global warming. Below the trend of daily evaporation measured in the area indicates that it is increasing and considered as a major threat for the lake water reduction. From the graph below the rate of evaporation from the water body as of 1979 was around 1800 mm but now reaches 2500 mm.

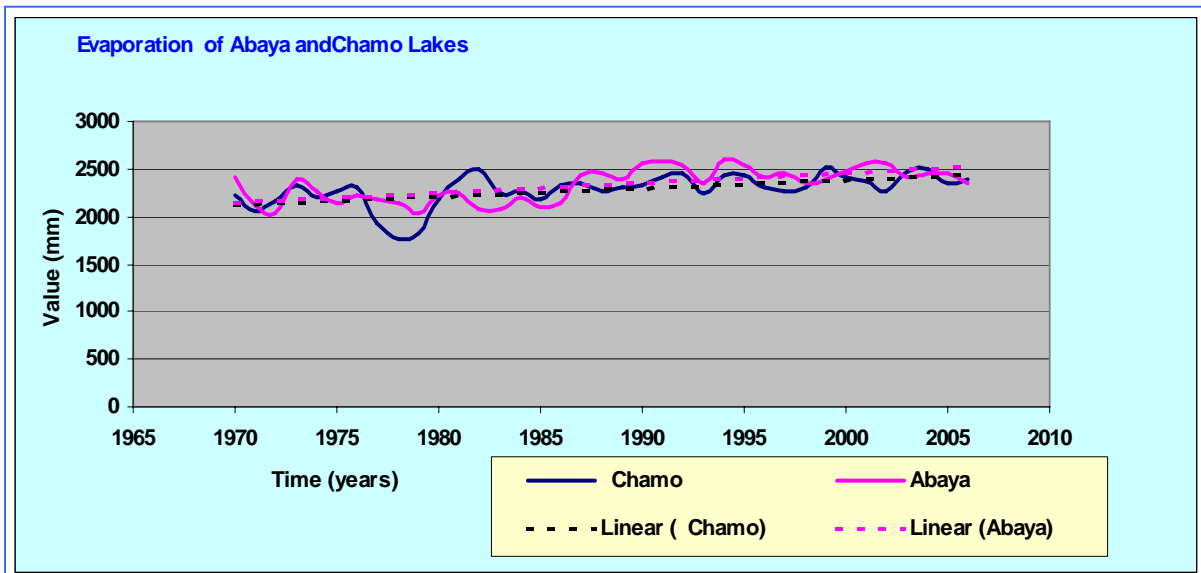


Fig.6.4 Trend of Evaporation on Lakes Abaya and Chamo

6.5 Inflow from gauged and un-gauged areas

The inflow data from all gauged and un-gauged areas was adopted from (Sileshi 2000). The mean annual runoff entering to the lakes presented below shows irregular trend with peck mean deviations. But other properties of the lakes like area variability as described above and volume and level variation presented in the next sections show that both lakes are denudating. One thing even though it is unlikely to say any thing on the lake from the inflow reduction trend it is possible to give reasonable justification of the lakes denudation. The real situation in terms of inflow to both lakes records does say something since almost all of the

existing major water uses, which are for irrigation and livestock occur in the valley, near the lakes and downstream of the gauging stations. The most important thing is that behind this there are water uses downstream of the gauging stations of the rivers up to the outlets, which are not recorded as inflow reduction but presented in section 6.6.

In this section only the inflow to the lake is considered but in the water balance model part of the paper where various hydrological components have been considered. Below this inflow reduction, which includes irrigation and other use of water for both lakes, have been analyzed and plotted for comparison purpose.

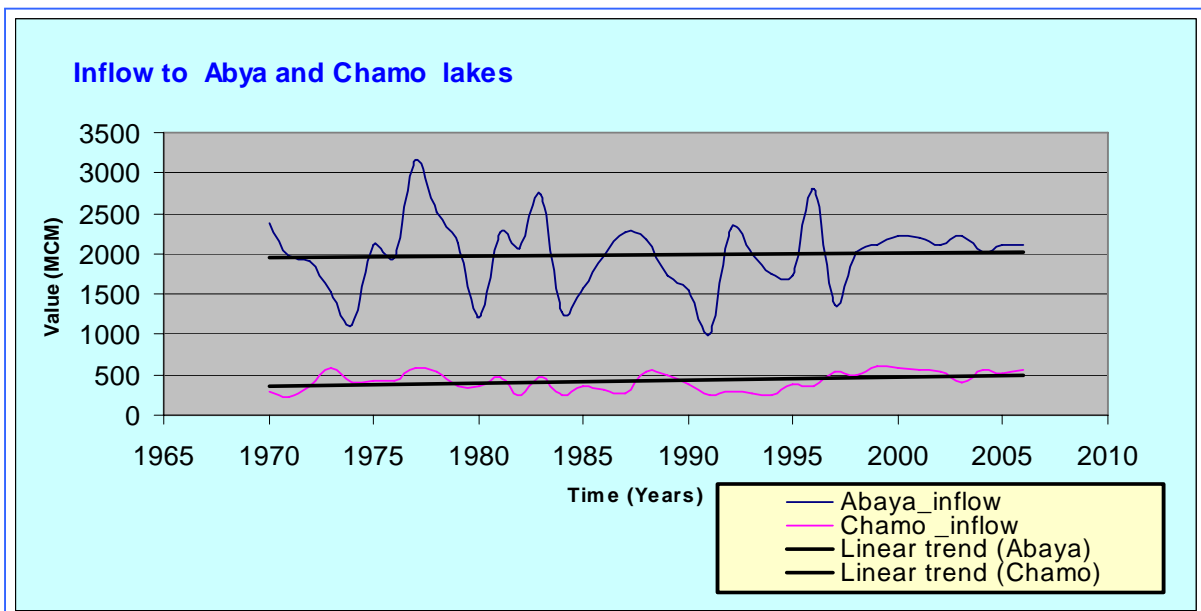


Fig. 6.3 Trend of Inflow to Lakes Abaya and Chamo

6.6 Over use of water resources for irrigation purpose

The problem facing wetland management could emanate from excessive use of wetland resources as a follow-up of the prevailing miserable poverty of communities residing in and around the wetlands. This in turn leads to application of unwise resource management methods/ technologies. In addition, other factors like absence/inadequacy of policies for wetland management and or misguided policies, and uncontrolled population growth have exacerbated the situation.

Due to population growth in water supply demand and the need for more agricultural food production and growth of water use in irrigation, the consumptive purpose would be expected

to grow in future. Impact of non- consumptive water uses such as in hydropower generation would have no effect on the water quantity. The non-consumptive uses with storage have even positive contribution to the water resources quantity residing in the lakes.

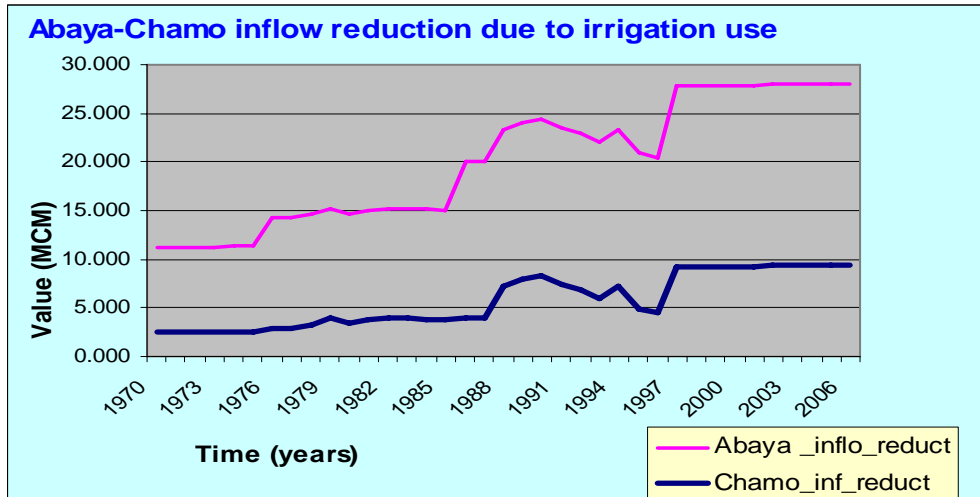


Fig. 6.5 Trend of inflow reduction in to Lakes Abaya and Chamo: (Source Seleshi, 2000)

Excessive/wasteful use of wetland resources leads to loss of biodiversity. The decrease in depth of lakes occurs as a consequence of shortage of rainfall, and as a result of human intervention such as establishment of irrigation schemes through extraction of water from the lakes and using rivers flowing into lakes. The use of rivers that feed the lakes for irrigation decreased the lakes water depth and consequently resulted in drastic effects on the fish and other aquatic communities.

The quest for agricultural land for food production, to meet the needs of the fast growing population in the area the regional government has planned to develop small and medium irrigation schemes. As it is clearly shown in the land use land cover change detection section the area of irrigation farmland has been drastically increasing, but it should be given attention in wetlands management. In this respect, it should be noted that the majority of irrigation areas are in wetlands. This indicates that the natural wetlands ecosystem is going to unstable equilibrium condition. Medium and small-scale irrigation schemes following the incoming

rivers such as the Bilate State farm and the farmers associated with settlement villages, the Wajifo State Farm, the ArbaMinch state farm and cotton plantation and a number of banana plantations, are reducing the inflow to lake Abaya (refer to the figure above). The inflow reduction is numerically presented in Appendix 3_10 & 11 and its simulation in the water balance of lakes.

6.7 Sedimentation and fill up of lakes and wetlands

The impact of sediment into the lakes which directly caused by inappropriate use of resources such as forest and other lands in the watershed have been threats to the existence of the lakes. Information is showing that the lakes are under threats of the sedimentation that fills their caring capacity. The sedimentation effect on the lake is well analyzed in the section 8.0.

Note: All of the above trend and Mean shifts of time series analysis of the variables were examined through a comprehensive time series analysis. Linear trend analysis revealed that there are no linear trends in all time series although in few occasions, outstanding deviations from stationary was manifested in yearly time series. These deviations depict that no statistical inference can be made on these deviations. Generally, no consistent shift in the mean is displayed by any of the time series; however, data series of some of the decades show marginal deviations. These variations could be attributed to isolated cases of measurement errors or faulty observations, which were commonly experienced during the data collection process.

However it is useful to see the time series analysis of all these factors so that the over all trend of theses natural and human process can be easily realized. In this regard the time series analysis of the factors supposed to have either positive or negative (direct or indirect) impact on wetlands variability has put a very good clue for further inference and analysis of wetlands spatial and temporal variability.

7 EVALUATING VARIABILITY OF MORPHOMETRIC PROPERTIES OF WETLANDS

The wetlands around Lakes Abaya and Chamo were exposed to various spatial and temporal variations. As all these factors, discussed above, influence the wetlands spatial distribution and trend of the wetland has relevant importance for monitoring, conservation and wise use of the wetland's resources, analyzing and predicting the change is very important. The change of the wetlands is considered as a function of both natural phenomena and man made activities. Therefore, this information is required to determine the ecological relationships in the wetlands. Even though, this information is not available in detail for several periods, limiting the analysis and explanation of the change in the wetlands analyzing these impacts in a temporal and spatial dimension is a paramount important. Some of the parameters of wetlands to be assessed are the lake morphometric properties, (includes area, length, depth and volume) and lake level properties. In the previous Section the spatial variability of the different non-wetlands and Wetlands have been assessed using image classifications in this section the wetlands specifically temporal variability of lakes morphometric characters are analyzed using different methods.

7.1 Computation of lakes parameters

The boundary of lakes, its volume and depth are not fixed throughout its life rather vary timely. Lake Boundary is vulnerable to change due to lakes periphery denudation and depth also varies due to sediment deposition process and other factors and both intern change volume of the lake. The previous boundaries may be inundated or denudated due to various reasons discussed previously. The boundary can be calculated from satellite imageries at different times. The purpose is to investigating the most important components of the physical morphometric characteristic of the two lakes at different time spans.

7.1.1 Bathymetry data

In computation of the lakes morphometric properties, bathymetry data is crucial to have; thus, the bathymetry data of the lakes done by Seleshi, 2000 was adopted in this research. The bathymetry map developed by seleshi has been scanned and digitized and the depth contour has been generated. The point data digitized from the bathymetry map data were interpolated to create grid data, using interpolation techniques provided in Arc GIS 9.1

software. The interpolated Grid data then were used to create continuous depth maps, which eventually help to derive various morphometric parameters of interest and maps of lakes. The map has both the Grid and the contour lines which both express the depth of the lake at fixed interval (2m). From the map it is possible to understand which part of the lakes is deep and which part of it shallow. Below in figure 7.1 and 2 the bathymetry map and 3D view of both lakes are presented.

7.1.2 Morphometric characteristics of the lakes

The most important parameters of lakes morphometric are; Area (A), Maximum effective length (L_{me}), Maximum effective width (W_{me}). Mean width (W), and Mean Depth (d). Except the mean depth all other parameters of the lakes morphometric were generated from the satellite image using digitization of TCT images.

Table 7.1 morphometric Parametrs of Abaya and Chamo Lakes

Parameters	Lake Abaya			Lake Chamo			Remarks
	1973	1986	2000	1973	1986	2000	
Time	1973	1986	2000	1973	1986	2000	
A (km ²) (Excluding Islands)	1108.703	1100.275	1095.45	338.596	329.865	308.9	Digitized From the TCT satellite image
L_{me} (km ²)	79	77	76	34	33	32	@5°,58',5''N&37°,39' E and 6°,35''N & 28°,02''E
W_{me} perpendicular to L	27.5	26.8	26	15.8	15.2	15	
W (km) A/ L_{me}	15.1	14.13	14.0	10.5	10.1	10	
D_{max} (m)	24.5			14.2			Note: Near the middle for Chamo & Around Islands for Abaya From bathymetry map, Seleshi (2000)
d(m) mean depth = V/A	8.52	8.12	7.33	11.98	10.12	9.56	Assuming 0.0349 for Abaya and 0.0178m for Chamo depth reduction per year due to sediment which is mild
Shore line (km)	269.1	268.5	268.1	109.2	108.1	107.89	
Volume (km ³) =Axd	9.4513	8.934	8.032	4.0563	3.3646	2.953	

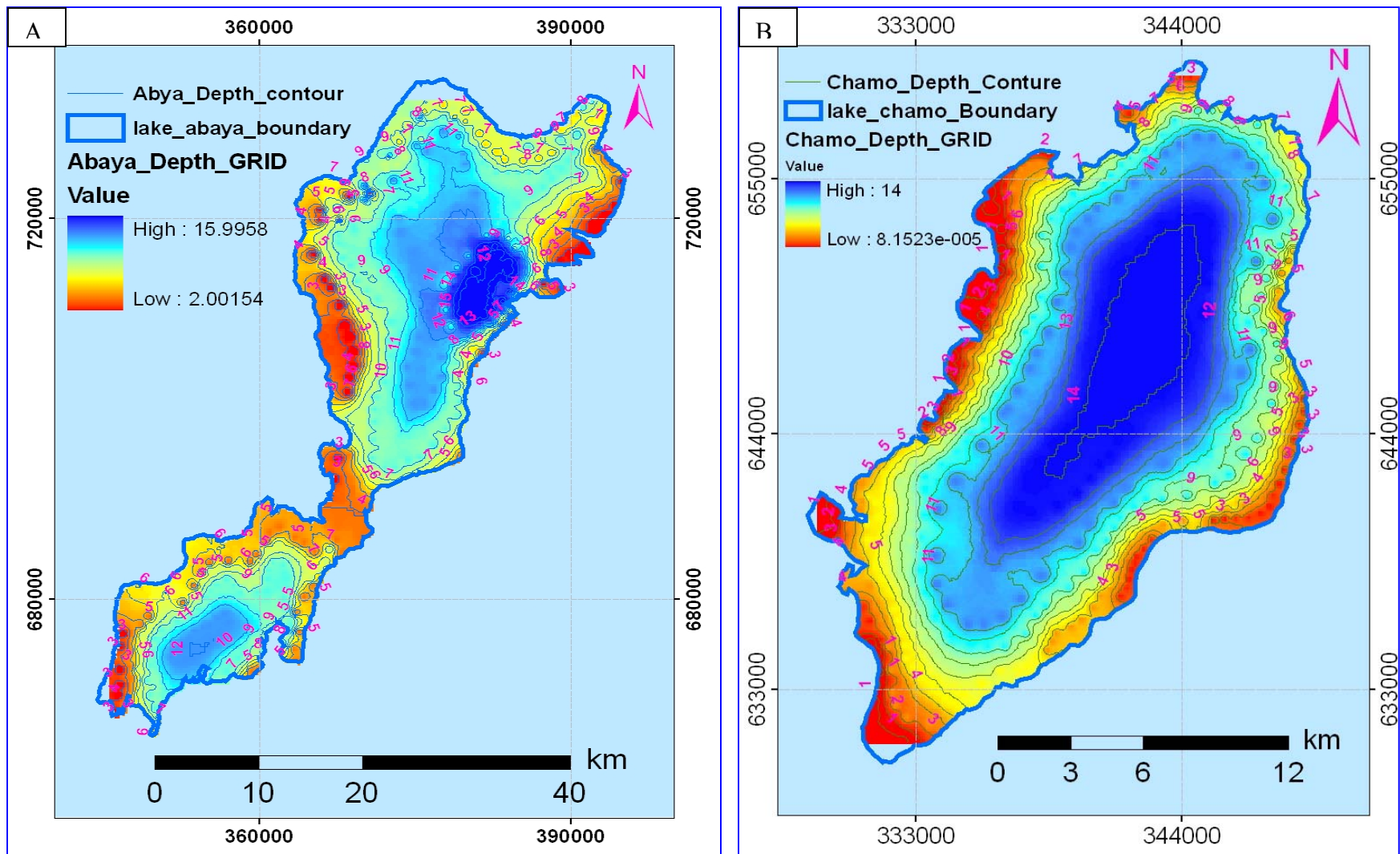


Fig 7.1 Bathymetry map of Lake Abaya (A) and Chamo (B)

