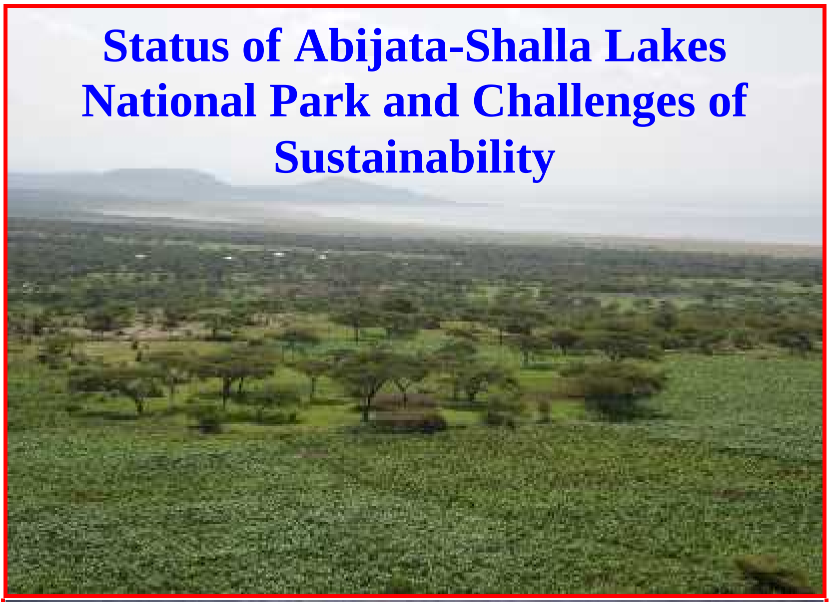
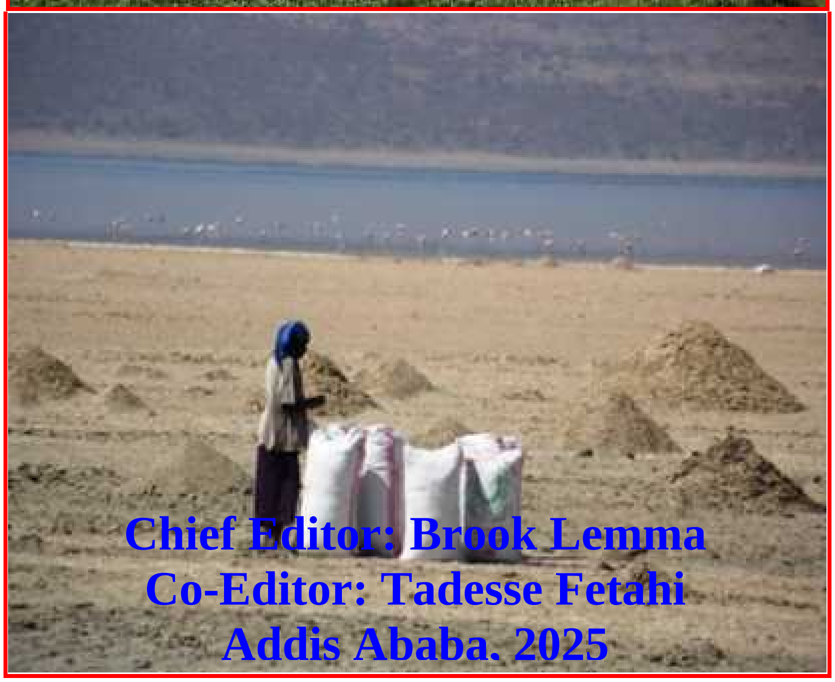
Status of Abijata-Shalla Lakes National Park and Challenges of Sustainability





Chief Editor: Brook Lemma
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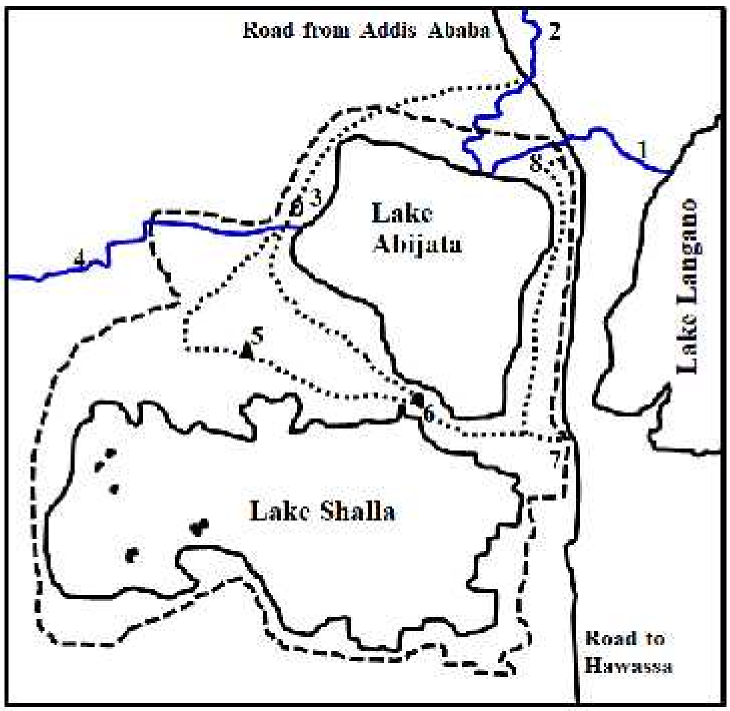
Addis Ababa. 2025

Status of Abijata-Shalla Lakes National Park (ASLNP) and Challenges of Sustainability



Premises of the ASLNAP indicated with dashed-line, 1: River Bulbula, 2. River Hera-Kelo, 3. A town in the Park, 4. River Jido, 5. Mount Fike, 6. View Point, 7. Main Park entrance and 8. Second Park entrance and dotted line represents dusty road for hiking and driving. The spots in L. Shalla are islands. Geographic reference: Lake Abijata: $7^0$33'N; $38^0$27'E and Lake Shalla: $7^0$24'; $38^0$23'E

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Publisher’s page

Title: Current Status of Abijata-Shalla Lakes National Park and Challenges of Sustainability

Editors: Chief Editor Brook Lemma and Co-Editor Tadesse Fetahi

Cover page upper **image**: Lake Abijata in the hinterland and the National Park with residences and farms; **lower image**: Lake Abijata with flamingoes grazing on phytoplankton, while a lady harvests salt from the lake shore as supplementary feed for livestock and whitewashing houses.

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Profiles of the Abijata-Shalla National Park
Images taken by Brook Lemma

Top-right: The main entrance to the Park on the Addis-Hawassa Road; **Top-right**: Hot springs injecting saline water and heat into Lake Shalla; and **Bottom**: Panoramic view of Lake Shalla (right) and Lake Abijata (left)

Top-left: Flamingos grazing on phytoplankton in an image captured in the 1980s; **Top-right**: Out of hundreds of birds, the hornbill basks in the sun; **Bottom-left**: Ostriches introduced by an ostrich farmer, now just left to roam around in the park; and **Bottom-right**: Among a number of game animals, gazelles grazing in the Park

Top-left: Salt abstraction as an additive to animal feed, a practice that continues as Lake Abijata regresses; **Top-right**: Saline sediments being used to craft souvenirs to tourists; **Bottom-left**: The expanding farms and tin-roofed houses in the Park with Lake Abijata in the background; and **Bottom-right**: Grass-roofed houses of the residents of the park

Above: Local people and tourists bathing in the hot springs of Lake Shalla; and **below** local people washing clothes on the shores of Lake Shalla

Table of contents

List of figures

List of tables

Acknowledgements

The editor of this book highly appreciate the authors of the chapters contained herein for their commitment to conduct such protracted research and provide their knowledge to the services of fellow Ethiopians, natural resources managers, policymakers and their enduring contributions to the world of science. This book materialized due to the unreserved support of the Department of Zoological Sciences of the College of Natural and Computational Sciences of AAU, the then Ministry of Science and Technology of the Federal Democratic Republic of Ethiopia and Sida/Sweden Research and Capacity Building Project at AAU for supporting the editors at various stages of the development of this book. The editors are indebted to Professor Zinabu Gebre-Mariam, Freshwater Ecologist at the Hawassa University, Hawassa, Ethiopia, who read the entire manuscript and provided comments that have substantially improved this book, Professor Seyoum Mengistou and Professor Abebe Getahun for their kind assistance at various levels of the organization of this book. The Main Library of Addis Ababa University is also acknowledged for uploading this book so that users from any corner of the world can access it.

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Preface from the chief editor

Lakes Abijata and Shalla are rift valley lakes located within the bounds of the Abijata-Shalla Lakes National Park (ASLNP), which is 887 km^2 wide, with 482 km^2 being covered by the lakes' water(inside cover page). It is one of the 11 National Parks in Ethiopia with a total of 436 bird species (among which 114 species are wetland birds), including Lesser Flamingo (*Phoeniconaias minor*), Greater Flamingo (*Phoenicopterus roseus*), and Great White Pelican (*Pelecanus onocrotalus roseus*). The Park also provides wintering ground and maintenance station for large number of terrestrial and aquatic birds including from Southern African, Sub-Saharan and Palearctic species. Consequently, ASLNP was established early on by Emperor Haile Selassie to protect and conserve these large numbers of water birds that use Lake Abijata as their feeding and the islands of Lake Shalla as their nesting and breeding grounds. The ecological services of ASLNP are enormous, including provisioning services (food, water, raw materials for industries and medicinal plants), regulating, supporting and cultural services. The Park's natural resources have been valued at US$ 15.9 million to US$ 308.5 million per year by international experts.

Nevertheless, the activities in the Park are not in line with sustainable utilization of the resources, as the reader may see in the various sections of this book. Rather, the Park is deteriorating largely due to anthropogenic interventions, such as, expanding human settlements with the complementary agricultural practices (increasing plant and animal husbandries mixed with the game animals), uncontrolled extraction of water, salts and charcoals, irrigation schemes in the upper catchments that divert feeder-rivers and other activities, which have continued over the years despite the national proclamation to govern such natural resources. These human interventions have adversely affected Lake Abijata together with climate change impacts. The water level of Lake Abijata has significantly dropped by about 100 km^2; reducing the total lake size to about half from what it was half a century ago.

Consequently, the physico-chemical and biological variables have changed such as the algal species whose composition has shifted from the dominance of *Arthrospira fusiformis* (formerly known as *Spirulina fusiformis*) to other species that are not preferred foods of planktivorous birds such as flamingos. The fishery operations by the local populations have been terminated as the fish in Lake Abijata disappeared with changes in water chemistry and disappearance of their breeding grounds as the lake shrinks. Subsequently, lesser flamingos, pelicans and other aquatic birds that were frequently observed in thousands migrated away to other suitable lakes within Ethiopia and other countries. Even though the Park landscape is a unique natural treasure suitable for the sustainability of biodiversity, the country is not benefiting from this gift of nature. Thus, protecting and conserving the Park is by default suggests protecting biodiversity, natural habitats and both aquatic and terrestrial ecosystems, thereby contributing to the global effort to preserve the paths and migratory birds that connect the ecosystems of the two poles in the North and South of the globe, extending across the eastern side of Africa along the Great Rift valley.

In this book, the first chapter recaps the painful total loss of Lake Haramaya. The second presents the hydrological changes in the Central Main Ethiopian Rift Valley Lakes Basins and its environmental implications with special emphasis on Lakes Abijata and Ziway. The third and the fourth chapters discuss on the limnology (aquatic ecology) and management options of Lakes Abijata and Shalla and the contributions of the Park in general towards greening of the tourism industry. The last chapter discusses on spatio-temporal lake-level changes of Lake Abijata in the Main Ethiopian Rift Valley using satellite imagery of the last four decades and by geo-referencing the current situation on the ground. This book is one additional effort to the dissemination of knowledge about the Park and the associated social-environmental issues. Attempts have been made to extend knowledge and experiences on the Park in the form of conferences, scientific publications, and social media communications, and so on. The editors felt that the publication of this book reaches out the society to create continued awareness about these natural treasures, provide information to decision/policy makers, and triggers some discourses and actions towards the sustainable use of this Park. By extension, the editors also believe that this book serves as research-based evidence for the conservation of such threatened natural environments in Africa and elsewhere around the World.

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Forward I

As we all know, what makes the planet Earth different from others is the presence of water and hence of life on it. It is ironic to note that our planet is largely made up of water (more than 70%) and hence the planet "Earth" could be a misnomer. Of this global water 97.5% is salt water and only 2.5% is fresh water. Of the 2.5% freshwater much of it is not available as habitat for living organisms. It is either in the form of glaciers or other forms like underground water or soil moisture. It is only less than 0.01% of the global water that is available in the form of rivers, streams, ponds, lakes, etc.for suitable habitation of organisms. It is this category of freshwater that humans also use for a number of purposes. It is surprising to note that a high proportion of the world's aquatic organisms live in this tiny portion of the global water. Considering fishes, for example, of the estimated 30,000 species about 58 % of them live in 97.5% of the world's water body and 42% of them in freshwaters, which is less than 0.01% of the global water volume.

This high discrepancy is due to the fact that fresh waters are shallow and more productive as well as discontinuous and patchy. All these attributes favor the major mode of speciation or specifically allopatric speciation.

Despite the fact that freshwater bodies are very important and scarce resources, they are unwisely used in most cases. Of course, there are legitimate reasons to use the freshwater resources; but the empirical evidences around the world show that humans tend to utilize these finite resources in unsustainable way.

Readers of this book might have heard of the case of Aral Sea. It is a lake lying between Kazakhstan in the North and Uzbekistan, in the South. Formerly, it was one of the four largest lakes in the world with an area of 68,000 km^2, which is about 20 times the size of Lake Tana. The Aral Lake has been steadily shrinking since the 1960s after the rivers that fed it were diverted by several irrigation projects. By 2007, it had declined to 10% of its original size.

The shrinking of Aral Lake has been called "one of the worst environmental disasters of our planet". As a result of the shrinkage, the water quality of the lake has declined due to increased salinity. Other kinds of pollution problems like bacterial contaminations, the presence of pesticides and heavy metals have also been reported in association with the shrinkage of the lake. Diseases like cancer, tuberculosis and allergies have escalated. The incidence of typhoid fever, viral hepatitis, tuberculosis and throat cancer have become three times the national average. The retreat of the lake has, reportedly, caused local climate change, with summers becoming hotter and drier, and the winters colder and longer than ever.

The region's once prosperous fishing industry has been essentially destroyed, bringing unemployment and economic hardships to the local people. From a total of 24 species in the 1960s only four exist now. The lake's fishing industry, which in its heyday had employed some 40,000 and reportedly produced one-sixth of the Soviet Union's entire fish catch, has been devastated, and former fishing towns along the original shores have become ship graveyards. The overall cost of the damage to the region has been estimated at billions of dollars. Recently, actions are being taken to change this disastrous state, through very expensive restoration measures.

Another major tragedy is here in Africa at Lake Chad. Once, one of the largest bodies of fresh waters in the African continent, Lake Chad has dramatically decreased in size due to drought and excessive water abstraction. Found at the intersection of four different countries in West Africa (Chad, Niger, Nigeria, and Cameroon), Lake Chad has been the source of water for massive irrigation projects. According to one study, the lake is now one-twentieth of the size it was in the 1960s.

Ethiopia is not at all immune from such incidences. In our recent history and in our life time, indeed, we have witnessed the total loss of Lake Haramaya. Some of us have enjoyed the scenic beauty and even investigated the scientific mystery of Lake Haramaya while we were students and even as full-fledged researchers. Now it is gone; probably forever; and I hope more will be forthcoming about it in this book.

Now, we are at the verge of losing one more lake; that is Lake Abijata; our focal subject matter in this book. Lake Abijata is a known scenic site in Ethiopia because of its bird population. It is a very suitable habitat for migratory and resident birds. Its fisheries were also used to be one of the productive ones. Again, I hope more will be discussed about this lake in the appropriate chapters of this book.

Lake Tana and its unique fish species flock are at their worst state and their future is gloomy. Other lakes including Ziway, Hawassa and Chamo are subject to various threats. Water bodies earlier considered remote, wild and virgin like the Ayima, Zarima, Shinfa, Dabus, Didessa, Lower Omo, Baro Akobo, and others are no more so with needy increasing population that uses contemporary technological tools to utilize wetland. Most of our water bodies are faced with eminent threats and their sustainability is doubtful.

What we are saying is that: Yes, we are entitled to use our aquatic resources for our livelihoods, economic growth, job creation and so on .

Yes, our resources are God given blessings to us and we need to use them.

But:

We are not entitled to destroy them; we are not entitled to abuse them. We need to sustainably utilize these finite resources and pass over to the next generation, as we have borrowed them from the latter. We need to recognize that it is not how much resource we have; it is how we use it that matters!! And there should always be wise use or alternative use of resources. I think it should be possible to reconcile ecology with economics and that is what reconciliation ecology is all about. I hope that we will read more on these issues agendas you go along in your discoveries in this book.

I would like to take this opportunity to thank the Office of the Vice President for Research and Technology Transfer, Addis Ababa University and the Ministry of Science and Technology, Sida/Sweden, the Center for Food and Nutrition as well as the Aquatic Thematic Research Group of AAU for support in the documentation of this book. I am highly appreciative of those who took up the challenges of compiling the chapters in this book after your long and meticulous research work.

Finally, I would like to thank and congratulate my colleagues, especially Dr. Tadesse Fetahi and Professor Brook Lemma, who have worked very hard in organizing these chapters, getting the materials read by anonymous experts and bring this book into its present form.

Professor Abebe Getahun
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Forward II

I am very much honored to be invited to write this forward on the environmental and social issues dealt with in this book; as they are of immense importance for this country and the world at large as we will see in the book.

As you all know, Ethiopia is endowed with huge water resources including 14 major lakes, 12 river basins and vast wetlands and no wonder it is referred to as the “the water tower of Africa”.

Though Ethiopia is naturally endowed with huge surface and groundwater resources, the country and its people have not yet benefitted fully from these resources. Instead, they have been misused and highly polluted partly because water appears to be a common resource without strict regulations in place. We have painful experience of the total loss of Lake Alemaya (now Haramiya), and some other less well-known lakes and wetlands in the country that have suffered similar fate.

The country cannot afford to lose any more water bodies; as they are irreplaceable and of tremendous importance. However, it seems we are now on the verge of losing other very important aquatic ecosystems, namely, Lakes Abijata and Shalla, which are located in the heart of the countryand have been officially protected as a National Park. The park is very popular with its large number of bird species and some game animals.

Imagine yourself on the shore of Lake Abijata, sitting in front of a beautiful panorama, watching a large congregation of birds, listening to enthralling bird songs, gaming with fish, playing with water etc., which is actually a breathtaking situation. But I am afraid this will not happen if we don't take the necessary protection measures immediately. One of the reasons for this apprehension is the fact that the water level of Lake Abijata has significantly dropped and it is shrinking before our eyes. There could be several possible reasons for the reduction of the water level of Lake Abijata, which this book is going to discuss about. Many investigators have projected that Lake Abijata could dry up in the next 20 or so years.

In this regard, the theme of this book is relevant and timely. It is relevant to AAU Community Service and research agenda as well as to the Growth and Transformation Plan (GTP) of the country. In fact, Ethiopia aims to achieve carbon-neutral middle-income status before 2025, by way of developing a green economy. The government has developed a strategy for transforming its ambitious plan of "Climate Resilience Green Economy" into reality through selected four initiatives for fast-track implementation.

Green economy is an economy or economic development based on sustainable use of natural resources and knowledge of ecological economics. Abijata-Shalla Lakes National Park can be maintained as part of Ethiopia's green economy strategy with lots of benefits for the present generation without compromising the use the Park for future generations. Accordingly, this collection of relevant chapters from the nation's prominent researchers is aimed to bring all stakeholders, including decision-makers, together and create a platform to discuss on how to protect and conserve these natural resources before the country faces another environmental and social crisis.

This book also discusses on how to rehabilitate the present deteriorating conditions for full utilization of the resources in the green economy.

The theme of this book is also in line with the Millennium Development Goal (MDG) in particular with MDG No. 7, which is to ensure environmental Sustainability. Its success is measured by targets for achieving sustainable development, reversing the loss of environmental resources and accessing safe drinking water and sanitation.

Furthermore, this book will be instrumental to implement Ethiopian Water Resources Management Policy (1998). The Federal Government of the Democratic Republic of Ethiopia issued a comprehensive and integrated water resources management policy in 1998 with one of its objectives stating that: "**Conserving, protecting and enhancing water resources and the overall aquatic environment on sustainable basis".**

Hence, it is high time we work on the themes of this book, and come up with tangible outputs that will salvage Lakes Abijata-Shalla and their ecological services.

Professor Teketel Yohannes
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The impact of climate change and human population increase on Lakes Haramaya and Hora-Kilole, Ethiopia (1986 – 2006)

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Abstract

Lakes Haramaya and Hora-Kilole have been monitored over the last 20 years (1986 - 2006) for purposes of scientific interest and use of water and biological resources to supplement the demographically unabated human population increase with some life sustaining programs. In L. Haramaya area, both the local communities and government agencies collected water from the lake directly or indirectly by digging boreholes along its shores. At the same time, all used the lake as a terminal recipient of household wastes. This has eventually led to the deterioration of the water quality and eventual complete transformation of the lake into a terrestrial environment by 2006. In L. Hora-Kilole area the local population had never used the lake ecosystem because of its high saline-alkaline nature that made the water unfit for human consumption, irrigation or animal watering. Instead, in 1988 an external agency, Ministry of Agriculture, Department of Infrastructure Development, Addis Ababa, constructed a weir dam across an adjacently flowing river to harvest water in the lake for dry season irrigation of the surrounding fields. This has transformed the lake into a highly dilute oligotrophic state with its water level rising to 29 m. Nevertheless, by 2006, the lake water had returned to almost its original level of 2.6 m depth, but its original ecological significance has been totally lost. The paper investigates the consequences of water deficiency in a region that is highly impacted by climate change and

human population increase. Finally accounts are made as to what uncontrolled human interference could make to natural aquatic resources and what lessons can be drawn for future actions.

***Key words**:* Lake Haramaya (Alemaya), Lake Hora-Kilole, Ethiopia, tropical lakes, climate change, population increase.

Introduction

Lake Haramaya (also known in the old literature as Alemaya) is located in the Southeastern Ethiopian Plateau about 525 km away from Addis Ababa and Lake Hora-Kilole (also known as Kilole or Kilotes) is found in Central Ethiopia, southwards about 62 km from the capital city. These two lakes were subject of numerous studies in the past. The origins and limnological features of these two lakes were different, although they are presented here in a contrasting scenario.

Lake Haramaya is more of a catchment lake for an area of slightly more than 200 km^2 watershed (Shibru Tedla and Feseha Haile-Meskel 1981, Brook Lemma 1987, 1991).There were no streams or rivers that were flowing in or out of this lake, except the seasonal run off – thus a closed lake. An adjacent and northerly-located Lake Tinike (also known as Kurro) overflows into Haramaya during the rainy seasons, as it is located on a slightly higher ground. The watershed of this lake is devoid of apparently all its natural vegetation and is highly populated, with the majority of the land being used for horticultural crops and a stimulant plant locally known as "*khat*" (*Catha edulis*) for export to neighboring Djibuti and Somali. Farmers in the watershed needed water for irrigation for about eight dry months of the year. Besides, the lake water was also pumped for municipal uses to the then Alemaya town of about 30 000 people and the nearby town of Harar, 20 km in the eastern direction with a population of about 150 000. The latter town is outside of the lake watershed, posing additional water budget deficit on the lake. Eventually the demand from Harar, the increasing water supply demand of the growing population in the watershed and climatic changes have led to extensive water budget deficit on the lake creating the scenario described below (see also Brook Lemma 1994a and b, 1995, 2002 and 2003).

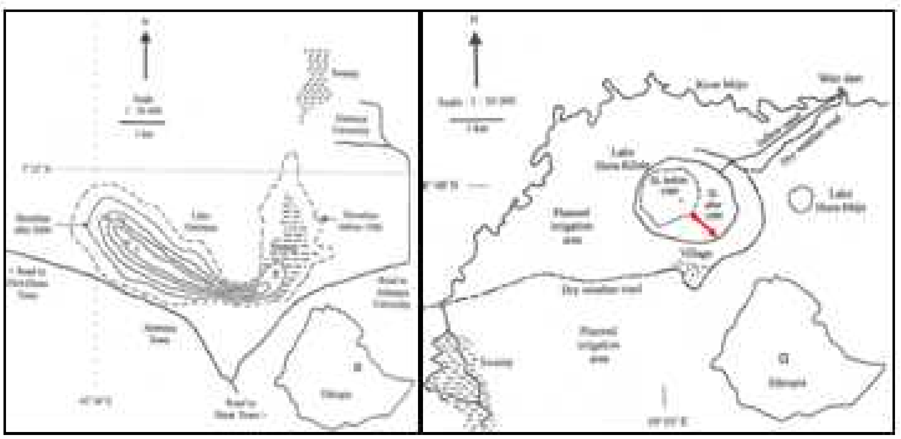
Lake Hora-Kilile was a saline-alkaline lake known in the literature for its high salinity, proliferation of more or less a monoculture of *Arthrospira fusiformis* (syn. *Spirulina platensis*) and flocks of spoonbills and lesser flamingos(Omer-Cooper 1930, Prosser, *et al*. 1968, Talling, *et al*. 1973, Wood, *et al*. 1976, Melack, 1981, Elizabeth Kebede, *et al*. 1986, Wood, *et al*. 1988, Green and Seyoum Mengistu 1991). Its water has never been used for human direct use, be it for irrigation or drinking water supply owing to its high salinity. However, its scientific value for studying salinity series and the consequent variations in ecological range of lakes made it an index of research, particularly in the study of African saline lakes along with Lakes Hora-Hado (Arenguade), Abijata (Abiata), Nakuru, Bogoria, Sonachi and many others. Since 1989, the Ministry of Agriculture envisaged using this lake as a reservoir by diverting an adjacently flowing River Mojo to collect or harvest water to irrigate the plains located south and westward from the lake (Brook Lemma 1994, 1995, 2002, 2003a and b, and Zinabu Gebre-Mariam 1994). This diluted the water so much so that all the life assemblages of the lake changed, bringing Lake Hora-Kilole to an ordinary freshwater system containing wide spectrum of algae, zooplankton and more than three different types of fish species which were not there before.

What these lakes have in common to deserve a parallel investigation is the impacts of population increase they were subjected to without any consideration of the consequences that could follow and the unavoidable impacts of climate change which probably had a considerable effect on the ecosystems of these two lakes. What is interesting and what should be kept in mind while going through this paper is that the manmade impact on Lake Haramaya was excessive water withdrawal, while on Lake Hora-Kilole it was water addition in so short a time bringing about contrasting scenarios on these two lakes.

This long-term investigation was set out to follow up the various changes that occurred over the years as seen from limnological parameters, the consequent anthropogenic impacts on these two lakes, and the lessons that could be learned from the changes that took place in these lakes.

Materials and Methods

The study sites: Lake Haramaya is located in the southeastern Ethiopian Plateau margin bordering the Southern Afar, at 2000 m above sea-level, between 42^{0}02'E and 9^{0}25'N (Fig. 1.1). Lake Hora-Kilole is found in the Central Ethiopian Plateau at 1920 m above sea level, 39^{0}5'E and 8^{0}48'N (Fig. 1.2). The locations of these lakes at more or less similar altitudes and their exposure to similar climatic changes in the tropics make them quite comparable for study.



Figs. 1.1 and **1.2**: **Left**: Lake Haramaya and **Right**: Lake Hora-Kilole research sites

Field, laboratory and desktop studies: Over the years, particularly at the beginning, regular monitoring of the physical, biological and chemical parameters of the two lakes were conducted. These included depth measurements to monitor water level fluctuations, measurements of underwater light-climate variations using a Secchi disk of 20 cm diameter with black and white quarters, collection of water samples for phytoplankton identification and enumeration. The samples were taken with van Dorn water sampler of two liters capacity. The water samples were received in one-liter capacity opaque screw cap plastic bottles. The water to be used for phytoplankton identification and enumeration was immediately fixed with Lugol's potassium iodide solution.

Regular zooplankton sampling was made using plankton net with 55 µm mesh size net, and water samples were received in plastic bottles of 50 ml capacity and immediately fixed with sugar-formalin solution. Some fishing was also conducted to identify the fish species thriving in both lakes. For this purpose, gill nets with 10 cm mesh size with sizes of 25 m long and 2.5 meters wide were used. Throughout the study period visually observable data were collected by taking color images of such changes. Meteorological data for the study periods were collected from Haramaya University and from Bishoftu Agricultural Research Center for Lake Haramaya and Lake Hora-Kilole, respectively. The findings from the data generated throughout the study period, were presented at various national and international conferences and scientific articles were published. These activities have helped to make information available to those who needed it and for collecting constructive feedbacks for further analyses.

Results and Discussion

Lake Haramaya: Over the past 20 years L. Haramaya has been observed to shrink continuously. Some of the evidences in terms of morphometric and physico-chemical changes are shown in Fig. 1.1 and Table 1.1. By 2004, the lake had altogether disappeared and turned into an ephemeral lake where some water percolated at the lowest spot of the original lake basin.

Human demographic and climatic changes have contributed to the transformation of L. Haramaya to an ephemeral lake. The increase in population in Harar town and in the lake watershed demanded high municipal water supply over the years that had never considered any water budget scheme. The farmers in the watershed were pumping water out of the lake twenty-four hours a day (Table 1). This was mainly to irrigate a commercial crop locally known as "*khat*" (*Catha edulis)*. Succulent leaves of this plant are chewed and the extract swallowed as stimulant with the belief that it stimulates the brain to work harder, faster and longer. It is also exported to neighboring countries like Djibouti and Somalia. Farmers obtain quite satisfactory incomes as observed from the rate of conversion of food crop fields into "*khat*" fields.

Table 1.1:Changes in Lake Haramaya from 1986 to 2005; by 2005, the lake completely dried out.

Parameters	Upto 1987	1988 – 2000	2005
Altitude	2000 m asl	2000 m asl	2000 m asl
Surface area	4.72 km^2	2.17 km^2	
Maximum depth	7.0 m	3.5 m	
Mean depth	3.13 m	1.33 m	**Transformed into complete terrestrial ecosystem**
Volume	0.15 km^3	0.005 km^3	
Secchi depth	0.98 - 1.81 m	0.8 - 0.9 m	
Water temp.	19.2 - 23.8 ^{0}C	19.0 - 24.0 ^{0}C	
pH	7.4 - 8.8	8.0 - 9.2	
Dissolved oxygen	3.0-5.0 mgO_2L^{-1}	6.0-10.0 mgO_2L^{-1}	
Conductivity	960-1180 $mScm^{-1}$	990-1200 $mScm^{-1}$	

There is a marked increase of about 3^0C in the air temperature of the region between 1960 and 2006 (Fig. 1.3). The rainfall pattern over the years has not changed much except that it is highly erratic. However, when rainfall of the region is viewed in comparison with the increase in air temperature and the change in human demography, it is obvious that the lake was operating at water budget deficit.

