BATHYMETERIC SURVEY AND ESTIMATION OF WATER BALANCE OF LAKE ZEWAY, CENTRAL RIFT VALLEY OF ETHIOPIA

By
Abdo Bedasso Ogato

A Thesis Submitted to the Department of Water Resources Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resources Engineering (Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

Adama, Ethiopia
October, 2020

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ADVISOR APPROVAL SHEET FOR THESIS SUBMISSION

To: Water Resource Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled Bathymetric Survey and Estimation of Water Balance of Lake Zeway, Central Rift Valley of Ethiopia submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering), the Graduate program of the department of Water Resource Engineering, and has been carried out by Abdo Bedasso Ogato, (ID. No A/PE 16419/10), under my supervision and guidance. Therefore; I recommend that the student has fulfilled the requirements and hence here by he can submit the thesis to the department.

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Name of Advisor	Signature	Date

BOARD OF EXAMINERS APPROVAL SHEET

We, the undersigned, members of board of examiners have read and evaluated the M.Sc. Thesis entitled 'Bathymetric Survey and Estimation of Water Balance of Lake Zeway, Central Rift Valley of Ethiopia'which prepared, presented, and defended by Mr. Abdo Bedasso Ogato.

This is, therefore, to certify that the thesis has been accepted for partial fulfillment of the requirements for the degree of Master of Science in water resources engineering (Specialization in Irrigation Engineering).

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DECLARATION

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

Name of the Student____:

Signature:____

This MSc Thesis has been submitted for examination with my approval as thesis advisor

Advisor

Name: ______________________________

Signature: ___________________________

Date of submission_____________________

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LIST OF ACRONYMS AND ABBREVATIONS

ANRB	Agricultural and Natural Resources Bureau
ASTU	Adama Science and Technology University
ATJK	Adami Tulu Jido Kombolcha
CRV	Central Rift Valley
CSA	Central Statistical Agency
ERV	Ethiopian Rift Valley
Et	Evaporation from Lake Surface
ETo	Evapotranspiration
FAO	Food and Agricultural Organization
GPS	Global Positioning System
ITCZ	Inter Tropical Convergence Zone
MoLRD	Ministry of Land and Sea Resources Development
Masl	Meter Above Sea Level
MCM	Million Cubic Meter
Mm^3	Million Meter Cubic
MoANR	Ministry of Agriculture and Natural Resources
MoWR	Ministry of Water Resources
NGO	Non-governmental Organization
NMSA	National Meteorological Service Agency
OIDA	Oromia Irrigation Development Authority
RAD	Rural and Agricultural Development
RH	Relative Humidity
GNSS	Geometric Notes and Supplement Solutions