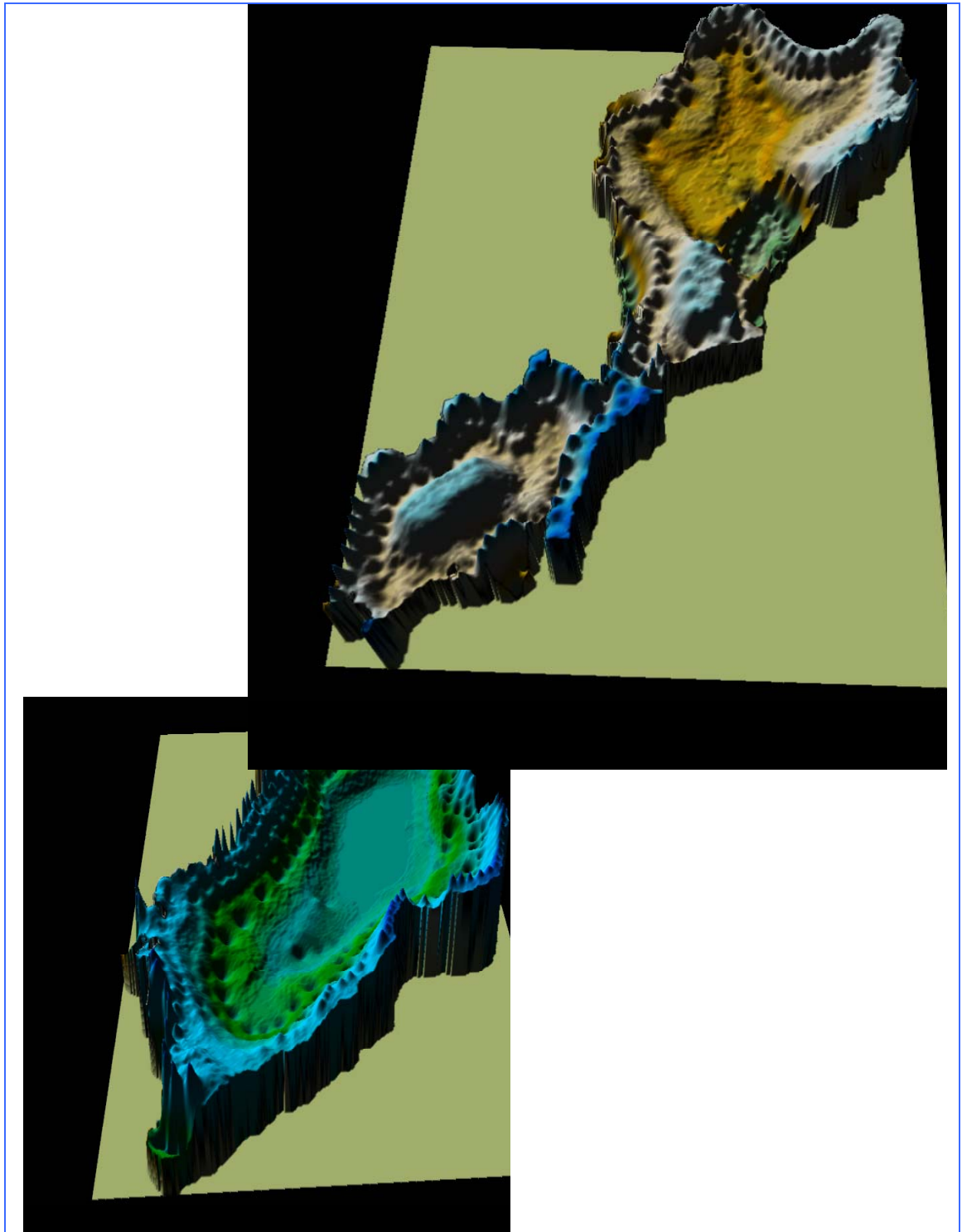


Fig. 7.2 3D view of Lakes Abaya and Chamo

7.1.3 Elevation and Volume curve of Abaya and Chamo lakes

Based on the previous discussion, the processed data is related to a reference lake level and used for computation of elevation–area-volume relationship of the two lakes. For various elevation points based on general grid, planer and surface areas can be computed. The surface area considers slope and elevation in to effect to compute the area; while planer area computes the projected two-dimensional plan water area parallel to the water surface. Silashi, 2000 has calculated the relation manually. In this research area and volume have been calculated using Arc GIS 9.1 3D analyst using the DEM of the lakes developed by depth contour map of the lakes and the result is presented in Appendix 4 and below the graph shows the volume curve of both lakes plotted from a table presented in Appendix 4. The relationships can be used to determine the change in water surface area and the storage change respectively for any level change or vice versa.

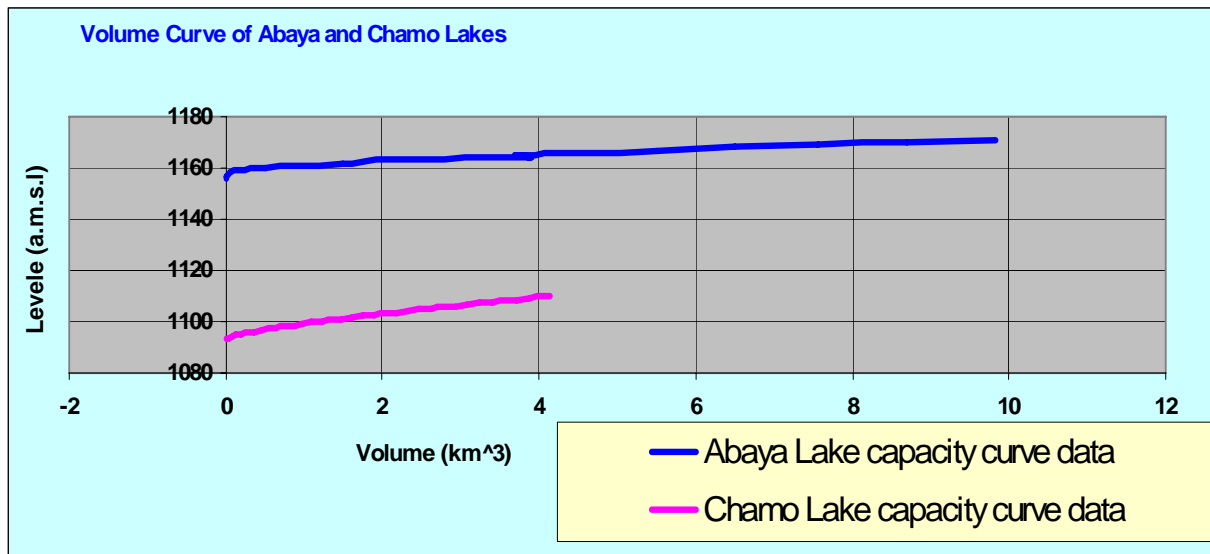


Fig. 7.3 Volume curve of Abaya and Chamo

Volume-Depth Equations for both lakes have been developed from the table presented in Appendix 4

$$V = -4 \times 10^{-5} d^5 + 0.0016 d^4 - 0.0235 d^3 + 0.167 d^2 - 1.456 d + 9.889 \quad R=0.994 \quad \text{For Abaya}$$

$$V = 2 \times 10^{-6} d^5 - 3 \times 10^{-5} d^4 - 0.0003 d^3 + 0.0031 d^2 - 0.319 d + 3.2419 \quad R=1 \quad \text{For Chamo}$$

Where V is Volume and d is depth of water measured down ward from lake level 1171 for Abaya and 1107.25 a.m.s.l for Chamo

7.1.2 Volumetric variability of Abaya and Chamo Lakes

The volume of the lakes at various periods was calculated as presented in table 7.1 and their trend was plotted in the figure below. The volume of both lakes is in a decreasing trend specially Lake Chamo is desiccating speedily as compared with lake Abaya. In 1973 it was 4.05 km^3 but now reaches 2.978 km^3 which is a hug loss for lake Chamo.

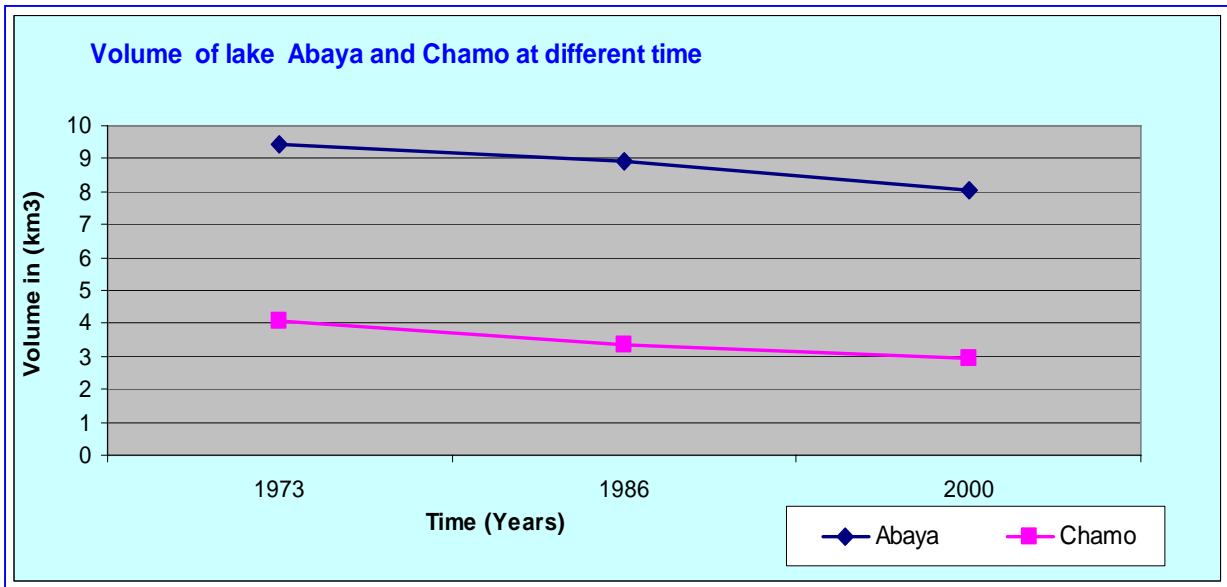


Fig. 7.4 The temporal variability of volume of the lakes

7.2 Water balance of the lakes

The knowledge of water balance of lakes is an essential component of water management, which shows the variation of lakes water at various time scale. Water management decision as far as possible should be based on a thorough qualitative understanding of the hydrological cycle of the lakes. So the usefulness of the water balance model for planning water resources and to evaluate the direct impacts of possible future development can be evaluated using the model. Using it one can predict the direct impact of future development and variation around the lakes (Seleshi, 2000). As it is generally assumed; the total amount of water remained constant on the globe level and the term water balance expresses the idea that the amount of water in earth is fixed. However the distribution of quantity and constituting quality in the cycle changes by natural phenomenon and human impacts. In this view the Abaya and Chamo lakes and wetlands have been confronted with a number of problems, which need to be addressed urgently, and these problems are relevant to the lakes; among these include,

Rapid population growth and need for water use, use of water for irrigation, deforestation in the catchments result increased erosion and sedimentation and combined all above the lakes may undergo recession and reach to unrecoverable state.

Generally, the water balance model of the lakes is paramount important to evaluate the impacts of some of the consequences of the stated problems above. Thereby the water balance model of the lakes helps to make future sustainable plans for development of the available potential and devise appropriate management strategies. If the water balance for the lakes is modeled the volume of the lake can be predicted and their fat also evaluated. However the water balance of the lakes have been well done by researchers for example namely Seleshi and Fekadu, The water balance of the lakes done by Seleshi, 2000, is limited only till 2000 and needs to include data till 2006. In this regard the water balance of the lakes done by the stated researchers along with some modification and addition of the remaining times is presented below.

Table 7.2 Summery table of Water balance of the lakes 1969-2006(Source Seleshi, 2000)

Water balance Components	Abaya (10^6 m^3)		Chamo (10^6 m^3)	
	Inflows	Outflows	Inflows	Outflows
Rain fall	831.91 (25.8%)		202.98 (27.2%)	
Evaporation		2711.99 (83.59%)		713.85 (98.8%)
Partial Gauged inflow	1858.67 (57.5%)		345.69 (46.3%)	
Un gauged Inflow	539.35 (16.7%)		197.76 (26.5%)	
Irrigation Use		145.03 (4.5%)		5.66 (0.78%)
Outflow		385.85 (11.89%)		2.72 (0.376%)
Sum	3229.93	3242.87	746.43	722.23
Balance (Change in Storage)	-12.51		14.12	

The above table is summery of the water budget of Lakes Abaya and Chamo over four decades. The over all balance of the water budget for both lakes is -12.51 and 14.12 MCM for Abaya and Chamo respectively. To understand which components of the water balance highly affecting the lakes volume it is better to see the yearly water balance of each components of the water balance in the following graphs.

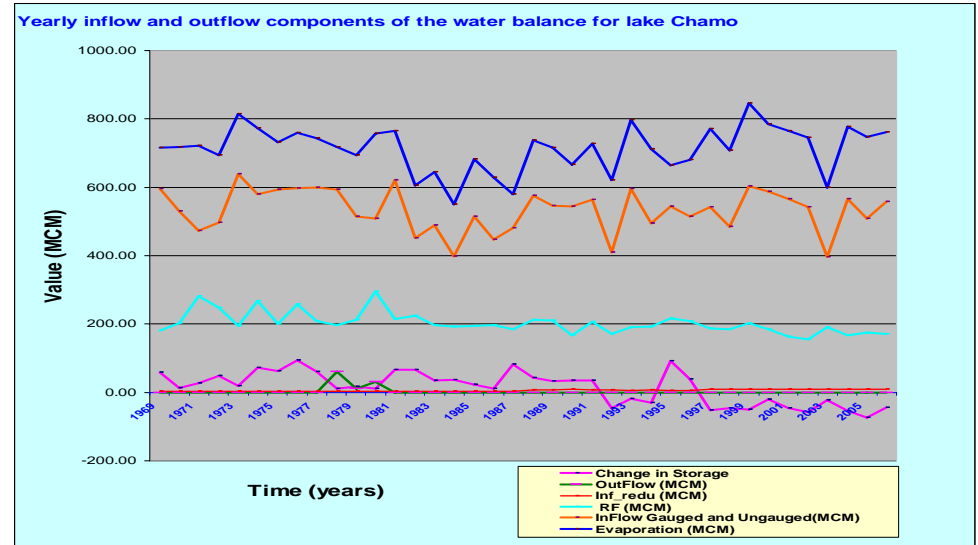
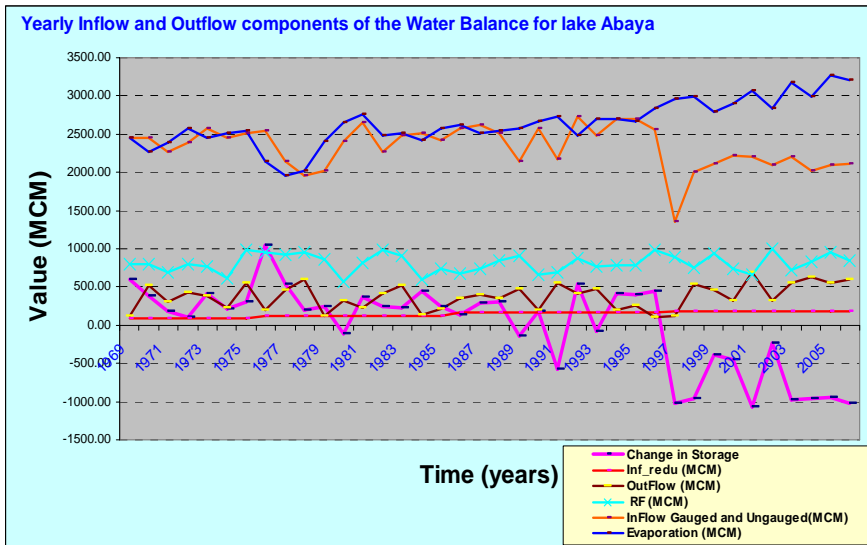


Fig. 7.5 Annual inflow and outflow components of the water balance

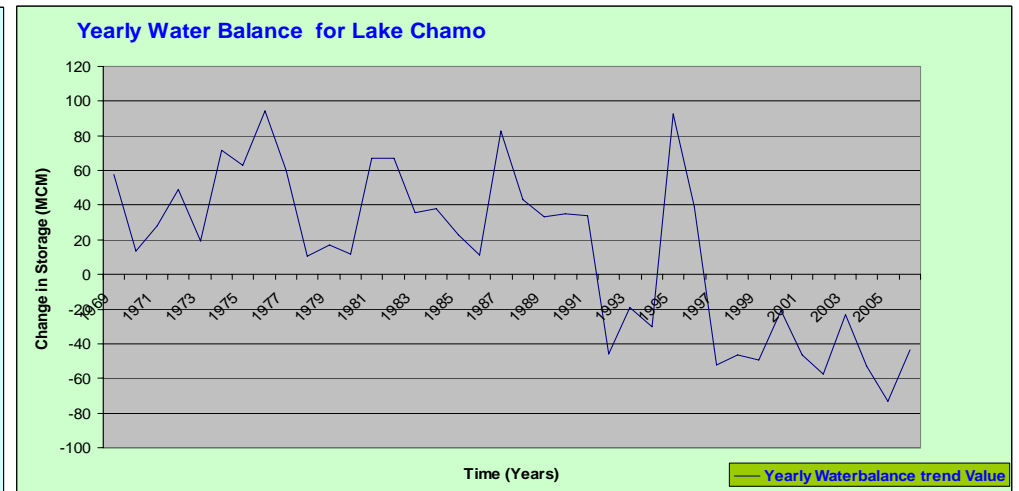
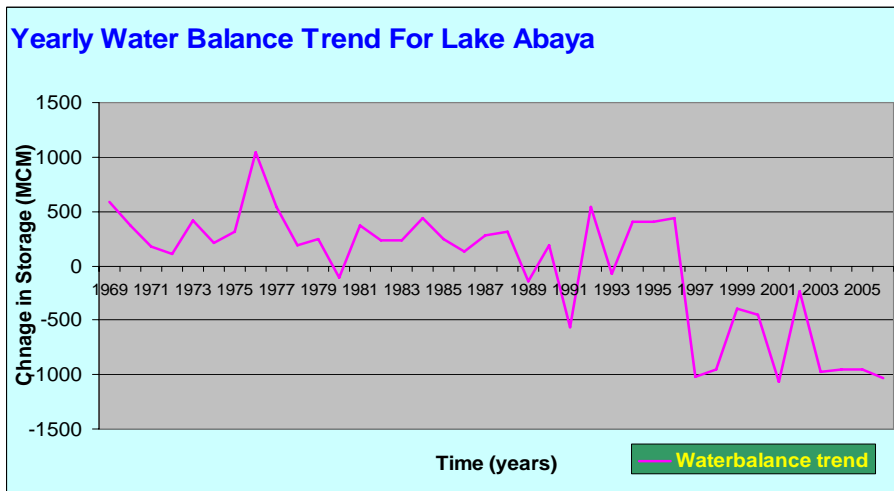


Fig. 7.6 Annual Change in storage of the water balance

Figuratively lake Abaya is under sever desiccation while lake Chamo has a positive balance. It doesn't mean that Lake Chamo is increasing in volume totally and has no problem of lake desiccation. In order to judge it is important to see the yearly water balance trend of each component for each lake.