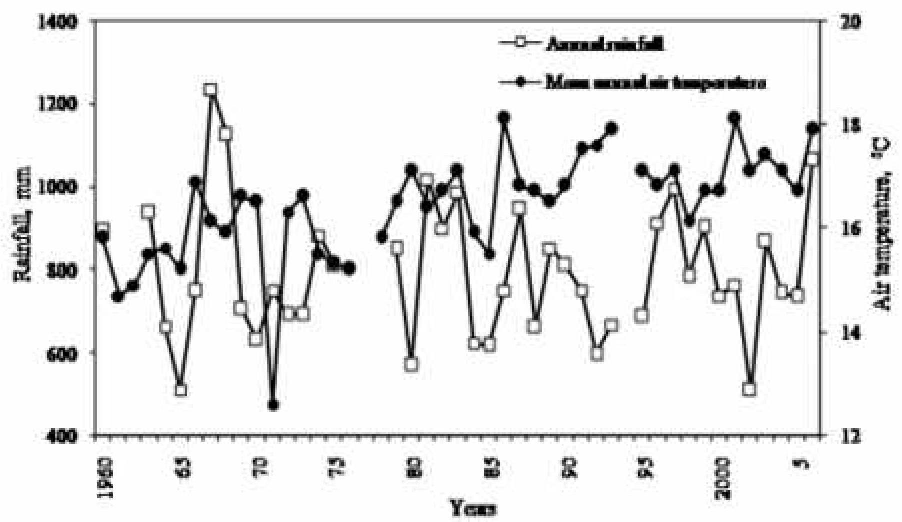


Fig. 1.3: Rainfall and Air temperature of Lake Haramaya area, 1960 - 2005

At the same time the household wastes dumped in the watershed of the lake and all that which came from Haramaya town were washed into the lake through storm water. Moreover, after the torrential rains, the runoff from the watershed brought into the lake high amounts of top soil and organic wastes (Fig. 1.5). These have greatly influenced the plankton community in favor of those species, particularly *Peridinium* spp., that proliferate on such food sources (Nakamoto 1975, Brook Lemma 1994) (Fig. 1.4). The zooplankton communities have gone in the direction of small cladocerans, copepods and mostly rotifers that are small-bodied, such as, *Brachionus* spp., *Filinia* spp. and *Lecane* spp. (Fig. 1.5).

As observed in many tropical lakes, these trends are sufficient indicators of lake water quality deterioration and progressive loss of the capacity of lakes to assimilate the organic and other wastes that come in by wind, runoff or direct dumping of wastes into the lakes (Nakamoto 1975, Brook Lemma 1994).

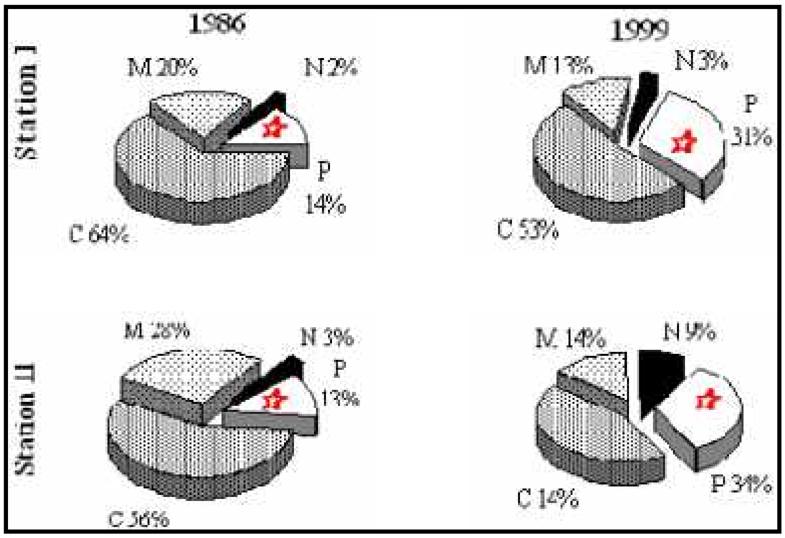


Fig. 1.4: Relations in phytoplankton biomass, Lake Haramaya, 1986 - 1999. **C** stands for *Cosmarium* sp. **P** for *Peridinium* sp., **N** for *Navicula* sp., **M** for *Merismopedia* sp.

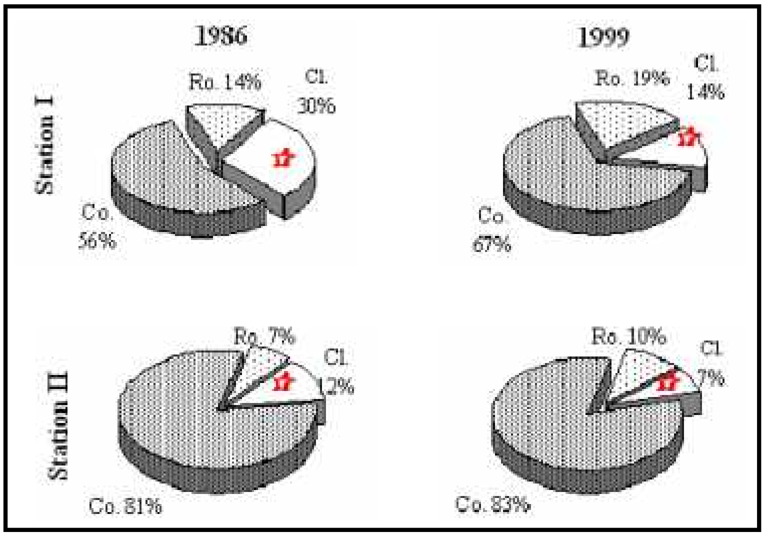


Fig. 1.5: Relations in zooplankton biomass, Lake Haramaya, 1986-1999. **Ro** stands for Rotifera, **Co** for Copepoda and **Cl** for Cladocera.

By conducting some fishing and by regularly observing the fish landings made by fishermen, it was found out that *Oreochromis niloticus* (Nile-tilapia, locally known as *Koroso* and *Clarias gariepinus* (the African catfish, locally known as *ambazza*) thrived in L. Haramaya. The gear the fishermen used (mostly beach seines) had no standard mesh sizes and all the nets observed were locally made without any consideration of their effect on fish populations. As a result the fishes caught were small in size much below the expected table-size and were operated from the shores, damaging brooding female and young fish populations. As the operation of water collectors, municipalities and irrigation schemes continued unabated, the lake size continued to decrease, fishermen had to follow the retreating water edge and the water below their boat continued to disappear (Fig. 1.6).

Fig. 1.6: Lake Haramaya: Gradual drying up by 2000. Today it has completely disappeared with grasses gradually covering the sediments

Lake Hora-Kilole:On the contrary, the diversion of River Mojo into L. Hora-Kilole resulted in increasing the lake volume tremendously, despite the increase of air temperature by about 5^0C between 1965 and 2006 (Figs. 1.2, 1.7, 1.8 and Table 1.2). In principle the increase in air temperature should have led to increased evaporation of the lake water and hence reduced lake volume. The volume of the lake was not significantly affected by irrigation either, as there was little water abstraction activity. Most of the agricultural practices was focused on food crops that mainly depended on seasonal rains (Fig. 8). However, this anthropogenic effect has turned L. Hora-Kilole from a highly saline-alkaline hypertrophic lake into a highly diluted typical oligotrophic tropical freshwater system. The Phytoplankton community, which was almost exclusively dominated by *Arthrospira fusiformis*, the zooplankton community which was dominated by *Paradiaptomus africanus* (Syn. *Lovenula africana*) and the flamingoes and spoonbills that thrived on these species of plankton completely disappeared as the essential preconditions of saline-alkaline nature of the lake was altered by the inflow from River Mojo. Instead of *A. fusiformis* the lake became full of *Peridinium* sp., which thrived on organic matter entering the lake with the river water and runoff from the surrounding (Nakamoto 1975, Brook Lemma 1994) (Fig. 1.9 and Table 1.2). The zooplankton community was replaced by *Daphnia barbata*, *Ceriodaphnia reticulata*, *Moina micrura dubia*, *Thermocyclops decipiens*, *Mesocyclops aequatorialis similis*, *Filinia* spp., *Brachionus* spp., *Leydigiaacanthocercides*, *Keratella* spp., *Asplanchna* sp. and *Lecane (Monostyla) bulla*.

Table 1.2: Changes in Lake Hora-Kilole by 1989 and 2005

Parameters	**Before 1988**	**Post 1989 – 2000**	**By 2005**(back to ~1988 scenario)
Altitude(m asl)	1920	1920	1920
Surface area (km^2)	0.77	1.18	~ 0.77
Maximum depth (m)	6.4	29.0	6.0
Mean depth (m)	2.6	1.69	2.6
Volume (km^3)	0.002	0.023	0.002
Secchi depth (m)	0.15	0.37 – 1.80	0.79
Water temperature (^oC)	19.0 – 23.0	19.3 – 24.0	23.0 (surface)
pH	9.6	7.4 – 9.2	8.98
Dissolved oxygen(mgO_2L^{-1})	1.0 – 6.0	3.4 – 10.6	9.7 (surface)
Conductivity (μScm^{-1})	5930	339	370

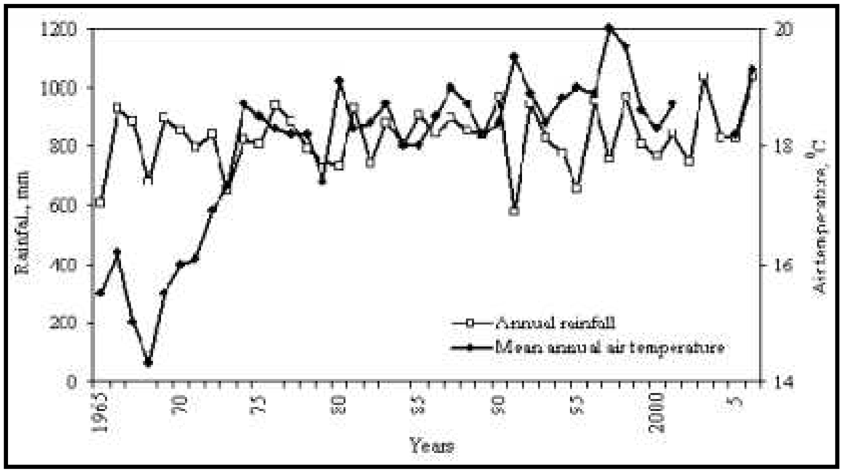


Fig. 1.7: Annual rainfall and Mean annual air temperature of Lake Hora-Kilole area, 1965 - 2005.

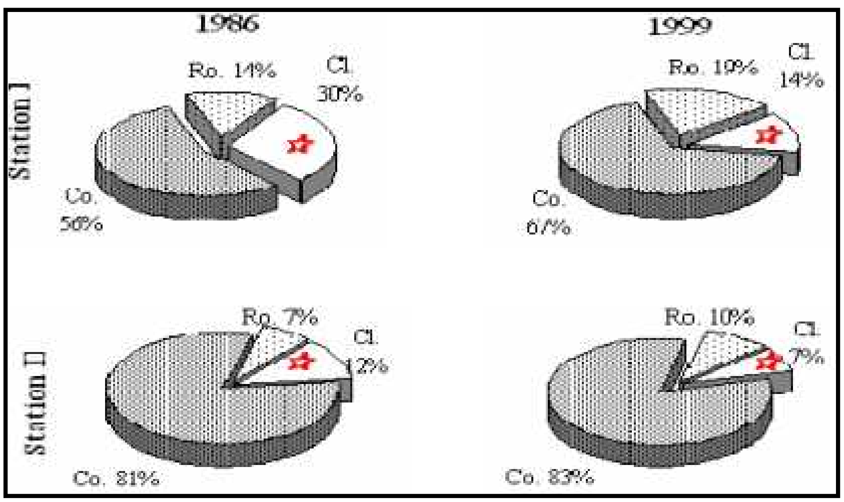


Fig. 1.8: Changes in zooplankton and phytoplankton biomass, Lake Hora-Kilole: 1990-1999.**Ro** stands for Rotifera, **Co** for Copepoda, **Cl** for Cladocera, **C** for *Cosmarium*, **N** for *Nitzschia* sp. **S for***Staurastrum* sp., **P** for *Peridinium* sp.

At least four species of fish, namely, *Oreochromis niloticus* and three other *Barbus* spp. came along with the river water into the lake These phenomena brought the two lakes in close contrast, although the first, L. Haramaya, has now disappeared while the second, L. Hora-Kilole, turned into a typical tropical freshwater system (Figs. 1.9 and 1.10). Today the decrease in salinity has allowed the surrounding community to use the water for domestic purposes including human consumption, animal watering, etc. Some fishing activity for sale in the closely located town of Bishoftu and practice of small scale irrigated horticultural farming has been introduced on Lake Hora-Kilole.

Fig. 1.9: Lake Hora-Kilole after 1989 as water from River Mojo enters lake through the diversion canal. ***Left***: as seen from the canal and ***right***: as seen from lake water surface or from boat.

Fig. 1.10: Lake Hora-Kilole at its highest water level during the "big" rains between 1989 and 2000

At Lake Hora-Kilole, between 2000 and 2003 about 0.002 km^3 (2×10^6 m^3) of water was lost and the lake has almost returned to its original surface area and maximum depth (Fig. 1.16 and Table 1.2). This change has not yet resulted in any appreciable chemical and biological changes. The salinity has remained low, the phytoplankton and zooplankton are still dominated by *Peridinium* spp. and *Daphnia barbata*, respectively, and the fish community continues to thrive with the on-going fishing practice.

Then the troubling question was "Where had all this water gone in such a short time?" At this stage of the study it was imperative that the evolutionary history of the lake should be revisited. As a consequence the search for the reasons had to put into perspective the storage of 2×10^6 m^3 of additional water by diverting River Mojo and that this water could have not been lost by evaporation alone in such a short time between 2000 and 2003. So, there should be another explanation for this unusual scenario at L. Hora-Kilole.

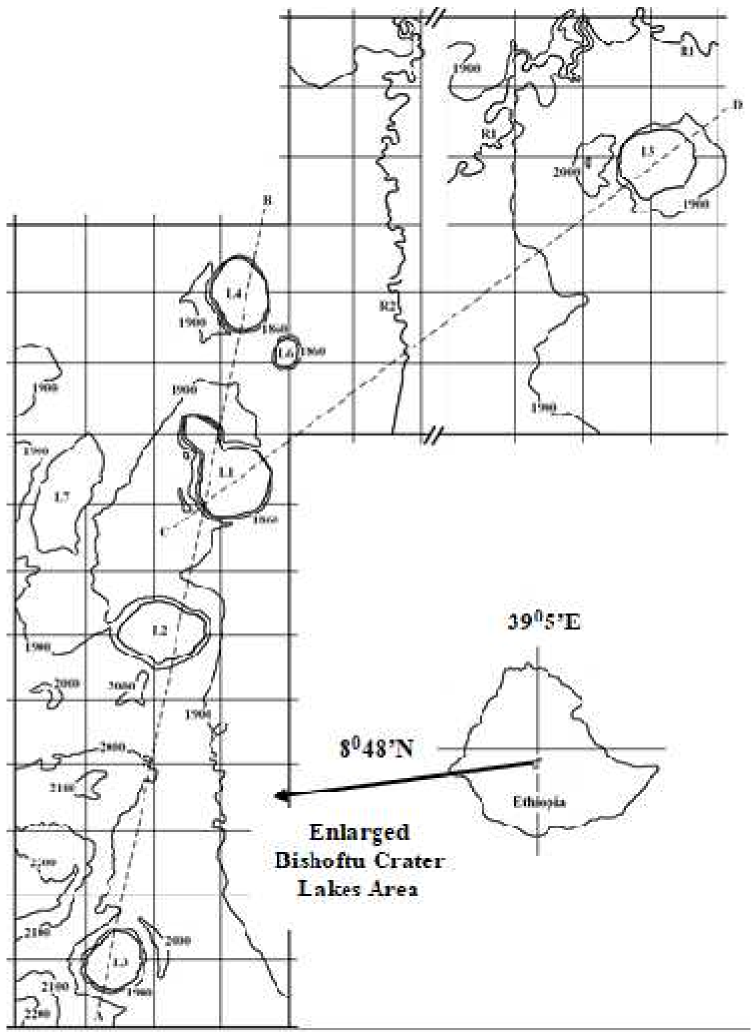


Fig. 1.11: Locations of the Bishoftu Crater lakes: **L1 -** Hora-Arsedi, **L2 -** Bishoftu, **L3 -** Hora-Hado, **L4 -** Bishoftu-Guda, **L5 -** Hora-Kilole, **L6 -** Kuriftu and **L7 -** Cheleleka (swamp). The broken lines indicate the direction of underground water flow in favor of the terminal lake, Hora-Arsedi. The inset in the map of Ethiopia represents the enlarged part (Map from the Ethiopian Mapping Agency, 1975).

Looking back into the studies of Mohr (1961), Prosser *et al*. (1968), Darling *et al*. (1996), Seifu Kebede (1999), Tenalem Ayenew (2004), Seifu Kebede *et al*. (2001) and Lamb (2001) it is evident that lakes are not separate hydrologic entities, but interlinked through surface and ground water, particularly those that are found in the same watershed. With regard to the case of Bishoftu Crater Lakes, it was found out that groundwater is the major supply of water for the lakes (Seifu, *et al*. 2001, Lamb 2001). This suggests that Lake Hora-Kilole which could only sustain water volume of about 0.002 km^3 throughoutits evolutionary history was faced with the addition of 2×10^6 m^3 of water over the years between 1989 and 2003. This must have very likely exerted anomalous mass on the basement rock creating a continuous and enormous pressure on groundwater flow rate.

The next step was to study the locations the lakes occupy in the region and the topographic position of the crater lakes with respect to each other. From Fig. 1.11, one can learn that the lakes are arranged along transects AB, CD and EF. The topographic map shows that the locations occupied by L. Hora-Hado and L. Hora-Kilole are elevated up to 2,200 m asl. These two points close down in the direction of L. Hora-Arsedi to an elevation of 1860 m asl. From the surface topography one can see that the latter lake surrounded by Bishoftu town lies at the base of a valley which extends in north-south direction and along which the Addis Ababa - Adama (Nazareth) highway is constructed. Further study in the topographic positions of the Bishoftu Crater Lakes (Figs. 1.12 and 1.13) has revealed that Lake Hora-Arsedi is found at the lowest position of all the crater lakes.

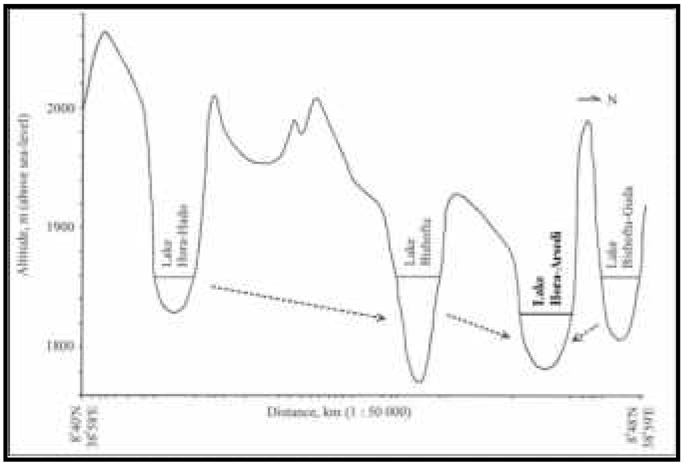


Fig. 1.12: Cross-section drawn along Line AB in Fig. 11 to show the topographic position of the Bishoftu Lakes: Lakes Hora-Hado, Bishoftu, Hora-Arsedi and Bishoftu-Guda. The broken arrows indicate the direction of groundwater flow.

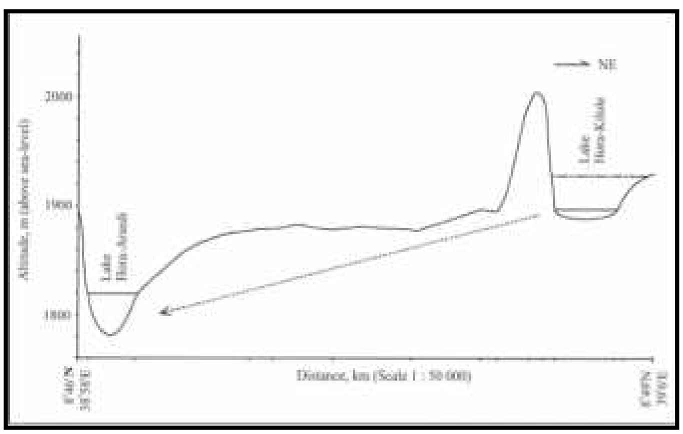


Fig. 1.13: Cross-section drawn along Line CD in Fig. 11 to show the topographic position of the Bishoftu Lakes Lakes Hora-Arsedi and Kilole. The broken arrow indicates the direction of groundwater flow.

This coincided with the study made by Seifu Kebede (1999), Seifu Kebede *et al*. (2001) who have used tracer isotopes to follow the pattern of groundwater in and outflow of the Bishoftu lakes. The studies clearly indicated that Lake Hora-Arsedi is the terminal lake of the region that receives groundwater inflows from the surrounding lakes. It was also an exciting phenomenon to notice the sudden increase in the volume of Lake Hora-Arsedi whose water column rose by more than two meters between 2000 and 2003. Apparently, most of the harvested water from L. Hora-Kilole percolated as underground inflow into L. Hora-Arsedi, either directly (Transect CD) or via L. Bishoftu-Guda (Transect EF). In other words, as the water harvesting continued at L. Hora-Kilole (Fig. 1.16), the basement rock on which it lies could not any more bear this unnatural mass (the weight of the additional 2 x 10^6 m^3 of water) and hence the basement rock eventually gave way to a sudden increase in the underground water flow rate. Currently, the footpath constructed by the late Emperor Haile Selassie along the water's edge of L. Hora-Arsedi and along which tourists had enjoyed hitchhiking has been submerged at most parts of the shore after 2003. The water chemistry and biological diversity of the Bishoftu Crater Lakes has become similar, as revealed in the studies done by Seifu Kebede (1999), Brook Lemma (2001, 2002, 2003a) and Zinabu GebreMariam (1994, 1998).

Conclusion

Lakes Haramaya and Hora-Kilole have been exposed to contrasting human interventions, where in the first scenario man has removed water beyond the water budget of the lake could allow (Table 1.3).

Table 1.3: Estimated annual water budget of Lake Haramaya (Fekadu Yohannes 2003 cited in Ayalew Wondie 2010, See also Shimelis Gebriye Setegn, *et al*. 2011)

Water budget and loss per year	Amount in m^3
Total water budget per year (rainfall and surface runoff from the surrounding catchments)	**6,731,614**
Water losses	
Evaporation loss per year	2,630,515
Abstractions	
For domestic water supply to towns of Harar, Haramaya and Awadai	1,752,000
For irrigation by the local farmers	751,680
Miscellaneous abstractions	1,728,080
Total abstractions per year	**4,231,760**
Total water loss per year (evaporation PLUS abstraction)	**6,862,275**
Water balance per year Total water budget MINUS total water loss	**-130,661**

As a consequence the lake continued to decrease in volume with all the household waste coming into it from the town of Haramaya and the community in the watershed (Fig. 1.14). Eventually, however much undesirable, the inevitable happened and the lake has now totally disappeared and transformed into a terrestrial environment (Fig.1.6). The lake areathat was once covered by water is now taken up by a few species of less competent grasses, which will eventually and inevitably be replaced by more competent, diversified and perennial land plants. The ephemeral lake that is now seen during the "big" rains (July, August and September) does not meet any of the human needs of the watershed and Harar Town require. What remains now is the human water requirement load that needs immediate response to let business-as-usual kind of life for the community in and outside L. Haramaya watershed. This demand has lead people of the region to tap underground water from the immediate area where the lake had once occupied. Currently there are around ten large waterholes with water pumps that throw large volumes of water twenty-four hours a day to all the sectors that were using Lake Haramaya, except to the "*Khat*" farmers. In recent years people have to dig much deeper into the ground to get only a small percentage of the water supply they used to collect at ease; and at a much higher cost compared with the past. Furthermore, conflicts on groundwater use have started to crop up between major groundwater users such as Harar Municipality, Haramaya University, Haramaya, Hamaressa and Aweday (Awadai) Towns. The latter two towns are located between Haramaya (the water source point) and Harar, the terminal water recipient town.

Fig. 1.14: Lake Haramaya: *Left*: Household wastes, including plastics entering lake with runoff in rainy seasons and *right*: liquid wastes (including from latrines) of Haramaya town directed into lake.

Lake Hora-Kilole faces complete alteration of its life assemblages and water chemistry. The high salinity condition before the dilution was the basis for the proliferation of *Arthrospira fusiformis* (Fig. 1.15).

Fig. 1.15: Lake Hora-Kilole before 1989, the diversion of River Mojo; the river flowing adjacent the lake at the upper edge of the image (from Google Map).

This particular phytoplankton species has disappeared before it could be exploited as a rich source of rare amino acids in the form of food additives - for instance in making chocolates which in recent years are used for sustaining HIV/AIDS patients. The *Spirulina* culture industry is now a worldwide business, which Ethiopia could have joined by harvesting *Arthrospira fusiformis* without any addition of fertilizers and simulation of the right environmental conditions, as all these were naturally available. It is also unfortunate that Ethiopia lost the revenue it could have obtained from tourists who could have visited the lake to watch the thousands of flamingos and spoonbills at such a close proximity from Addis Ababa. When Lake Hora-Kilole is seen from the scientific perspective, the importance of this lake as an index reference research material for scientific investigations on saline-alkaline lakes around the world has slipped away with the addition of water from River Mojo (Fig. 1.9 and 1.10).

Fig. 1.16: Lake Hora-Kilole after 1989 as water from River Mojo enters lake through the diversion canal. *Left*: as seen from the canal and *right*: as seen from lake water surface or from boat.

Incidentally it may be worth mentioning that a similar resource is being lost at Lake Abijata (Abiata) because of excessive water abstraction to produce soda ash and by diverting feeder-rivers (Bilbula and Hora Kelo) for irrigation purposes.

The major lessons that could be learned from these two contrasting water use scenarios are **(i)** Climatic changes remain a threat with the occurrence of increasing warming and recurrent droughts. This inevitably exerts a lot of pressure on fresh waters as observed in Lake Haramaya condition. **(ii)** Increasing human needs for fresh water with unplanned population growth in the tropics remain a threat to environmental degradation and misuse of freshwater systems. **(iii)** Planning and budgeting water use in relation to the water input budget of the respective aquatic system should be high on the agenda of tropical water use managers. **(iv)** Segregation of wastes into their respective types (metals, plastics, organic matters, etc.) and treatment of household and other wastes to environmentally friendly forms before putting them into aquatic systems should be most urgent instead of struggling for treatment of people who come down with waterborne diseases. Prevention of diseases and protection of environment are much cheaper and easier processes than risking the productive age of citizens to diseases and death. **(v)**Exploitation of natural resources should be approached with the objectives of rational use for the sake of conservation, healthy and sustainable use of resources.

The final question that may still remain would be what will be the fates of Lakes Hora-Arsedi and L. Hora-Kilole? This may depend on two conditions. Scenario one would be if the inflow from R. Mojo is completely stopped from entering into L. Hora-Kilole, then L. Hora-Arsedi will be receiving groundwater inflow as it used to receive it before year 2000 and hence it would return to its original water level and water chemistry within a number of years. In such a case L. Hora-Kilole may continue to concentrate its water, mainly through evapo-transpiration and seepage, and very likely someday reverting to its original saline-alkaline and hypertrophic status. Scenario two would be if R. Mojo continues to flow into L. Hora-Kilole. In that case, L. Hora-Arsedi will continue to receive groundwater inflow more than it used to experience before year 2000. However, this inflow will not have the capacity of raising the volume as that large volume of inflow that took place between 2000 and 2003. Therefore, the inflow rate would stabilize to an annual constant level and the lake would subside to a certain lower level than at present - but not as low as the level it had before 2000.

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References

Ayalew Wondie (2010): Current land use practices and possible management strategies in shore area wetland ecosystem of Lake Tana: Towards improving livelihoods, productivity and biodiversity conservation. In: Proceedings of the 2nd National Conference of the Ethiopian Fisheries and Aquatic Sciences Association (EFASA on *Management of shallow water bodies for improved productivity and peoples' livelihoods in Ethiopia*; February 20-21, 2010, Bahir Dar, Ethiopia. pp. 9-16.

Brook Lemma (1994): Changes in the limnological behaviour of a tropical African explosion crater lake: L. Hora-Kilole, Ethiopia. *Limnologica* 24(1): 57 - 70.

Brook Lemma (1995): seasonal limnological studies on Lake Alemaya: a tropical African lake, Ethiopia. *Archiv für Hydrobiologie/Suppl.* 107 (2): 263 - 285.

Brook Lemma (2002): Contrasting effects of human activities on aquatic habitats and biodiversity of two Ethiopian lakes. *Ethiop. J. Nat. Res.* 4(1): 123 – 144.

Brook Lemma (2003): Ecological changes in two Ethiopian lakes caused by contrasting human intervention. *Limnologica* 33: 44 - 53.

Darling, W. G., Berhanu Gizaw and Arusei, M. K. (1996): lake-groundwater relationships and fluid rock interaction in the African rift valley: Isotopic evidence. Journal of African Earth Sciences 22: 423 - 431.

Lamb, H. F. (2001): Multi-proxy records of Holocene climate and vegetation changes from Ethiopian crater lakes. *Biology and Environment: Proceedings of the Royal Irish Academy*101B(1-2): 35 - 46.

Mohr, P. (1961): The geology, structure and origin of the Bishoftu explosion craters. *Bulletin of the Geophysical Observatory, Addis Ababa* 2: 65 - 101.

Nakamoto, N. (1975): A freshwater red tide on a water reservoir. *Jap. J. Limnol*. 36 92 0 ; 55 - 64.

Prosser, M. V., Wood, R. B. and Baxter, R. M. (1968): The Bishoftu Crater Lakes: A bathymetric and chemical study. Arch. Hydrobiol. 65(3): 309 - 324.

Seifu Kebede (1999): hydrology and hydrochemistry of Bishoftu Crater Lakes (Ethiopia): Hydrogeological, hydrochemical and oxygen isotope modeling. MSc dissertation, Addis Ababa University, Faculty of Science, Department of Earth Sciences (unpublished thesis).127 pp.

Seifu Kebede, Tenalem Ayenew and Mohammed Umer (2001): Application of isotope and water balance approaches for the study of the hydrological regime of the Bishoftu Crater Lakes, Ethiopia. *SINET: Ethiop. J. Sci*. 24(2): 151 - 166.

Shimelis Gebriye Setegn, Chowdary, V. M., Mal, B. C., Fikadu Yohannes and Kono, Y. (2011): Water Balance Study and Irrigation Strategies for Sustainable Management of a Tropical Ethiopian Lake: A Case Study of Lake Alemaya. *Water Resources Management***25**:2081–2107 (DOI 10.1007/s11269-011-9797-y)

Talling, J. F. and Talling, I. B. (1965): The chemical composition of African lake waters. *Int. Rev. Ges. Hydrobiologia* 50: 421 - 463.

Tenalem Ayenew (2001): Numerical groundwater flow modeling of the central main Ethiopian Rift lakes basin. *SINET: Ethiop. J. Sci*. 24(2): 167 - 184.

Tenalem Ayenew (2003): Environmental isotope-based integrated hydrogeological study of some Ethiopian Rift lakes. *Journal of Radioanalyrical and Nuclear Chemistry* 257: (1): 11 - 16.

Tenalem Ayenew (2004): Environmental implications of changes in the levels of lakes in the Ethiopian rift since 1970. *Reg. Environ. Change* 4: 192 - 204.

Wood, R. B. and Talling, J. F. (1988): Chemical and algal relationship in a salinity series of Ethiopian inland waters. *Hydrobiologia* 158: 29 - 67.

