Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies
School of Civil and Environmental Engineering

ESTIMATING THE ENVIRONMENTAL WATER REQUIREMENT OF LAKE ABIJATA AS A BASIS FOR ECOSYSTEM DEVELOPMENT

A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in

Water Supply and Environmental Engineering

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A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Water Supply and Environmental Engineering

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AUTHOR'S DECLARATION

I, the undersigned, hereby declare that this thesis entitled, "Estimating the environmental requirement of Lake Abijata as a basis for ecosystem development" is my own work, and that all the sources I have used or quoted have been indicated or acknowledged by means of completed references.

Rekik Hibistu

Signature -----------------

CERTIFICATION

I, the undersigned, certify that I read here by recommend for acceptance by Addis Ababa University a thesis entitled "**Estimating the environmental water requirement of Lake Abijata as a basis for ecosystem development**" written in partial fulfillment of the requirements for the degree of masters of science in **Water Supply and Environmental Engineering.**

Belete Birhanu(Ph.D)

Advisor

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LIST OF ACRONYMS

ASLNP	Abijata-Shalla Lakes National Park
CRV	Central Rift Valley
E.U	European Union
MoWIE	Ministry of Water, Irrigation and Energy
m.a.s.l	meters above sea level
Mm^3	Million metre cube
NMSA	National Meteorological Services Agency
RVLB	Rift Valley Lakes Basin
OIDA	Oromia Irrigation Development Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization

ABSTRACT

Quantification of Environmental Water Requirement based on random percentage of annual mean flow do not address the actual needs of the water dependent ecosystems, it possibly overestimates or underestimate the requirements. Scientific communities worldwide are working to design an appropriate approach for the quantification of the environmental water requirements for an interest area. Among their efforts," habitat based approach" is a popular method in estimating environmental water needs. The environmental water requirement of Lake Abjiata is computed based on this approach by estimating the water requirement of Lesser Flamingos, which are dominant birds that feed on the lake but significantly reducing in number. Their water requirement was computed indirectly based on their food and energy requirement and on the water requirements of their main food, the microalgae known as Arthrospira Spirullina. In addition the estimation considers the direct evaporation from the lake and drinking water requirement of the birds, Therefore, this study estimated the environmental water requirement of Lake Abijata to support 108,275 Lesser Flamingos within 132 km^{2} *lake area as 221.8MCM. In addition the study evaluates the water balance of the lake to support, this environmental water requirement and confirmed that the environmental water requirement accounts for 50.6% of the mean annual inflow to the Lake, which includes the direct rainfall over the lake and river inflow from the lake catchment.*

Key Words**: **Environmental Water Requirement, Arthrospira Spirulina, Lesser Flamingos

CHAPTER ONE

1. Introduction

1.1. Background

Water dependent ecosystems play a key role in ensuring ecological balance and sustainable development. The water environment has a natural self-cleaning capacity and resilience to water shortage. However, it suffers from mismanagement due to continuously excessive withdrawals (M. Abbaspour& A. Nazaridoust, 2007). As a result biodiversity is lost, natural food sources like fish disappear and livelihoods that used to depend on their existence are affected. Besides the cost of cleaning up and rehabilitating a degraded ecosystem is enormous. Failure in planning and managing the resource at the involvement of all stakeholders causes the mentioned phenomena.

Increasing and competing demands leads to excessive abstraction of water resources ignoring the environmental requirements. Environmental Water Requirement (EWR) is the “quantity, timing and quality of water flows required to sustain fresh water and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems” (Leroy Poff et.al, 2009)

Since the supply is fixed or even diminishing through natural and anthropogenic activities. This trend is dangerous, resulting in fragile landscape ecology especially in arid and semi-arid areas. The worth of water dependent ecosystems is not fully realized especially in developing countries like ours, where preserving an ecosystem is considered a luxury compared to satisfying the basic needs of the rapidly growing population. (Zerihun Desta,2003).Authorities also focus on possible economic benefits expected from industries or companies to be located within the water bodies with little or no deliberation at all for the future wellbeing of aquatic ecosystem.

In Ethiopia particularly the Central Rift Valley is comprised of extensive bio-diverse water bodies. The CRV is a closed basin consisting of lakes Ziway, Langano, Abijataand Shalla. At the same time it is one of the most environmentally vulnerable areas characterized by arid and semi-arid climate in addition to continuous upstream water abstraction (Gebretsadik T.and Mereke K.,2017). Abijata-Shalla Lakes National Park is located in this valley. The park contains two terminal lakes named Abijata and Shala. Even though the precipitation has not significantly changed in the basin for the last five decades, certain lakes in the region are experiencing a decreasing trend.(Tenalem Ayenew, 2002) Lake Abijata, in particular is a home for endemic and near threatened bird species.(Reaugh-Flower,K.,2011). It receives its major inflow from Lake Ziway.

According to a report by Alemayehu et.al. (2006), Lake Abijata has experienced a drop of about 5 meters corresponding to a reduction by 25% in size over the last three decades. Extensive utilization of Lake Ziway through large scale irrigation activities and expanding horticulture fields along with direct abstraction of the Soda-Ash factory from Lake Abijata and other water consuming actions neglects the environmental flow required by Lake Abijata. This fact is the major reason for the depletion of this lake characterized by its receding shore lines and also increasing salinity eventually leading to an extinct ecosystem (Tenalem Ayenew, 2002).

The lake water reduction has caused precious wetland birds which are major sources of visitor attraction like Pelicans and Flamingos to abandon the lake in search of food which used to be available. Fish and fishery activity is no longer noticed and the lake has lost its scenic beauty (Tadesse Fetahi, 2016).

Acknowledging the environmental value of ecosystems followed by quantifying and reserving their water demand is a key approach in restoring the lakes integrity.

1.2. Statement of the Problem

The rift valley of Ethiopia consists of a chain of lakes, streams and wetlands. Specifically lakes of the central rift valley are known to be one of the biggest bird sanctuaries in Africa and habitat for a variety of flora and fauna.

The CRV of Ethiopia falls under the category of fragile ecosystem center due to its arid and rainfall deficient climate. Human activities are worsening this situation through excessive utilization of its water resources. The CRV contains four lakes Ziway, Langano, Abijata and Shala which are hydrologically-interconnected. LakesLangano and Ziway release flow to Lake Abijata through rivers Horakelo and Bulbula respectively.

However, according to Tadesse Fetahi (2016), the size of Lake Abijata has decreased significantly over the past 30 years due to: Direct pumping from Lake Abijata for commercial production of soda ash, Extraction along the Bulbula River, Decreased discharge from Lake Ziway to Bulbula River due to abstraction from it.

Lake Abijata has lost 46 % of its area between 2000 and 2006 alone (Vilalta ER,2010) as cited by Tadesse Fetahi (2016).Many researchers predict that, even with no further development of irrigation schemes in the Ziway-Abijata catchment, Lake Abijata could dry up in the next 20-50 years(Reaugh-Flower,K.,2011).

Lake Abijata and Shalla as the part of Abijata-Shala Lakes National Park is believed to be one of the most beautiful scenery providing spots of Ethiopia. The park supports various resident and migrant bird species. Species endemic to Ethiopia like Abyssinian black-headed Oriole and Yellow fronted parrot, Near threatened ones like Lesser and Greater Flamingo and other globally threatened, endangered and vulnerable species are supported by lakes in the park. The lakes and surrounding wetlands support wide range of habitat serving as a major feeding and breeding ground of many wetland bird species and other wild animals (TafesseKefyalew Estifanos, 2008).

The Lesser Flamingo, a near threatened bird species is prominent over the park with the highest estimate of 233,000 counted from 1991-1996.The record high population of Greater Flamingos was measured to be 59,000 during the same time (EWNHS,1996).According to Tewodros Kumssa and Afework Bekele (2014),Lake Abijata harbors 46.47% and 25.28% of Lesser and Greater Flamingos respectively.

Since the 1980s the water level of the lake has dropped significantly, fish and fishery disappeared totally and birds such as Great White Pelicans that feed on fish and Lesser Flamingos that feed on water dependent algae are migrating to nearby lakes due to food scarcity (Tadesse Fetahi, 2016).

The significantly lowering population of Lesser Flamingos over Lake Abijata costs the park its income as it makes the scenery less interesting to watch.

1.3. Objective of the study

1.2.1 General Objectives

The general objective of the study is to quantify the environmental water requirement of Lake Abijata to maintain sustainable ecosystem service

1.2.2 Specific Objectives

- Estimate the actual environmental water requirements of the habitat.
- Evaluating the water balance of the lake.

1.4. Research Question

- How much water is required to ensure a healthy water dependent ecosystem service?
- Is the supply enough to satisfy the demand?
- If not what is the ecological limit in which water can be withdrawn without affecting the environment?

1.5. Scope and limitations of the Study

This study is concerned in determining the environmental water requirement of the lake, with the aim of providing suitable habitat for a particular target species which is prominent over the area. The research is based on the past thirty year hydro meteorological data and does not consider its possible future alterations

1.6. Significance of the study

The research findings will provide insight for water resource managers and stakeholders regarding the extent of utilization of Lake Abijata and its inflows.

In addition, this research can be used as a background reference for those who want to carry out further environmental study over the area.

1.7. Thesis Outline

The thesis is made of five chapters organized as follows:

Chapter one gives a general introduction wetlands and their significance. Chapter two reviews literatures on the cost of over utilizing water resources, methodologies followed in estimating environmental water requirement of lakes and its surrounding wetlands, and selection of the appropriate method. Chapter three gives a brief description on the methodology of the study that includes study area description, types of data collected and outlines methods employed in estimating the environmental water requirement of water bodies. Chapter four focuses on the outcome of the adopted methodology Chapter five summarizes the study by stating a brief conclusion and forwarding few recommendations

CHAPTER TWO

2. Literature review

2.1. Status of the CRV

The Ethiopian CRV is part of the Great African Rift. It consists of a chain of lakes, streams and wetlands. Being a closed basin and located in an arid climate zone, it is one of the most environmentally vulnerable areas in Ethiopia (H.G.L and GIRD Consultants, 2009)

Lakes Ziway,Langano and Abijata are hydrologically and biologically linked. Lake Ziway which is the largest and freshest lake is fed by the Meki and Katar Rivers. In turn Ziway feeds Abijata via the Bulbula River which is the major inflow in to Abijata. Lake Langano is fed by smaller tributaries thus contributes a smaller amount of water to Abijata through the seasonal river Horakelo.

The level of Lake Ziway is dropping and according to Reaugh-Flower (2011) and numerous other authors it is concluded that the drop is not connected to rainfall variability but rather to excessive water abstraction from the lake and its feeder catchments. Irrigation schemes, industrial rose farms and state run and private agricultural farms are major users consuming a minimum of 171Mm3of water per year (Reaugh-Flower, K., 2011).

Should this trend continue and if planned developments over the area commence, many researchers predict that Lake Ziway will become a terminal Lake no longer feeding water in to the Bulbula river thereby depriving Lake Abijata which consequently result in its dryup. Moreover the lake could become too saline for irrigation in the next 5-10 years.