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ABSTRACT

Lake Zeway is locally called "Hara Dambal", is naturally existing exoreic reservoir located in the central Rift valley of Ethiopia with a total drainage area of 7444km^2 and at elevation of 1636 m.a.s.l. It is drained with two main rivers flowing in to the lake which are Meki and Katar and at the same time Bulbula River spills form the lake. The Lake is currently used for irrigation, water supply, fishing, transportation and recreation. Global change of climate, newly development activities around the lake, uncontrolled abstraction of water and human interference of the catchment inevitably changed the hydrological and ecological balance of the lake. The objective of the study was focused on bathymetric survey and assessing the water balance components of the Lake Zeway. The bathymetric map of the lake was established at a contour interval of 0.5 meter based on depth measurement of 652 geographic co-ordinate points using Arc GIS software while water balance components of the lake was analyzed using spread sheet . Average rainfall for the areal rain fall was quantified using stations arithmetic average method. Evaporation has been estimated using Penman Montheith method. The irrigation water abstraction was estimated using Cropwat. Bathymetric survey results showed that maximum depth of the lake, average depth, maximum length, maximum width of water lake perimeter, area and volume were 0.0062 km, 0.0026 km, 31.74 km, 20.05 km, 95.91 km, 469 km^{2}and 1174.23 MCM respectively. The water balance analysis of the lake revealed that, the inflow components such as gauged runoff (Katar and Meki), un-gauged runoff and precipitation on the surface of the Lake were 699.08 MCM, 121.33 MCM, and 356.51MCM per year respectively. While, the out flow components such as gauged runoff (Bulbula river), evaporation from the lake surface, and abstraction (irrigation and livestock consumption) were 173.45 MCM, 933.23 MCM, and 82.19 MCM respectively. The net groundwater flux estimated as a residual of the other water balance components was +11.95 MCM, indicating that the ground water inflow was substantial to contribute the flow to the lake Zeway having a positive impact to the storage of the reservoir system. The change in storage (ΔS) was estimated to be -11.93 MCM out of the total annual inflow percentage. The evaporation, Bulbula river outflow and abstraction (irrigation and livestock) consumption were 78.49%, 78.49% and 6.91% respectively out of the total out flow. Therefore; evaporation was highly responsible for the depletion of Lake Zeway annual water budget. In general, the mean annual inflow to the lake and mean annual out flow from the lake was estimated as 1176.93 MCM and 1188.86 MCM respectively. Annual inflow component of the lake was showed decreasing trend, while outflow components (evaporation and abstraction) showed increasing trend. This leads to the declining effect of Lake Zeway water level and flow of Bulbula River which supplies Abijata Lake. The rising trend of annual evaporation rate and siltation rate is responsible for this effect and will change this lake to Endoerhic Lake in near future and will attain the fate of Lake Haromaya and Abijata in the long run. Therefore, it is recommended to look a solution for minimization of the extent of out flow components (rate of evaporation and over utilizations of water from this lake) as well as applying important catchment development policy to minimize siltation for future sustainability.

Key Words: Bathymetric Survey, Water Balance, Human Interference, Lake Zeway

1. INTRODUCTION

1.1. Background of the Study

The Ethiopian Rift Valley and environment are important area in connection with water resources. The Central Rift Valley (CRV) areas consists four important lakes (Zeway, Langanno, Abijata and Shalla) and perennial Rivers (Ketar and Meki) and intermittent streams that drains to these lakes from adjacent highland areas. It is an area where water from the lakes and their environments are significantly used for domestic supply, agricultural, fishing, industrial and recreational purposes. Lands adjacent to the lakes are important for crop production using both rain-fed and irrigated agriculture (Dagnachew *et al*., 2005; Fransico *et al*., 2008). The wide diversity of landscapes and ecosystems of CRV comprises extensive biodiversity wetlands. At the same time the CRV is one of environmental vulnerable areas in the country. Being a closed basin, relatively small interventions in land and water resources can have reaching consequences for ecosystems and potentially undermine the sustainably of the water resources of the area (Tenalem, 2004; Dagnachew *et al*., 2004).

In contrast to the above facts, the CRV areas environmentally vulnerable in the country (Dagnachew *et al*., 2005; Scholten, 2007). The annual water abstractions from the Lakes and Rivers for different water uses are estimated above 215 MCM (Dagnachew *et al*., 2007). This situation in CRV is a typical example of computing claims for land and water resources (Dagnachew *et al*., 2007; Francisco, 2008; Scholten, 2007).

Population pressure and economic development as well as the settlement of large-scale foreign and national horticulture and floriculture enterprises are putting claims on land and water resources. Reasons for the increase in the last 10 years are suitable climate conditions and favorable governmental policies to attract foreign investment (Vuik, 2008). Small-scale irrigated agriculture has largely increased in recent years in the study area. In addition, NGO's are donating water pumps to poor farmers resulting in extra water extraction in addition to rain-fed farming. These developments have caused increased water consumption in and around Lake Zeway that results a negative impacts such as increasing siltation, chemical pollution from pesticide, herbicides and fertilizers and decreasing lake water level and storage volume which leads for drying up of Abijata Lake. Therefore, quantification of the water balance components and bathymetric survey is very crucial for sustainable management of the lake water. Bathymetric survey is the study of underwater depth of Lake Floor which is important for many purposes, such as estimation of sedimentation rate, quantification of lake morphology, fishing and other geophysical exploration purposes.