Zinabu GebreMariam (1994): Long term changes in indices of chemical and productive status of a group of tropical Ethiopian lakes with differing exposure to human influence. *Arch. Hydrobiol*. 132(1) 115 - 125.

Zinabu GebreMariam (1998): Science in Africa - Emerging water management problems. In: Human interactions and water quality in the Horn of Africa, Ed.: J. Schoneboon. 1998 Symposium of the American Association for the Advancement of Science (AAAS), Philadelphia.

Zinabu GebreMariam (2003): The water chemistry of the Ethiopian rift-valley lakes and their 142.

Hydrological changes in the central main Ethiopian rift lakes basins and its environmental implications: emphasis on lakes Abijata and Ziway

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Abstract

The Ethiopian rift is endowed with a chain of beautiful lakes of various sizes located in the floor of the rift under complex hydrological and hydro-geological settings. These lakes and feederrivers are being used for irrigation, soda-ash extraction, commercial fisheries, and recreation. They also support a wide variety of endemic birds and wild animals that are of both national and global significance. The water levels of some of these lakes have changed dramatically over the last four decades. This is especially the case for Lakes Abijata and Ziway where water is being abstracted for soda ash production and irrigation, respectively. The relatively untouched lake Langano is also showing slight reduction in water level, probably as a result of upstream water diversions for irrigation and land use changes. Further, if according to some unofficial suggested plan of pumping Lake Shalla into Lake Abijata to extract more soda-ash and if regulating (in the sense of draining) Lake Ziway for more water to flow into Lake Abijata are to be implemented, they would be very pressing issues of concern. The existing and future large scale abstraction plans without proper integrated watershed plan will likely result in grave environmental consequences. This demands integrated watershed management plan to use the lakes wisely without affecting the environment significantly. This paper attempts to illustrate the relative importance of natural and anthropogenic impacts on the Abijata-Shalla National Park ecosystem in relation to recent hydrological changes that have taken place in the lakes, and the association between catchment micro-climatic conditions. A special emphasis is made on the lakes that are being used for irrigation (Ziway) and soda-ash production (Abijata and maybe later Shalla).

Keywords: Lake Abijata, Lake Shalla, the Ethiopian rift valley lakes, soda ash abstraction, Abijata-Shalla National Park

Introduction

Ethiopia has considerable amount of freshwater resources, where out of 1,127,000 km^2 total area of the country, 7,444 km^2(0.66 %) is covered by surface water bodies (Yilma Abebe and Kim Geheb, 2003) (Fig. 2.1). Most of these water bodies are confined within the Ethiopian rift valley system, forming the rift valley lakes and the associated wetlands and feeder-rivers. Most of these lakes have undergone visible changes in sizes and water levels due to natural and anthropogenic factors (Ayenew, 2004; 2009; 2011).

Reconstructing the climactic and environmental changesthat have taken place over the last few decades is an essential task if we should understand the impacts that natural processes and anthropogenic factors exerton hydrological settings and ecosystems. This is especially relevant in regions characterized by large inter-annual changes in precipitation, such as the Ethiopian Rift (Vallet Coulomb *et al*., 2001), and where increasing population pressure makes areas more sensitive to fluctuations in water resources and land degradation (Servat *et al*., 1998). Analysis of the records available for recent decades has considerably aided our understanding of the responses of inland water bodies to climate change impacts and factors induced by man in many of the rift lakes(Makin *et al*., 1976; Chernet, 1982; Ayenew, 2002; Ayenew and Tilahun, 2008; Ayenew 2011).

The most important large-scale withdrawals of water in the Main Ethiopian Rift (MER) are for irrigation and soda ash production. These activities, coupled with discharges from urban and industrial effluents, have reduced the levels of some of the lakes, and modified the limnological settingsand the chemical compositions of the lakes (Gebremariam & Dadebo 1989; Ayenew 2009). Land degradation and deforestation of lake catchments haveincreased surface runoff, ultimately leading to slight rises in lake levels (Geremew 2000; WWDSE 2001; Ayenew and Tilahun, 2008). Most of the lakes that have undergone considerable changes are those located in terminal positions.

Apart from the various inflow and outflow components, the water balances of lakes are governed by climate impacts, anthropogenic factors, volcano-tectonics forces, and sedimentation(Karrow 1963; Slay 1973; Street 1979; Ayenew, 2009). There is currently no volcanic activity in the Main Ethiopian Rift System (MER), exceptfor the existence of geothermal activities, which have little influence on the water levels of the Ethiopian lakes (Ayenew 2003). However, frequent earthquakes and the formation of newfractures may have influenced the present-day hydrogeological regimes of some of the lakes (Ayenew 1998; Tessema, 1998, Ayenew, 2009). Most of the lakes in the rift fluctuate according to the precipitation trends in the adjacent highlands (Street, 1979; Ayenew, 2009), although in the last one-halfcentury, there has been little decline in rainfall in the region (Ayenew, 2002).

In this study, association is made between catchment climatic factors and the corresponding lake levels to illustrate the relative importance of natural and anthropogenic factors in the recent changes. Particular emphasis has been given to the lakes that are being used for irrigation and soda production.

1. General Overview of the Area

The Ethiopian Rift system extends from the Kenyan border up to the Eritrean border close to the Red Sea. It is divided into four subsystems, including (i) Lake Rudolf, (ii) Chew Baher, (iii) the Main Ethiopian Rift (MER), and (iv)the Afar. The Ethiopian Rift transects the uplifted Ethiopian plateau for a distance of 1000 km, extending from the Afar Depression south across the broad zone of basins and volcanic ranges, to the Lake Chamo watershed. The floor of the Rift is occupied bylakes with different hydrological and morphometric characteristics (Table 2.1). This study focuses on the Ziway-Shalla basin lakes and Lake Hawassa basins, all located in what is known as the central Main Ethiopian Rift (MER). Particular emphasis is given to the Lakes Ziway and Abijata.

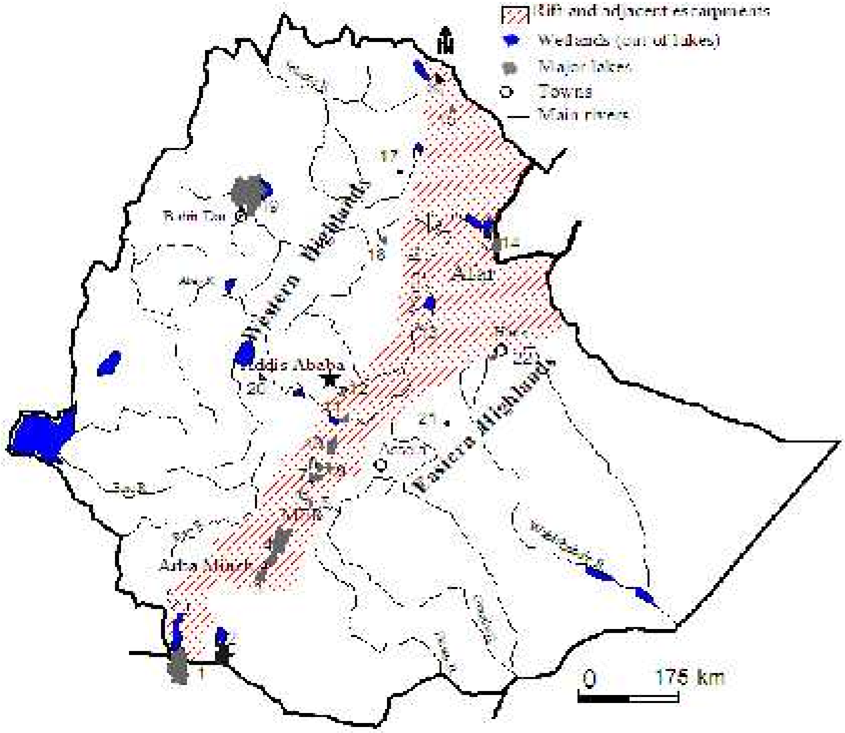

Fig. 2.1: Locations of the Ethiopian wetlands (lakes and rivers): 1–Turkana, 2–Chew Bahir, 3–Chamo, 4–Abaya, 5–Hawassa–Shallo, 6–Chitu, 7–Shalla, 8–Abijata, 9–Langano 10–Ziway, 11–Bishoftu crater lakes, 12–Beseka, 13–Afambo–Abhe group, 14–Afdera, 15–Asale, 16–Ashenge, 17–Hayq-Ardibo, 18–Tana, 19–Wonchi–Dendi, Lakes Wonchi and Dendi; 21–Lakes of the Bale Mountains, 22–Haromaya–Adele–Finkle

The rift valley is bounded to the east and west by high altitude plateaus characterized by high rainfall. The floor of the rift is occupied by a series of seven major lakes and one reservoir (Koka) fed by large perennial rivers originating from the highlands. With the exception of the largest lake in the north, Tana, in the highlands, all of the major lakes of Ethiopia are confined in the rift. These lakes are highly variable in size and hydrogeological and geomorphological settings (Table 2.1). The climate is semi-arid in the rift floor and sub-humid to humid in the highlands. The annual rainfall varies from 600 to 800 mm on the rift floor to around 1200 mm in most of the highlands.

Table 2.1: Basic hydrological data for the main MER lakes (some variables average out over the data recorded between 1970 and 2000). Sources: Wood and Talling (1988); Halcrow and Partners (1989); Ayenew (1998); Mamo (2002); WWDSE (2001)

Lakes	Elevation (m asl)	Surface area (km^2)	Catchment area (km^2)	Maximum depth (m)	Mean depth (m)	Volume ($x10^6m^3$)	Salinity (gL^{-1})
Beseka	953	40	402	--	6	--	--
Koka	1584	177	9909	--	--	1850	0,319
Zwai	1636	440	7380	9	2.5	1566	0.349
Abijata	1580	180	10740	14	7.6	957	16.200
Langano	1585	230	2000	48	17	3800	1.880
Shalla	1550	370	2300	266	8.6	37000	21.500
Hawassa	1680	100	1340	20	10.7	1340	0.290
Abaya	1285	1162	17300	13	7.1	8200	0.771
Chamo	1233	551	2210	13	--	--	1.099

The elevation within the MER varies from around 1500 to2000 meters above sea level (m.a.s.l). There are highly elevated volcanic mountains both within the rift and the highlands. Hills, ridges and volcano-tectonic depressions separate the lakes. Many of the lakes are located within a closed basinfed by perennial rivers. The major rivers are Meki, Katar and Dijo, which feed Lakes Ziway and Shalla (or Shalla),with the third river only flowing into Lake Shalla. Lakes Ziway and Abijata are connected by River Bulbula that originates from the former and flows into the latter. Lakes Langano and Abijata are connected by River Hora Kelo, which originates from the former and flows into the latter. Lakes Abijata, Shalla and Hawassa appear to be terminal lakes without surface water outlets, although their groundwater flow-direction is a different question. Lake Hawassa is connected to a wide swampy area by River Tikur Wuha, which extends in the direction of the Wondo Genet Mountains to the northeast.

The lakes occupy the rift floor, and are bounded to the eastand west by escarpments and high elevation plateau formed by Cenozoic era volcano-tectonic processes. Most of the flat rift plains around the lakes are covered by thick lacustrine sediments and volcanic Quaternary deposits with scattered volcanic centers (Barbieri *et al*., 1975; Zanettin *et al*., 1980). The rift is distinctly separated from the plateaus by aseries of normal step faults oriented parallel to the NNESSW trending rift axis. A persistent belt of intense and fresh faulting marks the floor of the MER. Considerable number of geothermal manifestations and caldera volcanoes characterize this active region.

Volcanism has persisted up to the present day in the Afar within small eruptive centers (Baker and Wohlenberg, 1971). There are also frequent earthquakes all over the Ethiopian rift; the epicenters are almost exclusively related to the major rift structures. The largest number of epicenters is located along and on the margin of the western plateau escarpment and along the large axial faults (Gouin 1979). Although the effect of recent tectonics on the hydrogeology of the lakes is unclear, there are some changes in lake levels, possibly due to the formation and/or reactivation of rift faults. This has been observed through changes in the discharges of springs around Lake Langano after recent seismic activities and formation of new faults (Ayenew, 1998). The most dramatic changes in the geomorphology occurred in the Lake Hawassa basin. Some small ponds have disappeared due to the formation of new ground cracks.

2. Methodology

This study is based on an assessment of existing hydro-meteorological records, the development of a systematic database from relevant previous investigations over the last two decades (Makin *et al*. 1976; Chernet, 1985; Halcrow and Partners, 1989; Ayenew, 1998, 2009), an interpretation of multi-temporal satellite images and aerial photographs, and on long-term hydrological field observations. Much of the evidence for the temporal and spatial changes in hydrology comes from lake level records. Recordings of lake levels began for most lakes in the early 1970s, and were carried out daily using staff gauges.

The lake level records were used to reconstruct the changes and to correlate the lake levels with other catchment hydro-meteorological factors, although some of the data were inconsistent and erratic. The erratic data from some meteorological stations were eliminated from the analysis.

Information on the extraction of water was gathered (up to the early 2000) from pertinent institutions. To evaluate the spatial variation of lake levels and to reconstruct the positions of the different shorelines, multi-temporal satellite images of Multi Spectral Scanner (1979), Thematic Mapper (1987, 1989) and SPOT (1993), as well as panchromatic aerial photographs at the scale of 1:50,000 (taken since the late 1960s) were used. The author made a detailed water balance assessments for the lakes where anthropogenic effects were thought to be high, .For the Ziway-Shalla lakes, including Hawassa, the conventional water balance approach (Ayenew 1998) and groundwater modeling (Ayenew and Tilahun, 2008) were used. The results from these water balance studies were incorporated into the present study to illustrate the relative importance of hydrological fluxes in lake-level changes along with anthropogenic factors.

Unfortunately, much of the abstraction of water from the lakes for various purposes had not been quantified accurately, as there were no records and controls on abstraction rate. However, the abstraction rate for irrigation from Lake Ziway and the extraction of water for soda-ash production from Lake Abijata were estimated, based on field observations, interviews of relevant personnel, and from actual records made up to the early 2000.

3. Results and Discussion

The lake level trends in the Ethiopian Rift, as establishedfrom monthly average stage records, are inconsistent (Fig.2.2). Lake Abijata showed the most drastic reduction. Lakes Beseka and Hawassa expanded. The former has engulfed parts of the town of Methara and submerged the highway that connected Addis Ababa and Djibouti. Currently, the highway is being diverted, resulting in property loss the value of which cannot be undermined.

Table 2.2 summarizes the water balances of some of the lakes, estimated according to long-term average monthly hydro-meteorological data and hydrological models (Ayenew, 2001). The average annual records between 1970 and 1997 were used when estimating the components of the water balances of the lakes. It was not possible to quantify all of the components of the water balances on a monthly basis, as there were no complete records for some of the components of the hydrologic cycle, such as surface runoff, evaporation and river discharges. Long-term observations (Table 2.2, below) of the study suggest that rainfall, river discharges, and evaporation all play very important roles. The temporal variation in the groundwater input to the lakes is influenced directly by the amount of recharge from rainfall.

Table 2.2: Estimated long-term (1970–1996) mean annual water balance of the lakes, in million cubic meter (mcm). Sources: Nedaw (1997); Tessema (1998); WWDSE, (2001); Ayenew, 2009. Note: P_i is for precipitation on the lake; R_{in} for inflow from rivers; G_{in} for groundwater inflow; S_{ir} for inflow from surface runoff; E_l for lake evaporation from lakes; R_o for outflow in river outlets; A for abstraction

Lakes	Inflow				Outflow			Difference ΔV in 10^6 m^3
	P_i	R_{in}	G_{in}	S_{ir}	E_1	R_O	A	
Beseka	22.0	30	52.8	--	98.8	--	--	6.0
Abijata	113.0	230	--	15.0	372	--	15	29.0
Langano	186.0	212	63.0	--	463	46	--	48.0
Shalla	232.0	245	18.0	40.0	781	--	--	246.0
Zwai	323.0	from Katar 392 from Meki 265	--	48.0	890	184	28	74.0
Hawassa	85.3	from Tikur Wuha 74	21.3	139.2	117	--	--	128.8

Many of the lakes fluctuated in accordance with the climaticconditions of the region (Street 1979; Chernet, 1982). In order to show the relationship between lake levels andrainfall, selected stations on the highlands and the rift floor were monitored (Fig.2.3). The third figure (bottom) in Fig. 2.3 shows the long-term rainfall pattern in the region, recorded at Addis Ababa station since 1961. It indicates that the levels of rainfall have remained fairly constant over the last one-half century, except for the usual inter-annual variations. In recent years, also there was not any clear trend of decline in rainfall. But, there was a slight rise in temperature.

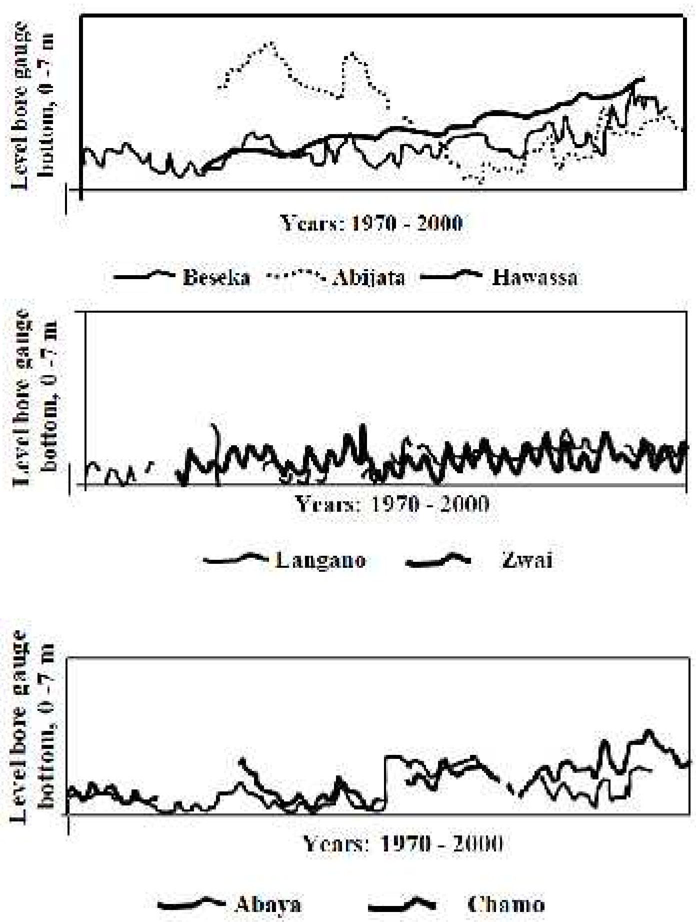

Fig.2.2: Lake level fluctuations since 1970 – 2000. ***Top***: Terminal lakes affected by man, ***Middle***: Open lakes of Zwai and Shalla Basins with limited human influence and ***Bottom***: Southern MER lakes (no detailed study on human influence)

An attempt was made to correlate average annual lake levels with the corresponding rainfall and pan evaporation records from nearby stations (Table 2.3), using available data from 1970 onwards, which were the most important components of the water balances of many of the lakes in the rift valley. The correlation of lake levels with those of evaporation and rainfall was not strong. From the available data since 1970 for evaporation and lake levels, the linear correlation coefficient ranged from 0.62 to 0.74, and for rainfall varied from 0.53 to 0.79. The monthly data showed even less correlation: for rainfall and lake levels the correlation coefficient ranged from 0.27 to 0.54. This is partly attributed to delayed runoff and groundwater inflow. The lowest correlation in all cases was obtained for terminal lakes with anthropogenic influences. The correlation between the mean annual lake level and the corresponding mean annual precipitation was much higher ($r = 0.65–0.81$) before the 1980s for many of the lakes. Low correlations occurred after the mid-1980s, when water abstraction and land use changes increased dramatically.

Despite the lack of any distinct rising or falling trend in rainfall for more than half a century, the terminal Lake Abijata showed unusual lake level changes. This is likely to be related to pumping of water for soda ash abstraction and reduction of the flow of the River Bulbula as a result of pumping of water in the Ziway (Zwai) catchment for irrigation.

Of all the lakes, the most notable lake-level change was recorded at Lake Abijata. This lake is relatively shallow, small, alkaline terminal lake, fed by Rivers Hora-Kelo and Bulbula, originating from the upstream Lakes Langano and Ziway, respectively. The main inflow is from direct precipitation and discharge from the two rivers. As a closed lake, it has negligible groundwater outflow; the only significant water loss is through evaporation. Development schemes, including the pumping of water from Lake Abijata for soda ash extraction since 1985, and the utilization of water from Lake Ziway and its main feeder rivers (Meki and Katar) for irrigation since 1970s, have resulted in rapid shrinkage of the lake. Annual artificial water evaporation for soda ash extraction from Lake Abijata was estimated at around 15 mcm in 1998. This is equivalent to a water depth of 0.083 m, based on the then average lake area of 180 km^2 (Ayenew, 2004)

The annual water abstraction for irrigation in 2000 from the Ziway system was estimated at only 28 mcm. In recent years, the rate of water abstraction has risen sharply. The development of flower farms and more irrigation fields have resulted in the slight reduction of the lake size. The real recent concern is the construction of a dam at the outlet of Lake Ziway to regulate the flow of River Bulbula. If all of the proposed irrigated areas (5500 hectares) are developed around Lake Ziway, the estimated annual water requirement will be 150 mcm (Makin *et al*., 1976). This would result in a 3 m reduction in the level of Ziway that may lead to drastic reduction and finally the ultimate demise of Lake Abijata; since Lake Abijata may not survive without the Bulbula inflow.

The falling level of Lake Abijata is clearly visible from reconstructed shorelines. The greatest reduction in the level of Lake Abijata coincided with the onset of large-scale water abstraction for soda ash production and irrigation from Lake Ziway after 1985. In wet years, for 50% of the time between November and June, Lake Ziway showed a considerable net loss of storage due to the outflow of water to Lake Abijata. During August and September a net gain of storage occurred because of large inflows from Rivers Katar and Meki. The gain is transferred to Lake Abijata, and at times (1970–1987) reached as much as 17% of the total volume of the lake (Halcrow and Partners, 1989).

There were considerable reductions in the volume of Lake Abijata in 1985 and 1990, amounting to about 425 mcm or 51% of its present volume. According to site managers at the Abijata Soda Ash Factory, inflow from Ziway has diminished from the long-term annual average (1970–1993) value of 210 to 60 mcm in 1994 and 1995 due to upstream water abstractions. In the mid-2000s the size of the lake had shrunk by about 40% as revealed from satellite image analysis.

The fluctuation in the level of Lake Abijata followed the same pattern as that for Lake Ziway, with an average time-lag of about 20 days. Any abstraction of water in the Ziway catchment results in a greater reduction in the level of Lake Abijata than in that of Ziway. Over the past three decades, the depth at Lake Abijata reached a maximum of 13 m in 1970 and 1972, and 7 m in 1989. These extreme drops in water levels correspond to water volumes of 1575 and 541 mcm and lake surface areas of 213 and 132 km^2, respectively. Before 1968, lake level variations, as reconstructed from different sources (Street Perrott, 1982; Benvenuti *et al*., 1995; Ayenew 2001), showed average inter-annual fluctuations of around 1.6 m (except during extreme dry or wet years), with, for example, a high level in 1972, a low level in 1965 (inferred from aerial photographs) comparable to that of 1989, and very low levels in 1967 (aerial photographs), 1994 and 2003.

The magnitude of the lake level fluctuations in Ziway islower than those of Lakes Langano and Abijata, since lakes with outlets usually show smaller ranges of lake level changes. The lowest level of Ziway was recorded in June 1975 (0.13 m) and the maximum in September and October 1983 (2.17 m). However, for the last three years of the late 1970s and in the early 1980s the level was slightly lower due to the dry years of the 1970s. Lake Ziway showed a slight reduction after the late 1980s due to the abstraction of water for irrigation. In fact there were no large lake level changes at Lake Abijata. The cumulative effect of the abstraction of water from Ziway is passed to the terminal Lake Abijata via River Bulbula. As revealed from field visits by the author (May 2003), the extremely dry years of 2002 and 2003, and the extensive irrigation activities around the lake resulted in the complete drying-up of River Bulbula and a visible water-level drop (1.5 m below the long-term average)of Lake Ziway.

The level of Lake Langano is more stable than of the other lakes, which correlates with the groundwater water balance calculations (Ayenew, 2001). There is no irrigation activity in the Langano catchment. The stability is related to a large groundwater flow from springs and seepage through large faults. According to the local people, the discharges from these large feeder springs have increased recently, which could be related to the formation and/or reactivation of regional faults by recent earthquakes. However, in recent years, the flow of the River Hora-Kelo dropped due to the reduction of the level of Lake Langano. The slight decline of the water level of Lake Langano is likely to be related to upstream land use changes and local water diversions from feeder-rivers. All the aforementioned events are indicators of unsustainable signs of what is taking place in these rift lakes in recent years.

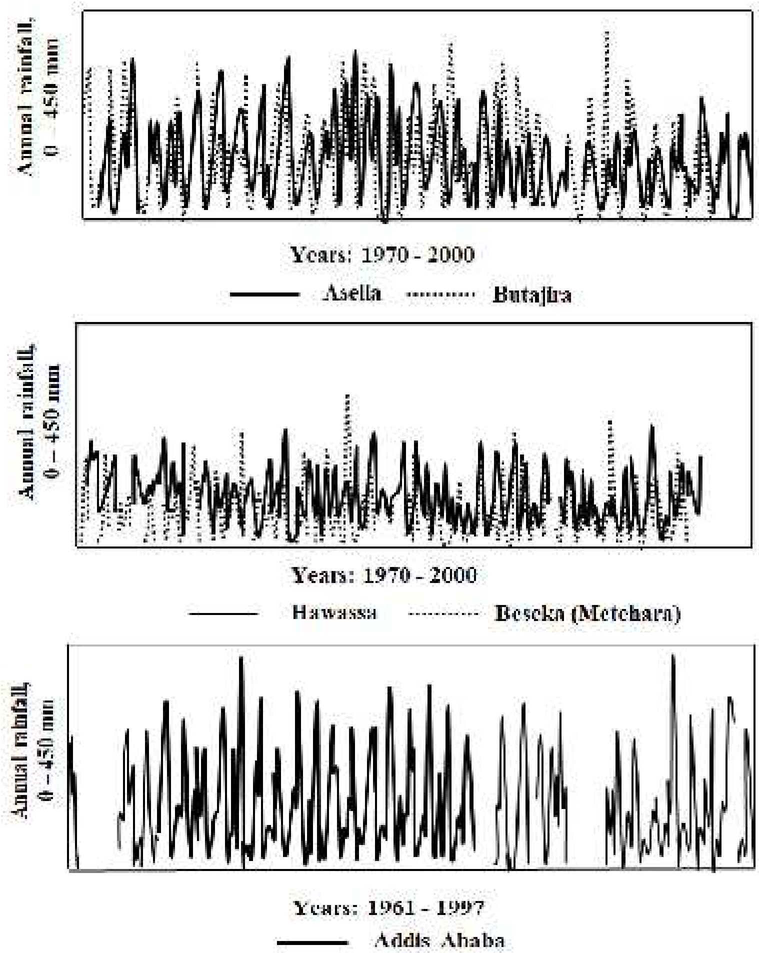

Fig. 2.3: Rainfall patterns in selected stations from the highlands and rift-valley regions of Ethiopia (after Ayenew, 2004) NOTE: ***Top two***: Selected highland metrology stations and ***Bottom***: Long-term monthly rainfall at Addis Ababa

Table 2.3: Average annual lake levels and other related hydro-meteorological variables. The pan evaporation and rainfall records for Lakes Abijata and Hawassa (Awassa) were obtained from meteorological stations located at Asella (Assela) and Hawassa towns, respectively. Note that time series evaporation data for Lake Abijata is not available.

Year	Abijata			Hawassa			Pan evaporation, mm
	Rainfall, mm	Lake level, m	Lake surface area, km^2	Rainfall, mm	Lake level, m	Lake surface area, km^2	
1970	--	--	--	951	0.92	91.4	--
1971	--	--	--	951	1.11	92.3	--
1972	--	--	--	951	1.54	93.1	--
1973	--	--	--	743	1.20	92.4	--
1974	729	4.69	184.9	940	0.79	91.0	--
1975	812	5.36	--	8262	0.65	90.8	--
1976	803	5.73	--	953	0.64	90.8	--
1977	961	4.67	--	1226	0.95	92.2	--
1978	1075	3.90	--	1043	1.68	94.4	--
1979	1020	5.04	--	978	2.02	95.2	--
1980	601	4.41	--	794	1.62	93.6	--
1981	989	3.11	--	1041	1.13	92.0	--
1982	1069	1.76	--	1029	0.99	91.8	1800
1983	962	0.75	--	1160	1.43	93.5	1884
1984	743	0.54	--	725	1.50	93.4	2364
1985	940	0.82	162.7	902	1.05	92.0	2060
1986	1015	0.96	--	1192	8.03	92.5	1974
1987	1004	4.21	--	959	1.55	93.2	1998
1988	860	1.28	--	957	1.60	94.4	2050
1989	1131	0.84	162.7	1010	1.99	95.2	1964
1990	827	0.52	--	757	2.06	94.8	2224
1991	738	0.82	162.7	867	1.61	93.4	2134
1992	1109	0.82	162.7	961	1.39	93.6	2074
1993	1136	1.75	--	754	2.00	95.2	2026
1994	--	1.41	179.5	855	1.97	95.3	2185
1995	--	1.78	--	1006	1.80	94.4	1751
1996	--	1.47	180.3	1189	2.20	96.1	1863
1997	--	1.52	--	1038	2.62	98.7	2170
1998	--	1.40	179.2	962	3.27	100.3	--
1999	--	1.40	179.2	--	--	--	--
2000	--	1.39	179.0	--	--	--	--

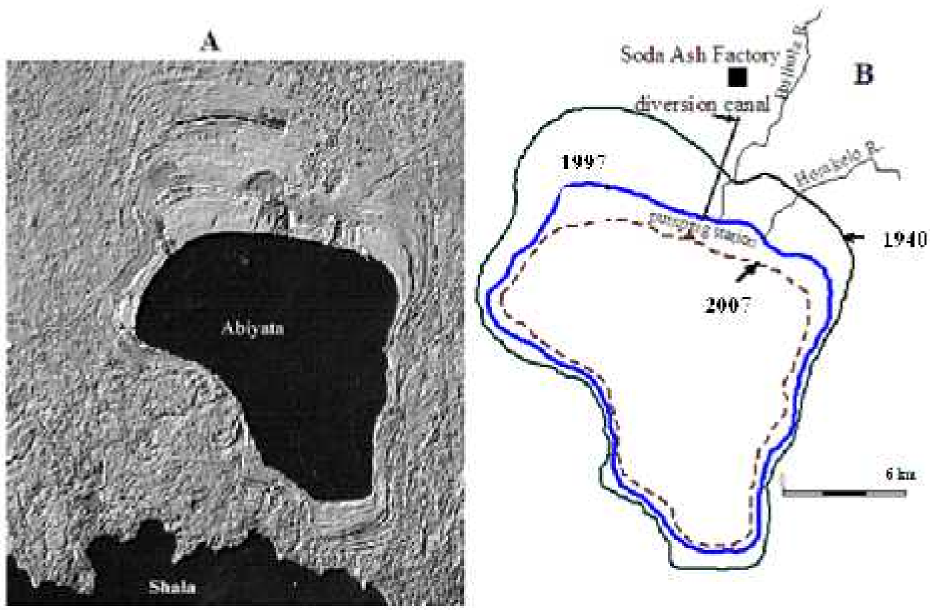

Fig. 2.4: (**A**) Satellite image showing the shrinkage of Lake Abijata (Abiyata) and (**B**) shoreline position at different times (modified from Ayenew,2011)

Lakes Hawassa has shown a rising trend in the late 1990s. Between 1969 and 2000, Lake Hawassa rose by about 13 cm per year. The maximum level recorded so far is 3.82 m on 13 November 1998. Before the mid-1980s, the level of the lake fluctuated in response to regional changes in rainfall. Since 1996, the lake level has exhibited a significant rising trend. During this period the rainfall recorded at Hawassa station had shown an increase from the long-term average value of 17% to 23%. In fact, these large lake level rises cannot be explained by climatic factors alone. Various authors have suggested possible reasons like climate and land-use changes (Geremew, 2000) and neo-tectonism (Ayenew, 1998). Whether the recent tectonism will affect the levels of lakes substantially in the near future remains a matter of conjecture.