Natural condition due to high evaporation, low rainfall in the region as well as climatic variations such as El Nino and La-Nina have considerable influences on the lakes water volume and over all water balance. In order to observe natural factors, mean yearly water balance components were also used in this paper. From the result it can be seen that rainfall contributes 25.85 and 27.2% on Abaya and Chamo lakes respectively. From all inflow components runoff takes the great percentage 57.5 and 46.3 % for Abaya and Chamo respectively. On the contrary on the outflow components Evaporation takes the highest percentage, 83.6% and 98.8% on Abaya and Chamo Respectively. The over all input output percentage of the lakes is 99.6 % and 101.9 % for Lakes Abaya and Chamo respectively. The input of Abaya is lesser than its output by nearly 0.06% which is considered as a deficit but Chamo has 1.9% high input over the output and this indicates that Chamo has no deficient in all over the considered time.

However, in real situation Abaya can be considered as having surplus water if overflow on the long-term to Chamo is neglected. On the other side if this component is ignored Chamo is always in a significant deficit. In order to see the effect clearly it is important to see the yearly balance components. See figure 7.6 which explain that the surplus in Abaya was entered as an overflow in the 1970s and late 1980s and the majority of this excess volume disappeared during overflow period in 1986s to 2000. In this period Lake Abaya also in sever desiccation (see figure 7.5). However due to absence of overflow from Abaya in recent times Chamo can't able to recover due to its own large evaporation compared to its flow from the rivers and Chamo is receding significantly.

Generally, the hydro meteorological phenomenon in the Lakes watershed and adjacent areas showed great variation on the hydrological regime of the lakes due to the reason that uncontrolled, misused, and over exploitation of water for irrigation especially in recent years. All Rivers flowing to the lakes at the same station showed a great change for the last four

decades. The lake water level evolution showed that a constant decrement in volume for Lake Abaya and Chamo. Figure 6.2 depicts Lake water balance calculations of the last forty years data of both lakes will disappear in the near century. Even though the long-term (nearly forty years) water balance indicates the positive value of the lake storage change for Chamo it doesn't mean that the lake has no predicament. In the last two decades, Lake Chamo has gone through repeated desiccations, especially in the northern and western parts of the lake. During the period 2000 to 2003, the northern and western parts of the lake had low water levels. Analysis of the monthly data of the water balance of the lakes after the spill in the second half of 1970s Abaya lake was showing decreasing trend and receding 1996 at time when generally very wet years in the southern region of Ethiopia occurred which has been associated with El Niño and which caused significant rise of water level. But currently especially since the years 1998 till now it has been going to severe desiccation.

The main causes for the substantial decrement of the storage of the lake Abaya is reduction of water flowing to the lake for irrigation purpose and evaporation. The reduction of excess inflowing water for irrigation purpose from: Kulfo, Bilate, and other rivers, which join the two lakes, results a significant reduction in the lakes volume. Therefore, the surface drainage to lake from excess irrigation since 1983 became inflated compared to the other inflow. The effect of unbalanced evaporation with rainfall (average yearly rainfall is 203 but evaporation is 714) and even evaporation is significantly increasing and on the contrary rainfall is reducing, all these are the major threats indicated from the water balance.

The temporal variation of the lakes hydrological condition is described in the above tables and figures. The analysis on the spatial (areal) extent of the lakes has also been measured using satellite imageries of averagely ten years intervals. To compare the satellite based analysis with the water balance model results breaking the water balance results with the same date of satellite imageries acquired is paramount important. These broken water balance results are presented in the above tables and figures. The result indicates that both lakes show an increment in the change storage value after 2000, which were a decrement trend since 1970s till 2000.

Table 7.3 Ten years break water balances of Lakes Abaya and Chamo

Time (Years)	Change in Storage	
	Abaya	Chamo
1969-1973	132.9185	33.53292
1973-1986	115.1729	43.85971
1986-2000	-74.03	6.827536
2000-2006	-12.9386	14.11989

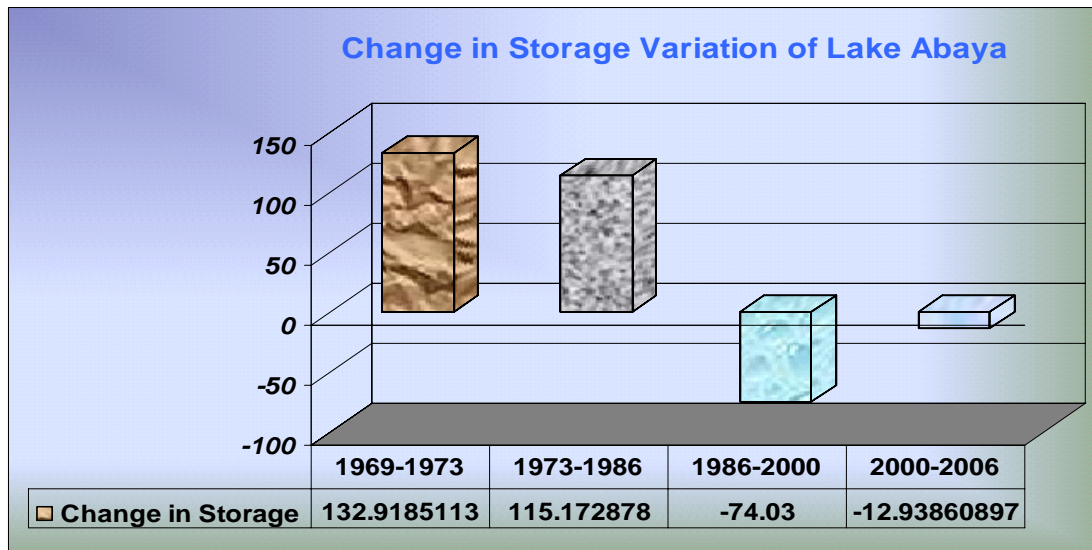


Fig. 7.7 Ten years break storage variation of Lake Abaya

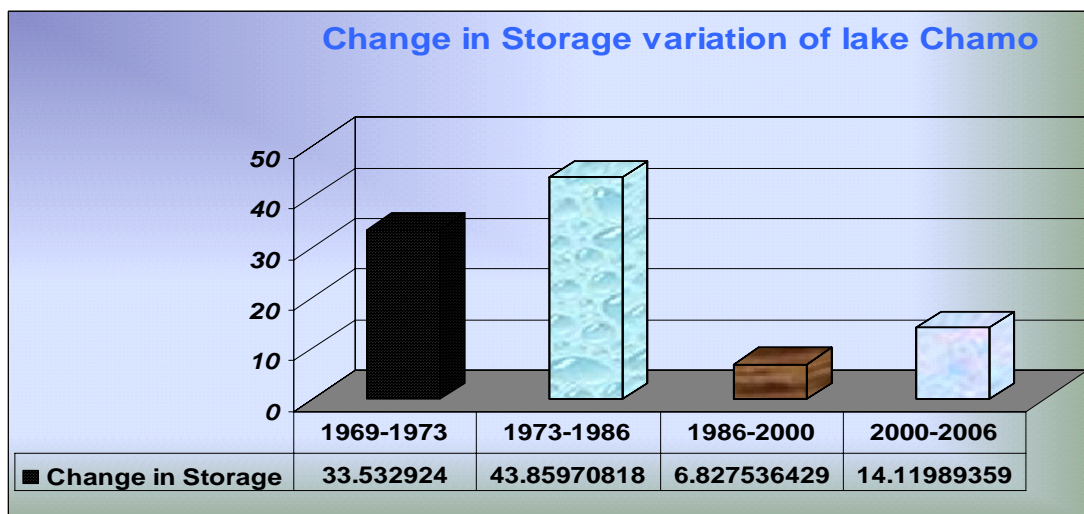


Fig. 7.8 Ten years break storage variation of Lake Chamo

7.3 Analysis of lake level variation

7.3.1 Background

The recorded water level of the lakes provides history and possible trends of the water contained in the lakes. The lakes level data recorded for Abaya and Chamo lakes on monthly basis have been compiled in the document Seleshi, 2000. Lake Abaya has three gauging stations for measurement of the lake level. These gauging stations are very important to understand whether there is error or not in the lakes level readings. Under correct record and comparison of a pair of station, the level recorded differences between two stations of the same lake should be remained constant. Any deviation from the constant value could be the result of data error or gauge location or gauge due to minor error in reading or wind setup or wave run ups. In this regard the water level of Abaya from all gauge station shows a great variation. Their difference of these readings and errors were filtered out and the corrected values of the periods until 1997 were taken from Seleshi (2000) but the others time data were corrected as follows.

7.3.2 Lake level data correction

A) For Abaya: utilizing the raw lake level data is a misleading approach since it has many errors. The causes of missing data include failure of reading recorded, broken gauges by animals and wind. In order to fill in missing data of either of the base stations correction of common data periods were made between measuring stations every correction was carried out for sufficient long periods of time in the neighboring missing data correction equations were used to fill in the gaps or correct erratic values. The correction equation developed from the relationship of the different gauge record is presented below.

To fill missing values in 1983 to 1988:

$La = 1.0086Am + 0.5-La$ means *La* means lake gauging station records and *Am* means Arbaminch gauging records.

B) For Lake Chamo: It has significant missing data and the gauging station location or method of recording have been changed a number of times. The causes for missing data are similar to that of Abaya but error correction or filling of missing data or adjustment of data during gauge movement can't be under taken for this lake, as there has been only one gauge station.

However for the analysis purpose the trend equation of the correct records were used to fill these missed data. The significant lake level variation for lake Chamo is brought from difference in method of measurement and Measuring gauge datum displacement since 1986.

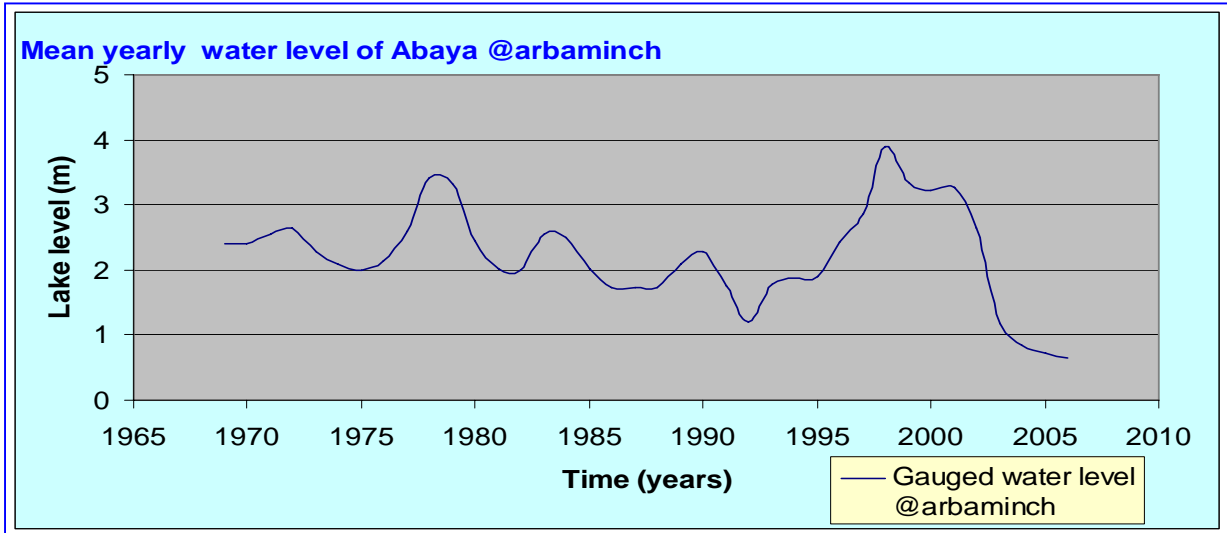


Fig 7.9 Mean monthly water level for Abaya

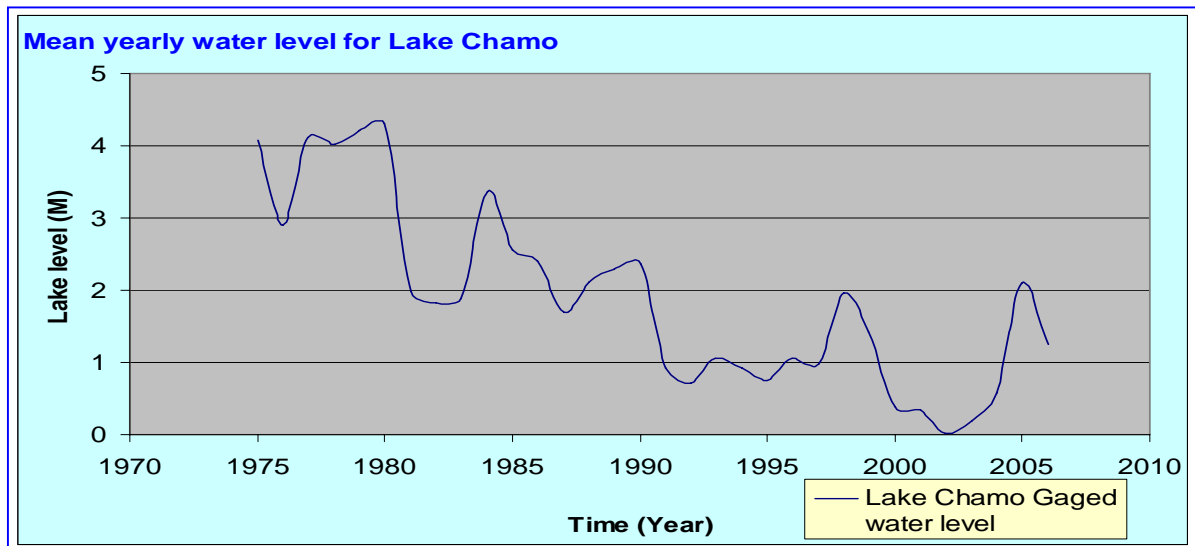


Fig 7.10 Mean monthly water level for Chamo

7.3.3 Factors affecting Lake Level fluctuation

There are various factors, which are responsible for lake level fluctuation. Some have been discussed above. But the major ones are the inflow and outflow components of the lakes. To mention some of them once again: Rainfall, runoff, evaporation, and sedimentation. All these components are discussed in section six of this paper in detail. But to come up with which has a determinant one over another a multiple correlation analysis in SPSS software has been applied on all possible factors and the result is presented below.

Table 7.4 Correlation analyses of factors responsible to lake level fluctuation

	Abaya					Chamo				
	Lake Level	Rainfall	Inflo	Evap	Extr	Lake Level	Rainfal	Inflo	Evap	Extr
Lake level	1					1				
Rain fall	0.245	1				0.525	1			
Inflow	0.58	0.877	1			0.58	0.303	1		
Evapor	0.68	0.35	0.23	1		0.72	0.146	0.818	1	
Extraction	0.72	0.16	0.01	0.45	1	0.69	0.28	0.29	0.37	1

The correlation analysis indicates that lake level is better correlated with extraction and evaporation as a result lake level fluctuation is highly determined by the lakes excessive use of rivers entering to the lakes and evaporation especially Lake Chamo. This also supports the water balance analysis result where evaporation takes the highest percentage of output components of the water balance.

7.3.4 Sediment deposition integration in Lake level simulation

The inclusion of the sediment even without having accurate data enables better understanding of the lake levels variation. As stated earlier, the impact of inclusion of sediment on simulation would provide higher water level than without inclusion. Contrarily, if sediment is not included the gauged appears to be lesser than the simulated result under correct data. It is supposed that the sediment delivered in to the lakes never go out and fully deposited. Even during the occurrence of overflow it is not expected to have significant outflow of sediment from the lakes due to the larger size of the lakes and the possibility of full settling of the sediment delivered in to the lakes, except permanently suspended particles to escape.

In order to include the lake level rise due to sediment component, the particular time interval the lake volume–depth relationship that was done in the previous section is used. With a given amount of volume added to the lake there is a corresponding value of lake level that can be derived from the lake volume capacity curve, which was presented in figure 6.2. However the volume of sediment that is added to the lake has to be either estimated or measured. Under this condition the yearly sediment volume was taken from section 8.3, Scenario I–2 for each lakes and their new lake level variation has been estimated. To get each year level increment the following formula was used.

$$D_t = t_i d_i \quad \text{Where; } D \text{ is depth of sediment, } t \text{ is year and } d \text{ is Average annual sediment depth}$$

Eventually the value of the lakes level was plotted in figure 7.11 and 12. Applying this value on the previous lake bathymetry data a new depth (lake level) has been generated. Using this depth increment the lake level would rise with an equal amount of the depth decrement. The value is 0.0349 m per year for lake Abaya and 0.017 m per year for lake Chamo. The value of D , is thus a continuously deducted to the measured lake level to get sediment free lake level, and new lake level is computed at each time interval, i.e. the effect of deposited sediment is included explicitly for each time setup. Figure 7.11 and 7.12 show the new simulation considering concentration-based mild sediment load for Abaya and Chamo respectively.