1.2. Statement of the Problem

Ethiopia is endowed with many lakes and rivers comprising diverse aquatic ecosystems of great interest and economic importance. The Rift Valley is particularly gifted and containing a chain of permanent lakes, with the exception of the largest Lake Tana on the highland. Hydrology and bathymetry of the major lakes in the main Ethiopian Rift lakes have been studed for more than half a century (Desie Nidow; 1997; Tenale Ayenaw, 1998; Vallet-Coulomb *et al*., 2001). Despite the importance of the various lakes scattered elsewhere in the country very few bathymetric survey and hydrological studies were carried out (Seifu Kebede, 1999; Molla Demelie, 2000). The increased competition for water resources in the CRV of Ethiopia puts a great pressure on the local hydrology and ecosystem of lakes and rises questions. Particularly for investigation of lakes and feeder Rivers hydrological behavior whether the lakes level and volume increase or decrease and to forecast the futurity of lakes with respective development activities in the area, climatic change and land use land cover change of Ethiopia. So far efforts made to investigate the problems of water resources of Lake Zeway and its catchment (Alemu, 2006), little emphasize has been given on assessing water balance of the Lake and the dominant components that significantly affects the Lake fluctuation and there is no clear information on the cause of the reduction of the size of the lake. Despite its importance in a wide spectrum of different purposes, especially the growing interest of irrigation development, shortage of relevant bathymetric and hydrological data in order to enhance inappropriate human induced activities (anthropogenic)and natural factors, lake Zeway is poorly understood. The existing problem related to over utilization, increasing trend of evaporation, siltation due to land degradation, plowing marginal areas of the lake basins and other misuse of the water resources resulted in decrease of the storage capacity of the lake.

Like other exoreic lake, Lake Zeway is undergoing all processes, such as fluctuation of lake level and volume with respective to anthropologic activities and climatic change. According to Tenalem (2007), if all proposed land area is irrigated, annual water abstraction from the Lake and major Rivers will be about 150 MCM with 3 m reduction in the level of Lake Zeway which ultimately lead to a drastic reduction in the level of Lake Abijata and drying up of the feeder Bulbula River.

Furthermore, there was high competition for Lake Zeway water among different water sources (such as; the lake, main Rivers and from its watershed of the rift) and spatiotemporal variations of land use land cover and climate change due to human interventions in the upper part of Lake Zeway Watershed are observed to be paramount problem in the study area.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study is to establish the bathymetric survey and to estimate the water balance components of the lake Zeway which are so essential elements for management and development scheme of lake water for intended purpose

1.3.2. Specific objectives

In order to meet the general objective of the study, the following specific objectives were set to:

- ✓ Establish bathymetric map of Lake Zeway
- ✓ Compute volume of sediment deposited and siltation rate in the Lake
- ✓ Quantify various water balance components of the Lake

1.4. Research Questions

- ✓ How morphology of the lake and temporal variation of the surface area and volume of the lake in the past looks like?
- ✓ What is the sediment flux and siltation rate of Lake Zeway?
- ✓ Which component of the water balance has been dominantly affecting the hydrological behavior of the Lake Zeway?

1.5. Significance of the Study

Lake Zeway is one of the economic, social and environmental important among the CRV of Ethiopia which characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics. Because, the Lake contains fresh water and it principally originated from the two incoming rivers (Ketar and Meki) and rainfall, it has been used for agriculture, domestic water supply and recreation (Dagnachew *et al.*, 2003).

Zeway Lake has a great significance for irrigation, providing protein from fisheries, fresh water for livestock drinking, recreation, transportation, and preservation of sound ecosystems and biodiversity. Bathymetric Survey and proper estimation of the components of the hydrologic cycle in terms of water balance of the lake for establishment of different parameters of the lake are extremely essential to identify the dominant factors contributing for fluctuation of the Lake water level and storage as well as the discharge of main feeder rivers. To develop the underwater contour as well as to quantify the recent parameters of lake morphology, such as; water depth, area, volume, length, width and perimeter of the lake. Eestimation of sedimentation rate, fishing and other geophysical exploration purposes. In addition to this; the generated data were utilized to compare multi temporal results between bathymetric surveys that were used to indicate changes driven by anthropogenic and natural factors. Environmental interpretation of the physical parameters of the lake presupposes a detailed understanding of the negative impacts which can help for the policy makers to develop integrated watershed management practices and for planning sustainable utilization of the water resources of the watershed using proper mitigation measures. Therefore, it is crucial to know the current and the futurity of Lake Zeway supply and demands of water resources.