On the other hand Lakes Langano and Shalla are much deeper and less climatically sensitive than Lakes Ziway and Abijata. They have smaller watersheds with smaller amount of current and planned irrigation over it. Therefore they have exhibited little change in water level over the years and are under far less threat.

2.2. Reviewed methodologies for estimating environmental flows.

Methods can be grouped in to three main categories.1) Hydrological rules,

2) Hydraulic-Habitat, 3) Holistic methodologies. (EU Technical Report, 2015) Among the three, the holistic approach is increasingly becoming the preferred method for determining EWR.

This method involves multidisciplinary team of experts (ecologist, hydrologists) so as to account for a wide range of components (flora, fauna as well as physical habitat) throughout the whole catchment of water bodies. However, it is data intensive and requires larger capital. The following table summarizes the character of the methodologies as follows.

Table 1 Comparison of three general categories of Environmental flow estimation methodologies (Linnansari et.al. 2012) as cited by EU Technical Report, (2015)

Methodology category	General purpose	Scale	Duration of assessment (months)	Relative costs	Relative frequency of use
Hydrological	Examination of historic flow data to find flow levels that naturally occurs in a river and can be considered "safe" thresholds for flow abstraction	Whole rivers, applicable for regional assessments	1-6	€	+++
Ecological	Lake water requirement is determined based on an ecological index represented by a target species and its water quantity and quality requirement	Applied at a study site	6-18	€€	++
Holistic	Examination of flows in an expert opinion workshop leading to recommendation of flows for all components of the river ecosystem, including societal and recreational uses	Whole rivers, applicable for regional or river specific cases	12-36	€€ - €€€	+(increasing)

2.3. Gaps and major contributions in determining Environmental flows

Various environmental studies have been undertaken in quantifying ecological water requirement of inland lakes. Jianhua Si et.al (2014) worked on determining basin scale and the ecological water requirement of Lake Juyan, in China. Their study followed the hydrological approach by focusing on quantifying the correlation between changes in inland lake surface area and Inflow over extended time scale to come up with the suitable lake area for a healthy ecology.

M. Abbaspour & A. Nazaridoust (2007) followed a different approach, the Hydraulic-Habitat method, by identifying the most critical ecological element of the ecosystem and estimating the water demand based on that element. They, assessed the environmental water requirement by first setting site-specific ecological targets: Salinity, Water depth, and Turbidity preference and tolerance range for a target species selected based on its influence over the ecosystem.)

A more detailed and scientifically sound holistic approach was pursued by Xue ET. al. (2015) in quantifying the EFR of oasis areas in North-West China. Three ecosystem services were considered as basis 1) maintenance of riverine ecosystem health. 2) Assurance of the stability of oasis-desert ecotone and riparian forests. And 3) restoration of oasis-desert eco-tone ground water

Christopher H. Tuite, 2000 didn't focus on directly estimating EWR of endoheric lakes in East Africa. However, he studied the distribution and density of Lesser Flamingos in East Africa in relation to food availability and productivity which helps to determine species based EWR over the area.

Estimating environmental water requirement based on ensuring healthy population of keystone species is a popular approach followed by Murray Darling Basin Authority in Australia and also other environmental research institutions.

Even though our country is gifted with many lakes and rivers, assessment of EWR is a new practice for Ethiopia. Most studies undertaken so far focus only on analyzing the damage and shrinkage observed over wetlands and lakes as a result of various anthropogenic activities.

Few but important studies are carried out with the objective of investigating the environmental flow requirements of rivers, lakes and wetlands. Shiferaw and McCartney (n.d.) investigated the environmental flow requirement of River Abay downstream of Chara Chara weir which is constructed to regulate outflow from Lake Tana to provide water for hydropower stations downstream.

They followed the hydrological approach, in estimating the water allocation essential for the environment between the Hydropower station and the TisIssat falls by using a hydrological model named The Desktop Reserve Model. Natural outflow series from Lake Tana prior to the construction of the weir is used as an input to the model. Then the model, based on the desired ecological class set by the researchers (ranging from class A to F) provides outcome which is the required environmental flow.

"Class a Rivers are largely unmodified and natural, class F Rivers are extremely modified and highly degraded (DWAF, 1999)"."Classes E and F are deemed ecologically unsustainable so class D (i.e. largely modified) is the lowest allowed “target” for future status."(Shiferaw and McCartney,n.d.).

Kumssa and Bekele (2014) studied the feeding ecology of Lesser Flamingos, prominent in the ASLNP which included findings on the flamingo’s food of choice and daily demand. This can be a crucial input in estimating the environmental flow requirement of the park based on fulfilling the demand of a particular target species which in this case is the Lesser Flamingo.

CHAPTER THREE

3. Materials and Methods

3.1. Description of the study area

3.1.1 Location

Lake Abijata, is a shallow small alkaline closed lake located in the Ziway-Shalla basin of the Central Rift Valley. The Central Rift Valley is situated between approximately 38015’E to 39025’E and 7010’S to 8030’S at150km south-west of Addis Ababa via the Shashemene asphalt road. It contains three lakes, Ziway, Abijata and Langano as well as three major rivers Bulbula, Meki and Katar. Lake Shala, adjacent to Lake Abijata forms the Abijata-Shala Lakes National Park (Fekadu T. &Fekadu B, 2014)

The area of the park is 887 square kilometers over half of which was covered by the two lakes. Nowadays, this coverage has dropped significantly due to the shrinking surface area of Lake Abijata. The ASLNP has one of the highest wetland bird diversity in Ethiopia. It is home to 144 water bird species, which is basically 70.6% of the total wetland bird species for the country (ethiovisit.com).

Lake Abijata and its watershed lie at a mean altitude of 1578metre approximately between 38015 'to 390 45'Longitude and 60 45 'to 9000'Latitude. Its beach is unstable and saline, and vehicles must not venture too close as there is a very real danger of sinking (ethiovisit.com, n.d.).

Table 2 Facts and Figures of Lake Abijata

No	Description	Figure
1	Location	$38^0$60' Longitude and 7 ^{0}61'Latitude
2	Altitude	1581m.a.s.l
3	Lake Surface Area	132.56 Km^2 (2009)
4	Total basin Area	10336.25 Km^2
5	Gauged area by Kerkersitu	7276.60 Km^2
6	Gauged area by Horakelo	1811.56 Km^2
7	Ungauged part of the basin	1116.09 Km^2
5	Depth	7.6 m mean and 12.5 m maximum
6	Volume	758.09 Mm3 at 1581 m.a.s.l
7	Major Inflows	River Bulbula and Horakelo
8	Outflow	None