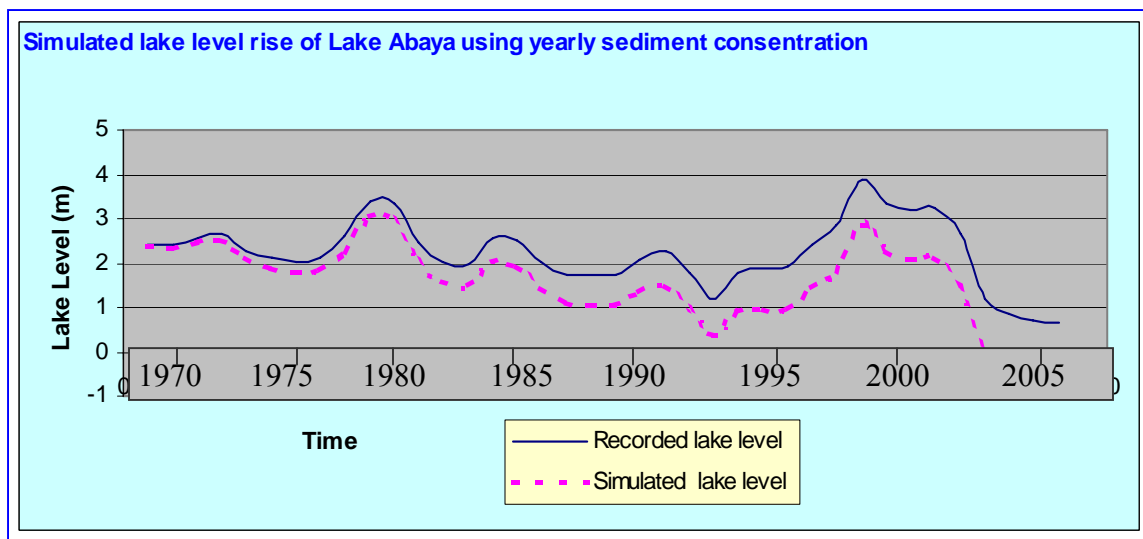


Fig 7.11 Mean Yearly water level for Abaya with Sediment concentration effect

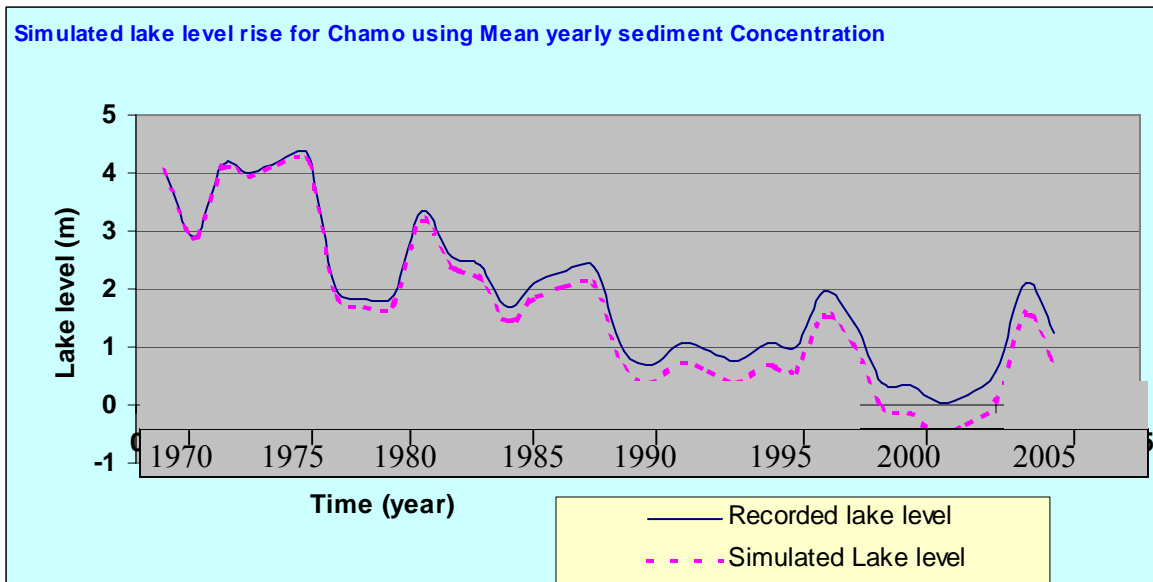


Fig 7.12 Mean Yearly water level for Chamo with Sediment concentration effect

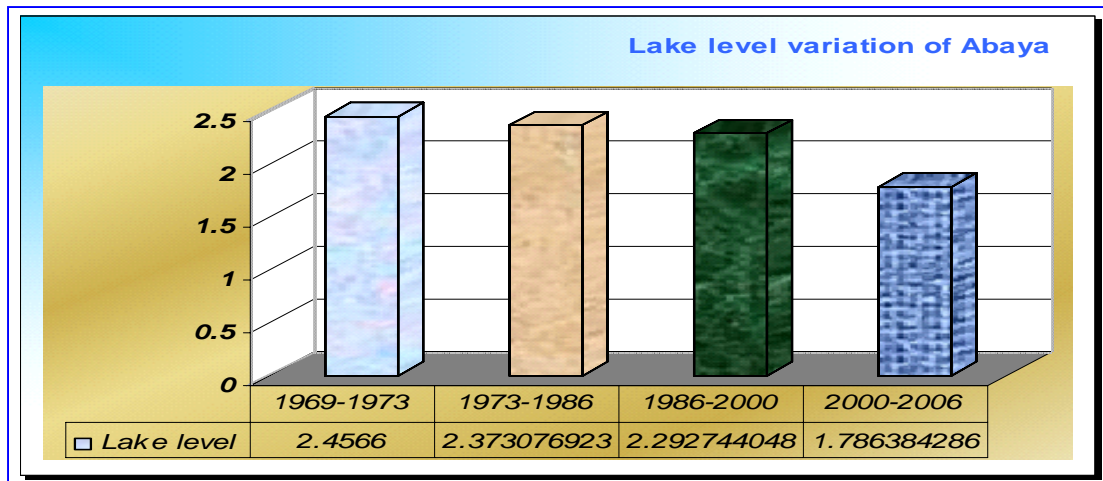


Fig. 7.13 Lake Level Variation of Lake Abaya in ten years break

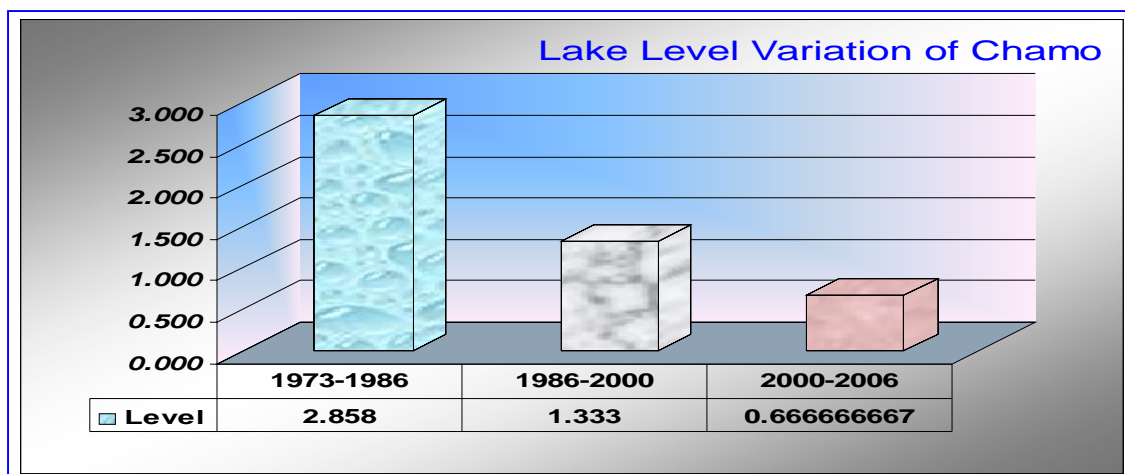


Fig. 7.14 Lake Level Variation of Lake Chamo in ten years break

8 SCENARIO ANALYSES OF LAKE SILTATION

8.1 Background

The life of the wetlands in general and lakes in particular which are located in lowlands is greatly determined by the sediment load coming from the uplands. The lakes water depth and the sediment loaded to the lake affects water volume. In this case it is very important to assess and see the rate and extent of erosion in the area with respect to sedimentation effect on these wetlands. Soil erosion and sedimentation studies in the area are very limited and have no reference to attach possible effects and impacts on the lake. Hence to evaluate the spatial and temporal variability of wetlands, the lakes sedimentation rate has to be estimated and predicted and eventually the siltation problem of the area has to be assessed and the effect on the lakes in particular and the wetlands in general would be determined.

Despite extensive research effort, knowledge of erosion and sediment transport still remains incomplete, and there is no accepted formula to be used accurate solution of the sediment transport rate and watershed sediment yield (Seleshi, 2000). The soil erosion data as well as sediment transport in rivers data in general in Ethiopia are very limited. As a research of SCRP of MoA, on countrywide there are six research catchments for which soil erosion data and associated parameters are available. Out of these, none is in the basin of Abaya and Chamo. Thus, it is not possible to obtain soil erosion data in the study area. The only possible approach is perhaps to adopt the semi-empirical relationship developed for the country or chose one of the research catchment of SCRP as a representative for the basin. Similarly, the sediment transport data for rivers in the basin is not available in usable form. The existing data for some rivers are short record and are not representative and could not show any spatial and temporal distribution. Further more, one dose not expect to have data on the amount of sediment entering in to the lakes, and it can be said that there is no data available on the sediment transport and delivery in to the lakes except for some rivers of very short duration

8.2 Erosion data and Sediment transport data

The effect of deposited sediment on the lake is detrimental to the water caring capacity of the lakes. Sediments entering to the lakes especially in to Lake Abaya is entering in substantial quantities through the rivers. Sediment load of Bilate river and that of western tributaries is large. The highest value of intermittent records in the research region, from data of February 1995, for Bilate at Alaba Kulito shows a concentration of sediment 19.7 kg/m³. The causes of large quantity of sediment are associated to intensified erosion in the catchment area due to deforestation, poor farming practices and over grazing. The consequence of this phenomenon is highly detrimental for both lakes, which are shallow. If sediment input into the lakes could not be controlled the lakes could be completely lose their water caring capacity and disappear due to deposition of sediment

Despite the seriousness of the problem, as stated earlier, there has been no compressive and continuous sediment transport data collection program in the study area. According to Seleshi, 2000 there has been short term data collection and correlation of this data try to deduce sediment transport for example for Gelana river, at Dima Tore which is aimed to serve feasibility study of Gelana irrigation project, based on data collection in 1986/87. According to Seleshi, 2000 the correlation these data resulted the following equation.

$S = 13.8 Q^{0.907}$: Where *S* is Sediment load and *Q* is discharge amount

This provides sediment loads in tons/day, while Q is in m³/s.

In order to make estimation through such an approach gauging station should be established and sufficient data should be collected. To attempt estimating the sediment load at this stage, the equation for Gelane at Dima Tore on Just three-year data might be employed just to see impacts of sediment on the lakes. This equation, despite its inappropriateness to be used even for entire Gelana River let alone for the whole rivers of the watershed, it is tested as crude estimator. Accordingly, the estimation based on the above concentration-based relationship is used to test the estimation capacity of the sediment transport at the outlet of the lakes.

The other alternative would be to make estimate based on judgment, which are based on the result of SCRIP data, average sediment transport rates of other rivers in Ethiopia, and the intermittent information available in the research area. Based on the SCRIP data, erosion rates in the various agro-climatic regions of Ethiopia provides annual mean loss rate for cultivated test plots to vary between as low as $100\text{t}/\text{km}^2$ to as high as $21,200\text{t}/\text{km}^2$ and in terms of annual yield the catchments have been reported to vary between $0.2\text{t}/\text{km}^2$ to $2,523\text{t}/\text{km}^2$ per year. The mean annual sediment concentration varies between $0.01\text{kg}/\text{m}^3$ to $50.76\text{kg}/\text{m}^3$ (Seleshi, 2000).

As another indicator for estimation Ethiopian rivers carry sediment loads of about $800\text{t}/\text{km}^2$ to $2,500\text{t}/\text{km}^2$ every year. Furthermore, as stated earlier infrequent data with in the rivers of Bilate to Lake Abaya it shows a maximum concentration up to $20.7\text{kg}/\text{m}^3$ and river of Kulfo Chamo has a maximum of $0.156\text{kg}/\text{m}^3$. In the absence of such information, Sileshi has made estimated life expectance of Lake Abaya and Chamo based on various assumed sediment inflow condition, 2000. Using theses information as a basis, until appropriate data and relationships are derived to estimate sediment inflow into the lakes, three scenario of sediment yield concentration based are assumed for simulation and estimating life expectance of lakes, which is discussed in the next section. These are based for small/tolerable sediment load, moderate load and high load conditions. The concentration based is considered to be 0.1, 2 and $20\text{kg}/\text{m}^3$ respectively (Scenario I-1, I-2, I-3).

8.3 Life expectance of the lakes with respect to Sediment Deposition

If the magnitude of the sediment input could be computed fairly accurately expected life of lakes could be estimated. In the absence of such information, estimate of expected life expectance of Abaya and Chamo lakes have been made based on various assumed sediment inflow conditions. For these purposes, the above previously assumed cases chosen as scenarios with three types of assumed sediment load data used to estimate the life expectance of lakes. Seleshi, (2000) has estimated the life expectance of the lakes for sedimentation effect. Seleshi has used 1979 lakes parameters to estimate life expectance of the lakes. But this study updates all lakes parameters in to 2006 and results show that there is a great difference in life of lakes as estimated by Seleshi, 2000.

The major differences were Lakes area, net inflow, and sediment concentration for more description see table 8.1.

Life expectancy would be the time period on which the *quantity of sediment inflow is equal to the capacity of the lakes*. In order to compute the life of the reservoirs the following definitions are important.

- Maximum capacity of the reservoir (V_{mx}) is reservoir volume and corresponding depth at which the maximum lake water level reached under outflow condition.
- Lakes are said to be completely disappeared; if the total volume of deposited sediment reached the lakes equal to V_{mx} . In terms of volume these correspond to V_{max} of 8.03246 km³ and 2.953 km³ for Abaya and Chamo respectively.

Accordingly, table 8-1 below summarizes the data and computation of the life expectancy of the two lakes, based on combined data gauged level and capacity curves. Thus, it can be seen in the results provided in the table the complete disappearance of Abaya and Chamo lakes due to sediment deposition under high sediment load (mean annual sediment load concentration of 20kg/m³) could be as low as 165 and 198 years respectively. These results computed based on V_{mx} related to maximum lake volume records of 2000. Under mild sediment deposition condition, the highest life expectancy is 932 and 1,161 years respectively.

If the result estimation is correct for Abaya Lake the life expectancy of Lake Chamo is much shorter after Lake Abaya is fully occupied by sediment. The lake Chamo disappearance would be dramatically shortened, as all sediment would enter to the Chamo Lake after filling the Abaya Lake. It is possible to argue that the sediment load at the current level of inflow is between mild and high load (Bilate and western Side Rivers sediment yield mentioned earlier). Considering this, and based on the above analysis the life expectancy falls between Scenario I-2 and Scenario I-3, and both lakes are endangered lakes due to the sediment deposition. Thus it is time to take corrective measures and alleviate problem of erosion in the watershed, sediment transport in the rivers and ultimately delivery in the lakes.

$$V_{sed} = 1/P_s (C * V_R)$$

Where the variables represent

V_{sed} : Volume of sediment

V_R : Net mean annual runoff

P_s : Density of sediment

volume

C : Sediment concentration

Table 8.1 Scenario analyses for Life expectance of lakes

Parameters	Abaya	Chamo
V_{max} (km ³) (in 2000)	8.03246	2.953
Net mean annual runoff (MCM) (Thirty seven years average value)	2398.0233	533.3718 (excluding Abaya over flow)
I Annual sediment load concentration (MCM) $V_{sed} = 1/P_s (C * V_R)$		
Scenario I (0.1kg/m ³)	0.043	0.012
Scenario I (2 kg/m ³)	8.617	2.543
Scenario I (20kg/m ³)	48.769	14.879
II Life expectance		
Scenario I-1 (0.1kg/m ³)	186, 801	246,083
Scenario I-2 (2 kg/m ³)	932	1, 161
Scenario I-3 (20kg/m ³)	165	198

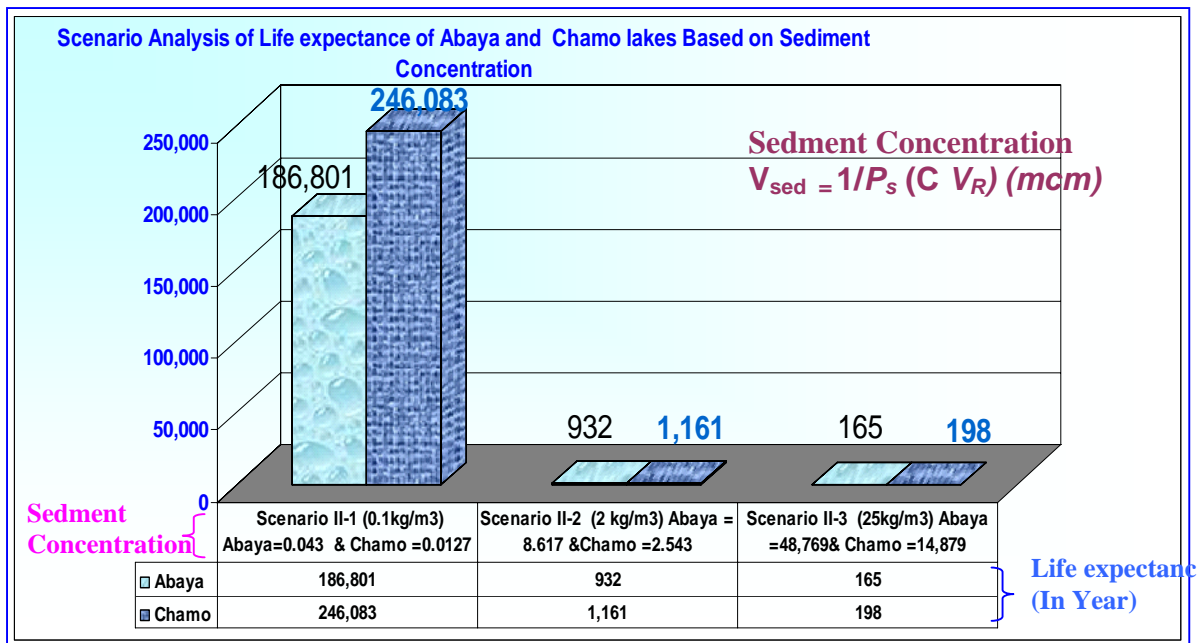


Fig. 8.1 Scenario analysis of Life Expectance of the lakes

9 MAPPING CONSERVATION ZONES OF WETLANDS

9.1 Background

To develop a management plan zoning the various components of the wetlands is important. Zoning is a key component of Protected Area (PA) management in general. It reflects the fact that different parts of the PA have different conservation values and / or can withstand different degrees of use intensity. The management zones can be divide into four, following an accepted method and nomenclature DSE, 200 as cited in EPA, 2000, namely '*Core Areas*', '*Buffer Zone*', '*Transition Zone*' and '*Rehabilitation Zone*'. To do all these GIS and Remote sensing are fast and effective tools.