1.6. Scope of the Study

This study is limited to watershed of Lake Zeway which is situated between latitude of $7^0$18' to $8^0$25' N and longitude of $38^0$15" to $38^0$22'E in the northern part of Ethiopia CRV catchment; partly in Oromia and partly in South People Nations and Nationalities (SPNN) regional states. It extends from Gurage Mountain in the west via main Ethiopian rift valley to Mountains Chilalo, Galema and Kakka of Arsi on its eastern side. The total catchment area is about 7444 km^2 where the watershed runoff is gauged before it joins Lake Zeway. The major components of Lake Zeway water budget are inflows, outflows and reservoir storage. The lake inflows consists of lake surface precipitation, Ketar and Meki rivers and direct surface runoff from un-gauged sub-catchment while the outflow components include Bulbula River, evaporation from surface of the lake and water abstraction from the lake for different purposes. Since ground water in flow and out flow has its own effect on storage of the Lake, it was considered as residual of the other water balance components.

1.7. Thesis Organization

Thesis Organization consist main body having six chapters and each chapter presents the work that has been completed and the details have been summarized below:

Introduction consists of the background of the study, statement of the problem, objectives, research questions, significance of the study, the scope of the study.

Next to introduction, the thesis has Literature Review which is essential in most of the research studies. It presents the comprehensive development of the problem background. It indicates what has already been studied by others, which has a bearing upon the present study. It is the balancing chapter of the research report.

Materials and Methods are also part of this main body and it indicates the line of approach of the study. The first aspect deals with the method, population and sample of the study and the second part provides the tools and techniques employed in the research. It also presents the procedure of the study. The whole plan of the study is discussed in detail under this chapter. Administration of tools and scoring procedure are reported systematically. The data organization and presentation has been discussed in this section.

Result and Discussion as well as analysis are reported so as to draw the inferences of the study. The analyses of data are presented in tabular form and in figures or pictorial presentation. The results are interpreted in detail. This chapter provides the original work or contribution by the researcher which used to highlight the importance of the study and describe the limitations of the study and implications for future research.

Conclusions and Recommendations is the section requires the creative and reflective aspect of the researcher. The results are discussed to make them more meaningful comparison of the results with the evidence in the review section which has been woven into the text whenever such a discussion can serve to clarify the points being reported. This is the final chapter of a report, thus findings and conclusions of the study are summarized and recommendations for further studies are also given. The main thrust in the section is the answer of the question or solution of the problem. The validity of the findings has been mentioned.

2. LITERATURE REVIEW

In this part of the review there were different theoretical approaches and related studies by scholars that have relation with bathymetric survey and water balances are described.

2.1. Bathymetric Survey

2.1.1. Theoretical approaches of bathymetric survey

It is the measurement of water depth at various places in a body of water (MoWR, 2005). The term bathymetry refers that; the ocean's depth relative to the sea level, although it has come to mean "submarine topography", or the depth and shape of underwater terrain.

Bathymetry is the foundation of the science of hydrograph, which measures the physical features of a water body. Hydrograph includes not only bathymetry, but also the shape and features of the shore line; the characteristics of the tides; the physical and chemical properties of the water itself.

On topographic maps, the contour is the line connects points of equal elevation. On bathymetric maps, they connect points of equal depth. A circular shape with increasingly smaller circles inside of it can indicate the lake trench. It can also indicate a seamount or under water mountain. Survey is conducted in grid pattern. The line spacing (contour interval) is decided based on the resolution required.