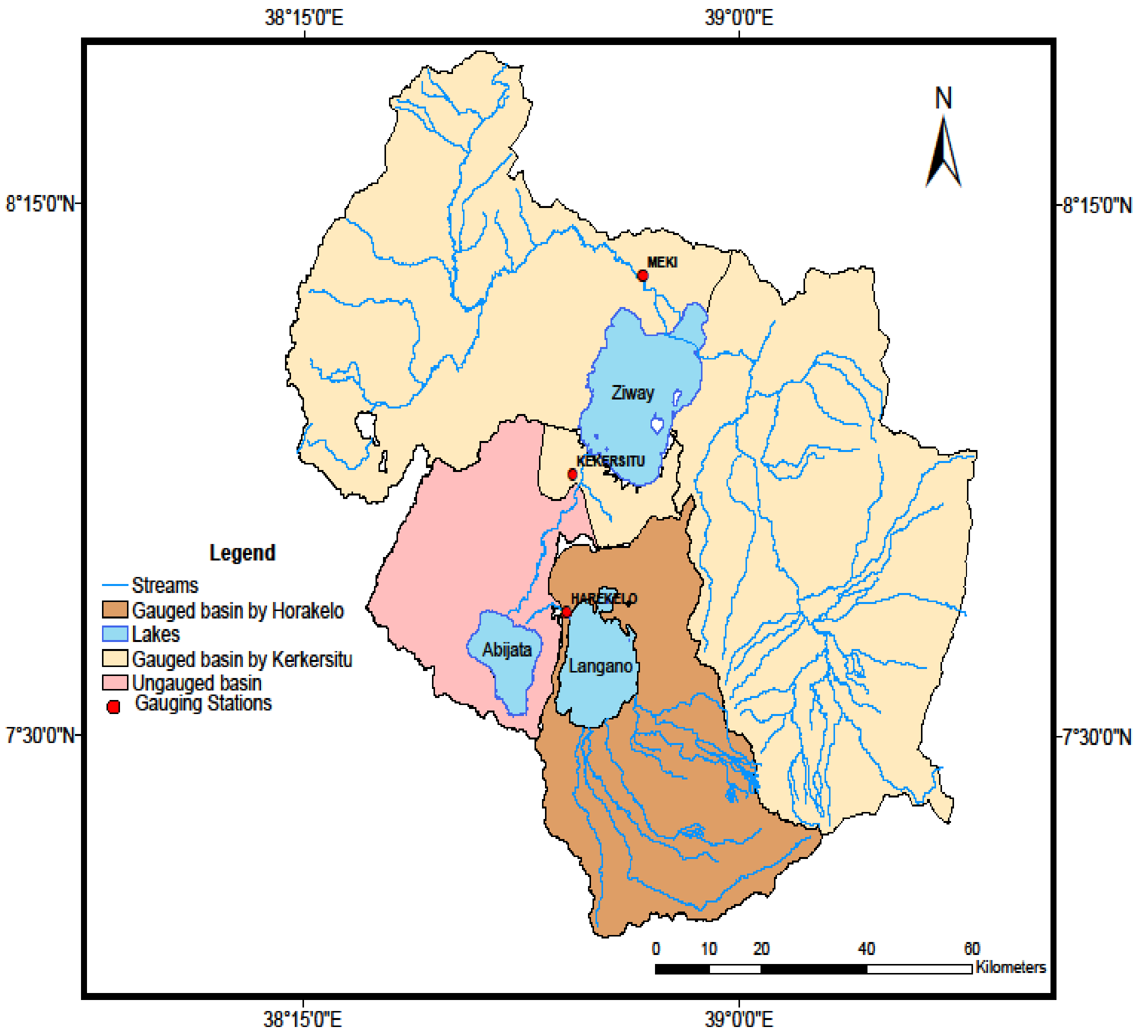

Figure 1 Basin of Lake Abijata

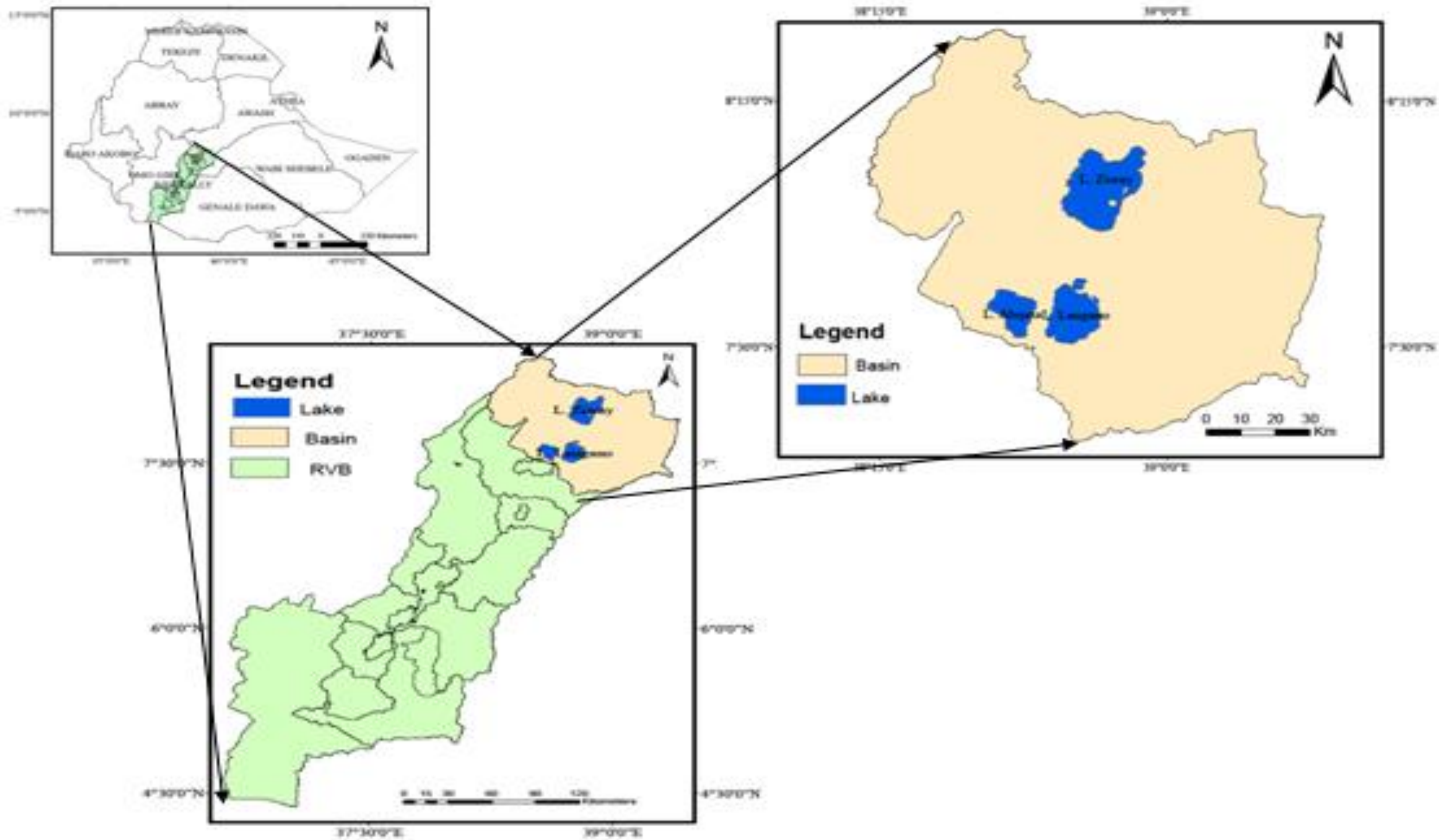

Figure 2 Location map of study area

3.1.2 Topography

The altitude of Lake Abijatas basin ranges from 4201-1529 metre m.a.s.l. The shallowest feature takes up most of the watershed area (36%) and is the place where the lake exists. Only 1.6% of the catchment has an elevation over 2020 metre m.a.s.l.

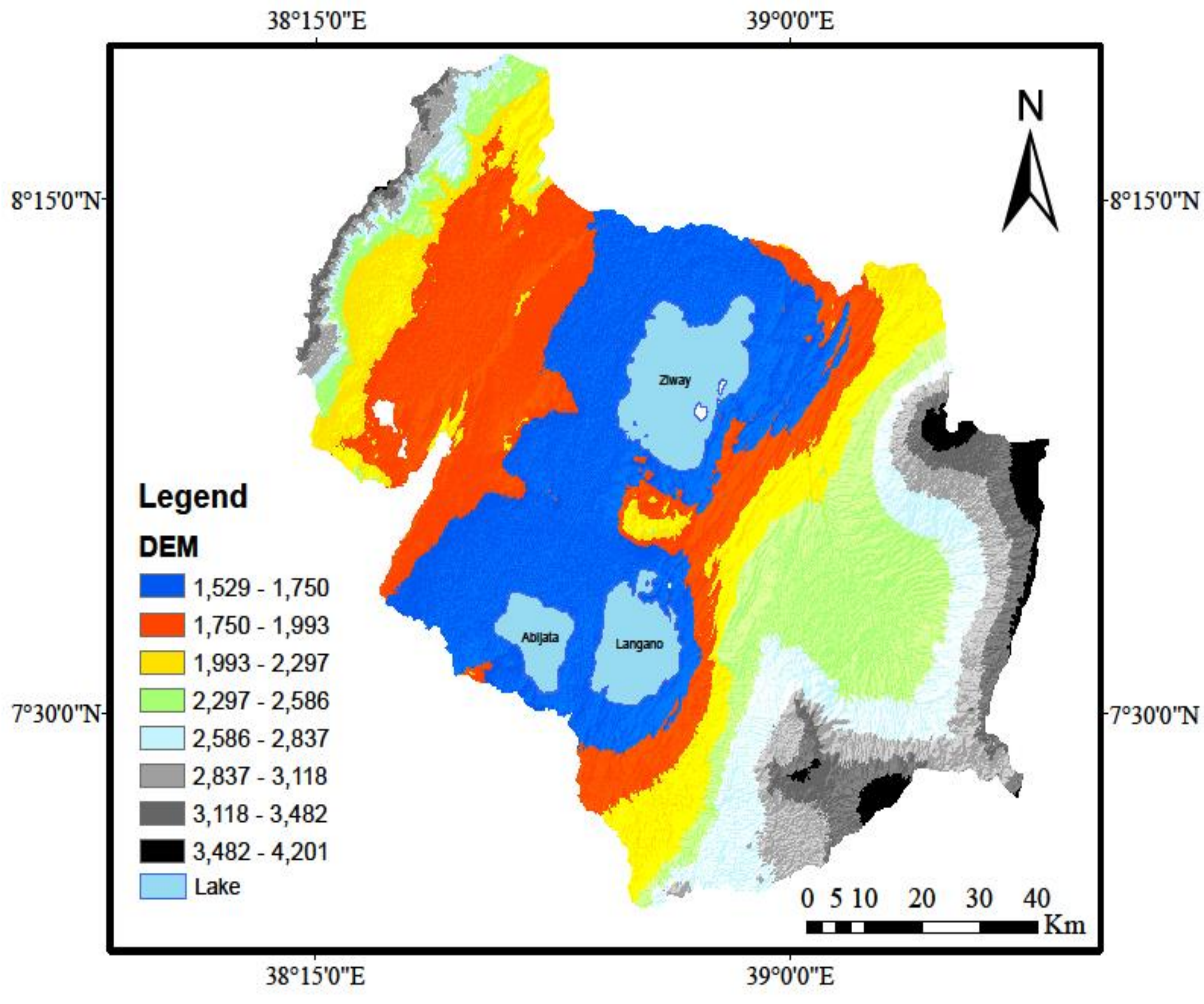

Figure 3 Topography of Lake Abijata basin

3.1.3 Climate

Altitude has a significant role for the variation of climate in the CRV. Noticeable gradients of rainfall and temperature exist between the high plateaus, in the eastern and western portion of the CRV, and the valley in the central portion of the CRV where Lake Abijata exists. Generally, the area is characterized by warm, wet summers with most of the rainfall occurring from July to September and dry, cold, windy winters”. (Jansen et al., 2007)

Spatially speaking the climate is humid to sub-humid in the highlands and semi-arid in the rift valley. Mean annual temperature is more than 200C in the rift floor and less than 150C in the highlands. The reference evapotranspiration over the basin varies approximately between 1250 to 1450mm per year. The spatial variation of reference evapotranspiration is much less than that of rainfall.(Jansen et al.,2007)According Jansen et.al.(2007),the mean annual rainfall over the basin ranges from a 1251mm in the western high margins of the basin(Chelektu)to 649mm at Bulbula in the proximity of Lake Abijata

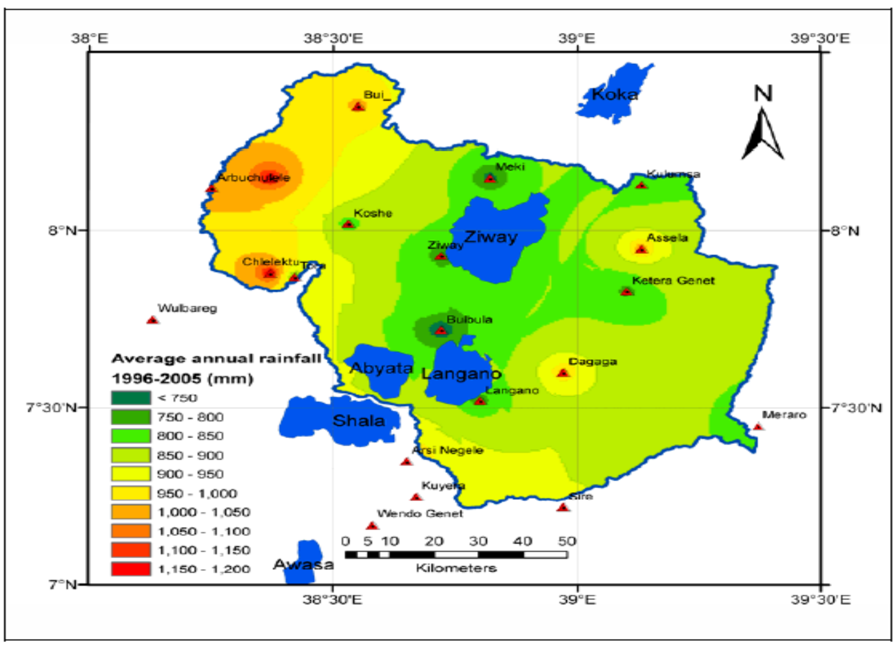

Figure 4 Isohyets of average rainfall over the CRV (Jansen et.al, 2007)

3.1.4 Hydrological Setting

The major incoming rivers in the basin of the CRV are the Ketar and Meki Rivers. Both are inflows to Lake Ziway. The former discharges the water from the eastern and south-eastern plateaus while the later discharges the runoff from the plateau west of Lake Ziway.Lakes Ziway, Abijata and Langano are hydrologically connected while Lake Shala has a closed catchment with no surface water connections to the other lakes.(TenalemAyenew,2002).

The major portion of inflow to Lake Abijata originates from Lake Ziway through the Bulbula River. Lake Ziway discharges water to Lake Abijata only when its level has reached above 1635.58 meters. Hence, a change in Lake Abijata has to be perceived jointly with the abstraction activities around Lake Ziway. Comparatively less water is discharged from Lake Langano to Lake Abijata by Horakelo River."As a closed lake, the only significant water loss from Lake Abijata is through evaporation. Ayenew (1998)"."Groundwater flow model simulations indicate negligible groundwater outflow from the lake (Ayenew, in press).”(Tenalem Ayenew, 2002)

3.1.5 Soil

The physical and chemical compositions of soils are very important in determining the occurrence, growth, diversity and distribution of plant species of the area. The soil of the study area is often alluvial and very fine in nature, and is very susceptible to both wind and water erosion.