A detailed study of the changes in lake levels of Lake Hawassa has been conducted by the Water Works Design and Supervision Enterprise (WWDSE, 2001) since the city of Hawassa is being threatened by the rising lake level. According to this study, the main cause of the lake level rise is land use changes and subsequent sediment depositions in Lake Cheleleka (Chelekleka), which feeds Lake Aweassa. The level of Lake Hawassa is strongly controlled bythe fluxes from the large Shallow swamp and the small lake of Cheleleka, which spills over into Lake Hawassa through the TikurWuha River. There are well-defined drainage patterns where dense stream networks originate in the mountains situated to the east, the southeast north and the northwest of the lake and drain the surface runoff in the form of river systems to Lake Cheleleka. The surface area of LakeCheleleka was about 12 km^2 in 1972, with an estimated average depth of 5 m and a storage volume of about 60 mcm. However, it is currently transformed into swamp with practically no open water surface area.

The runoff, which is temporarily regulated by the swamp, eventually drains via River Tikur-Wuha into Lake Hawassa. The same study (WWDSE, 2001) hasshown that the Lake Cheleleka (or Chelekleka) has lost its physicalcapacity by the deposition of about $44x10^6$ m of sediment load in the past 35 years. At present, the old lake is covered by newly-grown tall grass, indicating that transported sediments generated from the watershed have gradually covered the bed of the lake. The condition of Lake Hawassa can be pictured in a similar way to that of Lake Cheleleka, except that there is no indication of swamp formation in Lake Hawassa, and the large proportion of sediment load was previously trapped by Lake Cheleleka, which is currently filtered by the swamp effect.

Under these circumstances, the rising level of Lake Hawassa is obviously expected. The depletion of vegetation cover in the watershed not only increases sedimentation in lakes but also decreases canopy and interception losses, which in turn increase the runoff coefficient. The runoff coefficient for Lake Hawassa watershed was estimated to be of the order of 0.13 (Halcrow and Partners 1989). It is currently estimated to be of the order of about 0.20 (WWSDE, 2001).

4. Potential Environmental Implications

The life support system on which our livelihood depends is being degraded in front of our eyes. The lake and the associated wetlands are the principal components of this system. On top of the profound ethical and aesthetic implications, it is clear that the loss of biodiversity has serious economic and social consequences. Hence the rift lakes must be valued, conserved and developed in order to bring benefits to all. We must learn more about them and our interaction with the ecosystems.

Undoubtedly, the improper utilization of water and landresources has brought about noticeable negative changes, which have the following far-reaching environmental implications.

The Ethiopian rift lake environment is known for its rich biodiversity. The lakes form an important migration route for Palaearctic birds during the northern winter. As a result, the swampy shores of Lake Abijata are one of Africa's highly appreciated bird sanctuaries. The lake is part of the Rift Valley Lakes National Park, which is expected to play an important role in the promotion of Ethiopia's tourism industry. Although the income generated from the park is unclear, it is one of the most visited places in Ethiopia, particularly bybirdwatchers. In fact, one cannot underestimate the role these lakes play in tourism, biodiversity conservation and food production.

The relatively large populations of flamingos graze the blue-green algae of Lake Abijata, while many other birds are dependent on fish. Abijata also forms a vital feeding ground for Cape Wagon and White Pelicans and other fish-eating birds. The increase in the alkalinity of the lake and its shrinkage will result in the reduction of the fish population, ultimately leading to the demise of the birds. Therefore, the protection of the lake is critical to saving the precious fauna and flora that thrive in it.

With broad shallow margins fringed with swamps, dense macrophytes, and a high concentration of phytoplankton, Lake Ziway is one of the principal sources of commercial fisheries in Ethiopia. The annual production of fish at Lakes Ziway and Hawassa was 3,000 and 1,000 tons per year, respectively (Atkins and Partners 1965). This production has been dramatically reduced recently owing to human influences (Gebremariam, 1994). At the present time, over-fishing is a real danger in Lakes Ziway, Abaya, Chamo, Hawassa and Langano, with catches educed to as low as hundreds of tons annually instead of thousands (Golobtsov *et al*., 2002, see also reports of the Ministry of Agriculture and FAO). Therefore, the main economic consideration that needs to be made when diverting the waters of Lake Ziway for irrigation is the impact that this venture may bring about on the potential of the lake for freshwater fishery.

The other more subtle effect of lake level reduction is on the vegetation along the lake shoreline, which play an important role in providing food and shelter to numerous animals. Some species are apparently sensitive to short-term fluctuations and disruptions to their environment along the margins of the lake. Unfortunately, there has been no study on the rate of deforestation and habitat degradation of the wetlands of Zwai, hence there is little known about the changes in the marginal vegetation. Irrigation and deforestation have already profoundly affected the large mammalian population of the Ethiopian rift valley system (Makin *et al*., 1976). With population increase and expansions of settlements and cultivated land many of the large mammals in the rift are recognizably threatened.

The highly productive grasslands close to the shore of most Ethiopian lakes is the principal source of dry season grazing at high stocking densities. A drop in the level of the lake may result in an increase in the transpiration loss from the marginal vegetation and a drop in the groundwater level, which in turn causes the springs used for community water supply purposes to dry up (Ayenew, 2002).

The transformation of Lake Chelekeleka into a swampy area has completely changed the aquatic ecosystem and caused it to lose its capacity to regulate the level of Lake Hawassa. The tall grasses growing in the swampy areas, indicating the deposition of transported sediment from the uplands has been continuously filling the natural reservoir of this small lake. The expansion of Lake Hawassa due to the reduction in the size of Chelekeleka is clearly a major threat to the city of Hawassa, located on the eastern shores of the lake.

Improper irrigation practices may result in theinvasion ofboth plants and disease-causing organisms. Uncontrolled irrigation close to Lake Ziway may favor the introduction of Schistosomiasis (bilharzia), although there are no signs of the disease presently in this area. This problem has already been highlighted, but it has not been properly considered (Makin *et al*. 1976). The intermediate mollusk host of *Schistosoma mansoni* is present in Lake Ziway and the River Meki (Ayenew, 1998). The problem is likely to be serious if accidental introduction of the parasite is made into the area coupled with uncontrolled expansion irrigated agriculture.

The highlands where major feeder rivers originate from are highly cultivated and the deforestation rate is growing by the year. The use of fertilizers is also growing with time, and this will increase the external load of nutrients into the lakes. Clearing of forests, animal grazing and other land use and modifications that reduced the vegetation in the catchment areas of the Ethiopian lakes have expanded considerably (Hillman, 1988, Lemma and Desta 20116 and Desta and Lemma 2017).Forest clearing increases the silt and nutrient load from the catchment into the lakes. When erosion takes place, torrents pick up soil particles that are usually rich in nutrients, resulting in eutrophication and associated events like algal blooms, decreased oxygen concentration and other related consequences like fish kill. Such events have been reported in some of the rift lakes. Fish-kills, algal blooms, and associated death of wildlife in Lakes Chamo (Belay & Wood, 1982) and Abijata (Wodajo, 1982; Ayenew, 1998) have been reported.

If the proposed large irrigation projects in the Ziway catchment are fully implemented, the problem of eutrophication is imminent. The subsequent increase in the population of phytoplankton would have major long-term effects such as changes in the odor and color of water, fish-kills, and interference with navigation. The rapid growth of human populations, coupled with agricultural development and industrial activities, has affected the water quality of some of the rift lakes (Gebremariam, 2002). Human activities have already contributed to the continuous degradation of the pristine qualities of the lakes (Gebremariam and Dadebo, 1989). Aside from its effect on lake levels, diverting rivers for irrigation purposes initiates downstream water-demand conflicts. A notable example is the critical water shortage along the spill regime between Ziway and Abijata through the River Bulbula. The importance of maintaining year-round flow of the River Bulbula, apart from its regulatory effect on maintaining the level of Abijata, relates to the need for domestic water supplies and water for livestock. The Bulbula River represents the only source of fresh water for a large number of rural and urban communities in its 30 km stretch of the semi-arid rift floor, where potable water is extremely scarce.

5. The Way Forward

Ethiopia does not have legislation that is specifically directed towards the conservation and sustainable use of its wetlands. It is not also signatory partner to the Ramsar Convention. Even Lakes Abijata and Shalla that were said to be protected as part of a national park under the Conservation Policy of Ethiopia (FDRE, 1989 EC/1997 GC) have been adversely affected by human activities. No conservation efforts have been advanced because of uncontrolled human settlements, deforestation, and establishment of enterprises, like the Abijata Soda Ash Factory (currently Abijata – Shalla Share Company), whose activities have been associated only with economic interests. Cultivated spaces and livestock husbandry are expanding in the park. Although the Ethiopian Parliament has approved legislation on environmental protection, the implementation of this regulation has never been so much effective. The lakes and their tributaries are unique and vital resources that provide invaluable benefits to the local community in areas of agriculture, recreation, industrial development, domestic use of water, fisheries for cheap source of animal protein and as sanctuaries for wildlife. They influence the development of many areas and continue to be part of the defining natural beauty of the Ethiopian landscape. Protecting them is the quest that needs urgent intervention. Perhaps the greatest challenge to effectively manage the future of the lakes should be to wisely handle the complex institutional setup and to facilitate an efficient, credible and focused program for balancing our continued ability to benefit from them; while preserving their chemical, physical and biological integrity for future generations.

In the past, development plans were implemented with short-term interests. Now-a-days, there is a general consensus at various levels on the prevalence of negative environmental changes demanding urgent interventions including developing water management strategies which will lead to a ‘wise use’ of lakes.

The wise use of lakes involves the maintenance of their ecological settings as a basis not only for nature conservation, but also for sustainable development. However, the wise use of lakes is not possible if all stakeholders, traditional users and developers, who make use of them, are not involved in one way or another. The involvement of the traditional users and knowledge of their values is the basis for the implementation of wise use strategies. In particular, the local populations should be the beneficiaries of the improved management of water and land resources. But ‘wise use’ is a complex concept to implement and requires the support of national programs addressing several factors including information, policy, research, awareness, management and institution building.

Ethiopia's economic development is strongly dependent on the sustainable use of all its natural resources, but particularly its waters. The environmental threats to Ethiopia's lakes are real. Sustainable utilization and protection of these important resources requires an integrated and far-sighted program with a responsible agency that can coordinate national action. Because protection of lakes falls within the domain of a crosscutting issue, both public and private institutions which need to contribute their expertise and work together. The development of a management plan for Ethiopia's lakes will need basic studies, including awareness, surveys and inventories, which should be part and parcel of a wetland development program (Davis, 1993). A number of national institutions that could take the lead in the development of wise use of lakes and their management plans have already been involved in lakes-related work for some time. These include some of the universities, the Ethiopian Wildlife Conservation Organization (EWCO), Ethiopian Wildlife and Natural History Society (EWNHS), Ethiopian Lakes and Natural Resources Association (EWNRA), Environmental Protection Authority (EPA), the Rift Valley Basin Authority and Institute of Biodiversity Conservation (IBC).

The sustainable use of water resources demands a comprehensive water management and plan or strategy requiring that the process of protecting and developing the resources is treated in a broad, integrated, and far-sighted manner. In practice, this is a complicated endeavor, since comprehensive water management involves a number of functions that are closely related but which are carried out by different agencies and organizations that may have conflicting interests. The functions include putting in place water law and policy-making, relevant regulations, technical assistance and coordination, monitoring and evaluation, administration and financing, public education and public engagement. Comprehensive planning is needed to integrate the diverse functions necessary for proper water management. The purpose of these functions is to identify alternative courses of action to protect and develop the water resources. In the process, problems are identified, data are collected and analyzed, and projections are made. This process provides a basis for integrating all the functional components of comprehensive lake and watershed management.

Ethiopia has been initiating a number of agricultural and other development projects that are of immediate importance to meeting the population's food needs and establishing self-sufficiency. The changes in economic policies, based on a free market economy, are leading to industrial and agricultural activities that will unavoidably exploit water resources. It is also expected that there will be a substantial expansion of highly mechanized agriculture with extensive use of pesticides and fertilizers in places such as the Abijata-Shalla National Park. In fact, the factors that have already brought about changes in Ethiopia’s lakes and their watersheds, such as overpopulation, expanding cultivated land at the expense of degraded forests and bush-lands, excessive and unplanned water abstraction from feeder-rivers and lakes are already known problems that need immediate evidence-based responses. In fact many initially well-intended development projects have overtime developed adverse repercussions such as eutrophication siltation and decreasing volumes of lakes. Such projects have to be re-visited based on research-based evidences in consultation with local communities and administrators.

It is clear that many environmental problems arise from the process of development itself. Therefore, although all the development programs that the country is planning to carry out appear to be indispensable, their environmental impacts should be seriously considered before any of the development programs are launched; and their negative impacts should be minimized where and when possible. Increased emphasis should be placed on preventive and mitigation planning based on environmental impact assessment.

It is a known fact that lakes are integral parts of an entire watershed and should be considered as portions of the drainage basin that supply them with water, sediment, and allochthonous materials. Still, integrated management of lakes and their catchments seems far from being realized. For instance, deforestation/reforestation of a catchment area is always viewed independently of the wetland ecosystem. Those who are concerned about water quality changes are indifferent to the reforestation programs in the catchments, and *vice-versa*. In Ethiopia, the concept of integrated watershed management, i.e., the management of wetland ecosystems as a whole, instead of just the readily available water itself, and the management of the whole catchment area, should be introduced at different levels and emphasized.

Appropriate institutions have to be established at different levels with mandates to implement policies, provide alternatives to actions that cause wetland degradation and to formulate modalities for a national wetland management program. This would provide an understanding of wetland values and problems, as well as filling gaps to support the protection and wise use of wetland ecosystems.

Environmental Impact Assessments should be carried out when any development intervention is planned. Critical wetland ecosystems should be identified, their ecological and hydrological functions evaluated, and any development impact assessed. Integrated wetland ecosystem planning should be a requirement to enhance the understanding of the values of lakes in ecological and socio-economic development.

One of the basic problems is the lack of strong sense of ownership and responsibility for lakes at all levels of government, from federal down to the *woreda* levels. Until recently, the Government has neither given due attention nor allocated sufficient resources to support wetland management initiatives.

Although the mission and role of each stakeholder with regard to lakes is not clearly defined, there exist various government institutions that are directly or indirectly involved in wetland-related activities. Unfortunately, there is inadequate coordination and collaboration amongst them.

Without basic data on the physical, chemical, and biological aspects of the lakes it is difficult to evaluate the impacts of development initiatives on qualitative and/or quantitative changes in order to implement proper water management strategies. Conducting a comprehensive wetland inventory for the whole country linked to the setting up of a systematic database could help ensure a better understanding of wetland values, socio-economic importance and provide alternatives for future management action. In the absence of scientific information, policymakers seem to believe that water quantity and quality changes are not among the problems of the country. However, the impacts of climate change and the drought and floods that impacted much of the southern and eastern parts of the country have caught the attention of the public and local governments, although without much outcomes in the direction of sustainability.

The human pressure on lakes is expected to increase as the population grows. Unless strategic actions are put in place for conservation and harmonization of development projects of lakes with the environment in general, there will be more crises in the future. The construction of dams and diversion of rivers for mechanized and irrigated agricultural activities in particular have emerged as controversial development issues in recent years. Proponents of such developments in government, private and donor agencies have faced increasingly bitter opposition from NGO's, local communities and other affected people and environmentalists. The negative environmental impacts of the Wonji Sugar Plantation on the surrounding area and the rivers crossing it are extensively discussed in the literature.

The challenge of harmonizing effective environmental management actions and development is particularly challenging in developing countries like

Ethiopia. The desire to turn a quick profit and failure to use integrated planning strategies with no concern for ecological and social values, have already had harmful impacts on some lakes such as Ziway; Abijata and Haramaya. These problems are expected to be repeated with other lakes unless corrective measures are taken urgently.

However, it is worth mentioning that different interested groups may have hidden motives to hinder development efforts in the name of the environment without having concrete scientific evidence. The recent outcry of some NGOs and the other environmentalists to stop the construction of Ethiopia's hydroelectric dams can exemplify this. It should be noted that any development project affects the natural environment, including the local populations, in one way or another. However, one has to work to harmonize development projects with environmental protection issues and the interests of the local people. Ethiopia requires electric power for development to take place, and rural populations need power as well as improved infrastructure and services to get out of extreme poverty and contribute to the overall development of the country.

A healthy wetland environment requires protecting, restoring, and maintaining the natural resources of the whole watershed through improved management, monitoring, and research. It also demands an appropriate balance between ecosystem protection and economic development. Sustainable development is a strategy by which communities seek economic development and at the same time ensure natural resources of the watershed are also conserved and quality of life guaranteed for future generations. Sustainable development provides a framework under which communities can use resources efficiently, create efficient infrastructures, protect and enhance quality of life and create new businesses to strengthen their economies. Sustainable development offers real, lasting solutions that will strengthen the future for all.

The threat to Ethiopia's lakes can have far-reaching national and regional consequences. The sustainable utilization of the lakes and associated wetlands lies in a stronger and integrated will of all the stakeholders, international and national, based on sound wetland policies and encouragement for community participation in their management. Although the goal for protected lakes should continue to be conservation of endangered and fragile sites, greater efforts should also be focused on lakes outside protected areas. New management strategies should be formulated involvingall stakeholders including the Federal and local governments, associations, businesses, educational institutions, NGOs and local communities with a collective vision. They have to work together to protect, restore, and maintain the fragile wetland ecosystems.

As stated above, Ethiopia is not a signatory to the Ramsar Convention. Ratifying this convention may contribute its share to the efforts of wetland conservation and sustainable utilization. Appropriate institutions have alsogot to be established at different levels to protect the endangered wetland environment together with the development of an effective wetland policy.

References

Abebe, Y. and Geheb, K. (2003). Wetlands of Ethiopia. Proceedings of seminar on the resources and status of Ethiopia's wetlands. International Union for the Conservation of Nature and Natural Resources. Addis Ababa. 123 pp.

Atkins and Partners (1965): Development of the fishing industryin Ethiopia (unpublished report). Atkins and Partners Technical Agency, Addis Ababa, Ethiopia,

Ayenew, T. (1998): The hydrogeological system of the Lake District Basin: Central Main Ethiopian Rift; PhD Thesis, Free Universityof Amsterdam, The Netherlands, pp 259

Ayenew, T. (2001): Numerical groundwater flow modeling of theCentral Main Ethiopian Rift Lakes Basin. *SINET: Ethiop J. Sci.* 24(2):167–184

Ayenew, T. (2002): Recent changes in the level of Lake Abijata, Central Main Ethiopian Rift. *Hydrol. Sci J.* 47(3):493–503

Ayenew, T. (2003): Environmental isotope-based integrated hydrogeologicalstudy of some Ethiopian rift lakes.*J. Radioanal.Nucl. Ch.* 257(1):11–16

Ayenew, T. (2004): Environmental implications ofchanges in the levels of lakesin the Ethiopian Rift since 1970.*Regegional Environmental Changes*4:192–204

Ayenew T. and Tilahun, N. (2008): Assessment of lake–groundwater interactions andanthropogenic stresses, using numerical groundwater flowmodel for a Rift lake catchment in central Ethiopia. *Lakes & Reservoirs: Research and Management*13: 325–343.

Ayenew, A. (2009): Natural lakes of Ethiopia.Addis Ababa University Press. 256 pp

Ayenew, A. (2011): Current status and potential threats of selected wetlands of Ethiopia.*Annual Environmental Review II Forum for Environment* Addis Ababa, Ethiopia.

Baker B.H, Wohlenberg, J. (1971): Structure and rift evolution of theKenyan rift valley. *Nature* 229:538–542

Barbieri, F., Ferrara, G., Santacroce, R., Varet, J. (1975): Structuralevolution of the Afar triple junction. Schweizerbart, Stuttgart,pp. 38–54

Belay, A.&Wood, R.B. (1982) Limnological aspects of an algal bloomon Lake Chamo inGamoGoffa Administration region of Ethiopian. *SINET: Ethiop J. Sci*. 5:1–19

Benvenuti, M., Dainelli, N., Iasio, I., Sagri, M., Ventra, D. (1995): Reporton EEC funded project ‘‘Land resources inventory, environmentalchange analysis and their applications to agriculture inthe Abaya lakes region’’ (Report No. 4). University of Florence, Italy, pp 6–27.

Chernet, T. (1982): Hydro-geologic map of the lakes region (withmemo). Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia

Davis, T.J. (ed.) (1993):Towards the wise use of wetlands.Wise Use Project, Ramsar Convention Bureau, Gland, Switzerland, 180 pp.

Desta, H. and Lemma, B. (2017): SWAT-based hydrological assessment and characterization of Lake Ziway sub-watershed, Ethiopia. *Journal of Hydrology: Regional Studies* 13: 122-137. http://dx.doi.org/10.1016/j.ejrh.2017.08.002

FDRE (Federal Democratic Republic of Ethiopia) 1989 Ethiopian Calendar (1997): Environmental Policy of the Federal Democratic Republic of Ethiopia; Published by the Environmental Protection Authority and the Ministry of Economic Development and Cooperation, Addis Ababa.

Gebremariam, Z. (1994): Long-term changes in indices of chemicaland productive status of a group of tropical Ethiopian lakes with different exposure to human influence. *Arch. für Hydrobiol*. 132:115–125

Gebremariam. Z. (2002): The Ethiopian rift valley lakes: majorthreats and strategies for conservation. In: Tudorancea C., Taylor W. D. (eds); Ethiopian Rift Valley lakes. Backhuys, Leiden, The Netherlands, pp 259–271.

Gebremariam Z., and Dadebo, E.(1989): Water resources and fisheriesmanagement in the rift valley lakes. *SINET: Ethiop. J. Sci.* 12(2):95–109

Geremew, Z. (2000): Engineering geological investigation and lakelevel changes in the Hawassa basin. MSc thesis, Department of Geology and Geophysics, Addis Ababa University, Addis Ababa, Ethiopia, pp 185

Golobtsov, A.S., Dgebuadze, Y.Y., Mina, M.V. (2002): Fishes of the Ethiopian Rift. In: Tudorancea C, Taylor WD (eds) Ethiopian Rift Valley Lakes. Backhuys, Leiden, The Netherlands, pp 167– 256

Gouin, P. (1979): Earthquake history of Ethiopia and the Horn ofAfrica. International Development Research Center, Ottawa, Canada, pp 247

Hailu D., Hess M., Ayenew, T. (1996): The problem of high risegroundwater in Amibara irrigation project, Middle Awash basin

Halcrow and Partners (1989): Master plan for the development of surface water resources in ten Awash basin, Vol. 6. Ministry of Water Resources, Addis Ababa, Ethiopia

Hillman, J.C. (1988): Abijata-Shalla lakes: National park reports onstatus and proposals. Mimeo, Addis Ababa, Ethiopia

Karrow,P.F. (1963): Pleistocene geology of the Hamilton Galt area (Geology Report No 16). Ontario Department of Mines, Toronto, Canada pp 68

Lemma,B. and Desta,H. (2016): Review of the natural conditions and anthropogenic threats to the Ethiopian Rift Valley Rivers and lakes. *Lakes and Reservoirs: Research and Management* 2016 21: 133–151

Makin M.J., Kingham, T.J., Waddams, A.E., Birchall, C.J., Eavis, B.W. (1976): Prospects for irrigation development around Lake Ziway, Ethiopia (Study 26). Land Resources Division, Ministry of Overseas Development, Tolworth, UK, pp. 270

Mamo S (2002): Water balance evaluation, leakage rate and total water loss of Koka Reservoir, Ethiopia. Comments on previous studies and new determinations. *SINET: Ethiop. J. Sci*. (1):141–150.

MWR (1999): Study of Lake Beseka (Main Report, Vol 1). Ministry of Water Resources, Addis Ababa, Ethiopia, pp. 203

Nedaw, D. (1997) Hydrogeology of Hawassa Area. MSc thesis, Department of Geology and Geophysics, Addis Ababa University, Addis Ababa, Ethiopia, pp 106

Servat, E., Hughes, D., Fritsch, J.M., Hulme, M. (eds)(1998): Water resources variability in Africa during the XXth century. *Int. Assoc. Hydrol. Sci*. 252:462

Slay, P.G. (1973): Sediment processes in Great Lakes. In: Fluvial processes and sedimentation Proc. Hydrology Symp, University of Alberta, Edmonton, 8–9 May 1973. National Research Council Canada, Ottawa, pp 465–492

Street, F.A. (1979): Late Quaternary Lakes in the Ziway-Shalla Basin, Southern Ethiopia. PhD thesis, University of Cambridge, UK, pp. 457

Street Perrott, F.A. (1982): Twentieth century fluctuations in lake level in the Ziway-Shalla basin, Ethiopia. *Palaeoecol. Afr*. 15:99– 110

Tessema, Z. (1998) Hydro-chemical and water balance approach in the study of high water level rise of Lake Beseka. MSc thesis, University of Birmingham, UK, pp. 90

Vallet–Coulomb, C., Legesse, D., Gasse, F., Travi, Y., Chernet, T. (2001): Lake evaporation estimates in tropical Africa (Lake Ziway, Ethiopia). *J. Hydrol*. 245:1–18

Wodajo, K. (1982): Comparative limnology of Lake Abijata and Lake Langano in relation to primary and secondary production. MSc thesis, Addis Ababa University, Addis Ababa, Ethiopia

Wood, R.B. and Talling, J.F. (1988): Chemical and algal relationship in a salinity series of Ethiopian inland waters.*Hydrobiologia* 158:29–67

WWDSE (2001) The study of Lake Hawassa level rise (Main Report, Vol II). Unpublished report of the Water Works Design and Supervision Enterprise, Addis Ababa, Ethiopia, pp 291

Zanettin, B., Justin, V. E., Niccoletti, M., Piccirllo, E.M. (1980): Correlation among Ethiopian volcanic formations with special references to the chronological and stratigraphic problems of the Trap series. *AccademiaNazionaledeiLincei* 47:231–252

Lake limnology and management Options

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Abstract

This review paper presents description of the basins of Lakes Ziway, Abijata and Shalla which are also interconnected to Lake Langano basin. In all of these basins descriptions of the lakes, their feeder-rivers and other associated wetlands are described. It further goes to explain the changes that took place over decades in the water chemistry of all these water bodies. It continues to discuss the impact these water chemistry changes have on the living forms associated with these waters, namely, on the phytoplankton, zooplankton, fishes and even birds that visit these water bodies and continue their migratory journeys up into Europe or down into Africa along the Great African Rift Valley. The paper also discusses the impact of diversions of the feeder-rivers of Lake Abijata for irrigated agriculture and the abstraction of saline-alkaline waters of Lake Abijata for the purposes of soda ash production by driving out the water out from evaporation ponds. Using these data the paper demonstrates how the surface area of Lake Abijata continued to shrink over the years and finally suggests the possible sustainable corrective procedures that should be followed to save Lake Abijata, the biodiversity associated with it and social benefits it supports.

1. Description of Lake Abijata and the Ziway-Shalla basin

Presently, the Ziway-Shalla Basin contains four major hydrologically linked lakes of decreasing elevation and increasing salinity, namely, Lakes Ziway, Langano, Abijata and Shalla. These four lakes were part of a large paleo-lake before separation by faulting and desiccation during the Cenozoic period (Mohr, 1962). The three former lakes are of tectonic origin, while LakeShalla is volcanic occupying a deep caldera. The four lakes represent about 8.5% of the total area of the Ziway-Shalla Basin and they lie in the lower parts of the rift (Fig. 3.1). Because the rift floor is a rainfall deficit zone (evaporation exceeding rainfall), the lakes depend largely on surface water and groundwater inflows from the adjacent plateaus and escarpments. Despite their geographic proximity to one another and considering that they are one hydrologic unit, and despite the similar climatic context under which they occur, these lakes have differing chemistry, morphometry and hydrology.

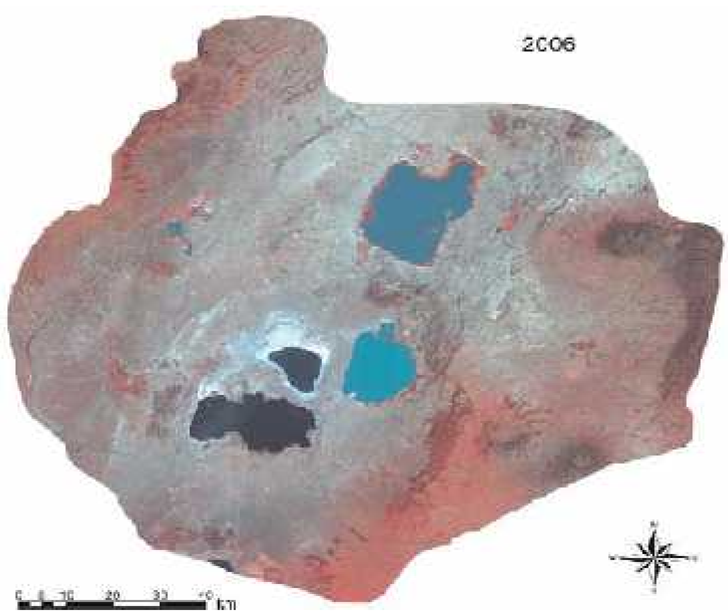

Fig 3.1: The Ziway-Shalla Basin showing the four lakes: The upper most is Lake Ziway, directly below it Lake Langano, the smaller dark one to the right is Lake Abijata and the lowest one is Lake Shalla

Lake Abijata, the smallest of the four major lakes, lies in a shallow depression about 18 km long. It is a terminal lake which receives inflows through the Bulbula and Hora Kelo Rivers, the former is a spillover river from Lake Ziway and the latter from Lake Langano. More than 50% of Lake Abijata's river inflow comes from Bulbula River (Legesse and Ayenew, 2006) and the relative importance of the inflowing River Hora Kelo and occasionally out-flowing River Gogessa is low (see Table 3.1, below). In addition to the overflows of the upstream Lakes Ziway and Langano, Lake Abijata may receive, during exceptionally prolonged high rainfall periods, an overflow from the Jido River, but the contribution of this river to the water budget of Lake Abijata is rarely mentioned in the literature.

Groundwater flows from the north and intermittent runoff from local drainage channels during the rainy seasons represent another important source of water to Lake Abijata (Ayenew 1998). The contribution of groundwater inputs in the Ziway-Shalla Basin has been regarded as insignificant (United Nations, 1973), although in Lake Abijata, an inflow of 15 Mm^3 water and an outflow of 1 Mm^3 annually was recorded by Tenalem (2004), making it of no big significance to the lake water budget. However, Tenalem and Tilahun (2008) argue that the Ziway-Shalla and other rift basins in Ethiopia are characterized by marked contribution of groundwater to the total basin inflow, as opposed to the Gregorian Rift lakes where groundwater has little or no contribution. In Lake Shalla, Ethiopia, groundwater contributes almost 50% of the lake's water budget. In Lake Abijata, groundwater inflow from Lake Ziway accounts for almost all the groundwater budget to the lake (Tenalem, 2002, 2003).