Two major facets of managing wetlands for protection include creating zone of conservation of wetlands from direct human pressures, and maintaining natural processes in surrounding lands that affect wetlands and that may be disrupted by human activities. Therefore, it would be futile exercise if all the research works would be ended with out indicating and putting in a map, which part of the wetlands are highly disturbed and respective conservation zones. As a major objective of the research, it was stated in the first part of the paper, mapping the different management option in this section the different zones of protection are mapped based on the available information and requirements to map conservation areas.

9.2 Buffers and Other Conservation Measures for Wetlands

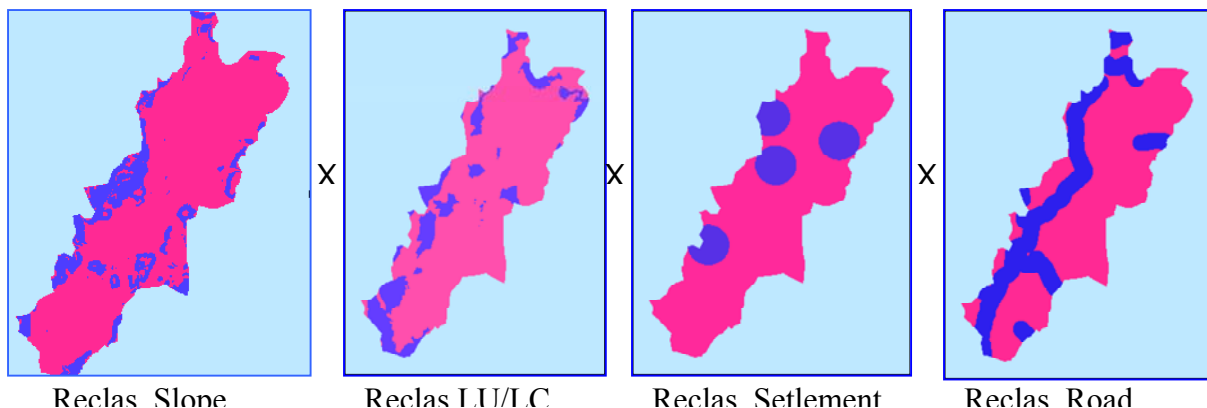
A buffer typically consists of a band of vegetation along the perimeter of a wetland or water body, preferably natural habitat, but including previously altered, stables native or introduced species. Once the need for a buffer is recognized, establishment of a suitable width is the critical task. In reality, many government agencies establish buffer requirements based on political acceptability and/or assumed aquatic resource functional value. Nevertheless, a fully informed buffer design must consider the nature of the encroaching activity, the buffer itself, the resource to be protected, and the buffering function to be performed. Castelle et al. (1994) identify four criteria for determining adequate buffer size to protect wetlands and other aquatic resources:

- I. Wetland functional value - level of disturbance, sensitivity to disturbance,
- II. Intensity of adjacent land use,
- III. Buffer characteristics - vegetation density and structural complexity, soil condition, and
- IV. Specific buffer functions required.

Castelle et al. found that buffers less than 50 to 100 m provides little protection of aquatic resources under most conditions. They recommended minimum buffer widths of 150 to 300 m under most circumstances, with the lower end of this range providing basic physical and chemical buffering, and the upper end being the minimum needed for maintenance of biological components of wetlands and streams. They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis. However, different states have guidelines on desirable buffer widths and a number of states have buffers that range from 45 m to 300 m (Buchsbaum, 1994).

9.2.1 Multi Criteria Evaluation of lakes periphery disturbance

Considering different conditions, the study area was classified as “major priority if the disturbance is high” and minor priority area if the disturbance is very less. To evaluate the level of disturbance around the lake four major conditions were considered; Settlement, Land use, Road, and Slope. All these factors were rasterized and reclassified to evaluate the level of disturbance in the area. Finally MCE using Arc GIS 9.0 were applied to develop disturbance level map which ultimately helpful to develop conservation zones of wetlands. Below each reclassified maps of considered factors are presented.



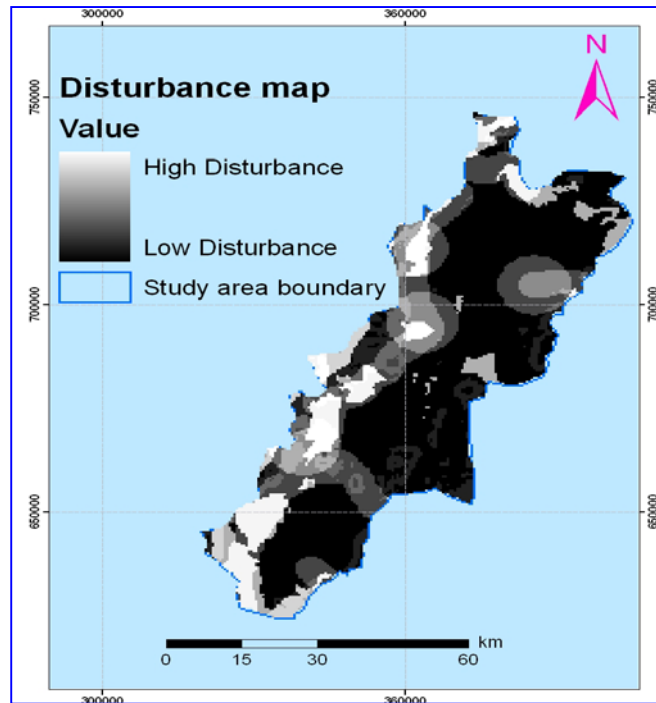


Fig 9.1 Level of Disturbance map for the wetlands

The figure above shows that the deep white part of the map are highly disturbed and deep dark areas are less disturbed part of the wetlands. From the figure above the lakes surrounding areas and the lakes periphery were divided in to two classes based on the level of disturbance to natural and human impacts, High and Low. As it is possible to interrelate from the LU/LC map, Slope, Settlement and road and other expressive issues of the previous sections of this paper the western parts of the lakes are highly vulnerable to change (labeled as high risk) and on the contrary because of terrain barrier and other effects the south west portion of the lakes is less susceptible and labeled as low to medium but north portion of lake Abaya and southern portion of Lake Chamo are highly disturbed areas and northern and north eastern part of lake Chamo and southern and south eastern part of lake Abaya considered as less disturbed areas.

9. 2. 2 Protection zones of Abaya lakes

Factors to consider in setting the designated use and developing a management strategy for a wetland include: wetland type, landscape position, surrounding land uses, cumulative impacts on, the wetland, (Settlement and urban expansion, Onshore cultivation, erosion

extent etc), etc. Based on the above principles of zonation of wetlands for protection the following portions of wetlands have been zoned for protection. With respect to the lakes water body lakes would have the following protection areas. For more explanation of the protection zones presented in the above map, refer Appendix 5.

Core Areas of Abaya

The *Typha domingensis* dominated wetland close to the Bilate Farm is used as a source of grass for thatching roofs and for grazing. This is within 200 m distance from the lake, when the lake is at its highest level during the rainy season. Starting from Bilate Farm in the north to Chamo Donga village in the south is to be maintained as a ‘**Core Area**’ (core protection zone), free from interference. On the landside of this zone, the plants are submerged, floating or rooted in water (hydrophytes). These are wetland dependent plants. The same principle of conservation applies wherever there is some wetland on the eastern shores of the lake.

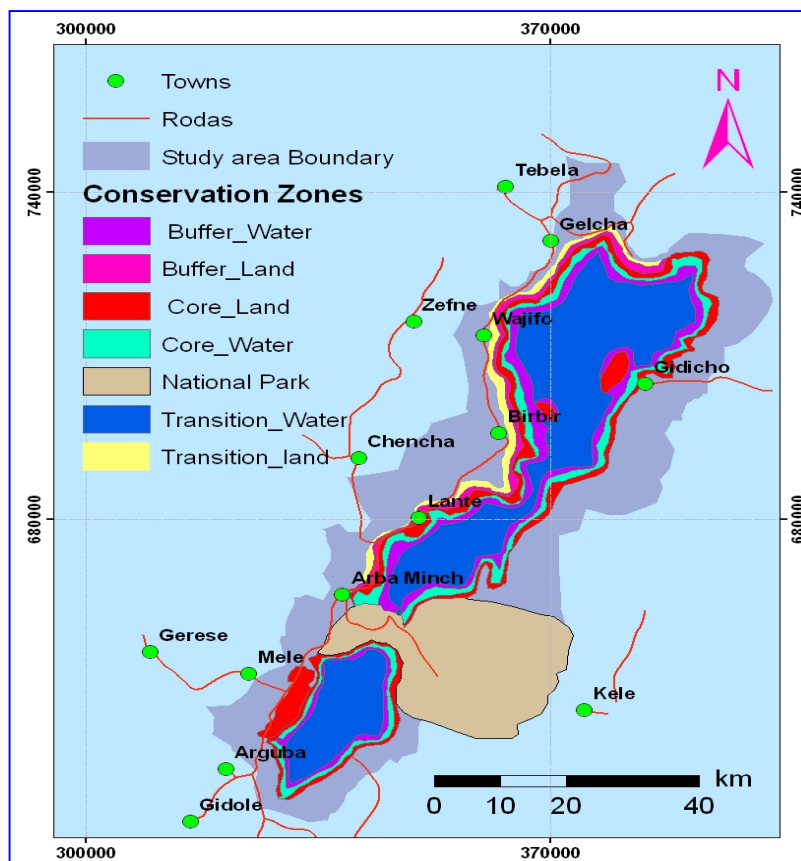


Fig. 9.2 Conservation zones developed for wetlands management

The '**Core Areas**' in the open water of the lake extends to 150m from shore during the dry season, and the '**Buffer Zone**' extends 200 m from the outer boundary of the '**Core Area**' inshore during the dry season, when the level of the lake is at its lowest. The rest of the water body in both lakes is considered as '**Transition Zone**'. In addition, the islands are considered as '**Core Areas**' and the water body zoning parameters applied elsewhere also apply to the water bodies surrounding the islands as well.

Buffer Zones: The inner boundary of the '**Buffer Zone**' is the outer boundary of the '**Core Area**'. Extensive wetlands occur beyond the 200 m distance from the shore at Chano Lante and Mirab Abaya (Birbir) to about 1000m east of the road. The species are either wetland dependent or wetland associated (facultative wetland plants). The area within this zone currently cultivated should be reclaimed through negotiation with the resource users (mainly cultivators), and put to a more regulated use than present.

Transition Zones: The inner boundary of the '**Transition Zone**' is the outer boundary of the '**Buffer Zone**'. The area beyond the 1000 m distance from the shore, on the lake side of the road (the road from Addis leading to ArbaMinch) can be considered as '**Transition Zone**', where sustainable use in agriculture or forestry, in harmony with the landscape, can be allowed. This can include settlements as well. In the lake, all the water body outside the '**Buffer Zone**' is considered as '**Transition Zone**'. In addition,

Rehabilitation Zones: The area west of the road including the hillsides and the river banks within the watershed are designated as the '**Rehabilitation Zone**', where nature can be allowed to restore its ecological function and structure. This could be enhanced through the necessary conservation measures.

9.2.3 Protection zones of Chamo

Extensive wetland vegetation around Lake Chamo is mainly confined to the western side as the result of the sharp slope on the east. The lake shrinkage has exposed areas that were under water in the recent past to invasion by cultivators and or settlers. The presence of settlements will make reclamation of the wetland very sensitive and extremely difficult. Agricultural activities on the western side of the lake start at River Sile. The area between Arbaminch and Sile River is partly occupied by *Acacia* woodland and partly by small villages in the vicinities of which cotton is grown.

The irrigation schemes on both rivers are so bad that most of the water gets lost on the way, before reaching the lake.

Most of the plantations and farms, except the Elgo Farm, are found west of the road to Konso. Intervention is limited to smallholders who are clearing the wetland vegetation for maize and sorghum cultivation. Most of the area between the road and Lake Chamo, which probably was a typical wetland, is currently occupied by scrub following a long period of recession of the lake. This area is now being grazed by livestock from the surrounding villages and from elsewhere. This protection zone helps not only buffering wetlands from direct human pressures, but also maintaining important natural processes that operate on wetlands from the outside and that may be altered by human activities. Management toward this goal should emphasize long-term sustenance of historical, natural wetland functions and values.

Core Area: The area west of the lake and east of the road leading to Konso, currently occupied by scrub vegetation or smallholder farms, have to be included in the ‘**Core Area**’, keeping in mind that this area in the recent past was inundated and was part of the wetland proper. This will require a series of serious negotiations between the resource users and the wetland management program-implementing agency.

Buffer Zones: In order to reduce the management problem, part of the above indicated ‘Core Area’ could be designated as a ‘Buffer Zone’, based on negotiations.

Transition Zones: The settlements all around the lake, the farms and plantations are considered as part of the ‘Transition Zone’.

Rehabilitation Zones: The area west of the road including the hillsides and the riverbanks within the watershed are designated as ‘Rehabilitation Zone’, where nature can be allowed to restore its ecological function and structure.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

Wetland information is part of Wetland Conservation Plan. This study planned and achieved mapping, the different types and locations, assessing and predicting the changes of the wetlands surrounding Abaya and Chamo lakes. The data and information would be useful as a planning tool.

The study has used an integrated approach to understand past, present and future conditions of the wetlands around and with in Lakes Abaya and Chamo. It comprises six major analysis; 1) LU/LC mapping and Change Detection 2) Wetlands type, location and distribution mapping and change detection 3) Meteorological data analysis that may affect wetlands 4) Hydrological data analysis (Lakes water balance, lake levels fluctuation analysis, 5) Lakes Siltation Scenario Analysis and 6) Conservation zones mapping for wetlands management. All the sections within this research provide past, current and future wetland information that can assist wetland and watershed managers. This information can help a decision-maker evaluate wetland ecosystems in a watershed to determine their functions, values, and roles in the watershed, assess risks, and prioritize protection

In this regard this research ensures that use of RS / GIS to study wetlands area within a large landscape can facilitate a proactive planning process that enhances the implementation of sustainable wetland management. Applying this technique to locate possible wetland priority area for conservation using several criteria and scenarios has provided better result for wetland conservation priority areas in the study area, particularly in the face of future population growth and development. This study used GIS as an integrating system and analysis tool to assess, evaluate and predict wetland changes and associated factors. Satellite images, field surveys and other research study results were very important sources for wetlands change mapping and detection analysis. GIS has advantages over the conventional methods in integrating various data sources, performing spatial analysis, and mapping the results in wetland change studies.

To identify, delineate and map the wetlands and non-wetlands (upland) various inputs have been utilized. These are Hydric soil map, Slope map, Wetland inventory, and satellite imageries. To identify wetlands from non-wetlands all the above input data were used intermingled. The implication of this is that there is no single method that can best identify and classify wetlands. In analyzing the satellite images several techniques were applied on the satellite images to discriminate wetlands from other lands. TCT has been found greatly important to identify wetlands from others since it converts the different bands of an image into three spectral bands i.e. greenness, brightness and wetness. The wetness component of the TCT image has taken the advantage of TCT for mapping the wetlands type. Since the Landsat image of 2006 was not available to utilize in this study as a result the research has put it as a research gap to be done in the future. Another important finding of the research reveals wetlands are spatially well distributed in most part of the study area. The maps also show that wetlands in the north and north west of Abaya as well as western of Chamo cover larger area as compared to eastern part of both lakes where topography is very rugged.

The four broad types of wetlands that exist in the area (riverine, lacustrine, and plaustrine, and Man made) have been identified through the methods employed in the research. It was found out that most inland wetland consists mainly of tall grasses and short grass or mixture of both tall and short grasses with open water. But the riverine wetlands exhibit wide range of classes, which include all the cover types.

In mapping wetlands different methods were employed. The results indicate that there are great differences in spatial and area coverage between images of criteria based wetlands identification, TCT and the other method i.e. supervised classification of satellite image. These differences could be due to differences in map scale used and time of image acquisition. When inspected visually the large wetland areas seem to be identified by all the methods. This is not the case for all with small wetlands of width less than 10 meters e.g. the irrigation canals and intermittent rivers. Therefore, for better wetland identification and mapping, field based mapping and supervised classification of image gives apparently better results than the NDVI and TCT. The good results were obtained when intermingled mapping of supervised classification, tasseled cap transformation of land sat images combines with the field supported inventory data.

After the wetlands are well distinguished from uplands and mapped subsequently the different time images were subjected to a change detection analysis using the ENVI 4.2 software. The change detection technique applied here was simple image differencing. The changes on wetlands and uplands in the study area for the last three decades are significant and induce a great pressure on the lakes. All the hydro-meteorological data analysis show that the lakes and associated wetlands are under threat even sedimentation effect alone could make come to an end for the life of the lakes. Of all the techniques (Satellite image, Volume variability, lake level fluctuation analysis, water balance and Sedimentation) used to analyze the spatial and temporal variability of the wetlands, the satellite image and volumetric based analysis are the best and are done with good accuracy but water balance and sedimentation effect analysis are done with some data recording errors and insufficient information.

Eventually the result of the research has been concluded by pointing out the major threats of the wetlands denudation: namely deforestation of the watershed (i.e. Poor land use practice), cultivation of wetlands (on the lakeshore) and Sedimentation due to very inadequate soil and water conservation measures put in place on the catchments of the rivers flowing into the wetlands. Conservation based crop production, management practices on farm adjacent to the lakes are non-existent, and too little attention, if any, is given to the conservation and sustainable use of wetland resources. In addition, there is insufficient awareness among policy makers, planners and general public about the economic, biological and scientific significance of the resources of the wetlands. Lake Chamo has a long history for fluctuation owing to its shallower depth, compared to Lake Abaya, and the few rivers draining to it. Excessive use of the rivers for irrigation and onshore cultivation has also contributed to lake size shrinkage and subsequent excessive degradation of the wetland.