Table 3 Soil properties of major soil types in Lake Abijata basin

Major Soil Types	Soil texture	Drainage Condition
Vitric Andosol	medium and coarse	Imperfectly to well drained
EutricCambisol	coarse	Moderately drained
Calcaric Fluvisol	fine and medium	Moderately drained
Leptosols	coarse textured	Well to excessively drained
Haplic Luvisols	fine and medium	Well drained
Rhodic Nitisol	fine and medium clay	Well drained
Haplic Solonetz	medium and coarse	Moderately well to well drained
Eutric Vertisols	fine textured	Imperfectly to poorly drained

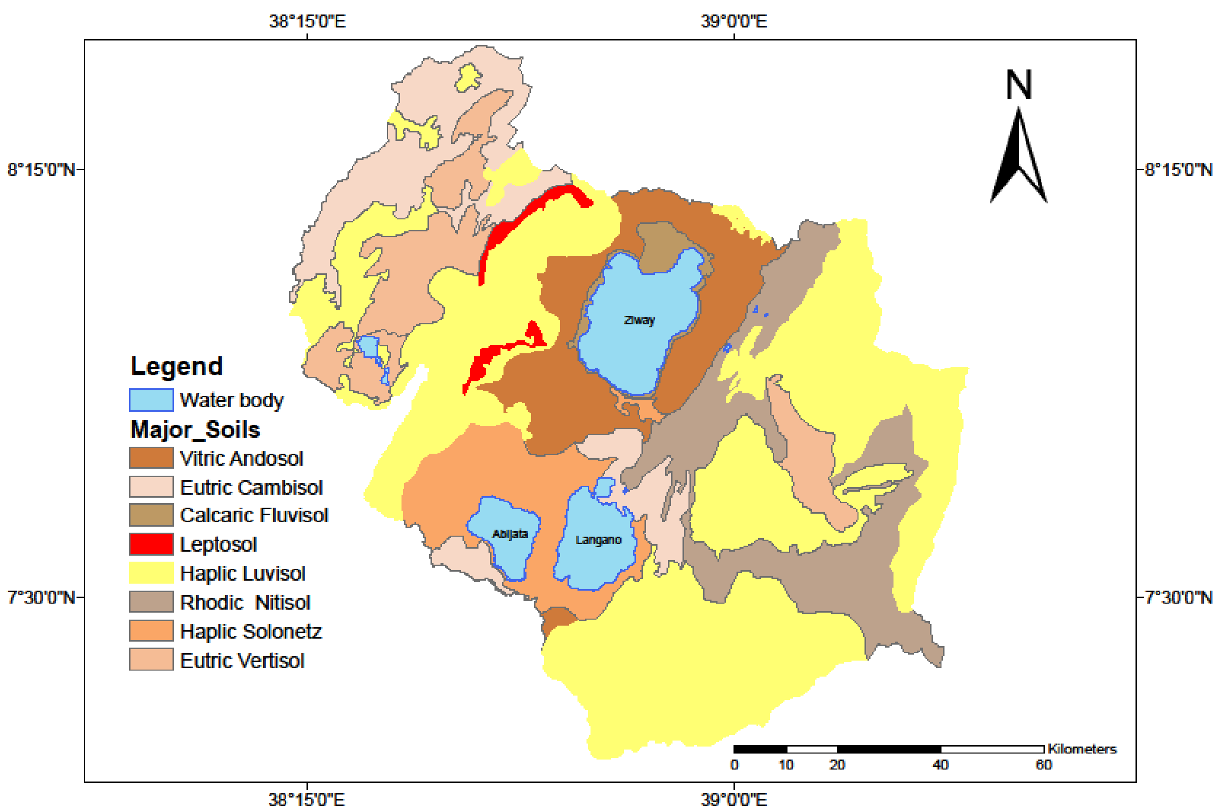

Figure 5 Major soil groups of Lake Abijata

3.1.6 Land Use

There is no discernable land use over the area left by the receded shorelines of Lake Abijata since it is degraded. Along the route of river Bulbula, which is the major inflow to Lake Abijata, the land is intensively cultivated for crop production. Areas occupied by rain fed croplands and sparse vegetation takes up 30% of the catchment. Mosaic vegetation and croplands cover only 10% of the area. Since ASLNP lies within the basin, closed and mosaic grassland, shrub lands and forests are seen covering 40% of the total area.

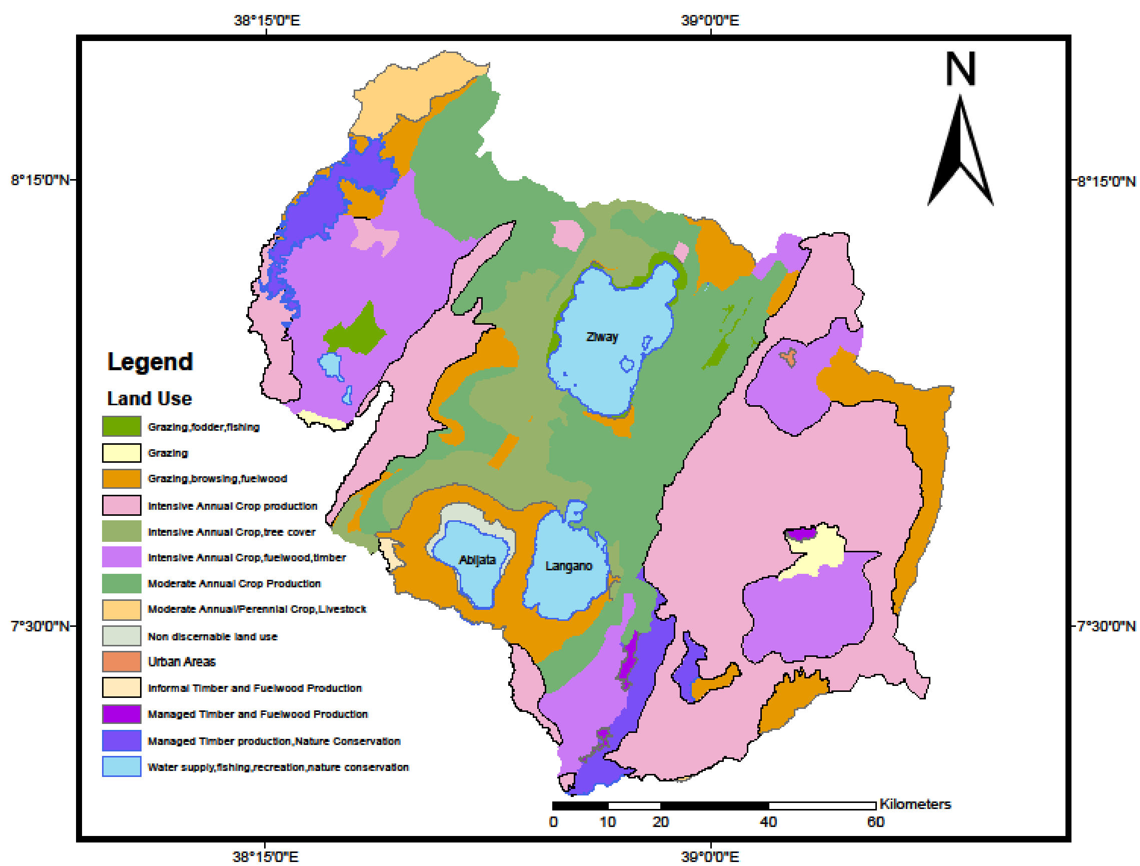

Figure 6 Land use of Lake Abijata basin (HGL&GIRD, 2009)

Table 4 Major Land Cover of the CRV

Major Land Cover	Percentage of area covered
Primarily Grazing and Browsing with some fuelwood production	12.7
Moderate Annual Crop production	18
Intensive Annual Crop production	29
Intensive Annual Crop production with appreciable areas of woodlots producing timber and fuelwood.	15.6

3.2. Tourism

ASLNP has one of the highest wetland bird diversity in Ethiopia.70.6% of the total wetland bird species of the country resides in the park.(ethiovisit.com).The scenic beauty of the lakes fringed with flat-topped acacia trees and the bird life it supports particularly Greater and Lesser flamingos seen wading along the shore lines are chief tourist attracting features. The park also serves as a stopover for high population of migrating birds including shoveler and Black-winged Stilt, Avocet and Little Stint, making it a paradise for bird watchers. LakeAbijata is specially known as a major feeding ground for the Lesser Flamingo and the Great White Pelican. (fanosethiopiatours.com).The relatively close proximity of the park to Addis Ababa in addition to its location alongside other tourist destinations like Lake Langano and NechSar Park are other factors that attract visitors.

According to Ethiopian Wild Life Conservation Authority, EWCA mentioned by TadesseFetahi, 2016, 8,611 people visited ASLNP in 2010/11 ranking second place on most visited next to Semien Mountains National Park at the same year.

3.3. Description of the ecosystem

ASLNP compresses the two hyper saline "soda" lakes Abijata and Shala with a thin strip of land along their shorelines. The park is well known for its large number of wetland birds of over 400 species.

This amounts to almost half the number recorded for the whole country (Abebe, Y.D. &Geheb, K., 2003).

The ecosystem supports important resident and migrant species that are listed in international agreements as Endemic, Endangered, Near-threatened, and Vulnerable.

Species endemic to Ethiopia like Abyssinian black-headed oriole and Yellow fronted parrot, near threatened ones like lesser and Greater Flamingo and other globally threatened, endangered and vulnerable species are supported by lakes in the park. (EWNHS,1996).The Lesser Flamingo, is prominent over the park with a highest estimate of 233,000 measured from 1991-1996.The record high population of Greater Flamingos was measured to be 59,000 during the same time.(EWNHS 1996). The sight of Lesser Flamingos wading along the shore lines of the lake searching for food attracts numerous visitors.

Lesser Flamingos are identifiable by their long curved necks and thin, pink legs. They have webbed feet, large wings, and a short tail. They tend to be light pink and white in color due to the type of food they consume. They are gregarious animals, flocking in large numbers (hundreds or even millions).Despite being the most numerous species of flamingo, it is classified as near threatened due to its declining population. Their colorful appearance, large size, unique behavior (such as standing on one leg), and gregarious nature, sometimes flying or feeding in very large flocks creates a spectacular scene showing special tourist generating potential of the species.(newworldencyclopedia.org)Presently, in Ethiopia there is no effective protection of flamingo feeding areas or law enforcement to protect the bird. (T. Kumssa and A.Bekele, 2014).

The phytoplankton biodiversity of soda lakes like Abijata is lower than that of nearby fresh water lakes due to its intolerable physio-chemical constitution. The blue-green alga known as Arthrospira fusiformis (formerly called Spirulina platensis) is the most abundant phytoplankton under natural conditions (S.V.Matagi,2004).Benthic diatoms are present where light can penetrate often at the lake edges, on the wet mud and shallowest portion of the lake.

3.4. Data Collection

3.4.1. Rainfall Data Collection

Gridded monthly rainfall data over the lake for a period from 1986-2016 is collected from NMSA both in excel and NetCDF format. The data is then filtered and sorted so as to get the specific coordinates of each grid that lies over the lake and its corresponding rainfall values.