Vallet-Coulomb *et al*. (2001) have calculated that groundwater outflow from Lake Ziway to Lake Abijata is about 0.13 km^3yr^{-1}, which represents about 10% of the inflow from the Bulbula River and 25% of the direct precipitation input to the lake. Thus, the major water budget of Lake Abijata is controlled by surface runoff and evaporation (Table 3.1).

The climate in the Lake Ziway-Shalla Basin consists of a four-month dry season (November to February) which is generally followed by a rainy season of eight months, with a mean annual rainfall of generally less than 600 mm. The rainy months are noted as the main rainy (monsoon) season from June to September and the "little rainy season" from March to May. Rainfall patterns may change slightly from year to year, and with an average contribution of 113 Mm^3year^{-1}, the contribution of surface runoff from rain does not appear to drastically affect the water budget of the lake. Still, during the rainy months, the lake level increases naturally and recedes by some meters during the long dry months (Nov - May). It is noted that due to its terminal position in the drainage basin, Lake Abijata is especially susceptible to changes in rainfall in the surrounding plateau. Nevertheless, variability of the discharge of the inflowing rivers is by far more important than that of the direct rainfall on the lake surface (Tenalem, 2004).

Table 3.1: Water budget determinants for Lake Abijata

	Annual averages of	
	Inputs	**Outflows**
1.	96-246 Mm^3y^{-1} from rivers	372 Mm^3y^{-1} loss by evaporation
2.	113 Mm^3y^{-1} from rainfall	2 Mm^3y^{-1} loss to Soda Ash Factory
3.	27 Mm^3y^{-1} from surface runoff	1 Mm^3y^{-1} loss to groundwater
4.	15 Mm^3y^{-1} from groundwater	----
Total	**251-401 Mm^3y^{-1}**	**375 Mm^3y^{-1}**

The major hydrological changes observed in LakeAbijatahave been linked to inter-annual climate fluctuations (Chalie and Gasse 2002). The water depth has dropped by more than 8 m over the past 40 years (Makin *et al*., 1976). The lake area which was about 213 km^2 and ~ 13 m deep in 1970 was reduced to 132 km^2 and depth of 7 m in 1989 (Makin *et al.*, 1976; Street-Perot 1982). Recent estimates in 2002 gave higher lake area of 180 km^2 but during most recent visits, the lake had shrunk considerably to perhaps an area of less than 100 km^2 (Fig. 3.2).

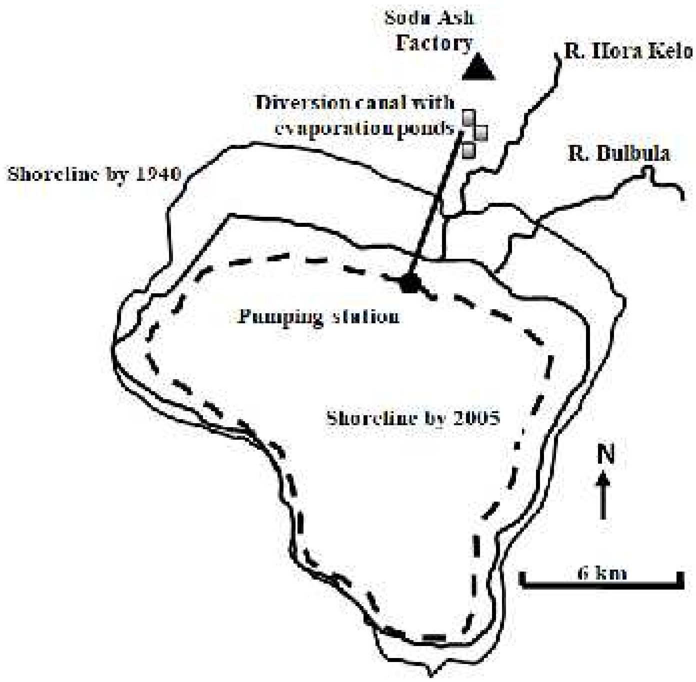

Fig 3.2: Hydrological changes represented here by lake surface area changes in Lake Abijata: 1940-2005.

This large hydrological variation between years has drastically affected the water chemistry and biology of Lake Abijata. A significant factor in the water deficit is believed to be the high evaporation in the lake basin. Evaporation accounts for almost 98% of the total output of the water budget, in addition to the considerable deficit the lake suffers from water withdrawals from Lake Ziway catchment, which affected the groundwater input, but more importantly, the contribution of the Bulbula River to Lake Abijata.

The future scenario for the water budget of the Lake Ziway-Shalla Basin under climate change is indeed bleak. Recent reports of the Ministry of Water Resources predicted that in the next 50 years, average annual temperature will increase by 1.5°C, rainfall will decrease by 10% and evapo-transpiration will increase by 10% with resultant 24% decrease in available surface water in the Central Rift Valley (HGL& GRID 2009). Thus drastic hydrological, chemical and biological impacts are expected in the Lake Abijata area in the future unless proper mitigation actions are put in place (see section 6B of this paper) .

2. Water chemistry

Lake Abijata is an exceptional highly saline-alkaline or soda lake. It is very rich in sodium carbonate and bicarbonates. At present Lake Abijata has been severely reduced in size by the combined effects of several years of low rainfall and the abstraction of water from its feeder-rivers for irrigation and soda ash production. Between 1926 and 1998 (over seven decades), water salinity and alkalinity fluctuated between 5.5 – 34.6 g/l and 39 – 349 meq/l, respectively, while pH varied between 9.1 and 10.3 (Wood and Talling 1988). Such large variations in water chemistry is prone to induce significant osmotic shock to the biota, with the resultant elimination of the less salt tolerant ones, and the dominance of the more halophilic and euryaline forms. Although very recent chemical data are lacking, studies done in 2000 indicate that Lake Abijata had experienced a leap of 300 $\mu mScm^{-1}$ in conductivity and the salinity had increased by more than 2.6 times and the alkalinity by about 4 times (Wood and Talling 2088; Wondie, 1997). This is a remarkable change and the most likely reason for the dramatic water loss from the lake could be the combined effects of rainfall shortage, high evaporation and surface inflow deficit caused by upstream irrigation.

Seasonal variations in the water chemistry of Lake Abijata were also noted earlier by Wodajo and Belay (1984) with alkalinity variations of about 100 $meqL^{-1}$ during the year (Table 3.2). Obviously, such large seasonal and annual variations in water chemistry will have considerable impact on aquatic life-forms in the lake. However, Lake Abijata is unsuitable for domestic, irrigation and industrial uses because of its extremely high ionic concentrations and salinity. However, with proper monitoring it could be good source of soda ash and *Spirulina* (*Arthrospira*) production.

Lake Abijata, with a catchment area of 10,740 km^2 has a very large drainage ratio (> 60); even taking the smallest lake area in recent surveys (180 km^2). Lakes with such high drainage ratio are expected to be less impacted by catchment inflows such as silt and nutrients (Kalff 2002). Thus the threat of eutrophication resulting from diffuse input of nutrients from the catchment area is less likely in Lake Abijata (Table 3.2). Nutrient enrichment threats from point source pollution like the agricultural and flower plants around lakes could be serious. The major threat to the biota appears to be physiological osmotic stress due to the huge fluctuations in salinity and alkalinity.

Table 3.2: Temporal changes in the water chemistry of Lake Abijata (values in mgL^{-1}) (after Ayenew and Legesse, 2007)

Sources	Salinity	Alkalinity	Ca^{+2}	Mg^{+2}	Na^{+}	K^{-}	Cl^{-}	Total cations
Omer-Cooper, 1930	8.1	80	0.5	0.8	125	---	42	---
Loffredo and Maldura, 1941	8.4	---	0.4	0.5	130	1.9	42	133
De Filippis, 1940	---	81	0.2	0.1	140	10.3	40	150
Talling and Talling, 1965	19.4	210	<0.15	<0.6	277	8.5	91	285
Wood and Talling, 1988	16.2	166	<0.10	<0.1	222	6.5	51	228
von Damm and Edmond, 1984	12.9	138	0.1	---	194	4.9	54	199
von Damm and Edmond, 1984	---	180	<0.01	0.01	231	6.9	82	138
von Damm and Edmond, 1984	21	197	---	---	378	9.9	121	388
von Damm and Edmond, 1984	26	126	0.1	---	416	9.7	88	425

Nutrient data

Very little data is available for the major nutrients of Lake Abijata or its influent rivers. Wood and Talling (1988) reported SRP of 88 μgL^{-1} for Hora Kello; a feeder-river flowing into Lake Abijata from Lake Langano. Although allochthonous (external) input of nutrients could be low due to the large drainage ratio, autochthonous (internal) sources are relatively high because of frequent wind mixing and high evaporation observed in Lake Abijata. According to Carlson's trophic index, with its average concentration of 85 μgL^{-1}, Lake Abijata qualifies to be classified as a eutrophic lake (Table 3.3).

Table 3.3: Relationships between Trophic Index, chlorophyll-*a*, phosphorus (both in μgmL^{-1}), Secchi depth (Z_{SD}, m), and Trophic Class (after Carlson 1996)

Trophic index	Chloropyll-*a*	Phosphorus	Z_{SD}	Trophic class
30-40	0-2.6	0-12	8-4	Oligotrophic
40-50	2.6-20	12-24	4-2	Mesotrophic
50-70	20-56	24-96	2-0.5	Eutrophic
70-100+	56-155+	96-384+	0.5-0.25	Hypertophic

3. Plankton biology

Wood and Talling (1988) reported *Spirulina* (*Arthrospira*) *platensis* (blue-green Cyanobacteria) and *Oocystis* (green algae) as the dominant algae in Lake Abijata. They also noted that *Anabaenopsis arnoldi* was found in lesser common form than the others. Kebede and Willlen (1996) later on reclassified *Anabaenopsis* in Lake Abijata as a new species, *A. abijatae*. *Oocystis*sp. was also reported to dominate *Spirulina* in some months of the year, especially during low-water levels, and this was attributed to its halophilic nature. Surveys done since then have reported the decline and even disappearance of *Spirulina* from the lake, with the concomitant emigration of the lesser flamingo to other Ethiopian soda lakes (Arenguade, Chitu) and even to Kenyan and Tanzanian soda lakes such as Lakes Bogoria and Natron where *Spirulina* is abundant.

Gasse *et al*., (1983) also reported a rich assemblage of diatoms in Lake Abijata, including *Navicula, Anomoeneis, Nitzschia* and *Rhopalodi*a species. During 1997, the phytoplankton of the lake consisted of 11 genera with *Anabaenopsis* representing more than 50 % of the community by abundance. Diatoms such as *Navicula* and *Nitzchia* were common during the wet months of March to April. *Spirulina (Arthrospira),* which was common in previous years, was found in very low abundance during 1997 (Wondie 1997).

Apparently there is high production of *Spirulina* (*Arthrospira*) to support the huge population of lesser flamingo in the lake. Despite low nutrient input from external sources, there must be continuous recycling of nutrients from autochthonous sources due to strong winds, because the algal biomass as chl-*a* was also relatively high. Various models give a value of 20 – 56 μgL^{-1} chla as reflecting the eutrophic state (Table 3). Phytoplankton biomass as chl-*a* was found to be below 100 μgL^{-1} in Lake Abijata. Wood *et al*., (1978) reported a value of 57 μgL^{-1} which was slightly higher in 1984 at 65 μg/l (Belay and Wood 1984). Wodajo and Belay (1984) reported a range of 30 – 73 μgL^{-1}chl-*a* in Lake Abijata, thus the chl-*a* values reported qualify the lake in the eutrophic category (Table 3).

Primary productivity is equally high in Lake Abijata but maybe not as high as in other alkaline soda lakes. A daily primary production rate of 11 gCm^{-2} was documented in the early 90's, which was observed to be slightly lower than for other Ethiopian soda lakes, such as, Arenguade (19 $gCm^{-2}d^{-1}$) or common rates for African saline-alkaline lakes (Wondie. 1997).

The zooplankton of Lake Abijata has changed with the water chemistry of the lake. During periods of concentration and increased salinity, euryhaline rotifers such as *Brachionus* sp. - including *B. angularis, B. calyciflorus, B. pliciatilis and B. quadridentatus,* as well as Cyclopoid *copepods* that included *Mesocyclops sp.* and *Thermocyclops gibsoni* dominated,. Calanoids have not been documented in the lake, although the high alkalinity and salinity during water recession favors dominance of *calanoids* (Kalff 2001).Cladocera are rare in the lake, probably because they cannot sustain on the large algae such as *Arthrospira* and *Anabaenopsis.* Diatom biomass may not be high to sustain the benthic cladoceran *Alona sp*. because it was very rare in counts. On the other hand, the greater flamingo and corixids, which feed on benthic detritus, were observed in large numbers at the lake shore, where detritus could be concentrated and scoured from the shallow parts of the lake by strong winds (Wondie, 1997).

4. Riparian vegetation and macrophytes

Lake Abijata has poor littoral development and macrophytes are lacking around most of its shore. The catchment is populated with trees and shrubs dominated by six major plant communities consisting of *Acacia tortilis, Dichyrostachys, Cynodon, Harpachne, Sporobolus* and *Cyperus laevigatus* (Regassa, 2005). Extensive removal of trees for charcoal production and farming has decimated the original vegetation cover to < 50% (Reaugh-Flower, 2011).

The riparian flora of Lake Abijata has shown progressive deterioration because of human intrusions such as farming, grazing space for cattle and wood felling for charcoal. The enforcement of the status of the lake area as a national park will go a long way to arrest degradation of the catchment and improvement of the lake biodiversity.

5. Fish and Birds

Lake Abijata has lost its resident fish fauna, which used to be Nile-tilapia (*Oreochromis niloticus*), also a favorite food source for the local community during the heyday of the lake fisheries in the late 1980's. What caused the demise of the fish stock has not been investigated, but it is suspected that osmotic stress (increasing salinity) associated with the abrupt recession of the lake after 1985 could be a contributing factor. Fish fry were observed in the dilute channel waters and some littoral parts of the lake in 1997, but the fishery never recovered from its decline after the late 1990's.

Lake Abijata is a shallow and highly productive alkaline lake and therefore its swampy shore supports a wealth of bird life (flamingos, white pelicans, etc.). On account of the high aquatic bird population (in particular lesser flamingos) that it harbors, Lake Abijata has been proposed as a Ramsar site of international importance (EWCO, 1989). Many northern palearctic migratory birds, such as, stilts, ruffs and ducks rest annually in the lake. On a single day in Lake Abijata an estimated counts of 230,000 lesser flamingos, 150,000 wagtails and up to 15,000 shovellerswere documented by various workers (e.g. Hillman 1998). Other birds of lesser importance in the lake include waders and wagtails.

The rift valley lakes also form an important migration route for palaearctic and Eurasian birds as a stopover site during the northern winter. The lake forms part of the Shalla-National Park, which although gazetted in 1978, has never been managed as a park at all. In recent times, the eco-tourism potential of the park has been increasing, despite the emigration of huge numbers of lesser flamingos elsewhere. The high population of flamingos used to subsist directly on the blue-green algae in the surface waters while many other birds were dependent on fish. Both groups of birds seem to have disappeared from Lake Abijata as the plant and animal life are very sensitive to lake area and size changes. Lake Abijata also forms a vital feeding ground for Cape Wigeon, Abdim's Stork and Great White Pelicans, which roost on Lake Shalla in large numbers. It is notable that the White Pelican on Shalla is one of the largest colonies in Africa. Due to its very high alkalinity, Lake

Shalla lacks the fish necessary to support high populations of fish-eating birds such as pelicans.

The alkaline water is conducive for mass culture of the blue-green alga *Spirulina* / *Arthrospira*. Thus management plans for the lake will have to compromise between its commercial, biological and economic attributes in order to sustainably utilize and conserve this lake. The rich resident bird life and the seasonal influx of palaearctic birds in Lake Abijata, plus its high potential for *Spirulina* production, indicate that the huge eco-tourism and economic potential of Lake Abijata have been overlooked against the short-term commercial gain from soda ash extraction.

6. Major threats to water budget deficit of Lake Abijata

a. **Irrigation in the Katar and Meki catchments**: The reduction of lake level is further aggravated by the diversion of water from the two main influent rivers of Katar and Meki originating from the Arsi Mountain to the east and the Guraghe Mountains to the west of Lake Ziway, respectively. This input from the two rivers has been reduced because of the large-scale diversion plan of the two rivers upstream. The water discharge of the Tiyo Woreda by gravity from Katar River amounted to around 1,200 litres /second during the design of the project but survey of the present condition indicates that the discharge only amounts to 860 litres/second (Tenalem, 2003).

   In addition to the above-indicated irrigation schemes, there are other modern irrigation schemes in Tiyo Wereda, which use gravity to discharge water from the river, feeding the Katar River. The land under irrigation using the Katar-Meki Rivers reaches around 156 ha and further expansions are inevitable; with the demand for more jobs by the increasing population of the watershed, the rapid growth of local investors and businessmen that are keen in using the freely available water from the two rivers for diverse irrigation projects and the policy of the Ethiopian Government that encourages the promotion of investments of such nature.

b. **Abstraction of water for soda ash production**: The water abstracted from Lake Abijata by the former Soda Ash Enterprise (ASAE) amounts to some 2 Mm^3 annually (Table 1). This may seem negligible in contrast to the huge amount of water lost by evaporation. However, caution has to be exercised in taking these figures for certain, as some of them are cited from grey literature and reports favouring the industrial sector. Nevertheless, as the water abstracted is not returned back to the lake, it is bound to contribute to the cumulative water deficit status of the lake. Another issue is the economic viability of the ASAE, which like Lake Natron, Tanzania, may not be economically sustained beyond a few years. In a sense, the volume water abstracted for soda ash production could have increased so much had the factory operated in full capacity. As a result, the production capacity of the ASAE has only been limited to around 8,500 tonnes annually. The production level in 1992 was reported to be about 15,000 tonnes per year with a projected expansion plan of 25,000 tonnes in the future. In 1998 the annual artificial water evaporation for soda ash extraction from Lake Abijata was estimated at 13 Mm^3 (Ayenew, 1998, 2002). This is equivalent to a depth of 0.07 m, based on the then average lake area of 180 km^2. The production has been increasing since then, and the pump position was progressively following the receding or shrinking lake. The present extraction is still considered to be in the first phase of a larger development scheme. There is a future plan of pumping saline-alkaline water of Lake Shalla into possibly the Abijata drying ponds. If this envisaged Shalla soda ash share company should undergo, strict environmental and social impact assessment and develop favourable management plans that will also consider the sustainability of both lakes and the biodiversity they support.

c. **Upstream irrigation from Lake Ziway**: From the estimated evaporation figure, it appears that the recent dramatic lake level changes cannot be explained in terms of artificial lake water evaporation alone. The lake level reduction is believed to have been amplified by the large water pumping from Lake Ziway for irrigation, which is the major supplier of water to Lake Abijata through the Bulbula River. The fluctuation of Lake Abijata follows the same trend as Lake Ziway, with an average time lag of about 20 days (Ayenew, 2003, 2004). Any abstraction of water in the Ziway catchment results in a greater reduction in the level of Lake Abijata than in that of Lake Ziway. Over the past three decades, the depth reached a maximum of 13 m in 1970 –1972 and 7 m in 1989. These extreme drops in levels correspond to water volumes of 1575 and 541 Mm^3, and lake surface areas of 213 km^2 and 132 km^2, respectively. Before 1968, lake level variations, reconstructed from different sources (Street, 1979; Benvenuti *et al*., 1995 and Ayenew, 1998), showed inter-annual fluctuations of the same order of magnitude, with, for example, a high level in 1940 and 1972, a low level in 1965 (inferred from aerial photographs) comparable to that of 1989, and a level even further reduced in 1967 (aerial photographs) and 1994and 2004 (field observations).

It is estimated that the total amount of water withdrawn from upstream sources in Lake Ziway by smallholders and state farms amount to a staggering 160 Mm^3, even though the total amount of land irrigated in the whole of the central rift valley (CRV) is less that 1 % (Reaugh-Flower, 2011). This indicates that a large amount of water is wasted unnecessarily through faulty methods of irrigation and absence of water conservation options in place. The continuous and unregulated abstraction of water upstream by different communities and entities difficult to identify even, is a critical cause for water depletion in Lake Abijata. At present, the lake has been reduced extremely in size showing the trend of complete extinction, if the rate of water abstraction is not changed.

d. **Damming of the Bulbula River:** Upstream damming and diversion of rivers results in lake level reduction and downstream water demand conflicts. At present water demand conflicts are surfacing out in some localities. A notable example is the critical water shortage along the spill regime between Lakes Ziway and Abijata through the Bulbula River, which represents the only source of fresh water for a large number of rural and urban communities in its 30 km stretch between the two lakes. The importance of maintaining year round flow River Bulbula, apart from any possible effect on the level of Lake Abijata relates to the need for domestic water supply. A similar problem exists in the Dijo River catchment due to the damming of the river some 20 km upstream of the confluence with Lake Shalla (Tenalem, 2004).

To make matters worse, the Bulbula River has since 2011 been dammed at its outlet site from Lake Ziway (Fig. 3). The damming was initiated to regulate the irregular flow of the Bulbula River during the rainy and dry seasons, and to store water for livestock watering during the dry seasons. The possible impacts of the new dam were investigated using models and simulations. The models indicate that a 30% reduction of the present flow of the Bulbula River will reduce lake volume below the minimum lake level of 1575 m for most months of the year, while 50% reduction will lead to water presence in the lake for only 3-4 months of the year, with complete drying up to the lake bed during the other months. Evidently, the Bulbula dam operation plan will have to consider this risk and danger in order to avoid ecological disaster of serious consequences to biodiversity and the local communities. With further reduction of 25% of surface waters in the next 50 years in the Ziway-Shalla Basin due to climate change impacts, the fate of sensitive lakes like Lake Abijata is only dim to contemplate.

Fig 3.3: The newly-constructed Bulbula River Dam

7. Suggested research problems and intervention actions

A. Researchable problems

1. How much water does the proposed Shalla Soda Ash Share Company envisage to extract from Lake Shalla and what will be the effect of the regulated release of water into Lake Abijata on annual and seasonal scale? Will it drastically change the minimum lake level required to sustain the flamingo population and lake biota (1575 m, asl)?

2. How much water does the Bulbula dam propose to extract for storage and regulated release and how will this affect the annual lake level dynamics in Lake Abijata?

3. How much water is extracted by local riparian communities of the Bulbula and Hora Kelo Rivers, considering trajectories of population and investment increases? How much water do farms extract from Lake Ziway and its catchment?
4. Exact determination of the number of pumps and water amount taken by smallholder irrigation users in the Ziway-Shalla Basin in general and the Ziway catchment in particular.
5. Study on methane and carbon dioxide levels in the hypolimnion of Lake Shalla.
6. Detailed study of flow discharges and extraction levels in major rivers in the basin, including Katar, Meki, Jido, Gorgessa, etc.

B. Major actions required

1. Environmental and social impact assessment of the Shalla-Abijata Soda Ash S.C. with addendum of environmental auditing and compliance commitments.
2. Operational management plan of the Bulbula Dam to include environmental flow regulation to avoid serious decline in Lake level.
3. Water use regulations for irrigation users, including state farms, smallholder investors, soda ash company, Bulbula dam managers, etc., with full compliance of ”pay for water used” and “the polluters pay principle”
4. Establishment of a Ziway-Shalla Basin Authority to oversee compliance and implementation of recommendations and manage the basin resources sustainably.

References

Ayenew, T. (1998): The hydrogeological system of the Lake District basin. Central Main Ethiopian Rift, PhD Thesis, Free University of Amsterdam, The Netherlands, pp 259.

Ayenew, T. (2002): Recent changes in the level of Lake Abijata, central main Ethiopian Rift. *Hydrol.Sci. J*. 47(3):493–503.

Ayenew, T. (2003): Environmental isotope-based integrated hydrogeological study of some Ethiopian rift lakes.*J. Radioanal.Nucl*. Ch. 257(1):11–16.

Ayenew, T. (2004): Environmental implications ofchanges in the levels of lakes in the Ethiopian Rift since 1970. *Regional Environmental Changes*4:192–204.

Ayenew, T. and Legesse, D. (2007): The changing face of the Ethiopian rift valley lakes: call of the time. *Lakes Res. Management* 12: 149-165.

Ayenew T. and Tilahun, N. (2008): Assessment of lake–groundwater interactions and anthropogenic stresses using numerical groundwater flow model for a Rift lake catchment in Central Ethiopia. Lakes and Reservoirs: Research and Management 13: 325-343.

Belay, A. and Wood, R.B. (1982): Limnological aspects of an algal bloom on Lake Chamo in GamoGoffa Administration region of Ethiopia in 1978. *SINET: Ethiop. J. Sci*. 5:1–19.

Benvenuti M, Dainelli N, Iasio I, Sagri M, Ventra D (1995): Report on EEC funded project ‘‘Land resources inventory, environmental change analysis and their applications to agriculture in the Abaya lakes region’’ (Report No 4). University of Florence, Italy, 6–27 pp.

Chalie, F. and Gasse, F. (2002): Lake glacial-holocene diatom record of water chemistry and lake level change from the tropical East African Rift Valley Lake Abuyata (Ethiopia). *Paleogeog.Paleoclimat.Paleoecology* 187: 259-283.

Gebremariam, Z. (1994): Long-term changes in indices of chemical and productive status of a group of tropical Ethiopian lakes with different exposure to human influence. *Arch für Hydrobiol*. 132:115–125.

Hillman, J.C. (1988):Shalla lakes: National park reports on status and proposals. Mimeo, Addis Ababa, Ethiopia.

HGL and GRID (2009): Rift Valley lakes Basin integrated Resources Development Master Plan Study. Phase 8.Halcrow and Generation Consultants,612 pp.

Kaflf, J. (2003): Limnology: Inland water ecosystems. Prentice Hall, New Jersey. 214 pp.

Kebede, E., Gebremariam, Z., and Ahlgren, I. (1994): The Ethiopian Rift Valley lakes: Chemical characteristics of a salinity-alkalinity series. *Hydrobiologia* 288:1012.

Kebede, E. andWillen, E. (1996): Phytoplankton composition and diversity in a salinity-alkalinity series of lakes in the Ethiopian rift valley. *Algol. Stud*. 89:63-96.

Legesse, D. and Ayenew, T. (2006): Effect of improper water and land resources utilization on the central main Ethiopian rift valley lakes. *W. Quaternary International* 148:8-19.

Legesse. D., Vallet-Coulomb, C. and Gasse, F. (2004): Analysis of the hydrological response of a tropical terminal lake, Lake Abijata (main Ethiopian rift valley) to changes in climate and human activities. *Hydrological Processes* 18: 487-504.

Makin M.J., Kingham T.J., Waddams A.E., Birchall C.J., Eavis B.W (1976): Prospects for irrigation development around lake Ziway, Ethiopia (Study 26). Land Resources Division, Ministry of Overseas Development, Tolworth, UK, pp 270.

Mohr, P.A. (1962): The Ethiopian Rift system. *Bull. Geophys*. 2:9-10.

Regassa, T. (2005): An ecological study of the vegetation around Lake Abijata. MSc Thesis. Addis Ababa University72 pp.

Reaugh-Flower, K. (2011): Abijata-Shalla Lakes National Park: Assessment of factors driving environmental change for management decision-making..

Street, F.A. (1979): Late Quaternary Lakes in the Ziway-Shalla Basin, Southern Ethiopia. PhD thesis, University of Cambridge, UK 457 pp.

Street Perrott, F.A. (1982): Twentieth century fluctuations in lake level in the Ziway-Shalla basin, Ethiopia. *Palaeoecol Afr*. 15:99– 110 .

Vallet-Coulomb, C., Legesse D., Gasse, F., Travi, Y., Chernet T. (2001): Lake evaporation estimates in tropical Africa (Lake Ziway, Ethiopia). *J. Hydrol*. 245:1–18 .

Wodajo, K. and Belay, A. (1984): Species composition and seasonal abundance of zooplankton in two Ethiopian Rift Valley lakes – Lakes Abiata and Langano. *Hydrobiologic* 113:136-140.

Wood, R.B. and Talling, J.F. (1988): Chemical and algal relationship in a salinity series of Ethiopian inland waters. *Hydrobiologia* 158:29–67

Wondie, A.(1997): Studies on the evaporation ponds of the Abijata Soda Ash Enterprise (ASAE).MSc Thesis, Addis Ababa University.

Abijata-Shalla National Park and its contributions towards greening of tourism

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Abstract

Abijata-Shalla Lakes National Park (ASLNP)was established for the purpose of preserving its rich wealth of aquatic birdlife and adjoining acacia woodland habitats with game animals. Over the years this national park has undergone severe demographic and natural pressures. These forces have resulted in the reduction and loss of biodiversity, falling water levels, structural changes of the landscape, and qualitative changes of the waters. This in turn has resulted in the downward spiral of human livelihoods contributing to poverty and unsustainable way of life. However, the environment in and around this rift valley park can be restored, and one of the ways can be through a form of sustainable tourism also known as green tourism or ecotourism, which is a form of green economy that can act not only as a means to bringing about sustainable use of resources but also as a vehicle to restore the original ecosystem this area had in the past. This paper describes the potentials, options and challenges of ASLNP as a demonstration site for green tourism.

Key words: Lake Abijata, Lake Shalla, Abijata-Shalla Lakes National Park, birds, ecotourism, green economy.

Introduction

Four to five decades ago, the section of the country between the towns of Mojo (Modjo) and Hawassa (Awassa) had far less people and it had picturesque nature. The abundant wildlife and splendid spreading of acacia trees gave this part of the country a breathtaking beauty. The attractive nature was unique and it didn't require a visionary to see that it would act as a center for tourism in the future. Entrepreneurs like Bekele Molla, were perhaps the first to perceive the assets and touristic values of the rift valley lakes. Emerging touristic ventures especially in the arena of providing hotels or lodges were on the way in the early 1970s in Ethiopia. At the same time, large groups of western visitors came to this area to experience Africa's wild nature and the astounding ethnic, cultural and historical assets of the local people were who also prime motivators for the growth of tourism. The creation of protected areas was primarily to satisfy the insatiable curiosity of the western tourists rather than the needs of local population residing in and around the protected areas. The creation of national parks, sanctuaries and wildlife reserves was introduced in Ethiopia at a much later date relative to other countries in Eastern Africa. When the time came, developing tourism by way of protecting specific areas was initially started with the aim of generating hard currency for the country. As a consequence, in those old times this action did not consider much what its impacts would be on the local population. As it continued to unfold, it carried with it the same philosophy of fencing off parks from local communities and virtually creating landscape islands. Protected areas always had criteria for establishment, which were usually based on biological or heritage values i.e. wildlife diversity, endemic species, culture and history rather than social values. Eventually, these criteria became central to the establishment of Ethiopian protected areas in the past. As a matter of consequence, conflicts between the local people and park conservation authorities stared to surface, making their roots in the dogmatic approach of establishing protected areas, such as the Abijata-Shalla Lakes National Park.