2.1.1.1. The lake

Lake is a natural large sized depression formed within the surface of the earth, when gets filled up with water. It is a large, inland body of fresh or salty standing water. Lakes are distinguished from other bodies of water such as bays and gulfs, and some seas, that have an interchange with the ocean and are subject to tides. Many geologic processes, such as buckling of stratified rock into large folds, displacement of large masses of rock by faults, and blocking of valleys by landslides, form lake basins. Lakes also vary form by glaciations. Glaciers carve out large basins by scooping up bedrock and redistributing loose material.

The source of lake water is atmospheric precipitation that reaches the lake directly and by means of springs and surface runoff from the catchment area, contributing to a particular lake, enters the lake through small drains or streams. Sometimes, the underground water through some spring also enters the natural depression and gets collected there, forming the lake . Lakes form and disappear over the course of varying lengths of geologic time. They may evaporate, as the climate becomes more arid, or they may fill up with sediment, leaving a bog or swamp in their place. In arid regions where precipitation is slight and evaporation great, lake levels rise and fall with the seasons and sometimes dry up for long periods. In lakes where evaporation prevents the water from overflowing the basin rims, substances dissolved in the water become concentrated. The dissolved matter, brought by tributary streams, varies in composition with the nature of the rocks in the local drainage system (Garg, 2005).

The quality of water in a lake is generally good and does not need much purification. Larger and older lakes, however, provides comparatively purer water than the smaller and newer lakes. Self-purification of water due to sedimentation of suspended materials, bleaching of color, removal of bacteria etc. makes the lake water purer and better. On other hand, in still waters of lake and ponds, the algae, weed and vegetable growth takes place freely, importing bad smells, tastes and colors to such water.

The quantity of water available from the lakes is, however, generally small. It depends upon the catchment area of the lake basin, annual and geological formation. Due to the smaller quantity of water available from the lakes, lakes are not considered as principal sources of water supplies.They may, therefore, be useful for only small towns and hilly areas (Garg, 2005).

Lakes are particularly vulnerable to change in climate parameters. Variation in air temperature, precipitation, and other meteorological components directly cause change in evaporation, water balance, lake level, ice events, hydro-chemical and hydro-biological regimes, and the entire lake ecosystems. Under some climatic conditions, lakes may disappear entirely. There are many types of lakes and classification according to lake formation and origin, the amount of water exchange, hydrochemistry, and so forth.

An important distinction is drawn between closed (endorheic), lakes with no outflow, and exoreic lakes, which are drained by out flowing rivers. This also means that they are very important indicators of climatic change and can provide records of past hydro-climatic variability over large area. Small endoreic lakes are most vulnerable to a change in climate (Tenalem, 2008); there are indicators even relatively small changes in inputs can produce large fluctuations in water level and lake chemistry in small closed lakes and exoreic lakes also may be sensitive to changes in the amount of inflow and the volume of evaporation (Tenalem, 2002). Climate changes also likely to have an effect on lake water quality, through change in water temperature and the extent and duration of ice cover (UNESCO, 1974).

2.1.1.2. Lake morphology

Lake Morphologic parameters are used to provide information to assess sedimentation rate, Water balance, and sustainable water abstraction. The most important parameters of the lake morphology, as studied by different researchers at different time are volume, area, depth, maximum length, width and shore line length (perimeter). The upper surface of the lake was defined as a horizontal planner surface that defines the water upper surface with a constant value.

2.1.2. Bathymetric survey analysis

A number of studies have been carried out in the Glob in general and in Central Ethiopian Rift Valley in particular that includes the study area. These studies have been focusing on bathymetric survey which directly or indirectly related to the current study. Some of the works are briefly described as follows:

Samaila *et al.* (2014**)** conducted the study on bathymetric survey and volumetric analysis for sustainable management, in Saluja Dam in Nigeria using GNSS solution software with the chart plotted on surfer software. The surface area of the dam was discovered to be 24.64 ha less than the designed area. Also the volume of the water was found to be 3.6 Mm^3 in contrast to the design volume 24.7 Mm^3. It also observed that the lowest water depth was 0.56 m and the highest water depth was 22.06 m. Therefore; a difference of 5.94 m was obtained as against of initial construction depth of 28 m. The undulating nature of the reservoir bed and the difference in volume of the water and surface area covered by the dam are clear indication of sedimentation and siltation process going on in the dam.