3.4.2. Lake Bathymetry

The bathymetry that shows the lake area and capacity is taken from MoWIE. This is the most recent study conducted in 2009 by HGL and GIRD Consultants. The lake area is measured to be 132.56 square kilometer at an elevation of 1581meter.

3.4.3. Hydrological Data Collection

There are two stations that measure the river inflows in to Lake Abijata. Station Kerkersitu gauges River Bulbula. Station Horakelo gauges River Horakelo. The river-discharge time series of stations Kerkersitu, Meki and Horakelo is collected from MoWIE.

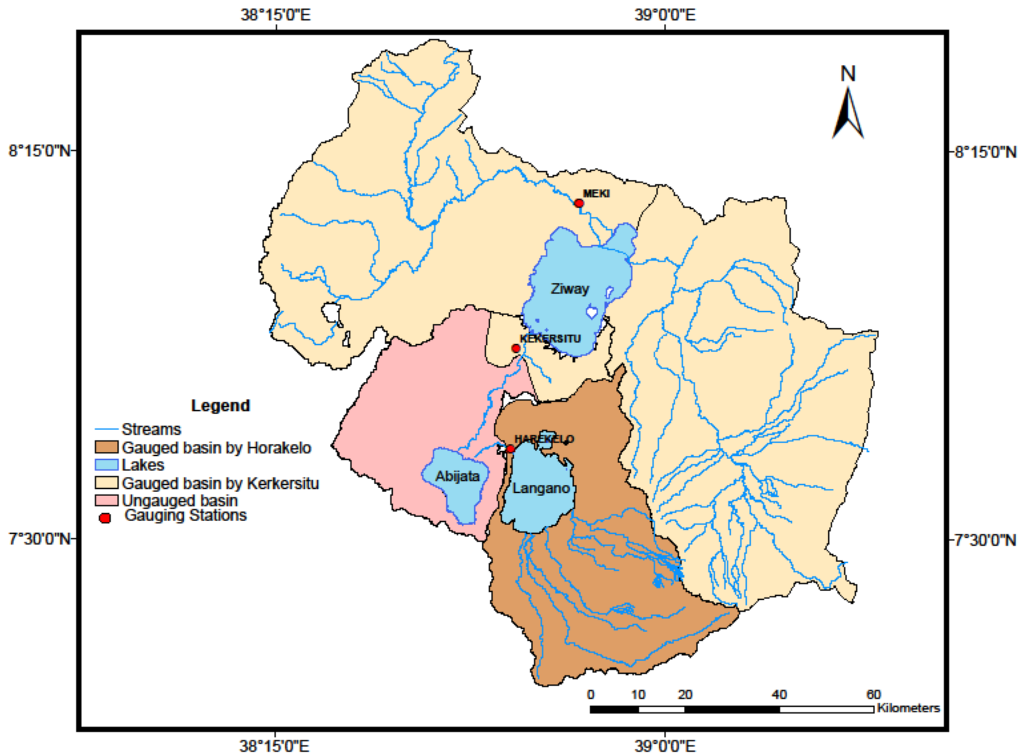

Figure 7 Basin of Lake Abijata

3.4.4. Ecosystem water requirement

Numerical facts regarding the nature and characteristics of Lesser flamingos residing the lake is collected from reviewing literatures. Information on the favorable condition for the bloom of the blue green algae (Arthrospira Spirullina) is also used from reviewing literatures. The status and inventory of Lesser Flamingos over the ASLNP throughout the years of the parks existence is taken from Ethiopian Wildlife Conservation Authority (EWCA).

The first two data's are processed to estimate the monthly water input into Lake Abijata, the facts and figures from the third one is essential in finding out the environmental water requirement of the lake taking Lesser Flamingos as the target species.

3.5. Tools used

GIS: To delineate the watershed of the CRV and calculate lake water evaporation

SWAT: To model the runoff at Kerkersitu station

Excel based equation: To calculate the water balance.

3.6. Selecting the method to estimate environmental water requirement

Generally the methods can be grouped in to three main categories. Hydrological rules, Hydraulic-Habitat, and Holistic methodologies. (EU Technical Report, 2015). Hydrological method is based on analyzing historically existing or simulated stream flow data. It does not operate at a species or community-specific level. Hydraulic-habitat method is analyzing physical or hydraulic status of water bodies and next by modeling of the biological associations with the physical environment. The latter considers different habitat parameters such as water depth, water temperature, substrate composition etc.

The goal is to come up with a suitable habitat for a chosen target species whose existence is under threat. Holistic method integrates human and ecosystem flow requirements into assessment framework.

"The philosophy of these approaches is that all major biotic and abiotic components constitute the ecosystem to be managed, and secondly, that the full spectrum of flows, and their temporal and spatial availability variability constitute the flows to be managed."(Arthington, 1998) as cited by EU Guidance Document (2015).

The hydrological method totally neglects the consideration of the biotic and abiotic components of the ecosystems simply focus on the natural flow variability. On the other side the holistic approach takes in to account all possible ecosystem interactions, which are difficult to examine in the given data scarce water body environment and in the absence of expertise in the field.

Therefore, the habitat based approach which takes the middle ground of the two extremes was selected for this study.

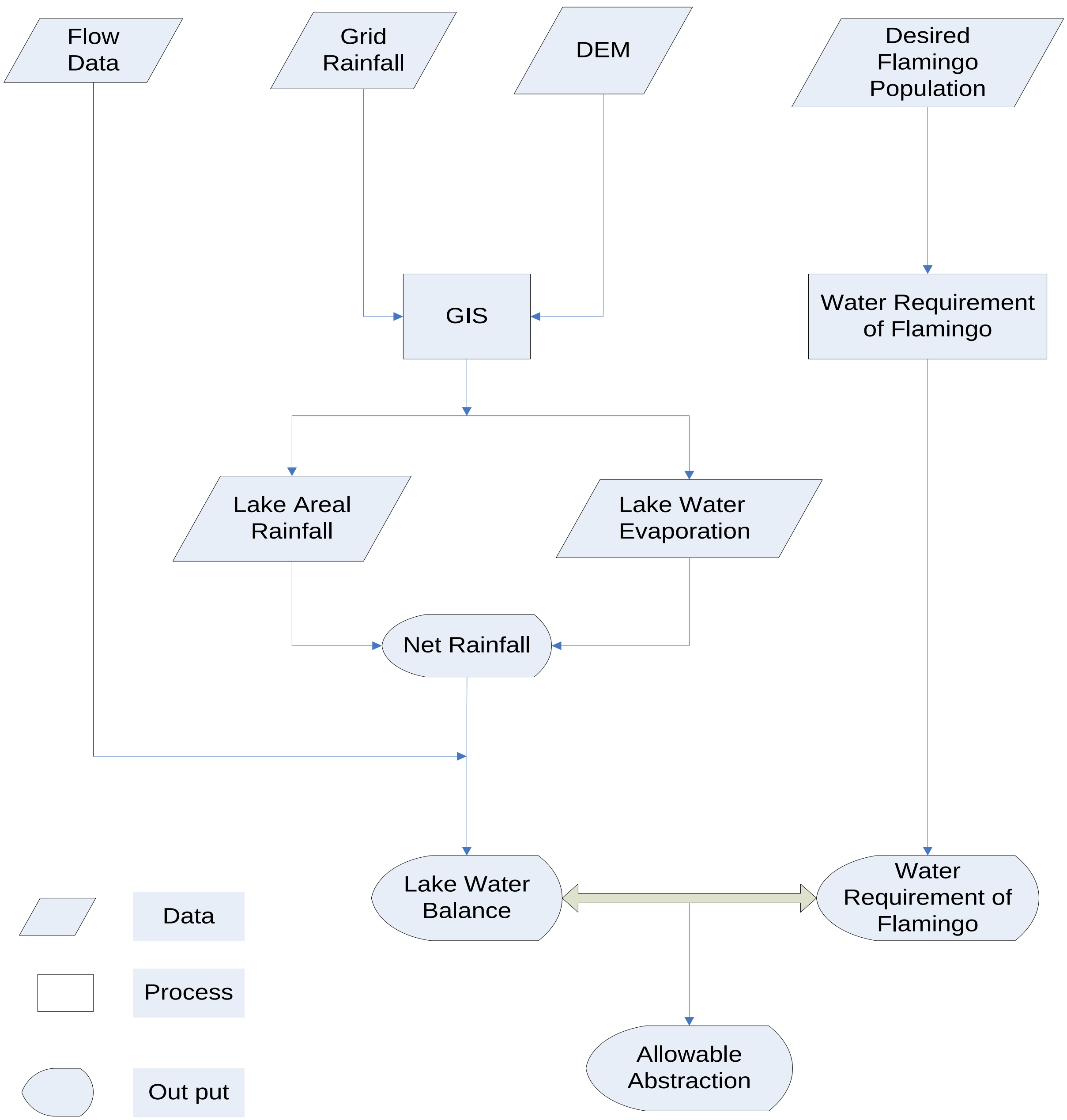

Figure 8 Methodology framework

3.7. Procedures followed

3.7.1 Lake areal rainfall

Reliable information on precipitation at sufficiently detailed spatial and temporal scale is an essential component for accurate computation of lake areal rainfall. There are five rainfall gauging stations around Lake Abijata, which area unevenly distributed or concentrated on one side (eastern) of the lake. Among the stations one has data up to 2010 only and the other four have significant percent of missing data. Therefore grid rainfall dataset from1986-2016 with a spatial orientation of 4 km by 4 km is used for this work.

The wettest, driest and normal years over the lake for the mentioned period of time is then identified to know whether the lake was able to satisfy evaporation demand at least at the wettest year or not and what maximum deficit has occurred during the driest year. The monthly areal over the lake for the three years is then estimated by using theisson polygon as shown below.