At establishment the central rift valley lakes, especially Lakes Abijata and Shalla, were earlier regarded as one of the finest sites for a diverse congregation of birds at one place. One of the significant features of this region is that it is dotted with a number of lakes. The origin, features, quality and structure of all the rift valley lakes is diverse. This diversity in their geomorphology and ecology has resulted in the richness and diversity of all sorts of tropical wildlife, including birdlife. The productivity of the aquatic systems and adjoining terrestrial ecosystems appears to be the main reason for the richness and diversity of the avian life. The teeming birdlife constituted of resident and migrant species, the cyclic and high productivity of *Spirulina* algae and Nile-tilapia, the flamingo-nesting sites of the islands of Lake Shalla, unique hot springs, and associated terrestrial habitats were primary factors for the establishment of this national park back in 1969. The rugged landscape around Lake Shalla, the isthmus between Abijata and Shalla, the Acacia-Euphorbia woodland around the lakes, the hot springs, lava caves add to the attraction of the park.

Abijata Shalla Lakes National Park (ASLNP) is located 200 km south of Addis Ababa within the Central Rift Valley of Ethiopia. Administratively, it is located in East Shoa Zone in Oromia Regional State. This national park was established to protect the diverse birdlife of the area. Out of an area of 887 km^2, 482 km^2 is comprised of wetlands and the rest 405 km^2 is terrestrial,with an altitude ranging from 1,500 - 2,075 m asl.It is classified in the upper sub-tropical agro-climatic type locally called referred to as "kolla" (EWNHS, 1997). Is annual rainfall ranges from 500-700 mm per annum and its mean annual temperature is 20.1°C. At rare and exceptional times the maximum temperature can go as high as 45°C and the minimum as low as 5°C during the night (EWNNS, 1997). Dominant vegetation types are *Acacia* savanna woodlands and *Acacia Euphorbia*. The park has 76 mammals, of which the Scott's Hairy Bat, White-toothed Shrew, Mahomet's Mouse, White-footed Rat, Ethiopian Grass Rat, and Harrington's Scrub Rat are endemic to Ethiopia (Mengistu and Yirmed, 1999). Larger mammals including the Grant's gazelle, Oribi, Black-backed Jackal, Warthog, Black and White Colobus Monkey, Anubis Baboon, Vervet monkey, and Klipspringer are known to occur in the park (Mengistu and Yirmed, 1999). Avian diversity is high and the number of species recorded to date is 436. Diversity in birds is a factor of the highly productive wetland system, the adjoining*Acacia* woodlands, and the dry hot weather. The White Pelican, Lesser Flamingo, and White-necked Cormorant are among the major bird species that are predominantly observed (EWNHS, 1997). The site holds more than 20,000 water birds on a regular basis. The national park has one endemic, six near endemics, four vulnerable, two threatened, 22 Afro-tropical and 24 Somali-Masai species (EWNHS, 1996, Mengistu and Yirmed, 1999).

Despite its richness in species diversity, the Abijatta-Shalla Lakes National Park faces a number of conservation challenges where the aggregate effect of threats could lead to the annihilation of biodiversity and total loss of accrued values. Most of the problems it faces are anthropogenic in character, and therefore, any mitigation measure intended to avert disaster will invariably need to consider the human element. The national park, since inception has been encroached by the local people. At the moment, people living inside the park, albeit living inside a national park, build houses, cultivate land, raise livestock, cut trees, make charcoal and collect mud and soil minerals from the lake. A soda ash factory inside the park is a commercial venture that is impacting Lake Abijata's quality and structure. This park in particular suffers overuse relative to other establishments as a result of highly fragile soils and its character of being a 'fresh water scarce' zone.

One way of averting the destruction of natural areas is to introduce ecotourism where the local population would benefit from the income generated. The UN Green Economy Report (UNEP, 2011) states that tourism can act as a major vehicle to transform programs like ASLNP. The report identifies tourism as a significant sector that can kick start the transition to a sustainable and inclusive green economy. Ecotourism is a more recent coinage and has to do more with trying to marry the diverse nature of the visitors, site and tour guides. While a number of preconditions are required to make tourism work, the general trend shows that sustainability and nature conservation can benefit tremendously from a strong tourism/eco-tour programs. Conservation can be assisted by tourism and there is an appreciation that they are intricately linked (Brandon, 1996). The major way in which tourism can assist conservation is through the provision of generating revenues that should be shared and used by all stakeholders with the inclusion of an agreed upon sum due to conservation efforts to sustain the operations.

Green Economy: An agenda for social and environment sustainability

The recent past has seen the world in a turmoil of financial crises that has left nations wondering what is next. The exigency has not only been financial, but also multidimensional including climate, biodiversity, food and water. The sum of problems has led scientists to come up with a new economic paradigm that would find solutions in a new development model known as "green economy", which is defined as A green economy is one which is low carbon, resource efficient and socially inclusive(UNEP/WTO, 2012). In other words, the definition suggests green economy as one that "results in improved human-wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP 2011).

This economic paradigm notes that tourism to be one of ten sectors that can energize the transition to a green economy. The UN Green Economy Report (2011) points out that substantial investment on sustainable use of water, energy and recycling and safe handling of wastes would motivate employment amongst deprived communities. Greening of tourism focuses on small to medium enterprises (SME) that require sound investment policies and financing for the envisaged program to take effect. This would have the effect of hiring and sourcing of jobs with a positive benefit to other parts of the economy.

Tourism world-wide is gaining momentum but at the same time its negative effects are being felt throughout. UNEP (2011) makes it clear that tourism is adding to the green-house gases (GHG) through travel, energy, waste management and water use. Plans to invest in green tourism will need to look at ways of reducing or averting the various mechanisms through which GHGs can be reduced.

Tourism: A key driver of the green economy

The prospect of tourism, as a major driver for the development of the global economy, is recognized globally (UNEP/UNWTO 2012). Tourism makes up to 5% of the global GDP and contributes approximately 8% of the total workforce. It is valued at one trillion USD per year globally and it ranks fourth in global income generation. It accounts for 30% and 6% of the world’s commercial services and total earnings, respectively. Tourism is considered to be among the five leading currency earners in over 150 countries. It is also the main source of foreign exchange for a third of all developing countries and a half of least developed countries (LDC). It is believed that travel and tourism is human resource dependent and, therefore, the opportunities for employment are enormous. It is anticipated that the employment potential of the sector will be reinforced by the greening of tourism, which requires efficiency in energy, water and waste handling. This will in effect increase local employment and reduce poverty. Greening of tourism is sustainable tourism that can be maintained over a long period of time by maintaining its dynamism of social, economic, cultural and environmental contexts (UNEP/UNWTO, 2012). Besides the direct employment benefits to society, tourism in the green economy ensures significant environmental benefits accrued from reductions in water consumption, energy use and CO_2 emissions.

There is perceptiveness now than ever that tourism and sustainable development go hand in hand (Eagles *et al*., 2002). With increasing evidence about the dangers of climate change on ecosystems, visitors are calling for sustainable destinations such as the ASLNP worldwide (Ringbeck *et al*., 2010). It is now apparent that governments and tour operators take environmental sustainability as a criterion for achieving the competitive edge in the tourism business (Ringbeck *et al*., 2010). Tourism can be an important driver for building a green economy but requires a strategy that takes into account the state of the environment and social settings.

Abijata-Shalla Lakes National Park: Opportunities for building a green economy

The opportunities in place at ASLNP are highly rated and potentially valuable for building a tourism-based green economy (sustainable tourism). The park and its surrounding ecosystems face some of the gravechallenges relative to other protected areas (EWNHS, 2000).At the same time, the biological value of the site is prominent. This gives all the reason to identify Abijata-Shalla area for interventions that would lessen pressures while at the same time saving the park. In this regard, it has been identified as a priority hotspot by the Ethiopian Wildlife and Natural History Society (EWNHS, 2000). The diverse birdlife, its proximity to major cities, access provided by an all-weather tarmac road, the presence of first-rate resorts on Lake Langano just across the road from ASLNP and accommodations in nearby towns all add up to justify upholding Abijata-Shalla area as a possible site for exercising greening of tourism. Furthermore, as an activity with a capacity for replication at a wider level, ASLNP can act as a demonstration site for experiments by researchers of all levels, and site-visits by different groups who aspire to undertake such activities in their respective areas.

Tourist flow to the park is relatively high albeit presently at a degraded state. This is partly accounted for by the fact that Abijata-Shalla is on the major bird-watching route that crosses the rift valley. Visitors who travel to watch birds into southern Ethiopia such as Wondo Genet, Bale Mountains, Neghelle, Yabello, Hawassa and Arba Minch will very often pay a visit to this section of the central rift valley. Visitors who want to maximize their bird sighting records usually enter the park to see both Flamingo species and a number of resident and migratory wader species. Trends show that the number of visitors to the park is growing from time to time (see Table 4.1). A program that envisages building on greening of tourism will have to seriously consider the lower tier sections of society to promote conservation and wellbeing of the environment in the long run (Brandon, 1996; Ashely, *et al.*, 2001; Eagles *et al.*, 2002)

Table4.1: Abijata-Shalla Lakes National Park: Visitor numbers and revenue over three years (2010-2012) (Source: Ethiopian Wildlife Conservation Authority)

Years	TotalNo. of visitors	Total revenue in ETB
2010	8,611	339,204.00
2011	10,181	563,810.00
2012	16,319	829,840.00

Interventions for building a green tourism at ASLNP

A green tourism scheme needs to pass through a number of stages. These stages are sequential building on the findings of the previous step. They can be seen as prerequisites to building a sustainable form of tourism in an area where stakeholders participate in its making. What should be known from the start is that any one site would not have similar settings and each would need to be dealt with on a case by case scenario. Destinations make the mistake of not truly assessing their situation and don't take into consideration the need to consult and work with stakeholders on site.

While there are several approaches, a straightforward strategy to build green tourism requires a three-tier process. Ringbeck *et al*. (2010) describes this process as:

1. A status assessment of the destination's environment
2. Developing a green strategy and 3).Collaborative execution of the green strategy.

Step 1: Assess the state of the environment

Carry out an environmental and social impact assessment to know short and long term actions. A baseline study will bring out the real issues that require attention and where the strategy should dwell upon. This could be in the form of an ESIA or environmental auditing that takes into consideration the major actors and their actions on the site.

Step 2: Planning the green strategy (Developing a road map for sustainability)

Develop an environmental strategy for the site. Create a site vision and goals taking the central theme of developing environmental sustainability. Destinations would next have to determine the impacts of the developed vision. The development of several green scenarios would have to be seen against the ecological, economic, commercial and social impacts they would have on the site. Is the vision comprehensive enough to address the needs of all stakeholders? Not the least, the vision should cover the impacts of the strategy on the environment and social conditions. A vision really is a green strategy scenario. The scenarios will reflect the balance between environmental welfare, expenses and the time needed to reach goals.

Step 3: Translating green strategy into action

A green tourism strategy aiming for a green transformation necessitates a holistic approach. It is essential for destinations to capture community interest, with active engagement of the government, private sector and civic society. While setting up a devoted establishment to manage environmental sustainability projects is mandatory, a collaborative approach is essential to forge the way forward. Yilma and Mengistu (2001) spell out the need to identify key stakeholders and form partnerships. According to this study the best management scenario would be a co-management of the site by government/community/private partnerships,each partner will have roles and responsibilities towards the conservation and wise use of the park. By the same token, a green tourism strategy should define the management structures before implementation of goals.

Abijata-Shalla Lakes National Park: Challenges and opportunities

ASLNP at present faces a number of environmental and social challenges. It appears that one problem has led to another and a lose-lose situation where both human livelihoods and the environment are now at risk. Having said this, it would be impertinent if there is no mention of government, private and civil society interventions in and around the park that are currently in place. These actions vary from research to community development from strengthening school nature clubs to rain harvesting. These actions have reasons and are objectively based. The actions are a mix of environmental and/or social treatments that try to develop human potential and strengthen livelihoods. However, these actions are isolated and need streamlining for effectiveness. Streamlining is essential as it can save time, effort and limited funding on project work. The biggest challenge towards the greening of tourism would be trying to get everyone onboard the bandwagon. Government would need to play a central role if not taking a leading position.

UNEP/UNWTO (2012), have produced a list of challenges that need to be addressed in any green tourism development locally. These include:

- Energy and greenhouse gas (GHG) emissions;
- Water consumption;
- Waste management;
- Loss of biological diversity;
- Effective management of built and cultural heritage; and
- Planning and governance.

All the challenges listed above are critical areas for which tourism globally is contributing its share. For instance, findings have confirmed that GHG produced by global tourism is significant and could be as high as 12.5% (UNEP/UNWTO, 2012). The task of planning for tourism becomes more complicated as a result of the economic crises that the world is facing presently.

In Africa and especially in Ethiopia, tourism can effectively become linked to poverty alleviation. Excellent examples of poverty alleviation where revenues from tourism have assisted alleviate poverty exist in various countries including Kenya, Rwanda, Zambia and Cape Verde. UNEP/UNWTO (2012), further give ideas on green tourism planning considerations for African conditions. These can apply to our case with some slight modifications. The main issues of concern include:

- Creating an enabling environment.

- Economic and financial issues
- The economy

Creating an enabling environment is in the arena of government and can include policy and legislation formulation, avoiding lengthy bureaucratic processes. Development of supporting infrastructure in transport, public health, communication, education, etc. to attract private entrepreneurs, there should be political stability, land tenure, suitable natural destinations, access and commitment. Local people would need to be exposed to and learn that tourism, specifically, eco-tourism is a positive intervention that cannot be done without their active participation and they should always ensure that it brings positive changes to their lives.

Conclusion

Birds or other wildlife should be seen as an option in the game of growth. These options allow us to prosper by placing us in an advantageous position relative to other places that don't have such resources. However, plenty our options are, unless we have the ability to come together to appreciate the common threads that hold communities and our societyat large, a program like green tourism will be another movement that will pass on without bringing change. Lake Abijata could be a good place to start, not only because of the diverse nature of the site, but because it provides a fertile condition to experiment a novel idea. Beyond this, such a project would allow us to save a globally famous hotspot. Green or sustainable tourism is promising but also not easy to plan and implement without the willful action oriented measures by all sections of society.

References

Brandon, K. (1996): Ecotourism and Conservation: A review of key issues. The World Bank, Environment Department, Washington, DC, USA. 80pp.

Ashely, C., Roe, D., and Goodwin, H. (2001): Pro-Poor Tourism Strategies: Making tourism work for the poor: A review of experience. Pro-Poor Tourism Report 1. ODI/IIED/CRT.64 pp.

EWNHS (Ethiopian Wildlife and Natural History Society) (1997): Important Bird Areas in Ethiopia: A first inventory. Ethiopian Wildlife and Natural History Society, Addis Ababa, Ethiopia, 300pp.

Mengistu Wondafrash and Yirmed Demeke (1999): Field survey report of Abijata-Shalla Lakes National Park. Unpublished technical report, 4pp.

Ringbeck, J., El-Adawi, Gautam, A. (2010): Green tourism: A road map for transformation. Booze and Co. Inc. 17 pp.

UNEP (2011): Tourism: Investing in energy and resource efficiency (UN Green Economy report). United Nations Environment Program. Nairobi, Kenya. 40 pp.

United Nations Environment Program and World Tourism Organization (2012): Tourism in the Green Economy – Background Report, UNWTO, Madrid.

Yilma D. Abebe and Mengistu Wondafrash (eds). (2000): Proceedings of the Workshop on Prioritization of Important Bird Areas for Conservation Action, 6th – 8th March, 2000. Ethiopian Wildlife and Natural History Society, Addis Ababa, Ethiopia.

Yilma D. Abebe and Mengistu Wondafrash (2001): Site Action Plan for Abijata-Shalla National Park, Ethiopian Wildlife and Natural History Society, Addis Ababa, Ethiopia. 97pp.

Greening a tropical Abijata-Shalla Lakes' National Park, Ethiopia

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Abstract

The aim of this review is to assess and document the status of Abijata-Shalla Lakes National Park (ASLNP) to investigate the possible causes for the water level reduction of Lake Abijata and to promote sustainable utilization of the Park. The Park was established to protect and conserve large number of water-birds that use Lake Abijata as feeding and Lake Shalla as nesting and breeding grounds. Actually, Lake Shalla is the continent's most important breeding colony of the great white pelicans. The Park also provides wintering ground and maintenance station for large number of birds including from Southern African, Sub-Saharan and Palaearctic species. Consequently, the Park was recommended for conservation to the Ramsar Conventionon wetlands. However, this natural heritage is currently deteriorating due to human encroachment, grazing by cattle, uncontrolled water abstraction and other anthropogenic activities .Since the 1980s, the water level of Lake Abijata has significantly dropped, fishery has totally collapsed, and birds such as Lesser Flamingos (*Phoeniconaias minor,* Geoffroy) and Great White Pelican *(Pelecanus onocrotalus roseus)* have been migrating to nearby lakes. Briefly, the lake is shrinking (so far by greater than 100 km^2) and facing imminent threats of collapse obliterating the existence of the Park. Despite the importance of the Park as one of the Important Bird and Biodiversity Areas (IBAs), it is currently in danger of disappearance. To improve this

deteriorating condition of the Park, I demonstrate here to use the resources of the Park within the framework of green economy, which protects ecosystem services and utilizes natural resource sustainably. I have also outlined a few recommendations for management measures to protect the ecosystems and the Park.

Keywords: eco-tourism, green economy, Lake Abijata, water-birds, rift valley lakes, soda ash.

1. Introduction

About 97% of the world's water is found in oceans while continental waters cover only about 3% (Fig. 5.1), of which the direct usable inland freshwater is tiny when compared to water resources available on the planet. Symbolically, if all of the world's water is represented by the length of a football stadium, the water essential for human life can be represented by a length of approximately 1 cm of the field. Although tiny, this is the fraction that is easily used, rapidly renewed, and is essential to life, as well asa key to agriculture, industries and domestic supply (Downing 2014). Interestingly, inland waters contain a richness of useful biodiversity disproportionate to its area coverage, of which <5% has been discovered and described, while a substantial fraction is disappearing (Ricciardi and Rasmussen 1999). In developing countries such as in Ethiopia, the biodiversity of the inland waters is poorly known while the rate of degradation of the environment is very high (Getahun and Stiassny 1998). Water quality degradation and pollution is wide-spread in the country. For instance, Eutrophication is a key water quality problem in some water bodies like Lake Koka where *Microcystis aerogenosa*, form frequent blooms, is affecting domestic consumption and its recreational values. Moreover, factories or industries discharge their effluents into the nearby aquatic ecosystems, apparently, with little treatment (Gebremariam and Desta 2002).

Habitat and ecosystem losses are also prevalent in the country. In actual facts, Ethiopia has painful experience regarding total loss of Lake Haramaya and other less popular ponds/lakes, streams and wetlands. Lake Haramaya, exposed to impacts of climate change like any other water system in the country, it disappeared due to unbalanced use of its fresh water. It was actually overused mainly for drinking and irrigation, while also used for fishing, recreation and washing. All these services have collapsed primarily due to human use (UNEP (no date) and Lemma 2003) and the local community has suffered from shortage of fresh water subsequent to the collapse of the lake. In addition, the biodiversity and its beautiful scenery have gone forever.

The ecological structure and functioning of lakes provide a wide range of services that can be valued in conventional monetary terms. However, many values, such as scenic, cultural, and biodiversity values, are more difficult to monetize or even quantify (Schallenberg *et al*. 2013) and these indirect values may have been overlooked during societal development plans and actions thereof.

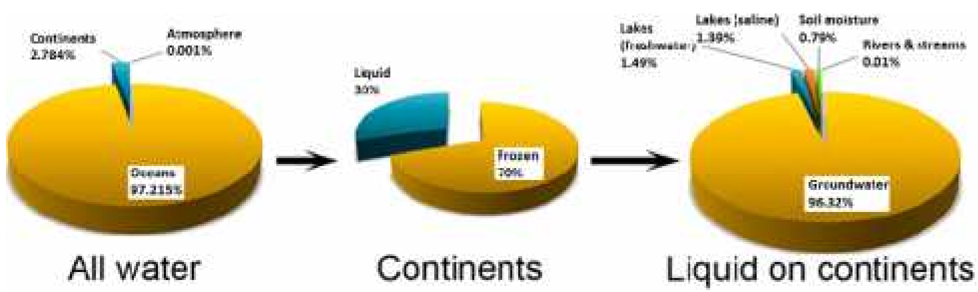

Fig. 5.1: Distribution of earth’s water (Downing 2014).

Inland waters have always been the most strategic resources in the past, present and the future (Downing 2014). Hence this country cannot afford to lose any more aquatic systems as they are unique resources with tremendous importance to the growing human population. However, it seems that the country is now on the verge of losing lakes Abijata, although it is officially protected as part of a national park by the name the Abijata-Shalla Lakes National Park (ASLNP), was established in the first place to protect and conserve the large number of water birds (e.g., great white pelicans, greater and lesser flamingos) that use Lake Abijata as feeding and Lake Shalla as nesting and breeding grounds Tefera and Almaw 2002). The islands of Lake Shalla are among the few nesting and breeding sites of pelicans found in Africa (UNESCO 2004). The Park provides wintering ground and maintenance station for large number of terrestrial and aquatic birds including Southern African, Sub-Saharan and Palaearctic species Legesse *et al*. 2005). Consequently, ASLNP was recommended to the Ramsar Convention on Wetlands as a candidate to be registered as an internationally important bird sanctuary for conservation (EWCO 1989).

Environmental valuation is used to monetize non–priced green goods and services, and accordingly the value of the Park is worth millions of dollars (Reaugh-Flower 2011) although it is currently deteriorating due to the presence of large numbers of households in the Park with a large number of domestic animals. Deforestation is pervasive, the water level of Lake Abijata has significantly diminished, fishery has totally disappeared, and birds such as lesser flamingos and pelicans have migrated away to other destinations (UNESCO (No Date), Reaugh-Flower 2011 and Ayenew 2002). The environmental conditions in the Park are worsening and the lake is shrinking eventually facing imminent collapse with all its services and benefits disappearing unless appropriate measures are immediately taken (Ayenew 2002).

The aim of this review is to assess and document the status of ASLNP as well as account for the possible causes of the reduction of the water level of Lake Abijata. The paper briefly discusses and enlightens the 5^{th} Crime against Peace – Ecocide, which is the destruction of large areas of the natural environment especially as a result of deliberate human action. This paper also promotes green economy as a way forward for sustainable utilization of natural resources of the Park. The rich biodiversity of the Park is a highway for Eco-Tourism Industry, *Arthrospira* production and other non-destructive revenue generating activities can be considered among others. Subsequent to the conclusions, a few recommendations for management measures are outlined as mechanisms to save the ecosystems and the Park.

2. Current Status of Abijata-Shalla Lakes National Park

According to IUCN, National Parks are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area. Hence, the primary objective of a National Park is to protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation (IUCN 2015). As a result, these protected public lands are prohibited to illegal hunting, livestock grazing, logging, mining, human residence and other activities that exploit natural resources.

However, the situation for ASLNP is different. There are more than 55, 000 people residing in the Park with a density of 10 people per household and consequently more than 40 km^2 of the parkland is converted into cultivated land. On average, each household has 18 domestic animals and overgrazing is visible. The vegetation cover in the Park has been reduced by more than 50% since the 1990s and is under severe threat due to demand for agricultural land and firewood. The biodiversity in the Park has diminished, and much of the savanna, riparian wetlands and dry forest ecosystems have been converted to farm and grazing lands [Reaugh-Flower 2011, and Estifanos 2008). The Park services such as food, water and raw materials (construction wood, wood for agriculture tools and household furniture, thatching grass, charcoal wood, firewood, animal fodder, etc.) are equally exploited by the residents in the Park and nearby villagers (Estifanos 2008), escalating the adverse pressure on the Park. Agriculture and livestock production are the main stay of the local people and all members of the villages consider the Park as their communal pasture area, and consequently the majority are disappointed by the mere designation of the area as a park (Kumssa and Bekele 2014)**.** ASLNP being one of the important bird and biodiversity areas (IBAs), it is under immediate danger of disappearance, requiring priority of protection as soon as now (see Important Bird Areas Factsheet).

The area of the Park is 887 km^2 and over half of which is covered by Lakes Abijata and Shalla. Nevertheless, Lake Abijata has shrunk some 100 km^2 from 194 km^2 in 1973 to 95 km^2 in 2006 (Fig. 5.2). Between 2000 and 2006 alone, the lake has lost 46% of its surface area (Vilalta 2010). Lake Abijata has lost some 6.5m height between 1985 and 2006, and 70% (~4.5 m) of the loss has been attributed to human-induced causes Seyoum *et al*. 2015).Briefly, the water level of Lake Abijata has significantly dropped since the 1980s, and most probably Lake Abijata will dry up soon unless appropriate measures are taken (Reaugh-Flower 2011). Lake Abijata is dying and while in the wake of the disappearance of Lake Abijata, Lake Shalla is being threatened with the prospects of soda ash production moving in its direction in search of saline-alkaline waters. All of this is happening under the watchful eyes and decision-makers, while research based-evidences are all out there for them for use.

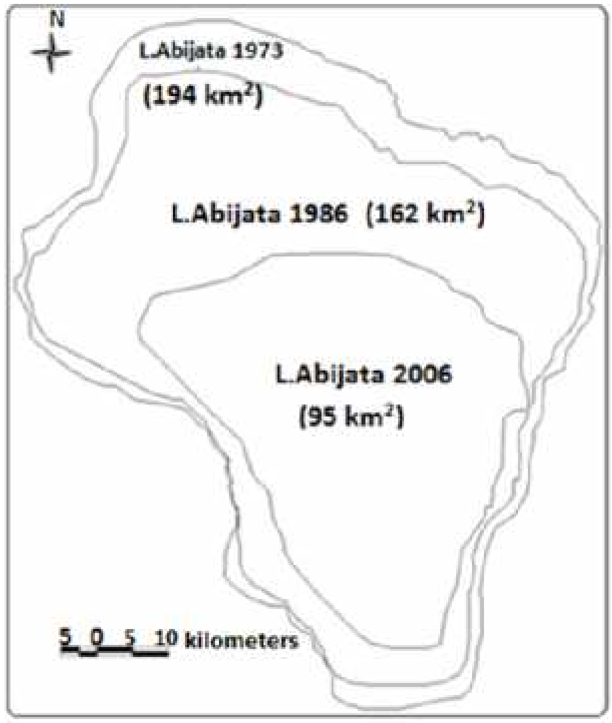

Fig. 5.2: Surface Area of Lake Abijata as obtained from satellite imagery (1973-2006) (See Important Bird Areas Factsheet)

2.1. Possible causes for water level reduction of Lake Abijata

The water level of Lake Abijata has significantly dropped since mid-1980s(see Fig. 5.2), which cannot be totally attributed to natural climatic variability and rainfall record (Temesgen *et al*. 2013). A recent study (Seyoum *et al*. 2015) showed that some 70% of the water loss from the lake was attributed to human-induced causes. Lake Abijata is a terminal lake, without visible surface water outflow, and is therefore more vulnerable to changes. The water budget of Lake Abijata is dependent on seasonal precipitation, river inflows from River Hora Kelo (contributing about 8% of the total inflows to the lake) and River Bulbula (an outflow from Lake Ziway)contributes the largest volume of water into Lake Abijata (Ayenew 2002). Hence, any intervention either on Lake Ziway or Bulbula affects the water budget of Lake Abijata. A number of irrigation projects on River Bulbula are underway and as a result the water flow in the Bulbula River is significantly reduced and at times during the peak periods of the dry seasons totally dries up (Ayenew 2002). Irrigation is the largest water user activity in the basin (Ayenew 2013 and Vilalta 2010) and hence large-scale irrigation agriculture from Lake Ziway, its tributaries, and the Bulbula River is used in the production of horticulture, vegetables, and flowers Seyoum *et al*. 2015).

In parallel, the Abijata Soda Ash Factory (ASAF) that collects water from Lake Abijata for soda ash production could also be the second possible anthropogenic cause for the water level reduction (Gebremariam 1998 and Kumssa and Bekele 2014). The factory was established by the Government of Ethiopia with a large production process that began in 1985 (Ayenew 2002). The factory has limited itself to produce trona ($Na_3H(CO_3)_2.2H_2O$). Currently, the factory is producing trona by pumping water from the lake into several evaporation ponds, numbering about 17 (Fig. 5.3). In this way, each year 13, 000,000 m^3 of water is removed from the lake (Ayenew 2002) and the amount of water removed can reach up to 30,000,000 m^3 per year (see below). Since the water extracted from the lake into the ponds does not return to the lake, the shore of Lake Abijata has been progressively receding for years. In around July 2002, the pump station was 215 meters away from the lake and only one year later (July 2003) it was 950 meters away (personal observation). Vilalta (2010) reported that Lake Abijata has receded 3 km from the pumping station and soda ash production has slowed down because of the excessive loss of water from the lake (Figs.5.4, 5.5).

Currently the factory produces on average, 4,500 tons of soda ash per year with a water requirement of 150 m^3 per ton of production (Vilalta 2010). The company plans to produce 200 thousand tons of soda ash per year requiring about 30,000,000 m^3 water to be sucked out of Lakes Abijata and Shalla. Intriguingly, the company is considering increasing the production to as much as 1 million tons per year, which is unrealistic for either Lake Abijata or Lake Shalla (Vilalta 2010). Or else, it would result in the worst environmental and economic tragedy ever seen in the country. Vilalta (2010) proposed 10,000 tons of soda ash production per year for acceptable lake level decline. The adverse impacts of Abijata Soda Ash Factory (ASAF) on the water level could have been known before it was initiated, if EIA was conducted.

Fig. 5.3: One of the evaporation ponds of Abijata-Shalla Soda Ash Factory.

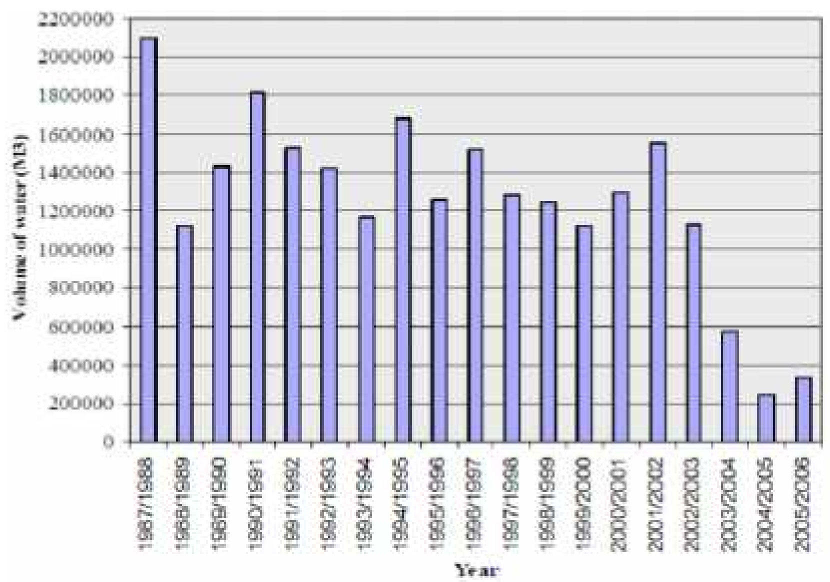

Fig. 5.4: Annual water use of Abijata-Shalla Soda Ash Factory from Lake Abijata: Years 1987-2006 (Estifanos 2008)

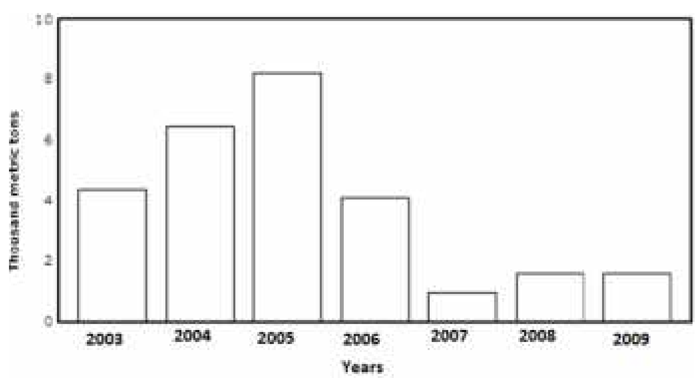

Fig. 5.5: Annual soda ash production by the Abijata Soda Ash Factory: 2003-2009 (Source:http:/www.indexmundi.com/minerals/?country=et&product=soda-ash&graph=production)

2.2. Physico-chemical and biological changes in Lake Abijata

Lake Abijata has shrunk by about 100 km^2 and has caused conspicuous physical, chemical and biological changes in the lake. Data since 1926 showed that the salinity has increased by more than 2.6 times (from 8.1 to 26 mg L^{-1}), alkalinity has changed from 80 to 326 mg L^{-1}, and pH varied between 9.5 and 10.1 (Ayenew 2002, Wood and Talling 1988 and Gebremariam 2003).