Generally, as to the wetland's future, that the outlook isn't so good. "Wetlands are dynamic ecosystems and are fairly resilient to cyclical periods of drought, regressing back and forth between marsh and desert. Historically, however, these changes have taken place gradually. However the prolonged drought and serious pressures of above-mentioned factors could push the wetlands over the edge, as it will become increasingly difficult to re-establish them. Therefore, urgent action is needed now, because the longer we wait, the more difficult it will be to bring the wetlands and their complex web of life back to their former splendor.

10.2 Recommendations

- The temporal and spatial variability of wetlands area definitely varied between years). However, the data included in the analysis (the years between 1973 and 1986 and 2000) was not enough to establish a significant change of the wetland detection since there could be significant changes between these years. These data only illustrated that change occurred in the period. In order to obtain a complete knowledge about the wetland change, monitoring of the seasonal change is recommended if possible. This can be achieved using the change calculated from consecutive year's images. Based on the results of this research, it is recommended the timely if possible seasonally in a year base generation of maps in the continued monitoring of changes and relations in the area.
- The study area is facing various anthropogenic and natural forces, which drive wetlands to death. Based on the observation and results during the study, the recommendations take into account three main guiding principles:
 - I) Awareness creation/rising of the importance of wetland functions and benefits for the environments, and human populations required for better appreciation of the wetland resources. To safeguard wetland degradation or loss, a possible solution could be countrywide awareness creation to change the attitudes of the resident communities by linking the economic and social benefits of wetlands to its conservation for its protection.
 - ii) To manage wetlands in a proactive and sustainable way, there is a need for regional government to involve the local residents and other stakeholders.
 - iii) The government can adopt a gradual and planned decentralized approach to manage these wetlands in order to institutionalize and strengthen ownership within the local communities.
- Mapping of Wetlands with too small-scale map is very much difficult especially for those small size wetlands ecosystems hence it is recommended that mapping of wetlands should be done at very large scale.

- The Government is committed to the development of irrigation in the area in spite of the various ecological and socio-economic problems facing the existing irrigation schemes. Extraction of water for irrigation and drainage of wetlands for agriculture causes degradation and loss of biodiversity. Proper studies, including adequate consultations with local communities, should be carried out to determine the best option for wetland conservation. Where agriculture is the option, there is a need to plan for proper management of all the likely environmental impacts.
- Integrated planning should be done to ensure that irrigation and drainage for agriculture takes due consideration of the concerns of all water users in such a way that use of water from the lakes and as well from the inflowing rivers has to be geared with lake level variation or in general based on the water budget of the basin.
- Institutional perception on the values, functions and utilization of wetlands should be harmonized. This could then be followed with formulation of policy on wetlands, promulgation of regulations to govern wetland use and capacity building for monitoring and control of wetland utilization.
- This research analysis the time span of lakes due to silataion with very limited data and assumptions, but to make the result very applicable soil erosion on the catchment and sedimentation on the lakes is considered as a research gap.

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APPENDIXES

Appendix 1 Data related to Wetlands

Appendix 1_1 Wetland Classification System for East Africa (Agreed by regional Wetland Biodiversity Group at Mbale, Uganda, in May 1996)

1.	Marine		
1.1.	Sub tidal		i. Coral reefs
1.2.	Intertidal		i. Rocky marine shores, reefs
			ii. mud flats, sand flats, salt flats
			iii. intertidal vegetated sediments: silt marshes, mangroves
2.	Estuarine		
2.1.	Subtidal		i. Estuaries and marine deltas
2.2.	Intertidal		i. mud flats, sand flats, salt flats
			ii. Estuarine marshes, salt marshes
			iii. Estuarine swamps, mangrove swamps
3.	Sodic and/or saline water		
3.1.	Lacustrine ^a	Permanent	i. sodic lakes, salt lakes
		Temporary	i. Seasonally/occasionally inundated depressions, salt pans
3.2.	Palustrine ^b	Permanent	i. sodic and salt marshes and swamps
			ii. Springs, soaks and resultant pools
4.	Freshwater		
4.1.	Riverine ^c	Permanent	i. Edges of perennial rivers, streams and waterfalls
			ii. inland deltas (including deltas in lakes)
		Temporary	i. Seasonal/occasional rivers, streams and waterfalls
			ii. riverine floodplains, river flats, deltaic plains, riverine grass lands, mbugas ^d
4.2.	Lacustrine	Permanent	i. Freshwater lakes (> 10 ha) including shores subject to seasonal or irregular inundation (drawdown floodplains)
			ii. Freshwater ponds, pools (< 10 ha)
		Temporary	i. Seasonal lakes (> 10 ha)
			ii. Seasonal ponds, pools (< 10 ha)
4.3.	Palustrine	Herbaceous	i. Permanent swamps, marshes, dambos ^e
			ii. Seasonal/occasional swamps, marshes, dambos
			iii. Peat lands, fens
			iv. Montana wetlands (including bogs)

			v.	Springs, soaks
		Woody	i.	Shrub swamps, thicket wetlands
			ii.	swamp forests
5.	Man-made wetlands			
5.1.	Aquaculture/mariculture		i.	Fish ponds, prawn farms
5.2.	Agriculture		i.	Farm ponds and dams
			ii.	Irrigated lands, rice paddy, channels, canals, ditches
			iii.	Seasonally flooded arable land
5.3.	Salt production		i.	Salt evaporation pans
5.4.	Urban/industrial		i.	Borrow pits, brick pits, mining pools, road impoundments, quarries
			ii.	Wastewater treatment facilities
5.5.	Water storage		i.	Ponds, dams, reservoirs

a. refers to a lake

b. refers to a swamp or marsh

c. refers to river

d. refers to a seasonally inundated grassland

e. refers to a run-off area with an impervious sub-surface that accumulates water

Source: (Bates and Jackson 1984).

Appendix 1_2 Training sets of Wetlands cover collected during field work

S No	X	Y	Cover type	S.N	X	Y	Cover type
1	397728	720340	Open	15	346028	670722	Dense Forest
2	372745	684948	Open	16	394952	723116	Dense Forest
3	381420	728668	Open	17	402586	719646	Dense Forest
4	329373	637759	Open	18	368582	720340	Dense Forest
5	360601	657190	Agriculture	19	340823	663782	Dense Forest
6	351927	681131	Agriculture	20	346028	663782	Tall grasses
7	331108	645392	Agriculture	21	366847	698480	Tall grasses
9	359213	684254	Mixed Short & long grasses	23	378297	682172	Riverian forest
10	367888	692929	Mixed Short & long grasses	24	354008	652332	Riverian forest
11	400504	723116	Shrub/Forest	25	397381	724504	Short Grasses
12	363724	662741	Shrub/Forest	26	395993	726586	Short Grasses

Appendix 1_3 Wetlands habitat types identified in the study area

<i>Main Wetlands system</i>	<i>Characteristics</i>
<i>Palustrine System</i>	<ul style="list-style-type: none"> ➤ Dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, ➤ Area less than 8 ha (20 acres); ➤ Active wave-formed or bedrock shoreline features lacking. Swampy areas where soils are wet almost all the times ➤ Water depth in the deepest part of basin less than 2 m at low water; Are all non-tidal
<i>Lacustrine System</i>	<ul style="list-style-type: none"> ➤ Situated in a topographic depression or a dammed river channel ➤ Lacking trees, shrubs, persistent emergent, emergent mosses or lichens with greater than 30% area coverage; and ➤ Total area exceeds 8 ha (20 acres). May be tidal or non tidal. Depth may exceed 2m.
<i>Riverine System</i>	<ul style="list-style-type: none"> ➤ Water body contained within a Channel ➤ Periodical or continuous, moving and or connecting between two standing water bodies
<i>Lake Water Bodies</i>	<ul style="list-style-type: none"> ➤ Any inland body of standing water that is larger and deeper than a pond ➤ Permanent water source <p>May be found in both the lacustrine and palustrine wetland systems.</p>

Appendix 2 Profile of Satellite images

Appendix 2_1 Profile of Satellite images used

Sensors (Instrument)	Satellite_ Name	Path and row	Date of acquisition	Spatial Resolution (m)	Spectral Resolution	Wavelength (um)
					Bands Name	
LandSat_MSS	Landsat_1	P_181_r_55	01-31-73	57.00	1 (MSS_BAND_4)	0.50-0.60
					2 (MSS_BAND_5)	0.60-0.70
					3 (MSS_BAND_6)	0.70-0.80
					4 (MSS_BAND_7)	0.80-1.10
Landsat_MSS	Landsat_1	P_181_r_56	01-25-76	57.00	The same as above	The same as above
Landsat_TM	Landsat_5	P_169_r_56	01-28-86	28.50	TM_BAND_1	0.45,0.52
					TM_BAND_2	0.52,0.60
					TM_BAND_3	0.63,0.69
					TM_BAND_4	0.76,0.90
					TM_BAND_5	1.55,1.75
					TM_BAND_6	10.40,12.50
					TM_BAND_7	2.08,2.35
Landsat_TM	Landsat_5	P_168_r_56	01-15-86		The same as above	The same as above
Landsat_TM	Landsat_5	P_168_r_55	01-15-86		The same as above	The same as above
Landsat_TM	Landsat_5	P_169_r_55	01-15-86		The same as above	The same as above
Landsat_ETM	Landsat_7	P_169_r_56	01-27-2000	14.5	The same as above	The same as above
Landsat_ETM	Landsat_7	P_168_r_56	01-15-86		The same as above	The same as above
Landsat_ETM	Landsat_7	P_168_r_55	01-15-86		The same as above	The same as above
Landsat_ETM	Landsat_7	P_169_r_55	01-15-86		The same as above	The same as above

Appendix 3 Hydro-metrological information

Appendix 3_1 Monthly lake water level of Abaya at Arbaminch after correction												
Source: Seleshi, 2000)												
Station: Arbaminch Latitude 6 degree 07 mini and longtiude 37 degree,38 minit												
Year	Jan	Feb	Mar	Apr	May	jun	july	August	Sep	Oct	Nov	Dec
1969	2.2	2.1	2.1	2.2	2.4	2.6	2.6	2.6	2.7	2.6	2.5	2.3
1970	2.3	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.6	2.8	2.8	2.6
1971	2.5	2.3	2.3	2.1	2.3	2.4	2.6	2.7	2.8	3.0	2.9	2.8
1972	2.7	2.6	2.5	2.4	2.5	2.6	2.6	2.7	2.8	2.8	2.8	2.7
1973	2.5	2.4	2.2	2.1	2.0	1.9	2.1	2.3	2.4	2.6	2.5	2.4
1974	2.3	2.2	2.0	2.0	1.9	1.9	2.0	2.1	2.2	2.3	2.3	2.1
1975	1.9	1.9	1.6	1.6	1.7	1.7	1.9	2.1	2.3	2.5	2.5	2.3
1976	2.2	2.1	1.9	1.8	1.9	1.9	2.2	2.2	2.4	2.4	2.4	2.2
1977	3.2	2.1	1.9	1.9	2.2	2.3	2.4	2.5	2.7	2.9	3.5	3.4
1978	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.5	3.6	4.0	4.0	3.8
1979	3.7	3.4	3.5	3.4	3.4	3.4	3.3	3.3	3.2	3.2	3.2	3.0
1980	2.8	2.6	2.4	2.5	2.6	2.5	2.4	2.3	3.2	2.2	2.1	1.9
1981	1.8	1.7	1.7	1.9	2.0	2.0	2.0	2.1	2.3	2.4	2.4	2.2
1982	2.1	2.0	1.7	1.7	1.8	1.8	1.9	2.0	2.1	2.2	2.4	2.4
1983	2.3	2.2	2.0	2.1	2.2	2.3	2.4	2.7	2.9	3.2	3.2	3.2
1984	3.0	2.8	2.7	2.6	2.5	2.5	2.4	2.2	2.5	2.4	2.3	2.1
1985	2.1	2.1	1.9	1.9	2.0	2.1	2.1	2.0	2.0	2.2	2.1	1.9
1986	1.8	1.6	1.6	1.4	1.4	1.7	1.8	1.9	1.9	2.0	1.9	1.8
1987	1.7	1.5	1.5	1.5	1.8	2.0	1.9	1.8	1.8	1.9	1.8	1.7
1988	1.6	1.5	1.3	1.4	1.3	1.2	1.4	1.9	2.1	2.4	2.4	2.3
1989	2.2	2.2	2.0	2.1	2.1	2.0	2.0	1.9	2.0	2.2	2.3	2.3
1990	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.4	2.3	2.3	2.2	2.2
1991	2.1	2.0	2.0	1.9	1.9	1.8	1.9	1.8	1.7	1.5	1.4	1.2
1992	1.2	1.1	1.0	1.0	1.0	1.1	1.0	1.1	1.3	1.5	1.6	1.5
1993	1.6	1.6	1.4	1.4	1.8	1.8	1.9	2.0	1.9	1.9	2.0	2.0
1994	1.9	1.6	1.5	1.5	1.7	1.7	1.7	2.2	2.2	2.3	2.2	2.1
1995	2.0	1.8	1.9	1.8	1.9	1.9	1.9	1.9	1.9	2.0	2.0	1.9
1996	1.8	1.7	1.6	1.6	1.8	2.4	2.7	2.9	3.2	3.3	3.2	3.1
1997	3.0	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.8	2.5	2.9	3.9
1998	3.9	4.1	4.1	4.0	3.9	3.7	3.6	3.7	3.8	4.0	4.1	4.0
1999	3.9	3.7	3.4	3.3	3.4	3.2	3.1	3.1	3.1	3.1	3.3	3.2
2000	3.1	3.0	3.2	3.3	3.3	3.2	3.2	3.2	3.1	3.2	3.4	3.4
2001	3.4	3.4	3.3	3.2	3.2	3.1	3.0	3.1	3.1	3.3	3.5	3.5
2002	3.3	3.2	3.1	3.1	3.1	3.1	2.9	2.5	2.2	1.9	1.6	1.5
2003	1.4	1.3	1.1	1.1	1.2	1.2	1.2	1.2	1.4	0.9	1.1	1.1
2004	1.0	1.1	1.1	1.0	1.0	0.7	0.5	0.7	0.7	0.8	0.8	0.8
2005	0.7	0.6	0.4	0.3	0.5	0.8	0.6	0.7	0.8	1.0	1.1	1.0
2006	0.9	0.7	0.6	0.5	0.5	0.8	0.3	0.3	0.2	1.0	1.1	1.1

Appendix 3_2 Monthly lake water level of Chamo at Arbaminch after Approximate partial Adjustment

Source: (Sileshi, 2000)

Note: The Chamo Lake level of 1975 - 1989 should be 2.7 m. So initial is then 2.91m

Station: Arbaminch Latitude 5 degree 56 mini and longitude 37 degree,32 minit

Year	Jan	Feb	Mar	Apr	May	jun	july	August	Sep	Oct	Nov	Dec
1975	4.0	4.0	4.0	4.1	4.0	3.9	4.0	4.1	4.2	4.4	4.3	4.1
1976	3.9	4.1	4.1	4.0	4.0	4.0	1.2	1.2	1.2	1.2	2.0	3.9
1977	4.0	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.3	4.8	4.7
1978	4.6	4.6	4.8	4.8	4.8	4.6	4.7	4.8	4.8	5.2	5.2	5.1
1979	5.0	4.9	4.9	4.9	5.0	5.0	4.8	4.8	4.8	4.7	4.7	4.6
1980	4.5	4.4	4.3	4.3	4.6	4.6	4.2	4.3	4.3	4.2	4.1	4.0
1981	3.1	3.3	3.5	3.5	4.0	3.9	3.9	3.9	4.2	4.1	4.1	4.1
1982	3.0	3.2	3.2	3.6	3.6	3.2	3.2	3.9	4.0	4.1	4.21	4.7
1983	2.2	2.9	2.8	3.0	2.8	2.9	3.0	3.9	4.0	4.3	4.3	4.2
1984	4.1	2.9	2.6	2.9	2.6	2.8	2.8	3.5	3.9	3.9	4.0	4.0
1985	3.1	2.9	2.6	3.0	4.1	2.6	2.5	3.2	3.5	2.9	2.9	3.0
1986	3.0	2.6	2.5	2.5	2.6	2.8	2.8	2.7	2.7	2.6	2.5	2.4
1987	2.2	2.1	2.9	2.7	2.4	2.5	2.4	2.1	2.1	2.3	2.2	2.0
1988	1.9	1.8	1.6	1.8	2.0	1.9	2.1	2.3	2.4	2.7	2.6	2.4
1989	2.3	2.2	2.1	2.2	2.3	2.2	2.3	2.2	2.2	2.5	2.5	2.5
1990	2.4	2.4	2.4	2.6	2.7	2.6	2.4	2.4	2.3	2.2	2.1	1.9
1991	1.8	1.8	1.7	1.6		1.7	1.6	2.0	1.6	1.3	2.0	0.9
1992	0.8	0.7	0.5	0.5	0.7	0.6	0.6	0.6	0.6	1.0	1.0	0.9
1993	1.0	0.7	1.2	1.2	1.6	1.8	1.6	1.5	1.4	1.5	2.0	0.8
1994	0.9	0.7	0.6	0.7		1.2	1.2	1.4	1.3	1.2	1.1	0.9
1995	0.7	0.6	0.5	0.8	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.6
1996	0.5	0.3	0.3	0.5	0.9	1.4	1.4	1.5	1.6	1.5	1.5	1.3
1997	1.0	0.8	0.7	0.8	0.9	0.8	0.8	0.8	0.6	1.0	1.8	1.8
1998	2.0	2.1	1.9	1.9	2.0	2.0	1.9	1.9	1.8	2.0	2.1	1.9
1999	1.8	1.7	1.7	1.6	1.6	1.4	1.3	1.3	1.1	1.2	1.4	1.1
2000	0.9	0.7	0.5	0.4	0.5	0.5	0.4	0.4	0.3	1.1	1.9	1.8
2001	0.4	0.3	0.1	0.1	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.3
2002	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.5	0.3	0.2	0.9	0.5
2003	0.5	0.3	0.1	0.2	0.6	0.7	0.6	1.0	1.0	0.7	0.8	0.1
2004	0.1	0.7	0.0	0.9	1.1	1.0	0.8	0.7	0.6	0.7	0.7	0.6
2005	0.2	0.2	0.0	2.0	3.7	4.1	3.9	3.8	3.7	3.7	5.5	10.6
2006	0.5	0.3	0.1	0.2	0.6	0.7	0.6	1.0	1.0	0.7	0.8	0.1

Appendix 3_4 Summery of monthly precipitation on lake Abaya (mm)