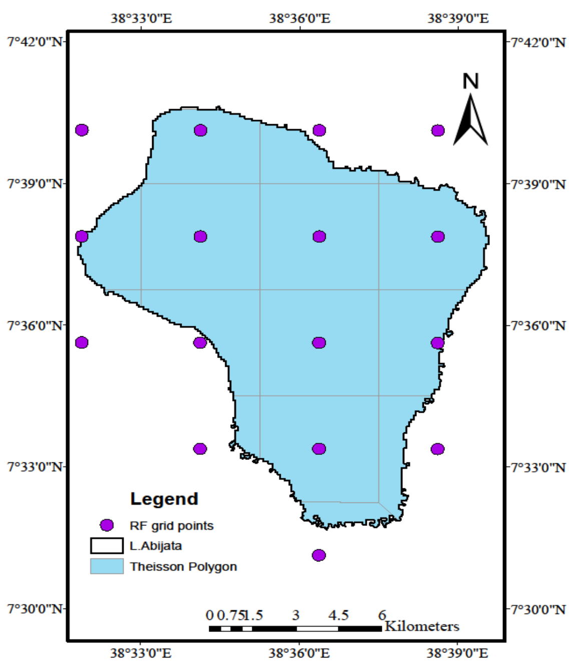

Figure 9 Theisson polygon over Lake Abijata

3.7.2 Open water evaporation

Evaporation from ponds, lakes and reservoirs is a key hydrologic parameter and cost-effective method of estimation is desired especially in areas where monitoring resources are limited. Chow et al. (1988) explains that evaporation form an open water surface is influenced by two main factors; the supply of energy to provide the latent heat of vaporization and the ability to transport the vapor away from the evaporative surface. Solar radiation is the main source of heat energy while the ability to move vapor away from the evaporative surface is dependent on wind velocity over the surface and gradient of specific humidity in the air above it. Evaporation estimation methods range from the complex as Penman-Monteith method to the simple pan method. The more complex the method gets more meteorologically measured and estimated input parameters are required. The error in measurement and estimation of input parameters increase the error in the calculation of evaporation. Thus adopting simpler methods especially in geographical areas where there is limited resource for monitoring is an option worth considering. (Monteith, J.L, 1990)

"The Simple Method "also cited as Abitew method requires single measured parameter only, solar radiation, that can be acquired through satellite observation apart from ground based surveillance. This method was applied to Rift Valley Lakes of Ethiopia, and the monthly lake evaporation estimates from this approach corresponds very well with Penman and energy balance approaches. The simple method has also been tested and applied in South Florida where it is currently the standard method for lake evaporation by the South Florida Water Management District. Application of the method to other regions is also cited. Generally, the method should provide good evaporation estimate in tropical and subtropical areas where humidity is high, wind speed not high and temperature correlated to radiation (Melesse, Abtew and Dessalegne, 2009).

In areas like the Rift Valley Lakes of Ethiopia where there is limited observed meteorological data, complex methods are less effective.

Thus in this study the Simple Method is applied to estimate the potential evaporation from Lake Abijata under varying climatic conditions. Three specific years representing dry, normal and wet years from the considered time frame (1986-2016) are selected. The Simple Method also cited as Abtew Equation or Simple Abtew Equation in published literature reads as:

$$ET = K_1 \frac{R_s}{\lambda}$$

Where:

ET: is daily potential evapotranspiration (mm d-1),

Rs: is solar radiation (MJ m-2 d-1), Rs= (0.25+0.5n/N)Ra,

n=Sunshine hour,

N=Maximum possible duration of sunshine or daylight hours (hour)

Ra=Extraterrestrial radiation [MJ m-2 d-1]

λ: is latent heat of vaporization (MJ kg-1), and

K1 is a coefficient (0.53).

The latent heat of vaporization, (MJ kg-1), is given by (Harrison, 1963) as

$$\lambda = 2.501 - 0.002361T$$

Where:

T (°C): is the daily mean air temperature (equal to the average of maximum and minimum air temperature) for 24-hour time step computations, while hourly temperatures are used for hourly computations. The latent heat of vaporization is set equal to 2.45 MJ/kg in FAO-56 Penman-Monteith evapotranspiration estimates. For water 1 kg = 0.001m3.

The monthly net rainfall over Lake Abijata (Rf-Et) for the dry, wet and normal years is then calculated.

3.7.3 Inflow estimation

Surface water inflow in to a lake includes water by rivers, streams, and direct overland flow. There are two gauged rivers dominating surface water inflow in to Lake Abijat flowing from Lakes Ziway and Langano. Comparatively, less water is discharged from Lake Langano to Lake Abiyata. Lake Ziway receives its inflow from major incoming rivers Katar and Meki. The former discharges from the eastern and south-eastern plateaus while the later discharges the runoff from the plateau west of Lake Ziway. Stations Kerkersitu and Horakelo measure the inflows of Bulbula and Horakelo River respectively. Mean monthly values from 1986 to 2010 are used as monthly inflow components from the gauged rivers.

Ungauged catchment refers to catchments having topographic and climatic properties that are available with little or no observed discharge data. There are a number of approaches available for predicting flows from ungauged catchments.

Usually the methods are based on transferring or extrapolating information from gauged to ungauged area. The area ratio, spatial proximity, sub-basin mean and model regionalization methods are used to estimate flows of ungauged areas. For this case, flow of ungauged catchment is determined using Rainfall-Runoff model named SWAT. The, basin draining in to Bulbula River is calibrated taking the flow measured at station Kerkersitu from year 1990 to 1996 for calibration. The catchment of River Bulbula and the ungauged portion Lake Abijatas surrounding lie in a closed basin thus,share common features such as; type of vegetation cover, soil type, and agricultural practice. Therefore, once the suitable parameters are set for the acceptable range of NSE and R2 values, these parameters are used to determine flow to the ungauged basin. The station at River Bulbuladrains a catchment of 7488 Km2 while the ungauged portion of Lake Abijatas watershed is 1116.09km2.

3.7.4 Selecting the target species

Saline lakes of the East African Rift Valley like Lake Abijata, are known for their aquatic bird life mainly flamingos which are a big tourist attraction bearing economic advantage for local people.(Harper et al.,2003).“These economical potentialities are adversely affected by unpredictable changes in flamingo population distribution as well as hydrological regimes, probably caused by cyclic changes in the water quantity and quality of the lakes (TANAPA, 2005).”(Emilian Kihwele1, Charles Lugomela, Kim M. Howell, 2014).Flamingos are morphologically adopted to exploit microscopic food resources from saline water bodies via filter feeding (Vareshi, 1978).They separate food item from water and unwanted particles with their large, fatty and highly sensitive tongue with numerous fleshy spines complemented by a bill that has special plates adopted for sieving out food items. The microalgae, Arthrospira fusiformis sustains the life of the flamingos in the area and the carotenoids contained in it is renowned for giving them their distinct pink/orange coloring. Lesser flamingos depend on these microalgae, Arthrospira as its primary food source. A dense flock of lesser flamingos is a spectacular sight and it is observed where high density Arthrospira blooms occur. When spirulina is not available at a high enough density, Lesser flamingos switch to feeding on benthic diatoms. However, though widely distributed, production and carrying capacity of diatoms is much lower. Besides, diatomic microalgae are said to be too small to meet the size requirements of the highly specialized bills of Lesser Flamingos thus resulting in their malnutrition with a low mean body weight (1525gm) as reported by TewodrosKumssa and AfeworkBekele(2014) for flamingos of the ASLNP. This weight in comparison to 1760gm reported by Brown(1973)and 1800gm by Bartholomew and Pennycuick(1973) cited by C.H Tuite(2000) which is the average weight of a Lesser Flamingo that is in a good nutritional state reveals that L.flamingos of the ASLNP are malnourished. Besides, this scattered sparse presence of the diatoms force the flamingo population to disperse and even disappear from Lake Abijata. Similar situation has occurred in Lake Nakuru of Kenya where the75%

decline in the standing crop of A. fusiformis, was followed by a massive migration of Lesser flamingos from over one million birds in January to below 10,000 by August–September of the same year (C.HTuite, 2000).

The above and other documented evidences lead to the conclusion that Lesser Flamingo is taken as the target species for Lake Abijata and to create a suitable habitat for it abundance of arthrospira that can support the population is mandatory.

3.7.5 Population of Lesser Flamingo

The largest number of Lesser flamingos recorded in ASLNP was 233,000 back in 1993(EWNHS, 1996).Lake Abijata harbors 46.47% of these wetland birds (T. Kumssa and A.Bekele, 2014) meaning 108,275 of Lesser flamingos were present on the mentioned year. Increased carrying capacity (dense flocks of lesser flamingos) guarantees spectacular sight of the natural world which is a popular attraction for eco-tourists. This number is believed to restore the scenic beauty of the lake thus attracting more visitors.

3.7.6 Productivity of Arthrospira

C.H. Tuite (2000) calculated a range of predicted productivity values for arthrospira over East African soda lakes at different standing crop densities using data on chlorophyll concentration He found out that the estimated net productivity for arthrospira blooms peaked at 7Watts/m2 and didn't decline below 1Watt/m2.The net primary productivity of arthrospira blooms is much higher than that of benthic diatoms implying larger flock density of flamingos over a lake. However, there is a dramatic fluctuation in its concentration due to natural as well as manmade factors. The sampling data gathered by C.H. Tuite (2000) showed that this microalgae was either not available or only present at a very low density at most lakes of East African Rift. Therefore, the lowest productivity value of 1Watt/m2is considered for the arthrospira of Lake Abijata as a safer estimation.

3.7.7 Required production of Arthrospira

To guarantee the above mentioned population, sufficient production of Arthrospira that support the energy requirement of the Lesser Flamingos has to be ensured. According to Tuite(1978) cited by C. H. Tuite(2000),the estimated average metabolic rate of a Lesser Flamingo in a good nutritional state is 6.2 watts with an assimilation efficiency of 80%.Therefore, the required energy rate for 108,275 Lesser Flamingos is known which in turn helps to know the required productivity of Arthrospira

3.7.8 Water required for arthrospira

O. Ciferri (1983) stated that arthrospira has 0.63 percent of protein content per gram and requires 1000m3of water per tonn of protein production. Taking this value and the required productivity the water demand is calculated.

3.7.9 Water balance and demand

The lake water balance is calculated using the following basic equation. The calculated water demand is then subtracted from the output of the water balance to estimate the water available for safe abstraction.

$\Delta S/\Delta T = (P + SI\ Ungauged + SI\ Gauged + GWI) - (Eo + So + GWo) + SS$

Where:

P = Lake area rainfall [L3T-1]

SIUngauged=Surface water inflow from ungauged catchments in to the lake [L3T-1]

SIGauged=Surface water inflow from gauged catchments in to the lake [L3T-1]

So = Surface water outflow from the lake [L3T-1]

GWI = Subsurface water inflow in to the lake [L3T-1]

Eo-=Open water evaporation from the lake surface [L3T-1]

GWo=Subsurface water outflow from the lake, and [L3T-1]

SS=Sink Source term [L3]

CHAPTER FOUR

4. Results and Discussion

4.1. Data quality verification

Even though the quality of gridded rainfall data was evaluated with in national level (Tufa,D. et.al, 2018), additional quality verification for the local scale was done using Bulbula rainfall station nearest to the lake. The performance of the grid data quality verified with statistical measure of coefficient of and 0.72 respectively (Figure 5).