The lake was dominated by blue–green algae such as *Arthrospira fusiforms*, *Oocystis* and *Anabaenopsis* during 1960 to 1988 [Wood and Talling 1988 and Kumssa and Bekele 2014), 24]. *A. fusiformis* was a strongly dominant species usually found forming dense blooms at the surface of the water. However, it was gradually replaced by *Anabaenopsis* and diatoms subsequent to the establishment of the Soda Ash Factory (Kumssa and Bekele 2014 and Kebede and Willén 1996). This change in dominance of the phytoplankton species composition from *A. fusiformis* to *Anabaenopsis* species has affected the vast flock of lesser flamingos that depended on *A. fusiformis* as their primary food source. The numbers of the lesser flamingos has been greatly reduced at Lake Abijata as they migrated to the nearby Lake Chittu which is rich in *A. fusiformis* (Kebede 1997).

The lake was full of fish and commercial-scale fishing of Nile-tilapia (*Oreochromis niloticus*) was conducted at Lake Abijata, using gill nets and beach seines and transporting catches with trucks to nearby towns and cities, the furthest being Addis Ababa which is about 200 km away (Reaugh-Flower 2011 and see also Important Bird Areas Factsheet). However, Abdi (1993) noted the disappearance of fish and fishing effort from Lake Abijata in 1993, some 8 years after the establishment of the Soda Ash Factory. Currently, there are no fishes and fishery activity at Lake Abijata, which could be due to the decline in the water level of the lake, high salinity and associated effects (e.g., reduced breeding grounds for the tilapia, and osmotic stress due to high salt concentrations). As a result, piscivorous birds such as pelicans also moved to other lakes because of the absence of fish at Lake Abijata [UNESCO (No Date and see Important Bird Areas Factsheet).

2. Ecocide, the 5th Crime against Peace and Lake Abijata

Crimes against Humanity, War Crimes, Genocide and Crimes of Aggression are the existing four international crimes against peace. The fifth international crime against peace – Ecocide has been proposed to the United Nations (Higgins 2010). The legal definition of the proposed Ecocide is: "The extensive destruction, damage to or loss of ecosystem(s) of a given territory, whether by human agency or by other causes, to such an extent that peaceful enjoyment by the inhabitants of that territory has been severely diminished" (Higgins 2010).

Humans commit ecocide, when we destroy ecosystems. As we destroy the habitats and biodiversity, we also destroy our ability to live in that area. Recent investigations indicated that the fall of the Aksumite Empire in Ethiopia could have been due to environmental degradation (Terwilliger *et al*. 2011). The transformation of Lake Haramaya and other such waters in the country into terrestrial environments are vivid examples of the undesirable impact of humans on wetlands. Unfortunately, Lake Abijata is following the same course and several researchers have projected that Lake Abijata could dry up in the near future if humans do not change the current courses of action on the ground (Reaugh-Flower 2011). To avoid the impacts of this ecocide taking place at Lake Abijata, an alternative strategy should be green economy as a way forward to end the environmental degradation. Green economy initiative could generate substantial amount of revenue to the government and the local community while at the same time protecting the unique biodiversity of this fragile ecosystems.

3. Green Economy and Abijata-Shalla Lakes National Park

A green economy is one whose growth in income and employment is driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services (UNEP, No fate). Greening and green growth is the order of the day and probably the best known concept for sustainable development. To this end, Ethiopia aims to achieve carbon-neutral middle-income status before 2025 as per its Climate-Resilient Green Economy Strategy[1] document. Greening should include conserving ecosystems and greening industries as well as implementation of reforestation / afforestation programs.

ASLNP is worthy to be protected for green economy as well as biodiversity conservation. If we consider the ecosystem services and goods provided by the Park and convert it into monetary terms, the overall value ranges between US$ 15.9 million to 308.5 million per year (Reaugh-Flower 2011). I will briefly discuss the significance of natural resources and benefits of the Park to the local and national economy within the framework of green economy.

4.1. Ecotourism Industry

Sustainable development is an approach to economic planning that attempts to foster economic growth while preserving the quality of the environment for future generations. One of the most important areas of sustainable development is ecotourism. Ecotourism is defined as "responsible travel of tourists to natural areas that conserves the environment, sustains the well-being of the local people and involves interpretation and education" (TIES 2015).

[1] See also the Climate Resilient Green Economy Strategy document of the Ethiopian Government, which is available in the Web.

Tourism is usually called smokeless industry. Being a smokeless industry, tourism equals other competing activities in creating added value, but it is much less destructive and disruptive to the natural and human environment if properly managed by considering the competing interests of all stakeholders. In actual facts, the business volume of tourism equals or even surpasses that of oil exports, food products or automobiles. Tourism has become one of the major players in international commerce, and represents at the same time one of the main income sources for many developing countries (UNWTO 2015).

Tourism can be a source of economic development for Ethiopia, and the government and public should work hand-in-hand to develop the sector as the country has historical, cultural and natural heritages. Eco-tourism is in line with the government's policies, because Ethiopia aims to achieve carbon-neutral middle-income status before 2025 while developing a green economy, which allows protecting and conserving tourism destination places such as Abijata-Shalla Lakes National Park.

In the Park, a total of 436 bird species (among which 114 species are wetland birds) have been recorded including Lesser Flamingo *Phoeniconaias minor*, Greater Flamingo *Phoenicopterus roseus*, Northern Shoveler *Spatula clypeata*, Pied Avocet *Recurvirostra avosetta*, Eastern Yellow-billed Hornbill *Tockus flavirostris*, Great White Pelican *Pelecanus onocrotalus roseus* (Estifanos 2008 and see also Important Bird Areas Factsheet). It is also a stopover site for large number of birds that migrate from Europe down into Africa along the rift valley and back depending on the season of the year. The Park is therefore a vital international migration route for migratory bird.

Of the birds, Lesser Flamingos are the major tourist attractions [Brown and Urban 1969 and Vareschi 1982), 34]. This species feeds primarily on *A. fusiformis*, which grows exclusively in very saline-alkaline lakes such as Lake Abijata. Hence, Lake Abijata is a source of food for the Lesser

Flamingos while Lake Shalla is the breeding ground for these birds. Lake Shalla, the deepest Lake in Ethiopia (with 266 m of maximum depth), is the continent's most important breeding place for a large colony of great white pelicans (Krienitz *et al*. 2003). Stephenson [36] considered Lake Shalla the second-most important of eight regular pelican breeding grounds of the whole of Africa. In fact, the lake has eight islands including Pelican Island which indicates it's a breeding site. For successful breeding, fish food and difficult to access by humans make this site a safe breeding-ground of choice for the birds and these conditions are met at the Lake Shalla colony (Krienitz *et al*. 20013).

The magnificent views of the lakes, the biodiversity (such as abundant number of bird species and mammals) and the close proximity of the Park to Addis Ababa with first class tarmac road attract visitors. In addition to that, its position alongside with other touristic destinations such as Lakes Langano, Hawassa, Arba-Minch Nechi-Sar Park are some of the underlying factors that attract visitors even though the Park is not well managed.

Table 5.1: Number of visitors and total revenue of Abijata-Shalla National Park from year 1980-1992 (Source: Ethiopian Wildlife Conservation Authority (EWCA).

Types of visitors	Number of visitors	Total revenue (in birr)
Students	8,005	
Adults	39,037	
Foreigners but residing in Ethiopia	15,912	
Foreigners	33,805	
Total	**96,759**	**2,322,769**

The number of visitors and collected revenue is comparable with other national parks (Tables 1 and 2). Estifanos (2008) analyzed the number of visitors from 1999/2000 to 2006/07 and found that the revenue has increased by approximately three folds. This demonstrates that if the condition of the Park is improved and appropriate services are installed, the revenue that could be gained from the Park could increase significantly. Eco-tourism is not only a lucrative business, but also sustainable and environmental friendly undertaking provided its management is participatory and dynamic that proactively operates by considering changes as they come. Estifanos (Estifanos 2008) found out that 71.4% of the foreigners and 28.4% of the local visitors who visited the Park were engaged in research in one or other environmental issues. Several students belonging to various national and high schools and universities have also visited the Park through educational tour programs.

Table 5.2: Number of visitors to different national parks and total revenues (in Birr) in 2002 (Source: Ethiopian Wildlife Conservation Authority (EWCA).

Name of Parks	Number of visitors	Revenue
Awash National Park	9363	604,589
Abijata-Shalla National Park	8611	359,599
Bale Mountain National Park	3955	347,014
Simien Mountains National Park	14016	3,154,216
Total	**35,945**	**4,465,418**

The practices of ecotourism and sustainable tourism have the potential to assist in conserving natural areas, alleviating poverty and revenue generation, empowering women, enhancing education, and improving the health and wellbeing of local communities. World tourism is recognized as the world's largest industry with 6 trillion USD in 2011 globally. It is also the world's largest employer, generating 260 million jobs, or nearly 1 out of every 12 jobs globally (Bricker *et al*. 2013), which demonstrates that ASLNP can offer lots of jobs and absorb large number of employees other than employees from Soda Ash Company. Unfortunately, the contribution of tourism to economic wellbeing of communities depends on the quality of the tourism and the revenue that could be generated Bricker *et al*. 2013). Hence, ASLNP should be prohibited from human residence, livestock grazing, logging, mining (soda ash), and other activities taking place in the Park. Furthermore, the Park demands rehabilitation and conservation programs, which can be performed by the government together with the community and the professionals.

4.2. Production of *Arthrospira fusiformis*

*Arthrospira fusiformi*s is a characteristic feature of soda lakes in tropical Africa forming persistent and almost uni-algal blooms (Kebede 1997, Vareschi 1982 and Melack 1979). It has been the focus of interest among researchers due to its overall nutritional qualities to humans and animals as is rich with proteins (60 to 70 % of dry weight), fatty acids (gamma-linoleic acid-GLA), essential amino acids, and vitamins (high B12 content), and hence its commercial importance. The species has also therapeutic effects against hyperlipidemia, nephrotoxicity, diabetes, obesity and hypertension (Gershwin and Belay 2007 and Richmond 1988). As a result of all these benefits, it is considered as 'health food,' as well as declared as best and cheap food to combat hunger and malnutrition in developing countries (UN 2005). This alga forms a dominant population in the saline-alkaline lakes of Ethiopia particularly lakes Abijata, Chittu and Arenguade. *A. fusiformis* was the most abundant alga in Lake Abijata (Kumssa and Bekele 2014).

*A. fusiformis*is also the major food source for the large number of Lesser Flamingo and accordingly the species were considered as non-toxic alga for a long period of time (Ciferri 1983 and Jassby 1988). However, Ballot *et al*. (2005) observed toxic and non-toxic *Arthrospira spp.*, while Krienitz *et al*. (2005) found toxic strains of *Arhrospira fusiformis* isolated from Kenyan lakes. Many Lesser Flamingos have died in East African saline-alkaline lakes of Kenya (30, 000 have died in Lake Bogoria, (Vick 2000) and Tanzania (43, 800 in Lake Manyara, (Keonig 2006)). The toxicity of *Arthrospira spp.* was the cause for these deaths, because this is the major food of Lesser Flamingos. To my best knowledge, there had never been any massive deaths of Lesser Flamingos in Ethiopia.

Producing *A. fusiformis* is part of the green economy undertaking and it can be produced both for commercial purpose in mass cultures as well as for combating hunger and malnutrition in small scale farms at community levels. Mass cultures of *A. fusiformis* exist in the USA, Thailand, India, China, and other countries. For instance, in China 19,080 tons of *A. fusiformis* was first produced in 2003 and rose sharply to 41,570 tons in 2004, worth around 7.6 million USD and 16.6 million USD, respectively (FAO 2008). In Ethiopia, the cost of nutrient media for biomass production can be significantly reduced by using saline-alkanine water of lakes with the appropriate pH and temperature. In a recent laboratory experimental studies Ogato *et al*.(2014) demonstrated that 25 % and 50 % supplemented Lake Shalla waters can be used to produce *A. fusiformis* mass production, thereby reducing the cost of nutrients by 75 % and 50 %, respectively. Mass cultivation of *A. fusiformis*has been ongoing on the shore of Lake Shalla (Reaugh-Flower 2011), which can be scaled-up to a marketable quality and quantity.

4.3. Methane for energy production

Lake Shalla is one of those exceptionally deep soda lakes in Africa (max. depth of 266m) and in comparative terms one of the least investigated and understood lakes in the country. Solar radiation vertically reaches few meters depth and the euphotic depth of Lake Shalla is about 5m (Melack 1988), leaving the greater depths of the lake in darkness. Organic matter in this dark region produces methane (CH_4) due to anaerobic biological organisms. Biogenic methane is produced by the activities of methanogens, a strictly anaerobic metabolic group belonging to the *Archaea* (Borrel *et al*. 2011) group. Electricity is now produced from methane in Rwanda directly from

Lake Kivu, and Rwanda is the first country to harness energy in such a fashion (Doevenspeck 2007). Since Lake Shalla has not yet been studied in this respect, it is prime time now to do the same. But this is one reason why we should maintain and protect ecosystems, not to lose ecological services without recognizing their values.

5. Conclusion

The condition of ASLNP is deteriorating largely due to anthropogenic interventions: human residence, agricultural practices, uncontrolled water abstractions and diversions of feeder-rivers and other activities. The water level of Lake Abijata has significantly dropped (receded by about 100 km^2), reducing the total lake size to about half of its original size. Consequently, the physico-chemical and biological variables have changed and even some organisms have vanished. The phytoplankton species composition has switched from *Arthrospira fusiformis* to other species such as *Anabaenopsis spp.*, Nile-tilapia has practically disappeared and fishery of lake Abijata has collapsed, and subsequently Lesser Flamingos and Pelicans have migrated away to other saline-alkaline lakes within and outside Ethiopia.

Protecting and conserving the Park is protecting biodiversity, habitats and nature as well as protecting the tourist industry, which is considered as the sustainable, smokeless and green economy. The ecological services of ASLNP include provisioning services (food, freshwater, raw materials and medicinal resources), regulating services, supporting services and cultural services (See important Bird Areas Factsheet). The Park's living resources have been valued at 15.9 million USD to 308.5 million USD per year (Reaugh-Flower 2011). However, activities in the Park are not in line with sustainable utilization of these resources.

Restoration can only be possible before the ecological damage beyond the resilience capacity (threshold) of the lake. Any action that may be taken after the resilience point is passed will be extremely costly and there will not be any guarantee situations would return to normal. The Government of Ethiopia has policies, strategies, proclamations and development programs to promote sustainable and equitable utilization of the available water resources (Vilalta 2010), including the Climate Resilient Green Economy Strategy. Therefore, the country should practice and implement its novel ideas and policies and should protect and conserve all water resources at large and Lakes Abijata and Shalla in particular so as to conserve them for the future generations. This paper provides baseline information on the condition of ASLNP and could initiate action to save Lake Abijata and the Park.

6. Recommendations

Some recommendations for the implementation of sustainable management of ASLNP are outlined below:

6.1. Environmental and Social Impact Assessment (ESIA) should be conducted for the Soda Ash Company as it part of the overall environmental setup of the ASLNP. This assessment should re-visit what had happened in the past and include the prevailing and changing situations of the present.

6.2. The Soda Ash Company is planning to use Lake Shalla as the water level of Lake Abijata has reached to a point where pumping is not possible anymore. If this action is taken without first ESIA on Lake Abijata, it would be repeating the same error at a higher magnitude as the next phase of the factory expansion will be at a much higher scale.

6.3. Uncontrolled water abstraction from Lake Ziway and the irrigation scheme on River Bulbula significantly affects the water level of Lake Abijata (Ayenew 2002). Hence, the minimum water flow on River Bulbula should be maintained so that Lake Abijata continues to receive inflows to sustain its ecological operations. To this end, integrated water resource management studies in consultation all stakeholders at basin-wide scale should be a cornerstone of saving Lake Abijata.

6.4. It is essential to assess all possible driving factors and acknowledge all stakeholders with different interests and promote sustainable utilization of the resources.

6.5. The Park should be prohibited for agricultural practices (crop cultivations and animal husbandry), logging, mining, human residence, illegal hunting, and other activities that exploit natural resources so as to endorse its park status.

6.6. Ecological restoration of the Park in general and Lake Abijata in particular should start as soon as possible as it will assist the recovery of an ecosystem that has been degraded, damaged, or destroyed (Melack 1988). Only then, would Eco-tourism becomes ecologically and economically feasible.

6.7. Agriculture and livestock production are the main stay of the local people (Kumssa and Bekele 2014) and any eviction of the inhabitants from the Park should be compensated in favor of the communities. Substitute arable land, establishment fund, infrastructure and transportation should be provided for compensation.

6.8. The operations of the Soda Ash Factory should be limited to sustainable levels.

6.9. The establishment of “eco-” lodges and eco-friendly recreational centers (eco-restaurants, earthen swimming pool and eco-terraces) within the reach of the Park are necessary to create “green jobs” to some sectors of the local community and revenues are generated to support the national economy, local communities and even to monitor and manage the ASLNP sustainably.

6.10. Finally, the crosscutting issue of climate change and its impacts on wetlands must always be monitored and incorporated in the planning and management of the “green economy” business of the ASLNP.

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References

Abdi, M. (1993): Impact of Human Activity on Abijata-Shalla Lakes National Park Ecosystem. MSc thesis.Agricultural University of Norway.

Ayenew, T. (2002): Recent changes in the level of Lake Abijata, central main Ethiopian Rift. *Hydrological Sciences Journal* 47: 493-503.

Ballot, A., Pflugmacher, S., Wiegand, C., Kotut, K., and Krienitz, L. (2005): Cyanobacteria and cyanobacterial toxins in the crater lakes Sonachi and Simbi, Kenya. *Harmful Algae* 4:139–150.

Borrel, G., Jézéquel, D., Biderre-Petit, C., Morel-Desrosiers, N., Morel, J. P., Peyret, P., Fonty, G. and Lehours, A. C. (2011): Production and consumption of methane in freshwater lake ecosystems. *Research in Microbiology* 162:832–847.

Bricker, K., Black, R. and Cottrell, S. (2013): Sustainable Tourism and The Millennium Development Goals: Effecting Positive Change. Jones and Bartlett Learning, LLC.

Brown, L.H. and Urban, E. K. (1969): The Breeding Biology of The Great White Pelican *Pelecanus onocrotalus roseus* at Lake Shalla, Ethiopia. *IBIS* 3:199-237.

Ciferri, O. (1983): *Spirulina* the edible microorganism. *Microbiol. Rev*.47: 551–578.

Doevenspeck, M. (2007): Lake Kivu’s methane gas: natural risk, or source of energy and political security? *Afrika Spectrum* 42: 95-110

Downing, J. A. (2014): Limnology and oceanography: two estranged twins reuniting by global change. *Inland Waters* 4: 215-232.

Estifanos, K. T. (2008): Integrated assessment of ecosystem services and stakeholder analysis of Abijata-Shalla Lakes National Park, Ethiopia. MSc Thesis in Environmental Sciences.Wageningen University.

EWCO (1989): Agro-Ecological Zonation Study. Ethiopian Wildlife Conservation Organization Addis Ababa, Ethiopia.

FAO (Food and Agriculture Organization of the United nations) (2008): A review on culture, production and use of *Spirulina* as food for humans and feeds for domestic animals. Food and Agriculture Organization of the United Nations, Rome.

Gebremariam, Z. (1998): Human interactions and water quality in the horn of Africa. In: Proceedings of the Symposium on Emerging Water Management Issues, Philadelphia, February 1998.

Gebremariam, Z. (2002): The effects of wet and dry seasons on concentrations of solutes and phytoplankton biomass in seven Ethiopian rift-valley lakes. *Limnologica* 32**,** 169-179.

Gebremariam, Z.and Desta, Z. (2002): The chemical composition of the effluent from Awasa Textile Factory and its effects on aquatic biota. – *SINET: Ethiop. J. Sci*. **25:**263-274.

Gershwin, M. E. and Belay, A. (2007): *Spirulina* in Human Nutrition and Health. Taylor & Francis Group, LLC.

Getahun, A. and Stiassny, M. L. J, (1998): The freshwater biodiversity crisis: the case of the Ethiopian fish fauna. SINET: *Ethiopian Journal of Sciences* 21(2): 207-230.

Higgins, P. (2010): Eradicating Ecocide: Laws and Governance to Stop the Destruction of the Planet. Shepheard-Walwyn Ltd, London. http://www.epa.gov/earlink1/ earthlink/00janfeb.htm

Important Bird Areas factsheet: Abijatta - Shalla Lakes National Park, Bird Life International websitehttp://www.birdlife.org/ (accessed 16 September 2015).

IUCN(2015):http://www.iucn.org/about/work/programmes/gpaphome/gpap _quality/gpap_pacategories/gpap_pacategory2/. (Retrieved on 09 March 2015**)**.

Jassby, A. (1988): *Spirulina*: a model for microalgae as human food. pp. 149–179. In: C. A. Lembi & J. R. Waaland (eds.) Algae and Human Affairs. Cambridge University Press, Cambridge.

Kebede, E. (1997): Response of *Spirulina platensis* (*Arthrospira fusiformis*) from Lake Chitu, Ethiopia, to salinity stress from sodium salts. *Journal of Applied Phycology* 9: 551-558.

Kebede, E. and Willén, E. (1996): *Anabaenopsis abijatae*, a new cyanophyte from Lake Abijata, an alkaline-saline lake in the Ethiopian Rift Valley. *Algological Studies*80:1-8.

Kelly, D. and McDowall, R. (2004): Littoral invertebrate and fish communities. In: Harding J, Mosely P, Pearson C, Sorrell B (eds) *Freshwaters of New Zealand*. Christchurch, The Caxton Press. Pp. 25.1 – 25.14.

Keonig, R. (2006): The pink death: die-offs of the Lesser Flamingo raise concern. *Science* 313: 1724–1725.

Krienitz, L., Ballot, A., Casper, P., Codd, G. A., Kotut, K., Metcalf, J., Morrison, L., Pflugmacher, S. and Wiegand, C. (2005): Contribution of toxic cyanobacteria to massive deaths of Lesser Flamingos at saline–alkaline lakes of Kenya. *Verh Internat Verein Limnol*. 29:783–786.

Krienitz, L., Ballot, A., Kotut, K., Wiegand, C., Putz, S., Metcalf, J. S., Codd, G. A. and Pflugmacher, S. (2003): Contribution of hot spring cyanobacteria to the mysterious deaths of Lesser Flamingos at Lake Bogoria, Kenya. *FEMS Microbiology Ecology* 43: 141–148.

Kumssa T. and Bekele, A. (2014): Phytoplankton Composition and Physico-Chemical Parameters Study in Water Bodies of Abijata-Shalla Lakes National Park (ASLNP), Ethiopia. *Greener Journal of Biological* 4 (2): 069-076.

Kumssa, T. and Bekele, A. (2014):Attitude and Perceptions of Local Residents toward theProtected Area of Abijata-Shalla Lakes National Park (ASLNP), Ethiopia. *Ecosystem and Ecography*4: 138. doi: 10.4172/2157-7625.1000138.

Legesse, D., Woldu, Z., Mebrate, A., Mengistou, S. and Ayenew, T. (2005): A Review of the Current Status and an Outline of a Future Management Plan for Lakes Abijata and Ziway. The Federal Government of Ethiopia; Oromia Environmental Protection Office.

Lemma, B. (2003): Ecological changes in two Ethiopian lakes caused by contrasting human intervention. *Limnologica* 33: 44-53.

Melack, J. (1979): Photosynthesis and growth of *Spirulina platensis* (Cyanophyta) in an equatorial lake (Lake Simbi, Kenya). *Limnology and Oceanography* 24: 753-760

Melack, J. (ed) (1988): Saline Lakes: Proceedings of the Third International Symposium on Inland Saline Lakes, held at Nairobi, Kenya, August 1985. *Developments in Hydrobiology* 44: 1-265.

Ogato, T., Kifle, D., Fetahi, T. and Sitotaw, B. (2014): Evaluation of growth and biomass production of *Arthrospira* (*Spirulina*) *fusiformis* in laboratory cultures using waters from the Ethiopian soda lakes Chitu and Shalla. *Journal of Applied Phycology* 26(6): 2273-2282.

Reaugh-Flower, K. (2011): Abijata-Shalla Lakes National Park. Assessment of Factors Driving Environmental Change for Management Decision-Making.Report to the Ethiopian Wildlife Conservation Authority's Sustainable Development of the Protected Area System of Ethiopia Program. January 2011. 81pp.

Ricciardi, A. and Rasmussen, J. (1999): Extinction rates of North American freshwater fauna. *Conservation Biology* 13: 1220-1222.

Richmond, A. (1988): *Spirulina* pp. 85-121. In: M. A. Borowitzka and L. J. Borowitzka (eds) Micro-algal Biotechnology. Cambridge University Press, Cambridge.

Schallenberg, M., de Winton, M. D., Verburg, P., Kelly, D. J., Hamill, K. D. and Hamilton, D. P. (2013): Ecosystem services of lakes. In: J.R. Dymond (ed) *Ecosystem services in New Zealand – conditions and trends.*Manaaki Whenua Press, Lincoln, New Zealand.Society for Ecological Restoration International Science & Policy Working Group, 2004.

Seyoum, W. M., Milewski, A. M. and Durham, M. C. (2015): Understanding the relative impacts of natural processes and human activities on the hydrology of the Central Rift Valley lakes, East Africa. *Hydrological Processes* 29, 4312–4324 DOI: 10.1002/hyp.10490.

Stephenson, J. G. (1978): An Appraisal of the Conservation of Nature in the Lakes Abijiata and Shalla Locality with Recommendations. EWCO Addis Ababa, Ethiopia.

Tefera, F. and Almaw, R. (2002): Conservation and Management Issues of Abijata-Shalla Lakes National Park. Addis Ababa, Ethiopia. Oromiya Natural Resources Conservation and Environmental Protection Authority.

Temesgen, H., Nyssen, J., Zenebe, A., Haregeweyn, N., Kindu, M., Lemenih, M. and Haile, M. (2013): Ecological succession and land use changes in a lake retreat area (Main Ethiopian Rift Valley). *Journal of Arid Environments* 91: 53-60.

Terwilliger, V. J., Eshetu, Z., Huang, Y., Alexandre, M., Umer, M. and Gebru, T. (2011): Local variation in climate and land use during the time of the major kingdoms of the Tigray Plateau in Ethiopia and Eritrea. *Catena* 85: 130–143.

TIES (2015): https://www.ecotourism.org/what-is-ecotourism.

UN (2005): http://www.un.org/ga/60/second/draftproposals.htm (Accessed on 12 June 2015).

UNEP (United Nations Environment Program) (No publication yaer): Lake Alemaya. Environmental Change Hotspots.Division of Early Warning and Assessment (DEWA). United Nations Environment Program (UNEP). <http://na.unep.net/atlas /webatlas.php?id=2173> (Accessed on 08 April 2015).

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2004):World Water Assessment Program: National water Development Report for Ethiopia. Addis Ababa, UNWTO (United Nations World Tourism Organization) (2015):Vareschi E (1982): The ecology of Lake Nakuru (Kenya) III. Abiotic factors and primary production.*Oecologia* 55: 81-101.

Vareschi, E. (1982): The ecology of Lake Nakuru (Kenya) III. Abiotic factors and primary production.*Oecologia* 55: 81-101.

Vick, K. (2000): Kenya's pink death. Washington Post, March 7, 2000: A12.

Vilalta, E. R. (2010): Water resources management in the Central rift valley of Ethiopia. MSc thesis, Barcelona, Spain.

Wood, R. B. and Talling, J. F. (1988): Chemical and algal relationships in a salinity series of Ethiopian inland waters. *Hydrobiologia*158:29–67.

Spatio-temporal lake-level changes of Lake Abijata in the Main Ethiopian Rift using earth observation satellite images for the last four decades

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Abstract

Satellite images have important roles for lakes management and the measurement of the spatio-temporal variation of lakes in size and shape. However, there are still some gaps in the scientific assessment methods, specifically utilization of satellite images from observation of Ethiopian lakes to compare them with earlier studies on lake-level changes. Therefore, this research aims on the spatial and temporal variability of decadal lake-level changes of Lake Abijata, using Landsat satellites images. The images were acquired for years 1972, 1984, 1995, 2003 and 2015. Then, these images were pre-processed and enhanced for the extraction of Lake Abijata's boundary. The result showed that in 1972, Lake Abijata has spatial extent or area of 198.4 km^2 and declined to an area of 179.2 km^2 and 150.6 km^2 in years 1984 and 1994, respectively. Then, the decline of the lake-level continued from the year 2003 to 2015 and the surface area of the lake was reduced to 144.9 km^2 and 131.8 km^2, respectively. That is, Lake Abijata shrunk to 66.6 km^2 surface area from year 1972 to 2015. Moreover, the decline of the lake is mainly on the northwestern direction with a distance of 3.64 km and in the southeastern direction the lake-level shifted to the center by 1.267 km over the last four decades. Thus, this research confirmed that Lake Abijata is a drastically shrinking or decreasing lake in the Main

Ethiopian Rift. This research has a great significance for decision makers in order to elucidate the spatial variation of lake-level changes of Lake Abijata over the last four decades and could be vital for mitigation and decision making, especially for environmental impact assessment and for better management of the lakes environment.

Key words: Remote sensing, Lake Abijata, lake-level changes, Landsat Satellite images

1. Introduction

A satellite-based remote sensing has enormous advantages and applications for Earth Sciences, because it can track land surface information in real-time macroscopically, multi-temporally, multi-spectrally, dynamically and repetitively (Jawak *et al.* 2015). Remote sensing is the acquisition and analysis of data about an object or area acquired from a device that is not in contact with the object or area, for example, earth. Most of the remote sensor devices are placed in earth-observing satellites and both high and low flying aircrafts (Fischer and Getis 2010). Earth observation satellites are satellites specifically designed for Earth observation from orbit, intended for non-military uses such as environmental monitoring, meteorology; map-making to monitor disasters to explore resources and others. These satellite images have an important role for lake management in both quality of the water and the spatio-temporal variation of the lakes size and shape besides their applications in water resources investigations. Surface water supply reservoir (lakes and reservoirs) mapping and monitoring, drainage network mapping, and watershed characterization are a few of those that depend on satellite images (Khorram *et al*. 2012).

The lakes/water bodies have been mapped using different earth-observing satellite imagery (Hui *et al*. 2008) as for example, measurement of the change of water bodies and their catchments, in terms of distribution and variation (Ouma and Tateishi 2007). One of the changes in water bodies (lakes) is the lake-level change that is described as the surface water-level change resulting from the shifting of water balance from its static state and this could be due to climate change and other natural and anthropogenic factors (Tenalem Ayenew 2002 and Xuchun *et al.* 2014).