Year	Jan	Febu	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1970	71.65	3.63	162.39	92.32	93.04	28.88	41.38	32.97	105.55	88.74	0.77	1.65
1971	21.82	2.56	73.9	74	91.25	78.28	15.34	105.55	49.37	90.76	23.53	4.09
1972	9.05	34.09	30.01	147.26	96.41	84.47	58.79	60.91	70.93	53.32	67.18	10.18
1973	35.53	5.07	5.45	63.18	51.2	60.18	167.6	84.21	81.58	104.5	26.21	5.1
1974	3.85	14.75	99.55	45.26	92.55	40.4	76.24	44.51	89.29	26.17	15.9	0.89
1975	0.84	2.75	45.32	106.26	156.4	79.8	149.13	154.9	109.43	111.8	39.08	6.77
1976	2.96	14.17	36.27	83.42	93.94	166.99	163.17	95.94	60.78	62.29	72.03	6.47
1977	72.59	27.38	33.47	120.11	155.36	82.93	76.53	63	77.87	240.2	112.44	15.81
1978	1.63	56.02	87.78	69.86	68.22	128.89	98.5	51.68	63.46	147.7	35.23	55.02
1979	70.08	61.31	78.26	53.46	147.78	80.15	71.04	59.84	69.41	58.12	13.43	20.14
1980	31.46	21.81	24.4	131.69	140.6	47.11	15.95	14.62	32.36	25.57	29.53	0.86
1981	0.82	16	138.63	140.29	55.82	51.2	86.37	47.7	85.09	71.29	35.1	5.53
1982	45.9	21.38	88.26	96.63	110.4	62.57	26.12	38.27	62.19	101.8	152.11	81.21
1983	31.92	22.25	38.29	103.32	138.74	48.73	115.29	93.54	72.87	81.28	38.83	27.44
1984	0	1.11	15.56	27.47	112.53	51.73	40.36	37.44	143.99	25.32	61.28	20.56
1985	25.8	9.62	64.62	117.8	166.82	75.64	72.25	28.76	38.57	34.55	20.52	5.22
1986	0	25.49	34.52	76.42	104.97	92.99	55.16	60.37	57.46	37.4	18.33	42.03
1987	13.7	18.73	84.49	60.05	202.65	70.83	19.37	43.21	49.18	75.85	19.98	11.7
1988	21.54	26.11	26.47	133.65	91.85	49.17	121.85	81.31	91.54	97.35	13.84	14.87
1989	31.52	48.85	54.14	110.4	54.85	69.13	77.62	62.98	40.93	82.11	76.11	115.9
1990	10.51	95.65	69.77	109.51	95.54	40.88	39.57	33.66	20.48	27.49	30.31	20.93
1991	11.52	41.25	78.8	46.14	96.41	81.1	43.06	94.57	58.2	35.36	17.98	20.83
1992	55.17	34.91	32.45	134.9	75.17	77.68	31.91	49.58	83.93	122.6	60.14	25.8
1993	48.49	91.47	19.13	92.55	200.76	54.96	11.76	25.48	33.25	88.18	20.62	1.56
1994	1.01	6.42	38.39	147.72	96.01	71.47	125.48	64.33	33.84	49.94	48.87	19.58
1995	0.96	17.7	70.72	209.88	80.94	52.06	42.83	21.54	85.35	65.77	38.29	23.72
1996	31.61	19.48	68.26	166.26	160.14	145.58	97.93	149.25	67.65	47.67	29.56	21.55
1997	15.8	29.62	34.62	127.8	186.82	65.64	82.25	88.76	36.57	34.55	20.52	8.22
1998	38.92	52.25	28.29	193.32	148.74	38.73	125.29	63.54	62.87	81.28	38.83	67.44
1999	32.92	42.25	88.29	113.32	198.74	68.73	135.29	83.54	99.87	81.28	38.83	77.44
2000	10.96	14.17	66.27	93.42	83.94	126.99	143.17	65.94	70.78	62.29	72.03	3.47
2001	21.82	5.56	4.9	44	51.25	38.28	75.34	145.55	69.37	90.76	23.53	1.09
2002	5.56	0.11	65.56	29.47	192.53	71.73	60.36	17.44	63.99	25.32	61.28	32.56
2003	15.82	36	168.63	146.29	65.82	91.2	56.37	57.7	65.09	71.29	35.1	4.53
2004	36.51	15.65	99.77	101.51	55.54	43.88	99.57	37.66	80.48	27.49	30.31	50.93
2005	23.7	38.73	34.49	68.05	222.65	76.83	59.37	49.21	79.18	75.85	19.98	31.7
2006	42.96	94.17	76.27	63.42	93.94	166.99	123.17	97.94	80.78	62.29	72.03	7.47

Appendix 3-5 Summary of monthly precipitation on lake Chamo (mm)

Year	Jan	Febu	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1970	58.72	0	175.83	83.99	72.35	15.8	26.34	8.76	87.34	94.31	0	2.16
1971	16.03	4.32	58.6	69.61	96.4	32.25	1.84	90.84	21.59	119.7	20.23	0
1972	7.44	0.49	0	134.08	72.46	60.47	23.37	65.39	61.45	85.48	73.01	0
1973	10.22	6.58	9.26	93.47	0	5.43	89.64	105.55	92.11	125.8	34.73	2.77
1974	0	15.43	55.74	28.84	143.21	48.59	50.08	29.41	78.24	32.82	10.21	0
1975	0.61	1.04	47.66	135.26	204.08	17.27	73.2	52.96	48.7	80.04	49.77	0
1976	0	7.91	9.02	87.19	76.39	45.44	59.16	44.22	43.74	56.25	33.42	2.92
1977	56.58	17.57	21.49	138.55	161.71	56.08	11.66	23.12	31.17	188.1	130.87	11.86
1978	0	106.37	97.7	112.38	94.92	31.4	71.09	79.73	77.6	188.7	70.91	60.72
1979	35.15	55.05	110.34	34.58	138.87	70.57	50.08	29.83	44.22	82.54	25.62	8.81
1980	17.19	37.42	17.41	84.46	191.13	29.69	5.02	28.13	24.74	42.16	38.59	0.87
1981	0.23	19.24	93.25	145.89	112.54	30.59	42.78	48.48	59.92	67.86	38.57	3.3
1982	11.32	8.23	76.05	113.62	157.3	85.84	6.75	30.03	57.01	108.5	128.61	83.93
1983	29.04	35.22	24.51	100.65	106.45	40.42	56.02	86.96	59.42	138.4	11.72	28.9
1984	1.19	2.96	14.34	53.37	118.76	23.45	24.67	42.23	121.56	12.9	47.07	18.81
1985	11.94	22.17	51.11	122.7	213.17	35.71	58.86	7.94	22.3	8.87	10.61	4.92
1986	0	15.22	40.13	102.4	94.04	66.09	12.95	33.91	19.58	38.1	17.58	20.33
1987	13.72	9.06	55.52	108.25	114.89	19.4	14.32	5.34	35.33	6.8	31.5	9.96
1988	39.11	20.12	27.16	114.75	95.53	68.41	73.48	72.9	77.93	118.8	26.54	9.6
1989	40.6	66.7	41.37	120.28	84.43	45.51	87.21	51.35	35.89	117.5	58.59	75.56
1990	25.19	94.55	54.12	83.48	77.04	23.73	22.54	39.09	20.19	19.91	17.22	12.94
1991	74.18	39.88	66.51	40.72	96.53	79.23	22.62	60.12	57.59	35.42	24.58	7.44
1992	18.33	13.56	26.05	122.09	89.93	156.02	24.09	24.13	59.19	98.25	36.84	10.32
1993	25.45	90.36	33.07	70.26	127.1	62.2	2.33	13.86	25.93	66.65	11.26	0.44
1994	0.43	3.46	40.5	117.39	125.77	54.95	41.37	55.97	44.543	39.32	36.84	6.62
1995	24.82	23.84	45.33	114.83	79.47	106.9	33.62	56.91	68.12	67.36	36.04	10.22
1996	46.66	15.25	77.58	121.71	112.56	117.02	32.58	76.16	61.53	41.21	28.33	2.58
1997	0	15.43	55.74	28.84	143.21	48.59	50.08	29.41	78.24	32.82	10.21	0
1998	56.58	17.57	21.49	138.55	161.71	56.08	11.66	23.12	31.17	188.1	130.87	11.86
1999	7.44	0.49	0	134.08	72.46	60.47	23.37	65.39	61.45	85.48	73.01	0
2000	58.72	0	175.83	83.99	72.35	15.8	26.34	8.76	87.34	94.31	0	2.16
2001	10.22	6.58	9.26	93.47	0	5.43	89.64	105.55	92.11	125.8	34.73	2.77
2002	35.15	55.05	110.34	34.58	138.87	70.57	50.08	29.83	44.22	82.54	25.62	8.81
2003	29.04	35.22	24.51	100.65	106.45	40.42	56.02	86.96	59.42	138.4	11.72	28.9
2004	74.18	39.88	66.51	40.72	96.53	79.23	22.62	60.12	57.59	35.42	24.58	7.44
2005	0	15.22	40.13	102.4	94.04	66.09	12.95	33.91	19.58	38.1	17.58	20.33
2006	13.72	9.06	55.52	108.25	114.89	19.4	14.32	5.34	35.33	6.8	31.5	9.96

Appendix 3-6 Summary of monthly Evaporation of lake Abaya (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1970	176.2	203.3	212.49	203.97	189.72	171.87	174.01	177.19	183	171.6	169.02	182.44
1971	186.8	184.41	212.83	174.3	164.57	149.84	157.14	167.71	163.8	167.1	156.92	164.54
1972	176.8	192.1	214.4	188.79	183.93	175.92	162.79	157.84	179.4	179.7	165.71	182.16
1973	212.6	207.51	262.93	240.69	201.87	180.76	160.59	164.59	176.4	172.5	170.77	169.44
1974	194.4	195.93	207.22	202.61	188.76	170.87	164.96	169.51	171.9	185.6	174.01	179.92
1975	193.1	194.28	239.08	202.39	198.28	184.78	177.26	187.54	178	182.1	163.92	173
1976	229.5	214.64	238.29	195.9	189.84	173.21	162.57	202.5	178	177.3	165.73	172.34
1977	188.9	180.34	209.8	188.99	152.54	147.27	145.3	156.26	158.1	139.4	132.11	132.98
1978	164.3	150.6	170.04	160.26	146.83	127.27	115.04	145.93	146.4	149.7	144.23	150.22
1979	152.5	135.09	150.43	155.46	151.4	138.15	138.46	138.77	146.3	154.5	174.36	181.76
1980	199.5	197.93	227.34	194.9	187.33	169.78	175.82	180.99	173.9	170.5	139.22	159.46
1981	199.3	212.27	238.47	211.97	200.8	189.49	186.57	196.93	187.8	189.9	185.38	198.35
1982	220.1	200.63	226.51	222.75	217.04	202.27	198.21	215.06	205.1	197.8	191.43	199.64
1983	206.5	207.54	255.35	217.2	196.21	175.97	154.18	164.41	177	168.4	154.29	164.68
1984	198.9	198.55	217.61	214.27	196.67	174.2	167.34	182.02	181.8	184.2	172.65	178.89
1985	184.7	182.6	218.04	197.02	183.55	150.22	151.34	182.77	182.9	180.5	182.65	187.23
1986	217.8	196.72	226.4	203.46	189.36	175.84	178.38	187.45	190.1	192.9	181.1	190.4
1987	230	189.91	223.47	195.46	189.03	177.01	191.03	196.21	196	193.8	181.15	195.29
1988	222.3	219.38	242.18	210.72	193.88	181.92	148.91	165.71	168.3	177	161.99	175.48
1989	200.1	183.7	227.58	211.24	207.12	174.09	159.61	185.47	176.3	196.3	188.63	189.9
1990	178.3	196.22	209.55	198.19	197.4	180.79	179.5	193.09	197.8	197.5	194.18	196.25
1991	225.4	213.46	239.45	215.1	212.25	187.57	168.33	198.85	183.7	186.2	189.65	193.29
1992	217	238.02	276.89	237.57	220.53	191.75	176.86	181.89	185.1	189.3	164.94	183.22
1993	194.9	159.72	212.93	226.05	203.47	169.61	178.24	188.03	178.7	176.6	168.99	185.49
1994	224.7	225.99	259.57	212.16	195.51	178.15	160.73	182.61	215.5	188.8	189.63	195.61
1995	226.7	220.75	226.56	204.24	204.38	195.79	177.88	193.15	184.5	203.4	183.04	219.9
1996	220.4	225	236.25	214.36	203.91	166.94	164.8	181.03	174.9	175.5	165.09	180.32
1997	199.3	212.27	238.47	211.97	200.8	189.49	186.57	196.93	187.8	189.9	185.38	198.35
1998	176.8	192.1	214.4	188.79	183.93	175.92	162.79	157.84	179.4	179.7	165.71	182.16
1999	184.7	182.6	218.04	197.02	183.55	150.22	151.34	182.77	182.9	180.5	182.65	187.23
2000	193.1	194.28	239.08	202.39	198.28	184.78	177.26	187.54	178	182.1	163.92	173
2001	188.9	180.34	209.8	188.99	152.54	147.27	145.3	156.26	158.1	139.4	132.11	132.98
2002	220.1	200.63	226.51	222.75	217.04	202.27	198.21	215.06	205.1	197.8	191.43	199.64
2003	217.8	196.72	226.4	203.46	189.36	175.84	178.38	187.45	190.1	192.9	181.1	190.4
2004	230	189.91	223.47	195.46	189.03	177.01	191.03	196.21	196	193.8	181.15	195.29
2005	194.9	159.72	212.93	226.05	203.47	169.61	178.24	188.03	178.7	176.6	168.99	185.49
2006	206.5	207.54	255.35	217.2	196.21	175.97	154.18	164.41	177	168.4	154.29	164.68

Appendix 3-7 Summery of monthly Evaporation lake Chamo (mm)												
Year	Jan	Febu	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1970	210.3	209.42	260.1	214.43	188.03	179.9	191.32	206.46	210.5	196.6	162.53	176.06
1971	184.7	182.22	223.78	188.06	168.05	161.13	170.68	182.61	184.8	174.4	146.35	157.58
1972	176.6	179.9	212.5	179.76	161.67	155.12	164.09	175.05	176.7	167.3	141.15	151.67
1973	209.1	208.16	258.41	213.21	187.11	179.05	190.38	205.37	209.3	195.6	161.8	175.22
1974	198.2	196.5	242.79	201.93	178.61	171.06	181.58	195.19	198.3	186.1	154.92	167.36
1975	187	184.61	226.96	190.39	169.83	162.8	172.51	184.73	187.1	176.4	147.8	159.23
1976	193.9	198.84	236.77	197.56	175.29	167.94	178.15	191.23	194.1	182.4	152.23	164.29
1977	190.6	188.43	232.04	194.1	172.66	165.47	175.44	188.1	190.7	179.5	150.1	161.85
1978	185.9	183.54	225.53	189.35	169.03	162.05	171.69	183.78	186.1	175.5	147.15	158.49
1979	190.5	191.39	224.72	205.43	162.46	145.27	146.04	153.35	160.7	159.6	147.9	155.49
1980	161.7	172.98	215.51	182.83	159.4	147.33	201.25	215.97	208.3	206	172	185.59
1981	165.5	172.3	201.65	164.37	160.21	191.94	203.05	217.96	221.7	208.7	182.67	162.87
1982	182.3	187.91	219.59	176.47	167.31	157.05	158.25	169.08	178.4	166.5	154.26	158.74
1983	209.6	173.71	215.47	182.16	170.12	159.86	150.84	158.14	161.5	151.4	174.52	165.35
1984	183.5	194.9	226.45	208.35	183.4	176.37	174.61	179.07	189	178.6	149.82	161.74
1985	180.8	182.55	219.52	185.07	170.26	158.63	156.79	170.75	177.5	170	159.81	164.19
1986	186.9	184.79	227.47	190.56	170.49	162.56	171.11	183.08	186	176.1	148.09	159.69
1987	198.7	201.55	252.04	212.77	187.12	180.03	201.01	206.82	214.6	195.8	185	204.61
1988	237.6	249.66	288.86	219.37	205.43	192.56	171.59	176	185.8	193.8	170.05	174.08
1989	187.7	202.6	257.78	203.37	196.13	191.56	173.23	207.07	202.3	191.3	184.45	201.51
1990	186.4	220.09	233.32	205.92	210.02	201.02	198.4	210.53	227.5	229.6	221.25	207.01
1991	237	212.87	248.74	214.61	231.93	206.27	166.72	211.66	204.3	221.9	221.47	202.32
1992	215.6	249.57	306.43	230.93	212.22	195.06	191.18	194.68	199.8	174.3	167.06	200.32
1993	196.3	167.49	211.19	245.94	206.46	180.53	203.44	209.5	192.8	183.3	172.09	176.86
1994	216.1	240.41	301.77	231.72	192.84	179.24	174.01	187.85	291	211.5	190.56	175.65
1995	236.9	242	252.17	217.46	199.13	195.86	183.98	207.95	191.3	198.3	192.58	223.73
1996	230.1	252.23	250.1	225.28	194.64	156.9	162.43	194.98	183.2	197.5	181.86	183.73
1997	176.6	179.9	212.5	179.76	161.67	155.12	164.09	175.05	176.7	167.3	141.15	151.67
1998	209.6	173.71	215.47	182.16	170.12	159.86	150.84	158.14	161.5	151.4	174.52	165.35
1999	184.7	182.22	223.78	188.06	168.05	161.13	170.68	182.61	184.8	174.4	146.35	157.58
2000	187	184.61	226.96	190.39	169.83	162.8	172.51	184.73	187.1	176.4	147.8	159.23
2001	180.8	182.55	219.52	185.07	170.26	158.63	156.79	170.75	177.5	170	159.81	164.19
2002	198.7	201.55	252.04	212.77	187.12	180.03	201.01	206.82	214.6	195.8	185	204.61
2003	210.3	209.42	260.1	214.43	188.03	179.9	191.32	206.46	210.5	196.6	162.53	176.06
2004	236.9	242	252.17	217.46	199.13	195.86	183.98	207.95	191.3	198.3	192.58	223.73
2005	230.1	252.23	250.1	225.28	194.64	156.9	162.43	194.98	183.2	197.5	181.86	183.73
2006	165.5	172.3	201.65	164.37	160.21	191.94	203.05	217.96	221.7	208.7	182.67	162.87