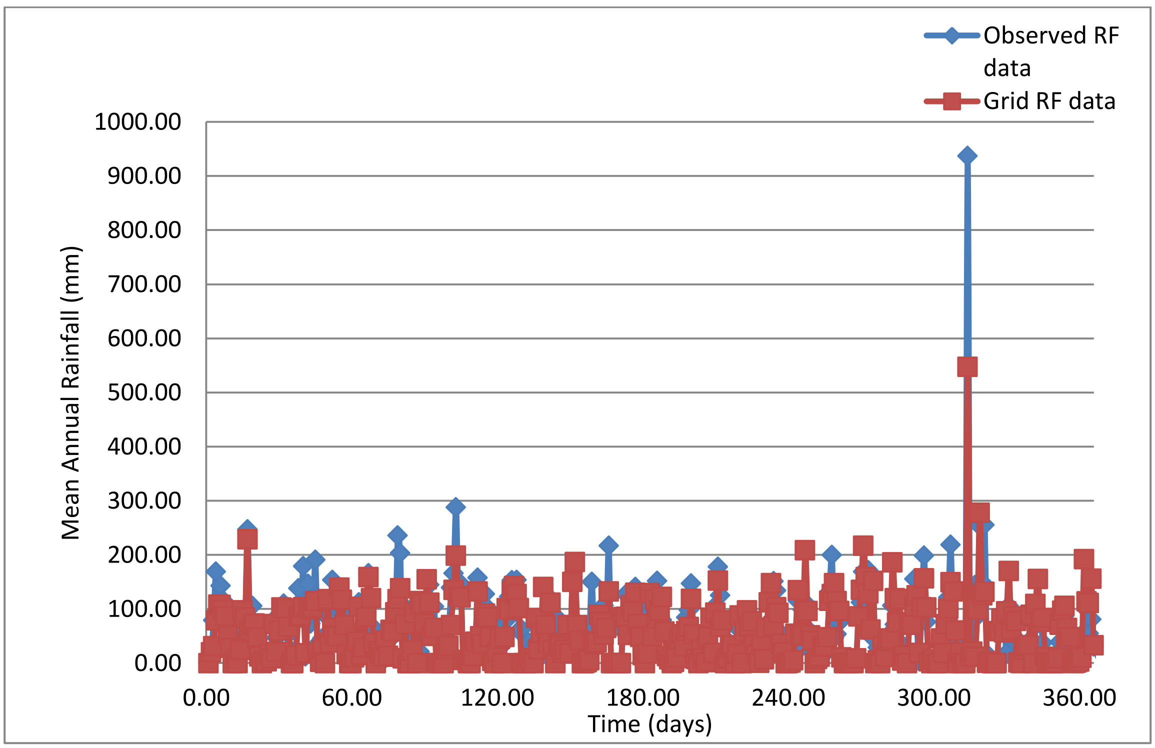

Figure 10 Grid and Observed monthly rainfall (1986-2016)

4.2. Lake areal rainfall

Dry, Wet and Normal years are chosen based on taking the year corresponding to 85%,10% and 50% exceeded yearly rainfall values from 1986-2016. And the year 1988, 1996 and 1994 become the representative years of Dry, Wet and Normal years respectively. The following monthly areal rainfalls over the lake for these years are then estimated using theisson polygon.

Table 5 Lake areal rainfall for Wet, Normal and Dry years

Rainfall(mm)			
Month	**Wet year (1996)**	**Normal Year (1994)**	**Dry Year (1988)**
January	56.74	0	12.98
February	0.89	0.88	24.3
March	84.91	27.51	7.11
April	91.04	62.12	88.17
May	119.18	75.39	41.95
June	172.88	128.76	82.1
July	160.18	249.13	120.21
August	152.72	140.29	132.72
September	123.68	145.08	129.5
October	18.66	4.95	69.45
November	3.69	18.86	0
December	1.06	0.97	0
Annual	**985.63**	**853.94**	**708.49**

4.3. Lake evaporation

The evaporation over the lake area is computed by using GIS based "Simple Abtews Equation "which requires only one parameter, Solar Radiation. Solar radiation "Rs" is obtained using the solar radiation tool in Spatial Analyst of ArcGIS. Choosing "whole year with monthly interval" in the "Time configuration" section for each year (wet, normal and dry) and checking on "Create output for each interval" gives thirty six outputs in a raster format. Table below shows the monthly evaporation over the lake for the years 1996, 1994 and 1996

Table 6 Lake water evaporation for Wet, Normal and Dry years

Evaporation(mm)			
Month	**Wet year (1996)**	**Normal Year (1994)**	**Dry Year(1988)**
January	121.25	122.04	121.65
February	122.15	122.08	122.25
March	149.78	149.56	143.80
April	149.57	149.35	144.20
May	152.06	151.04	146.37
June	145.45	145.40	139.00
July	150.85	150.12	145.00
August	153.82	153.88	148.76
September	150.99	151.00	151.00
October	134.88	134.88	134.98
November	120.90	120.90	120.90
December	116.92	117.13	116.93
Annual	**1668.62**	**1667.38**	**1634.84**

4.4. Net Rainfall

The net rainfall (Rainfall-Evaporation) over the lake is thus presented as follows

Table 7 Net rainfall over Lake Abijata

Net Rainfall (mm)			
Month	**Wet year (1996)**	**Normal Year (1994)**	**Dry Year(1988)**
January	-64.51	-122.04	-108.67
February	-121.25	-121.20	-97.95
March	-64.87	-122.04	-136.69
April	-58.54	-87.23	-56.03
May	-32.88	-75.65	-104.42
June	27.43	-16.65	-56.90
July	9.33	99.01	-24.79
August	-1.10	-13.59	-16.04
September	-27.31	-5.92	-21.50
October	-116.22	-129.93	-65.53
November	-117.21	-102.05	-120.90
December	-115.86	-116.16	-116.93
Annual	**-682.99**	**-813.45**	**-926.35**

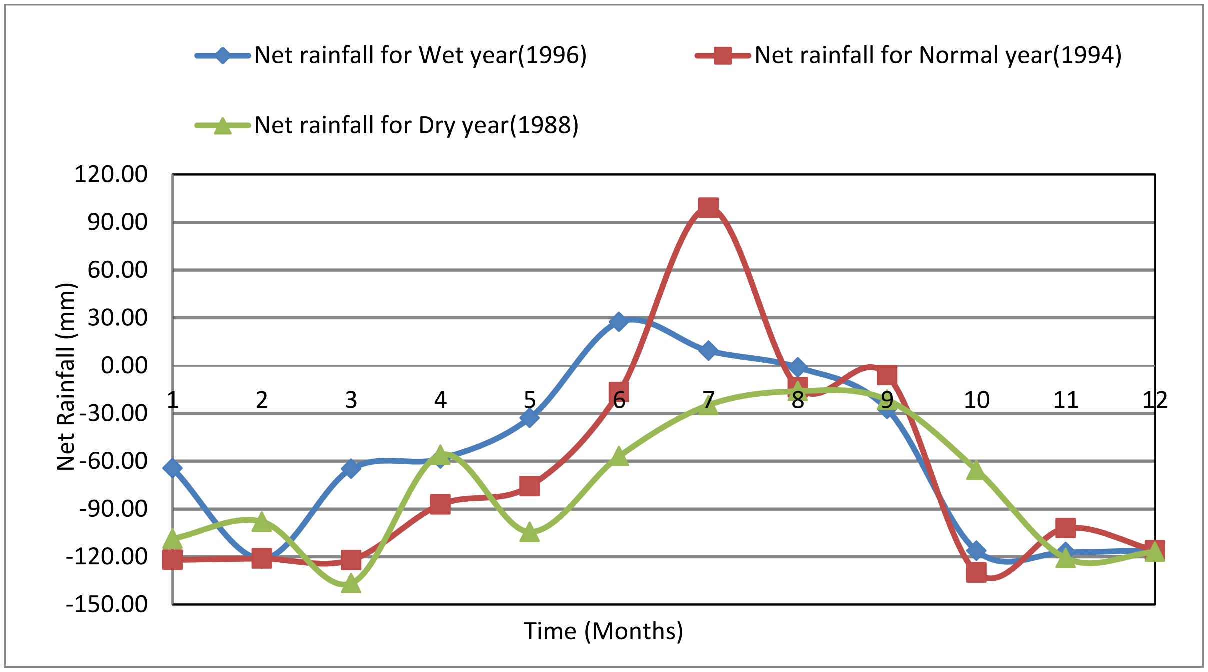

Figure 11 Net rainfall values for dry, normal and wet years

As shown in the table the lake cannot handle evaporation demand just by the rain falling over it even during the wettest year with the exception of June and July.

4.5. Ungauged Catchment flow estimation

Flow from the ungauged portion of Lake Abijatas catchment is estimated by calibrating the gauged catchment at kerkersitu and using the best fit parameters to represent the ungauged watershed since both catchments lie in the same basin and are likely to have similar characteristics. Flow for calibration is used from 1990-1996 and flow for validation is used from 1997-2003 resulting in a NS value of 0.51for calibration and 0.22 for validation. Calibrated flow parameters values and graph of Observed vs simulated values are shown below.

Table 8 Calibrated flow parameter values

Parameter Name	Description	Fitted_Value	Lower and Upper bounds
R__CN2.mgt	SCS runoff curve number	-0.08	±25.0
V__GWQMN.gw	Treshold depth for shallow aquifer	4230.37	0-5000
R__SOL_AWC.sol	Available water capacity	0.29	±25.0
V__ESCO.hru	Soil evaporation compensation factor	0.94	0-1
V__SLSUBBSN.hru	Average slope length	18.15	10-150
R__SOL_K.sol	Saturated hydraulic conductivity	0.30	±25.0
V__RCHRG_DP.gw	Deep aquifer percolation fraction	0.93	0-1
R__SOL_Z .sol	Depth from soil surface to bottom of layer	0.16	±25.0
V__GW_REVAP.gw	Groundwater "revap" coefficient	0.09	0.02-0.2
V__BIOMIX.mgt	Biological mixing efficiency	0.22	0-1
V__CH_K2.rte	Effective hydraulic conductivity	361.48	-0.01-500
V__CANMX.hru	Maximum canopy storage	94.68	0-100
V__SURLAG.bsn	Surface runoff lag time	22.81	0.05-24
V__EPCO.bsn	Plant uptake compensation factor	0.49	0-1

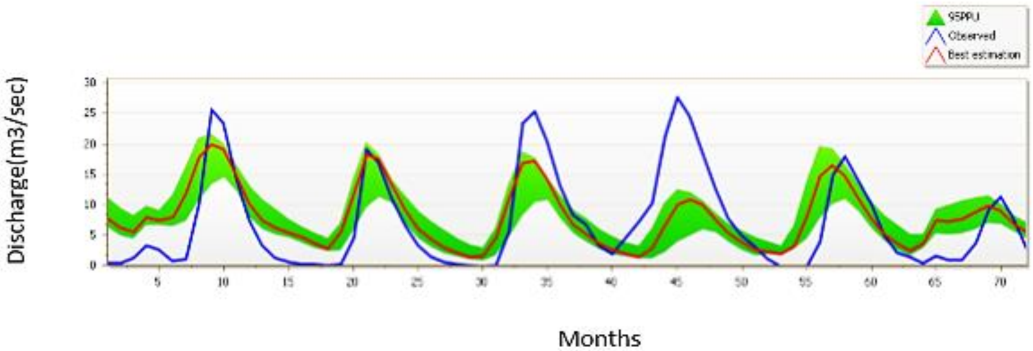

Figure 12 Calibration output using SWAT_CUP

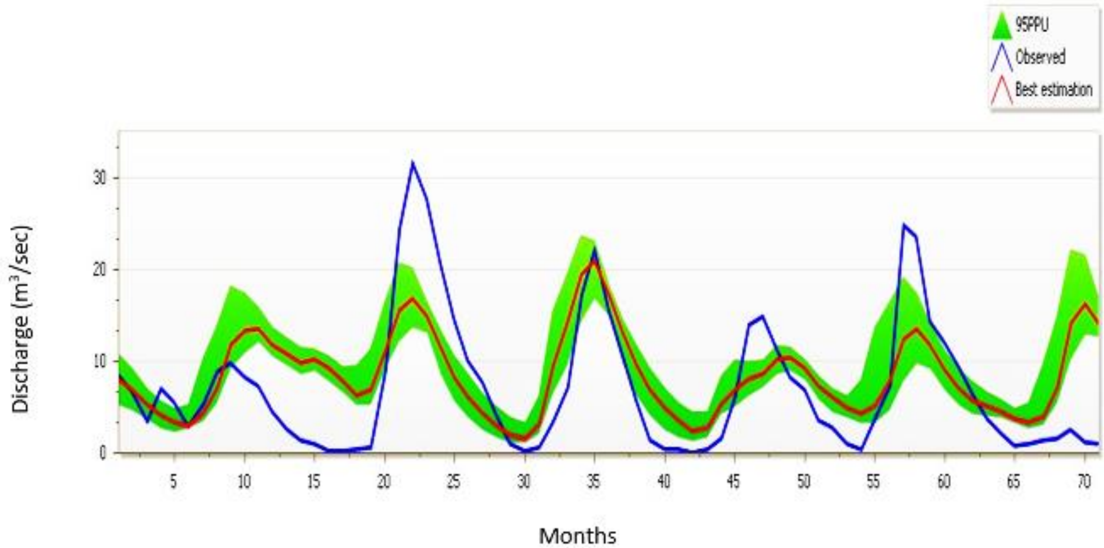

Figure 13 Validation output using SWAT_CUP

Table 9 Average monthly water balance component simulated for a base period of 1996-2013 for Bulbula catchment