The level of several Ethiopian lakes is changing drastically - either increasing or decreasing in surface area. Lake Beseka is rapidly increasing in water level or surface area (Megersa Olumana Dinka, 2012a) and Lakes Abijata, Chamo and Abaya, have shown significant decrease in water level over time (Tenalem Ayenew, 2002). Even though, there were many studies by researchers about the lake-level change in Ethiopia, there is still a gap on the scientific assessment methods of showing the lake-level change. Therefore, this research paper aims to show spatial variability in terms of lake-level change of Lake Abijata using earth observation satellites images with ten years interval for the last four decades.

These lakes have great importance in the development of economic, environmental and social programs for Ethiopia. Apart from these, the lakes have an immense role on the economic growth of the country and for the livelihoods of the surrounding communities (Seifemichael Abebe *et al.*, 2014). As a result, this research has a great significance to decision makers in order to elucidate the spatial variation of lake-level change of Lake Abijata for the last four decades. The information could be vital for mitigation and decision making on environmental impacts on the lake and for a better management of the lakes environment.

2. Study Area

The study area is located between 7.32° N to 7.45° N and 38.29° E to 38.42° E, in the Main Ethiopian Rift (MER), specifically MER lakes region. Main

Ethiopian Rift is a part of Ethiopian Rift Valley, which bisects Ethiopia land into two main physiographic segments (Corti 2009). MER has three subdivisions geographically: Northern MER, Central MER, and Southern MER. The Abijata lake is one of the lakes in Central MER besides Lakes Langano and Shalla (also Shala in the literature), which are situated East and South-West of Lake Abijata, respectively (Fig. 6.1).

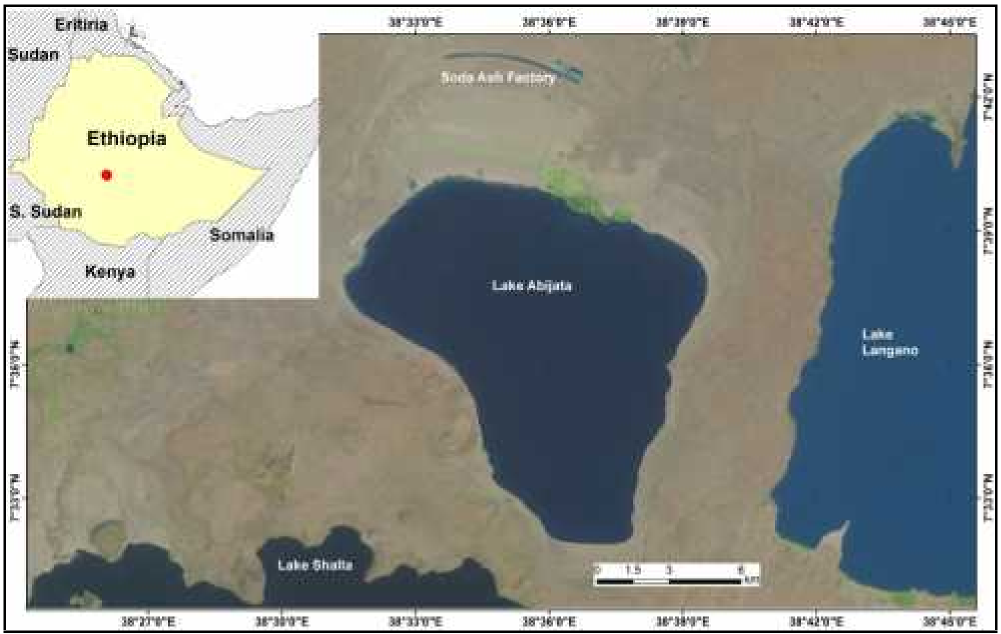

Fig. 6.1: Study area location showing Lake Abijaya with Lake Langano and Shalla in Landsat 8 satellite image acquired in 2015.

3. Materials and Methods

This study applied a remote sensing approach, in which satellite imagery integrating with field data, were analyzed using advanced image processing techniques (Fig. 5.2). Firstly, five earth observation satellite data were acquired in approximately ten-year intervals from 1972-2015 in order to get image with the same season and less cloud cover of the area. Secondly, these images were pre-processed such as sub-setting using pre-processing techniques. Thirdly, the lake boundaries of each year were extracted from the satellite images. Then, area and perimeters of the lake for each year images were calculated and tabulated in Geographic Information System (GIS) platform. Finally, the lake-level change of Lake Abijata was analyzed and validated from field observation.

3.1. Materials

3.1.1. Earth Observation Satellite data

The satellite image data that were used for the lake-level change of Lake Abijata was Land satellite (Landsat) images. These satellites have been collecting multispectral images of Earth from space since 1972 each image contains multiple bands of spectral information which may require significant pre-processing in order to get the valuable image for different applications. In order to ease this significant time taking pre-processing, these images became available for users with natural color composites of multi-spectral images. These images are full resolution files derived from Landsat Level 1 data products, in which the geometric and radiometric correction were done before distributing to the users (USGS, 2015). The natural color image is a composite of three bands are to show a natural looking ("false color") image. Reflectance values were calculated from the calibrated scaled digital number (DN) of the source image data. The band combination for the natural color or false color composite is different on the Landsat series based on the band arrangement and combination (Table 6.1). The Landsat program is the longest-running enterprise for acquisition of satellite imagery of Earth (USGS, 2015). Landsat images band combination of natural colors were dependent on the sensors type and the description of bands also varied as shown in Table 6.1.

The Multispectral Scanner (MSS) sensor was launched on-board Landsat 1–5 starting from July 1972 to January 1999 (Levin, 1999). Most of the scenes are processed with Standard Terrain Correction (Level 1T) and the revisiting date of this sensor is 18 days (Gyanesh *et al.*, 2009). The Landsat Thematic Mapper (TM) sensor was carried onboard Landsat 4 and 5 from July 1982 to May 2012 with a 16-day repeat cycle. Most Landsat 4 and 5 TM scenes are processed through the Level 1 Product Generation System (LPGS). The image product from this sensor has projection of UTM_WGS 84 which is taken with repeating cycle of 16 days.

Enhanced Thematic Mapper Plus (ETM+) was built by SBRS (Santa Barbara Remote Sensing) and mounted on Landsat 6 and 7. Landsat 7's ETM+ is a derivative of the Thematic Mapper (TM) engineered for Landsat 4 and 5 with some additional features. LANDSAT 8 satellite sensor is part of the Landsat Data Continuity Mission was successfully launched on February 11, 2013. The satellite has two main sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) (Nischal*et al.* 2014). OLI will collect images using nine spectral bands in different wavelengths of visible, near-infrared, and shortwave light whereas TIRS was added to the satellite mission when it became clear that state water resource managers rely on the highly accurate measurements of Earth's thermal energy (Nischal*et al.*, 2014).

Table 6.2~~1~~: Landsat image band combination and description

Landsat Satellite Sensors	Year	Band combination	Band Description		
Landsat 8 OLI	2015	6, 5, 4	Band 6 – *SWIR 1 (Short-wave Infrared),*	Band 5 – *NIR (Near Infrared),*	Band 4 – *Red*
Landsat 7 ETM+	2003	5, 4, 3	band 5 *SWIR – l (Short-wave Infrared),*	band 4 – *NIR (Near Infrared),*	band 3 – *Red*
Landsat 4–5 TM	1995	5, 4, 3	band 5 *SWIR – l (Short-wave Infrared),*	band 4 – *NIR (Near Infrared),*	band 3 – *Red*
Landsat 4–5 MSS	1984	2, 4, 1	band 2 – *Red,*	band 4 – *Near Infrared,*	band 1 – *Green*
Landsat 1–3 MSS	1972	7, 5, 4	band 7 – *NIR (Near Infrared),*	band 5 – *Red,*	band 4 – *Green*

3.1.2. Digital Elevation Model (DEM) and Field Data

In addition, to these satellite images, Digital Elevation Model (DEM) data with 30 m spatial resolution of the study area was utilized to determine the altitude of the lake. After the analysis and extraction of water bodies from the Landsat image, the result was validated from field work. The field data also used for checking the status of the lake-level in 2015 using Global Positioning System (GPS) device to collect the coordinates at the contact between the lake water level with the surface. The fieldwork also incorporates some photographs taken at the same season of the acquisition of satellite images.

3.2. Methods

3.2.1. Earth Observation data acquisition and processing

The methods used in this research was commenced with acquisition of Landsat imagery for the year 1972, 1984, 1994, 2003 and 2015 (Fig.6.2). These images were acquired at the dry season of the years in which the month ranges from October to March of each year in order to get images at same seasons and with very low cloud cover, which is less than 10% at these months. After the successful data acquisition, the data were pre-processed in order to get appropriate information about the lake boundary each year (Fig. 6.2). This pre-processing stage includes sub-setting, which is a process of clipping the study area for each year from each satellite images. Then, the images were enhanced by using band combination method. This method is useful to combine bands in Red, Green, and Blue colors (RGB composites). Therefore, in this research, different bands of the five sensors were combined in RGB as described in Table 6.1.

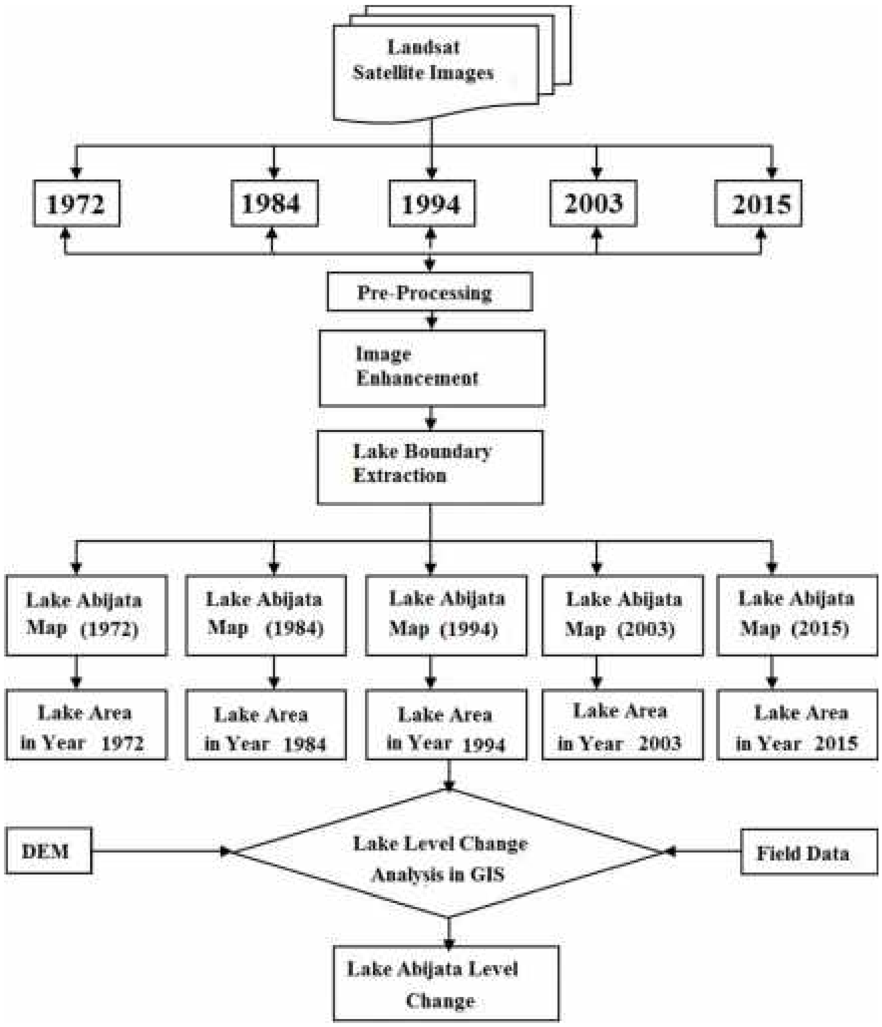

Fig. 6.2: Schematic representation of the methods used to maplake-level changes of Lake Abijata

3.2.2. Mapping lakes

The lakes were mapped by extracting each lakes feature from the acquired and processed Landsat images. Extracting is the process of converting features into a digital format and it is one way of generating digital data. There are several ways to extracting new features from satellite images, these includes extracting features on-screen or heads up over an image, extracting features from a hard copy of a map on a digitizing table or board, or using automated extraction method. From these, extracting features on-screen, which is also alternatively known as heads-up extraction of features is one of the most common methods. This method was used in this research and the extracted Lake Abijata boundaries of each year were used for lake-level change analysis in order to investigate the change of Lake Abijata from year 1972 to 2015. Finally, the change in 2015 was checked with fieldwork that was taken at the same season with the acquired satellite image.

4. Result

The result shows that Lake Abijata is a drastically shrinking or decreasing lake (Fig. 6.3). Initially, in 1972, Lake Abijata had spatial extent or an area of 198.4 km^2 and declined in the first two decades by 19.2 km^2 and 28.6 km^2 in year 1984 and 1994, respectively (Fig. 6.4 and 6.5). That is, it had area of 179.2 km^2 in year 1984 and 150.6 km^2 in year 1994. Then, in the third decades relatively the lake declined slightly by 5.7 km^2 with area of 144.9 km^2 in year 2003. From year 2003 to 2015, which is the in the fourth decade, it further declined by 13.1 km^2 and had an area of 131.8 km^2. Starting from 1973 to 2015, Lake Abijata declined by 66.6 km^2 in its lake area (Figure 3 and 4).Moreover, the direction of decline of the lake is mainly on the northwestern direction shrunk by a distance of 3.64 km and in the southeastern direction where the lake-level shifted to center by 1.267 km through the last four decades as shown Fig. 6.4.

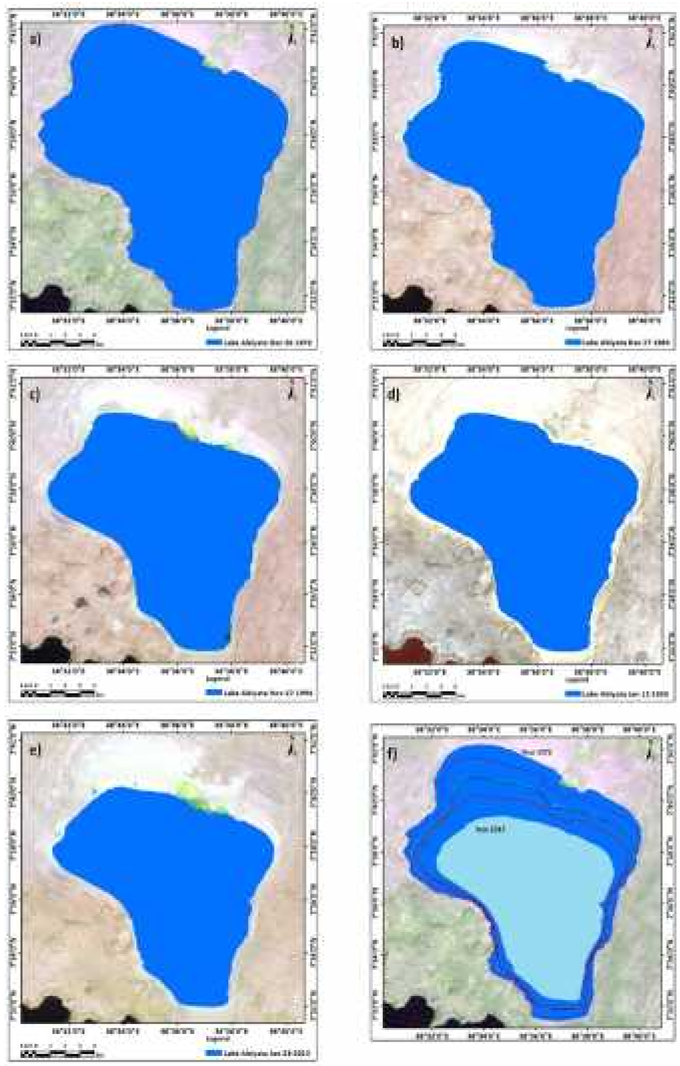

Fig. 6.3: Lake Abijata water level changes: **a)**Year 1972 **b)**Year 1984 **c)**Year 1994 **d)**Year 2003 and **e)**Year 2015 **f)** lake-level change from year 1972 to 2015

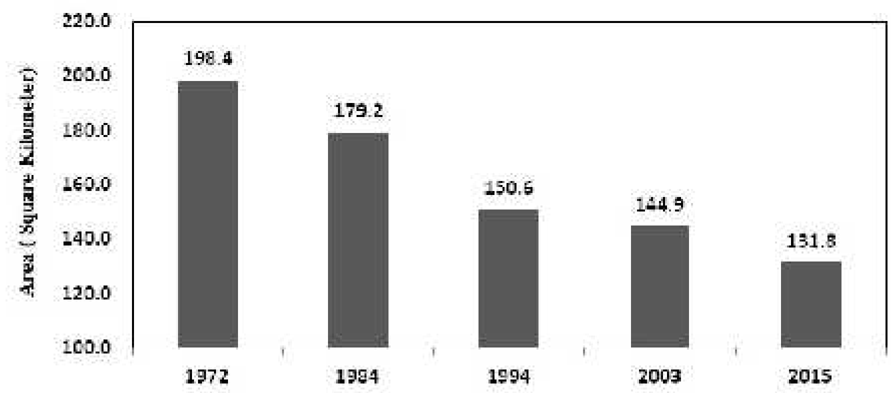

Fig.6.4: Surface area change of Lake Abijata from Year 1972 to 2015.

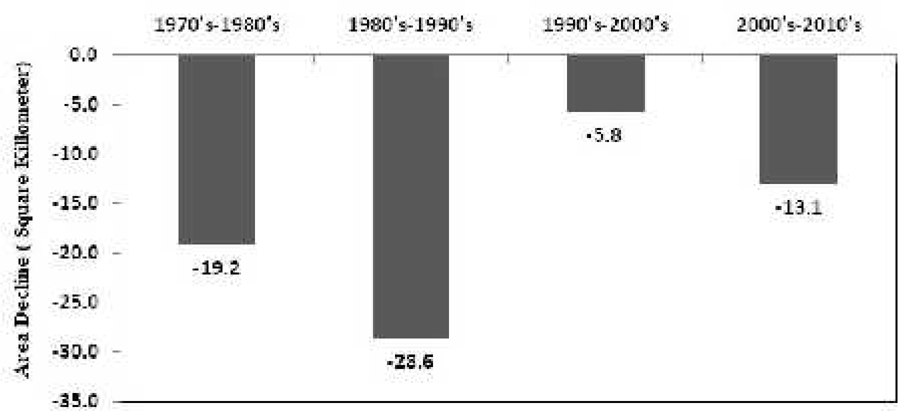

Fig. 6.5: Decadal lake-level change of Lake Abijata

The GPS data collected from lake's surrounding shows the current status of the lakes boundary. These data were used in validating the lake-level change extracted from the Landsat satellite imagery. For instance, the GPS reading taken at the southern tip of Lake Abijata was taken in January 2016, which is the same season of image acquisition, shows that there is a 1.267 km distance variation from the boundary extracted year 1972 Landsat satellite image (Fig. 6.6).

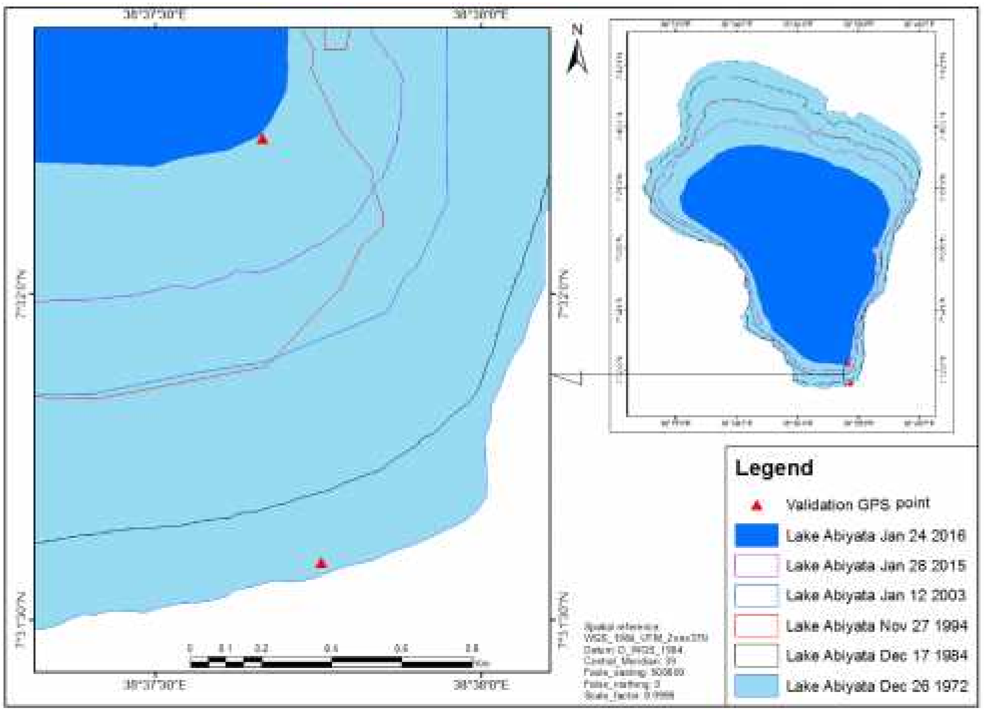

Fig. 6.6: Lake-level changes of Lake Abijata at the southern part of the lake with GPS point data.

5. Discussion

Remote sensing has a great advantage in detecting the spatio-temporal change of geographic features. The satellite imagery is one way of assessing the variation of geographic features through specified time interval. Worldwide there are various satellites, which produce different types of imagery used for different purposes. From these satellites imageries, Landsat satellite image is the major in representing the world’s longest and continuously acquired image data since 1972. The images from Landsat satellite have been providing a unique resource image data for different applications such as agriculture, geology, forest, settlement area, and water bodies researches (Herold *et al*., 2003 and Wilson *et al*., 2003), which is like the application used in this research. Moreover, the Landsat images areused in water body management to detect the level changes of lakes using the spatiotemporal image data. For instance, water level change of Lake Seyfe in Turkey was studied using Landsat image by Reis and Yilmaz (2008).

The Landsat satellite images are also used by different researchers as an essential input data alone and also by integrating with other relevant data for the assessment of lakes level change for some of Ethiopian lakes. For example, Tenalem Ayenew (2002) used the Landsat satellite imagery with other data to study the lake-level change of Lake Abijata integrating it with the Hydro-meteorological data to study the hydrodynamics of selected Ethiopian Rift Lakes. Even though this research utilized Landsat images, the identification of lake-level change in a decadal variation and continuous declining of the lake-level were the main result that makes it different from other researches.

According to D. T. Meshesha *et al.* (2012), the decline in the size of the lake was mainly affected by Land use - land cover (LULC) and land degradation. This effect was also seen in this research after creating a land use and land cover (LULC) map of Lake Abijata and surroundings as shown in Figure 7. This LULC was mapped with knowledge based classification method from year 2015 satellite image in order to know what causes the drastic lake-level change of Lake Abijata though this was beyond the objective of this research. The result of LULC shows that the surrounding area was covered by dry sand that is represented as bare land on the map (Fig.6.7). Therefore, the land cover changes could be considered as one of the driving factors for the declining of the lake. The land use type of the watershed of the lake directly or indirectly affect the levels of the lakes, because of the replacement of forest and land-cover vegetation by bare land area and exposed soil might enhance the evaporation of the lake water.

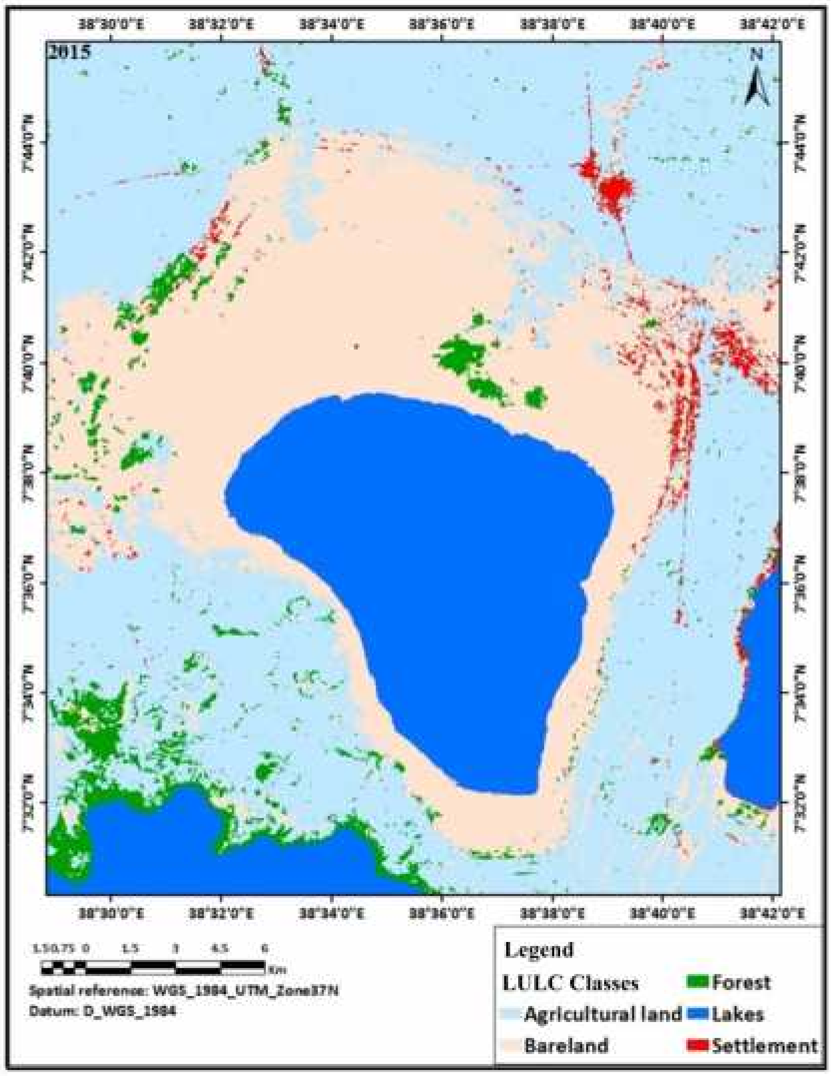

Fig. 6.7: Land use land cover changes of the watershed of Lake Abijata

Furthermore, the decline of Lake Abijata was associated with the establishment of soda ash factory since 1985. According to Elizabeth Kebede *et al.*(1994), Tenalem Ayenew (2002), Tenalem Ayenew and Dagnachew Legesse (2007), the establishment of soda ash industry was mainly considered as the major cause for the rapid decline of the surface area of Lake Abijata. This investigation found out that water-abstraction from Lake Abijata is not the only factor for the recorded shrinkage of the lake. The satellite images and all available data indicate that Lake Abijata has been shrinking by 1.0837 km in the north direction and by a total surface area of 19.165 km^2 even before the establishment of soda ash factory in 1984 as shown in Figs. 6.3a and 6.3b.

6. Conclusions and recommendation

The Landsat satellite images are used for different applications related to environmental management aspect. From these images, it was found out that Lake Abijata had drastically declined by 66.64 km^2 (33.59%) from its initial spatial extent of Year 1972 to Year 2015. This decline of lake-level continued without any fluctuation as shown in Fig. 6.4. Therefore, researchers and concerned government bodies should give attention on the sustainability of the lake in the region. Although this research focused on remote sensing application for lake-level change, there is a need to integrate this technology with other methods and ground-trothing in order to concretely validate satellite images and quantitatively measure the volumetric changes lake.

References

Corti, G. (2009): Continental rift evolution: From rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa. *Earth Science Reviews*96: 1–53.

D. T. Meshesha Tsunekawa, A. and Tsubo, M. (2012):Continuing Land Degradation: Cause-Effect in Ethiopia's Central Rift Valley.*Land Degradation and Development* **23**(2)**:** 130–143.

Elizabeth Kebede, Zinabu Gebremariam and Ahlgren, I. (1994): The Ethiopian Rift Valley lakes: chemical characteristics of a salinity-alkalinity series.*Hydrobiology*288 (1): 1–12.doi: 10.1007/ BF00006801

Fischer, M.M. and Getis, A. (eds.) (2010): Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications, Springer, Verlag Berlin Heidelberg, 15 pp.

Gyanesh, Ch. Brian, L. M. and Dennis, L. H. (2009): Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO–1 ALI sensors. Remote Sensing of Environment 113: 893–903.

Herold, M., Goldstein, N.C. and Clarke, K.C. (2003): The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment*86: 286–302.

Hui, F., Xu B., Huang, H., Yu, Q. and Gong, P. (2008): Modeling spatial- temporal change of Poyang Lake using multi-temporal Landsat imagery. *International Journal of Remote Sensing*29: 5767–5784.

Jawak, S.D., Kulkarni, K. and Luis, A.J. (2015): A Review on Extraction of Lakes from Remotely Sensed Optical Satellite Data with a Special Focus on Cryospheric Lakes.*Advances in Remote Sensing*4: 196–213.

Khorram, S., Koch, F. H., van der Wiele, C. F., C. and Nelson, S. A., (2012): Remote Sensing. Springer, New York, Heidelberg, Dordrecht, London, 65 pp.

Levin, N. (1999): Fundamentals of Remote Sensing, Remote Sensing Laboratory, Geography Department, Tel Aviv University, Israel.

Megersa Olumana Dinka (2012a):Analyzing the extent (size and shape) of Lake Basaka expansion (Main Ethiopian Rift Valley) using remote sensing and GIS.Lakes and Reservoirs: *Research and Management*17: 131–141.

Nischal, M., MdObaidul, H., Larry, L., David, A., Dennis, H and Brian, M. (2014): Radiometric Cross Calibration of Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+). *Remote Sensing*6: 12619–12638.

Ouma, Y. O. and Tateishi, R. (2007): Lake water body mapping with multi-resolution based image analysis from medium- resolution satellite imagery. *International Journal of Environmental Studies*64: 357–379.

Reis, S. and Yilmaz, H. M. (2008): Temporal monitoring of water level changes in Seyfe Lake using remote sensing. *Hydrological Processes*22: 4448–4454.

Seifemicahel Abebe, Jema Haji, and Mengistu Ketema (2014): Impact of Disappearance of Lake Haramaya on the Livelihood of the Surrounding Community: The Case of Haramaya District in Oromia National Regional State, Ethiopia. *Journal of Economics and Sustainable Development*5(18)**:** 141–147.

Tenalem Ayenew (2002): Recent changes in the level of Lake Abijata, Central Main Ethiopian Rift. *Hydrological Sciences Journal*47(3): 493–503.

Tenalem Ayenew and Dagnachew Legesse (2007): The changing face of the Ethiopian rift lakes and their environs: call of the time. *Lakes and Reservoirs: Research and Management*12: 149–165.

USGS (United State Geological Survey) (2015): Landsat 8 (L8) Data users handbook:version 1.0, Department of the Interior U.S. Geological Survey, 2–3 pp.

Wilson, E.H., Hurd, J.D., Civco, D.L., Prisloe, M.P. and Arnold, C. (2003): Development of a geospatial model to quantify, describe and map urban growth. *Remote Sensing of Environment*86: 275– 285.

Xuchun, Ye, Yunliang, Li, Xianghu, Li and Zhang, Q. (2014): Factors influencing water level changes in China’s largest freshwater lake, Poyang Lake, in the past 50 years. *Water International* 39(7)**:**983–999.