Appendix 3-8 Summary of inflow to Abaya Lake from gauged and un-gauged region of the catchment (x10 ⁶ m ³)												
Year	Jan	Feb	Mar	Apr	May	jun	july	August	Sep	Oct	Nov	Dec
1970	76.4	37.0	185.8	218.9	313.1	142.7	236.6	171.5	259.1	448.0	184.8	99.9
1971	50.3	36.5	30.8	83.0	162.4	376.6	252.2	246.6	290.4	249.9	133.4	59.3
1972	35.8	34.8	30.2	123.6	202.1	215.3	182.5	268.4	271.8	195.2	263.9	91.1
1973	54.7	32.1	20.2	38.8	87.8	86.4	181.5	208.2	345.5	306.8	116.0	57.0
1974	37.9	23.1	52.8	71.7	125.6	82.4	109.2	157.6	235.6	140.0	59.4	33.7
1975	26.2	19.4	16.9	67.4	124.5	141.0	253.5	362.9	473.3	383.6	162.6	72.7
1976	46.7	26.9	24.9	62.7	227.2	206.7	284.9	315.5	320.3	214.5	160.7	66.7
1977	52.8	39.2	23.8	88.4	231.5	188.9	296.2	331.8	412.5	708.5	612.8	176.1
1978	85.6	101.8	118.1	122.2	175.7	196.7	313.7	349.5	353.1	420.0	190.8	93.7
1979	77.4	96.5	103.4	150.9	275.6	284.4	206.6	226.0	277.6	279.8	102.5	51.7
1980	31.4	22.1	17.2	102.0	266.8	178.9	122.3	127.7	147.4	125.6	47.5	27.9
1981	17.7	11.8	134.5	389.8	296.5	174.3	216.4	163.7	380.7	308.8	119.1	57.6
1982	32.8	22.3	27.7	90.0	316.5	290.2	180.4	225.5	267.7	305.2	224.8	90.6
1983	56.0	42.2	55.1	152.4	282.1	247.7	181.7	418.5	506.7	503.2	210.1	81.3
1984	52.3	38.5	38.0	69.5	137.1	97.5	135.4	203.3	252.3	131.8	76.9	48.9
1985	36.9	28.2	28.6	165.5	334.4	202.4	140.1	198.7	170.4	174.5	52.7	35.3
1986	22.2	24.1	29.7	171.7	358.4	355.7	225.4	214.4	255.5	206.1	67.7	40.8
1987	30.4	19.6	111.4	195.6	446.0	395.7	240.7	158.7	171.2	303.3	148.1	55.1
1988	36.9	24.8	13.0	85.8	116.3	85.7	207.7	411.0	448.7	470.9	190.8	78.3
1989	41.0	54.3	40.2	141.7	172.2	122.5	123.3	172.0	298.9	324.7	134.6	104.8
1990	58.9	84.4	158.9	188.2	156.9	125.2	153.1	173.1	174.2	170.5	65.9	31.4
1991	28.7	31.3	73.6	52.6	136.6	123.0	112.3	116.3	159.0	92.3	49.7	39.2
1992	81.6	55.5	54.2	81.0	129.6	217.3	141.8	192.9	351.4	437.1	319.2	251.5
1993	59.9	76.8	37.9	129.3	435.2	352.8	177.4	178.0	191.1	223.9	104.3	37.7
1994	43.5	27.8	21.7	103.0	251.2	196.7	222.4	334.5	253.4	182.0	83.8	41.0
1995	39.1	32.2	37.8	221.2	278.2	159.9	171.3	202.4	258.4	193.3	72.7	50.1
1996	32.9	24.8	147.6	170.7	353.3	464.2	359.9	425.3	385.7	261.4	105.3	62.7
1997	52.3	38.5	38.0	69.5	137.1	97.5	135.4	203.3	252.3	131.8	76.9	48.9
1998	77.4	96.5	103.4	150.9	275.6	284.4	206.6	226.0	277.6	279.8	102.5	51.7
1999	30.4	19.6	111.4	195.6	446.0	395.7	240.7	158.7	171.2	303.3	148.1	55.1
2000	32.8	22.3	27.7	90.0	316.5	290.2	180.4	225.5	267.7	305.2	224.8	90.6
2001	77.4	96.5	103.4	150.9	275.6	284.4	206.6	226.0	277.6	279.8	102.5	51.7
2002	41.0	54.3	40.2	141.7	172.2	122.5	123.3	172.0	298.9	324.7	134.6	104.8
2003	28.7	31.3	73.6	52.6	136.6	123.0	112.3	116.3	159.0	92.3	49.7	39.2
2004	26.2	19.4	16.9	67.4	124.5	141.0	253.5	362.9	473.3	383.6	162.6	72.7
2005	35.8	34.8	30.2	123.6	202.1	215.3	182.5	268.4	271.8	195.2	263.9	91.1
2006	59.9	76.8	37.9	129.3	435.2	352.8	177.4	178.0	191.1	223.9	104.3	37.7

Appendix 3_9 Summary of inflow to Chamo Lakes from all gauged and un gauged region of the catchment (x10⁶ m³)											
Year	Jan	Feb	Mar	Apr	May	jun	july	Augu st	Sep	Oct	Nov
1970	7.72	4.85	38.01	46.99	43.93	22.64	18.23	11.21	30.55	44.19	20.15
1971	9.57	7.05	12.70	15.98	28.80	21.08	11.62	29.26	17.48	41.01	22.53
1972	9.24	6.84	5.45	31.15	44.59	41.43	28.51	34.24	37.88	43.54	44.94
1973	13.53	9.39	6.94	15.76	31.49	55.22	81.14	86.86	99.08	101.8	61.09
1974	14.68	10.50	22.16	21.91	65.26	53.85	52.88	45.27	49.49	38.03	19.14
1975	8.41	6.29	5.59	20.28	66.24	48.80	52.63	53.39	50.76	52.11	34.52
1976	10.91	7.88	6.34	14.81	50.15	58.74	71.03	62.30	39.47	44.65	35.69
1977	17.84	10.98	13.76	30.11	75.66	69.47	52.79	30.98	29.10	89.86	114.2
1978	23.52	36.82	50.06	49.74	49.71	27.23	38.77	40.25	41.88	85.79	58.93
1979	28.35	26.14	39.13	26.95	47.99	42.91	34.79	23.66	26.54	32.48	18.74
1980	8.20	6.72	5.32	32.10	117.9	76.05	32.43	23.87	18.61	13.97	12.77
1981	6.05	5.02	22.69	88.10	88.00	37.02	40.25	53.95	49.75	45.73	25.55
1982	10.29	7.59	8.70	11.78	23.36	23.45	13.40	11.00	14.93	31.39	50.75
1983	24.10	15.67	10.86	28.73	53.59	45.76	37.27	47.67	55.46	90.07	45.87
1984	15.42	10.66	7.85	11.85	42.46	24.33	15.79	14.22	25.52	22.99	22.33
1985	12.83	9.12	12.20	35.34	83.81	54.41	57.34	26.48	28.91	18.78	12.68
1986	6.75	5.39	5.15	21.84	49.72	72.36	33.94	26.80	30.75	32.32	16.21
1987	8.16	6.05	13.01	27.74	52.67	48.17	23.93	15.70	17.09	26.12	17.43
1988	8.39	6.40	5.43	25.54	54.21	68.06	96.85	94.45	77.87	57.42	30.44
1989	14.30	15.38	23.51	30.09	46.49	31.67	47.24	41.97	42.55	66.85	64.09
1990	29.38	43.28	51.36	63.46	61.35	37.95	27.50	19.33	14.71	10.78	13.13
1991	8.24	8.79	9.67	9.04	24.96	34.47	36.90	38.27	29.66	27.84	15.88
1992	7.19	5.61	4.70	26.81	32.40	37.94	32.82	18.27	30.60	40.47	29.22
1993	24.96	25.88	15.68	18.55	52.66	56.05	22.26	14.08	11.52	17.19	10.03
1994	5.48	4.41	5.06	15.97	24.58	22.48	38.44	46.30	29.65	26.27	24.43
1995	8.67	7.09	10.09	45.96	81.07	77.48	42.17	22.03	21.99	32.23	19.59
1996	10.04	6.96	14.79	39.89	49.04	52.05	45.44	46.73	37.69	34.80	18.23
1997	24.10	15.67	10.86	28.73	53.59	45.76	37.27	47.67	55.46	90.07	45.87
1998	13.53	9.39	6.94	15.76	31.49	55.22	81.14	86.86	99.08	101.8	61.09
1999	28.35	26.14	39.13	26.95	47.99	42.91	34.79	23.66	26.54	32.48	18.74
2000	10.29	7.59	8.70	11.78	23.36	23.45	13.40	11.00	14.93	31.39	50.75
2001	8.16	6.05	13.01	27.74	52.67	48.17	23.93	15.70	17.09	26.12	17.43
2002	10.91	7.88	6.34	14.81	50.15	58.74	71.03	62.30	39.47	44.65	35.69
2003	9.57	7.05	12.70	15.98	28.80	21.08	11.62	29.26	17.48	41.01	22.53
2004	28.35	26.14	39.13	26.95	47.99	42.91	34.79	23.66	26.54	32.48	18.74
2005	23.52	36.82	50.06	49.74	49.71	27.23	38.77	40.25	41.88	85.79	58.93
2006	6.05	5.02	22.69	88.10	88.00	37.02	40.25	53.95	49.75	45.73	25.55

Appendix 3-10 Summary of inflow reduction Abaya Lake due to water use (x10⁶ m³)

Year	Jan	Feb	Mar	Apr	May	jun	july	Augu st	Sep	Oct	Nov	Dec
1970	0.601	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1971	0.601	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1972	0.601	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1973	0.601	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1974	0.841	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1975	0.841	0.601	0.601	0.733	0.937	0.908	0.937	0.917	0.630	0.601	0.601	0.601
1976	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1977	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1978	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1979	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1980	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1981	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1982	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1983	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1984	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1985	0.841	0.841	0.841	1.002	1.538	1.494	1.494	1.478	0.895	0.285	0.285	0.285
1986	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1987	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1988	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1989	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1990	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1991	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1992	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1993	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1994	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1995	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1996	1.111	1.111	1.111	1.470	2.218	2.167	2.218	1.999	1.198	0.492	0.492	0.492
1997	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
1998	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
1999	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2000	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2001	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2002	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2003	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2004	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2005	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150
2006	1.38	1.38	1.38	1.38	2.1	2.1	2.1	2.1	1.150	1.150	1.150	1.150

Appendix 3_11 Summary of inflow reduction Chamo Lake due to water use (x10 ⁶ m ³)												
Year	Jan	Feb	Mar	Apr	May	jun	july	Augu st	Sep	Oct	Nov	Dec
1970	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1971	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1972	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1973	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1974	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1975	0.000	0.000	0.000	0.151	0.521	0.504	0.521	0.521	0.302	0.000	0.000	0.000
1976	0.000	0.000	0.000	0.176	0.605	0.586	0.605	0.605	0.352	0.000	0.000	0.000
1977	0.009	0.009	0.009	0.179	0.602	0.583	0.602	0.602	0.352	0.007	0.009	0.009
1978	0.020	0.020	0.020	0.200	0.654	0.634	0.654	0.654	0.386	0.014	0.008	0.008
1979	0.020	0.020	0.020	0.236	0.780	0.756	0.780	0.790	0.459	0.014	0.008	0.008
1980	0.024	0.024	0.024	0.208	0.673	0.652	0.673	0.673	0.398	0.017	0.010	0.010
1981	0.024	0.024	0.024	0.227	0.740	0.716	0.740	0.740	0.437	0.017	0.010	0.010
1982	0.023	0.023	0.023	0.240	0.788	0.763	0.788	0.788	0.464	0.016	0.009	0.009
1983	0.023	0.023	0.023	0.241	0.790	0.765	0.790	0.790	0.467	0.016	0.009	0.009
1984	0.022	0.022	0.022	0.235	0.770	0.746	0.770	0.770	0.454	0.016	0.009	0.009
1985	0.022	0.022	0.022	0.229	0.751	0.728	0.751	0.751	0.443	0.015	0.009	0.009
1986	0.022	0.022	0.022	0.244	0.815	0.789	0.815	0.815	0.467	0.015	0.009	0.009
1987	0.025	0.025	0.025	0.243	0.807	0.782	0.807	0.807	0.463	0.017	0.010	0.010
1988	0.025	0.025	0.025	0.551	1.472	1.425	1.472	1.472	0.734	0.017	0.010	0.010
1989	0.025	0.025	0.025	0.232	1.342	1.564	1.615	1.615	1.260	0.209	0.010	0.010
1990	0.025	0.025	0.025	0.642	1.685	1.631	1.685	1.685	0.829	0.017	0.010	0.010
1991	0.025	0.025	0.025	0.612	1.356	1.313	1.440	1.515	0.819	0.222	0.056	0.010
1992	0.025	0.025	0.025	0.483	1.285	1.244	1.285	1.391	0.818	0.174	0.162	0.020
1993	0.025	0.025	0.025	0.403	1.232	1.193	1.224	1.150	0.570	0.017	0.010	0.010
1994	0.025	0.025	0.025	0.597	1.565	1.515	1.542	1.330	0.638	0.017	0.010	0.010
1995	0.025	0.025	0.025	0.198	0.870	0.842	0.886	0.971	0.598	0.149	0.310	0.010
1996	0.025	0.025	0.025	0.138	0.446	0.828	1.003	1.003	0.793	0.125	0.010	0.010
1997	0.102	0.102	0.11	0.11	1.98	1.98	1.98	1.01	1.01	1.01	0.150	0.150
1998	0.102	0.102	0.11	0.11	1.98	1.98	1.98	1.01	1.01	1.01	0.150	0.150
1999	0.102	0.102	0.11	0.11	1.98	1.98	1.98	1.01	1.01	1.01	0.150	0.150
2000	0.102	0.102	0.11	0.11	1.98	1.98	1.98	1.01	1.01	1.01	0.150	0.150
2001	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590
2002	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590
2003	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590
2004	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590
2005	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590
2006	0.11	0.11	0.15	0.15	2.1	2.1	2.1	1.51	1.210	1.210	0.590	0.590

Appendix 4 Capacity curve data for Abaya and Chamo Lakes

Abaya Lake capacity curve data				Chamo Lake capacity curve data			
Depth (m)	Level a.m.s.l	A (km ²)	V (km ³)	Depth (m)	Level a.m.s.l	A (km ²)	V (km ³)
0	1171	1139.786	9.8185	-2.75	1110	334.9209	4.1366
0.5	1170.5	1133.525	9.2503	-2.5	1109.75	332.6729	4.053
1	1170	1126.449	8.6853	-2	1109.25	329.4012	3.8877
1.5	1169.5	1119.066	8.1239	-1.5	1108.75	326.181	3.7238
2	1169	1087.462	7.5666	-1	1108.25	322.9976	3.5615
2.5	1168.5	1059.014	7.0303	-0.5	1107.75	319.8447	3.4008
3	1168	1023.684	6.5082	0	1107.25	316.7274	3.2416
3.5	1167.5	994.2173	6.0037	0.5	1106.75	313.6382	3.0841
4	1157	966.122	5.5136	1	1106.25	310.5723	2.9280
4.5	1166.5	937.443	5.0377	1.5	1105.75	307.526	2.7735
5	1166	907.98	4.5763	2	1105.25	304.3241	2.6205
5.5	1165.5	878.89	4.1295	2.5	1104.75	299.9028	2.4694
6	1165	847.178	3.6979	3	1104.25	295.1472	2.3206
6.5	1164.5	814.92	3.2824	3.5	1103.75	290.3585	2.1742
7	1164	779.62	3.8836	4	1103.25	285.3287	2.0330
7.5	1163.5	741.217	2.5031	4.5	1102.75	280.0637	1.8889
8	1163	699.6	2.1429	5	1102.25	274.5478	1.7503
8.5	1162.5	654.609	1.8042	5.5	1101.75	268.3927	1.6145
9	1162	605.163	1.4891	6	1101.25	262.0135	1.4819
9.5	1161.5	551.679	1.1996	6.5	1100.75	255.6527	1.3525
10	1161	498.813	0.9379	7	1100.25	248.9295	1.2263
10.5	1160.5	446.618	0.7008	7.5	1099.75	241.4114	1.1037
11	1160	385.169	0.4935	8	1099.25	233.5681	0.9850
11.5	1159.5	310.460	0.3186	8.5	1098.75	225.5972	0.8702
12	1159	230.264	0.1825	9	1098.25	217.0398	0.7595
12.5	1158.5	134.955	0.0886	9.5	1097.75	208.131	0.6532
13	1158	67.576	0.0431	10	1097.25	198.8365	0.5514
13.5	1157.5	41.862	0.0150	10.5	1096.75	188.1499	0.4546
14	1157	8.2182	0.0033	11	1096.25	175.2752	0.3636
14.5	1156.5	2.385	0.0010	11.5	1095.75	161.1198	0.2795
15	1156	0.694	0.0003	12	1095.25	146.389	0.2026
				12.5	1094.75	129.1542	0.1336
				13	1094.25	104.5254	0.0745
				13.5	1093.75	73.87478	0.0300
				14	1093.25	26.2	0.00300

Appendix 5 Definition and meanings of protection zones of wetlands

Core Areas: This area is legally established; providing long-term protection to landscape, ecosystem, and species; uses: monitoring (research), it might be traditional extractive uses by local communities.

Buffer Zones: Surrounds the Core

Area; Could include rehabilitation areas, where nature can restore their ecological function and structure; Organized activities allowed, however they should not hinder conservation objectives; Restrictions (based on rules and regulations) are placed upon resource use or special development activities are undertaken to enhance the conservation value of the area; Buffer Zones with sustainable uses in agriculture or forestry in a harmonious cultural landscape may be allowed; however settlements and cultivation areas should better be outside or be very limited in extent.

Transition Zone: Regulated lake fishing, limited cultivation, cut and carry of grass resource are permitted. Parts may be left to rehabilitate their sustainable use; e.g. planting of 'SOKE' may be required.

Rehabilitation Zone (not shown on the map).

- Comprises the watershed along all the rivers that feed both lakes;
- Cooperation extending outwards, agricultural activities, human settlements;
- Area to manage and sustainably develop the area's resources for the benefit of people (greater economic and social significance for regional development).