Months	Surf Q(mm)	Lat Q(MM)	Water Yield(MM)	ET(mm)	PET(MM)
1	6.43	0.9	9.28	46.59	170.98
2	2.58	0.71	4.65	56.76	174.97
3	18.01	1.58	21.48	105.36	196.11
4	14.39	1.89	18.62	117.17	188.57
5	14.81	2.2	21.02	128.08	197.66
6	26.54	2.68	36.13	119.29	161.74
7	40.05	4.46	55.96	118.85	142.01
8	31.96	5.34	63.37	95.4	168.61
9	18.92	4.41	60.53	86.41	181.43
10	13.61	2.76	49.56	73.15	185.47
11	4.12	1.34	13.52	44.93	166.48
12	3.07	0.8	6.66	34.24	163.22
Annual	**194.49**	**29.07**	**360.78**	**1026.23**	**2097.25**

Table 10 Mean monthly inflows in to Lake Abijata

Mean Monthly Flow(m3/sec)			
Month	**Kerkersitu**	**Langano**	**Ungauged catchment**
January	4.29	0.98	3.19
February	2.81	0.65	2.99
March	1.66	0.42	2.98
April	1.27	0.29	3
May	1.09	0.26	3.5
June	1.12	0.32	4.5
July	1.86	0.49	4.5
August	5.46	1.53	4.28
September	12.8	3.09	3.11
October	15.24	3.89	3.5
November	11.61	2.73	3.08
December	7.26	1.67	2
Annual Flow	**66.47**	**16.32**	**40.63**

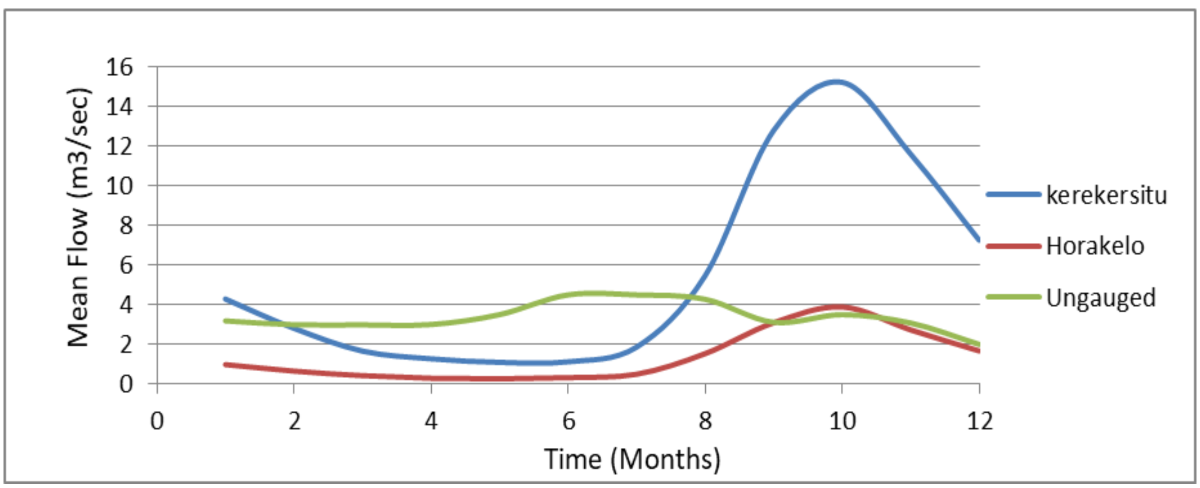

Figure 14 Mean monthly gauged flows in to Lake Abijata

4.6. Habitat water requirement of the lake based on the water demand of Arthrospira

The optimal population of Lesser Filamingo that is set for ecologically sound condition is estimated as 108,275 based on the inventory of the birds in the Abijiata-Shalla Park (Reaugh-Flowe, 1996). According C. H. Tuite(2000),the estimated average metabolic rate of a Lesser Flamingo in a good nutritional state is 6.2 watts with an assimilation efficiency of 80%. Thus, to accommodate the estimated number of Lesser Flamingo with good nutritional state, 839,131.25 Watt is required.

Consequently, one gram dry weight of arthrospira with 65% protein content generates 4.840kcal (E.Vareschi 1982), of energy and 1000kg of protein production of arthrospira requires 1000m^3 water(O. Ciferri,1983). Therefore the monthly dry weight production of arthrospira and its corresponding water requirement is computed and presented in table (10).

Table 11 Monthly Dry weight and water requirement of arthrospira

Months	Dry Weight of arthrospira (kg)	Water Requirement (m3)
January	110,992.9	72,145.37
February	100,251.7	65,163.56
March	110,992.9	72,145.37
April	107,412.5	69,818.1
May	110,992.9	72,145.37
June	107,412.5	69,818.1
July	110,992.9	72,145.37
August	110,992.9	72,145.37
September	107,412.5	69,818.1
October	110,992.9	72,145.37
November	107,412.5	69,818.1
December	110,992.9	72,145.37
Annual water Requirement		**849,453.55**

4.7. Demand and Supply analysis

Table 12 Monthly water balance of Lake Abijata

Month	Total inflow in to Lake (Mm3)	Rainfall over the lake (Mm3)	Evaporation over the lake (Mm3)	Habitat based ecosystem Water Requirement (Mm3)	Supply demand difference (Mm3)
Jan	22.66	0	16.18	0.072	6.408
Feb	15.61	0.12	16.18	0.065	-0.515
Mar	13.56	3.65	19.83	0.072	-2.692
Apr	11.82	8.23	19.80	0.0698	0.1802
May	12.99	9.99	20.02	0.072	2.89
Jun	15.4	17.07	19.27	0.0698	13.13
Jul	18.35	33.02	19.90	0.072	31.39
Aug	30.19	18.6	20.4	0.072	28.32
Sep	49.25	19.23	20.02	0.0698	48.39
Oct	60.61	0.66	17.88	0.072	43.32
Nov	45.15	2.5	16.03	0.0698	31.55
Dec	29.27	0.13	15.53	0.072	13.8
Annual	**324.85**	**113.2**	**221.03**	**0.85**	**216.17**

The demand and supply of lake water is analyzed using the basic water balance equation with the two water sources (rainfall and river flow) as supply side and the environmental water requirements (i.e., lake evaporation and habitat ecosystem water requirement) as the demand side. The difference of the two is considered as the potential water for any other economic activities

The results above are obtained through following habitat based approach in estimating the EWR of Lake Abijata. In this case the environmental water is quantified based on enhancing the habitat for the most dominant bird over the area, Lesser Flamingos, and satisfying the lake water evaporation demand.

The water requirement for lesser flamingos is worked out indirectly through knowing the volume of water required to grow their food of primary choice. A desired number for flamingo population of 108,275 is used for the estimation due to the fact that this number is the highest recorded number back in 1996 G.C and is of huge touristic significance since numerous visitors come to ASLNP for the sole purpose of bird watching.

In addition it goes in line with the purpose of the parks inauguration which is to provide suitable environment for both wetland and terrestrial birds, Lesser Flamingo, being the species with a dominating presence. Accordingly, the results reveal mean annual evaporation to be 221.03 Mm3 and annual water requirement of Lesser Flamingos as 0.85 Mm3 which accounts in total for 50.6 % of the available volume of water. Even during the wettest year, the rainfall over the lake cannot satisfy the evaporation demand with the exception of two months (June and July) for the wet year (1996) and July for the normal year (1994). Rainfall and inflow in to lake is taken as a supply component of the water balance while lake area evaporation and EWR is considered as a demand component. The supply-demand difference is the allowable abstraction from the lake inflows that can be withdrawn without affecting the lakes potential of serving the desired number of flamingos as their food source.

As a result in the months of February and March there can be no withdrawal, rather additional amount of flow is required to null the deficit. For the rest of the month's abstraction ranging from a minimum of 0.18 Mm3 in April to a maximum of 48.39 Mm3 in September is considered safe. Generally the total annual allowable limit of diversion from inflows in to Lake Abijata is estimated as 216.17 Mm3.

CHAPTER FIVE

5. Conclusion

There are three basic methodologies the world uses in estimating the EWR of water bodies. Hydrologic, Hydraulic Habitat and Holistic. Among the methodologies followed habitat based EWR estimation is used for this research.

Based on this objective the water required for ensuring suitable habitat for the most dominant birds over the lake, Lesser Flamingo, is estimated as 850,035.37m3 per year. This value in addition to the annual lake water evaporation volume is the EWR calculated as 221.88 Mm3. Thus the net annual water volume is calculated as 216.17 Mm3 as the allowable limit of diversion for human need. Any volume of abstraction beyond the mentioned amount is considered unsafe for the existence of the already diminishing population of Lesser Flamingos and the ASLNPs appeal as a bird's sanctuary.

CHAPTER SIX

6. Recommendation

The concept of determining EWR and respecting ecological limit of abstraction is at its early stages in our country. Releasing certain percentage of water for the downstream environment lacks detailed knowledge of the existing ecosystem and its demand for water. Thus the flow released would be either too much or scarce thereby degrading rather than preserving the downstream aquatic ecosystem.

Understanding the overall functioning of ecosystems helps to know the quality and quantity of water it requires. Particularly in vulnerable areas like the CRV a serious analysis of the EWR that involves experts over the field is a very important part of nature protection and conservation policy.

Ethiopian Wildlife Conservation Authority(EWCA) has to not only be part of the stakeholders deciding on the degree of hydrologic alterations over lakes and their inflow rivers but also the one who has the power to cancel planned water abstraction activities and terminate the existing ones which go beyond the ecological limit set for healthy performance of the ecosystem.

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