Tenalem and Molla (2004) studied on bathymetric survey and estimation of the water balance of the Crater Lake Arbido in Northern Ethiopia, using GPS and Graduated Plastic Tape. Based on the study, the bathymetric map of the lake was established at a contour interval of 10 meter based on depth measurement at 176 points and the maximum recorded depth was 62.4m.The surface area of the lake, as calculated from the 1992 topographic map prepared by the Ethiopian mapping Authority is 15.80 Km^2.The area of the lake was much larger in the early 1950s (Molla, 2000). The cause of the reduction of the lake level in the main Ethiopian Rift was irrigation water abstraction and climate change (Tenalem, 1998).

Yesuf *et al.* (2013**)** conducted the research on bathymetric survey on Lake Hayq to map bathymetric chart and to derive morphologic parameters, including depth, volume, area, width and length and to plot curves illustrating the relationships between these parameters using a combination of a Sonar light Portable Echo Sounder and Global Positioning System (GPS) to generate three-dimensional (XYZ) hydrographic data. Surfer 8.01 and Arc GIS 9.3 software program were used for surface, gridding and morph metric analyses. Comparison of the results of this study with the previous study conducted in 1941 indicated the lake has experienced changes in depth and surface area. Finally, the researcher recommend that, to reduce the negative impacts of human induced activities of the echo hydrology of the lake and to maintain ecological integrity, appropriate lake management practices must be adopted. This will necessitate policy formulation, actual lake basin stake holder involvement and implementation of basin-wide lake management to ensure sustainable use of the lake and its basin resources.

Tenalem (2003) conducted the research on bathymetric survey of Lake Zeway using ArcGIS, GPS and Tape Meter. According to the study, the bathymetric map of the lake was established and the storage capacity of clear water was determined to be 1466 MCM in an area of 462 km^2 and average depth of 4 m.

Ministry of Water Resource (MoWR) (2005/2006) conducted the research on bathymetric survey of Lake Zeway using Arc GIS, GPS and Echo Sounding. According to the study, the bathymetric map of the lake was established and the storage capacity of water was determined to be 1565.85 MCM in an area of 437.71 km^2. When compared with the long term average for

31 years since 1976 bathymetric survey, the average annual volume and average annual area was 1655.01 MCM and 446.53 km^2. Comparison of the results of this study with the previous study conducted in 1941 indicated the lake has experienced changes in volume and surface area. Therefore; the undulating nature of the lake bed and the difference in volume of the water and surface area covered by the lake are clear indication of sedimentation and siltation process going on in the lake.

2. 2. Water Balance and Water Balance Components

2.2.1 Water balance

According to Garg (2005), the water budget represents the inventory of water for a specific water body (or hydrologic region) during a certain time interval. The study of water balance is the application in the hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage within the volume. In general, the use of water balance technique implies the measurement of both storage and fluxes (rate of flow of water, through appropriate selection of the volume and the period of time for which the balance will be applied).

2.2.2 Water balance equation

In quantitative terms, the hydrologic cycle can be represented by a closed equation which represents the principle of the conservation of mass, often referred in hydraulics as a continuity equation. Many forms of this expression, called the water balance equation, are possible by subdividing, consolidating, or eliminating some of the terms, depending on the purpose of computation.

There are three applications of the water balance equation described in (Garg, 2005). These are water balance equations for large basin areas, water balance equations for water bodies, and water balance equation for the direct runoff. In the first two cases the entire phase above and below the ground surface is considered in the equation in terms of the stream flows. In its general form, the equation may be represented by (Garg, 2005):

$$(P + Qsi + Qgi) - (Eo + Qso + Qgo) = \Delta S \quad \text{------} 2.1$$

Where, P = Precipitation

Qsi = Surface water inflow

Qgi = Ground water inflow

E_o = Evaporation,

Qso = Surface water outflow

Qgo = Ground water outflow

ΔS =Net change of storage volume within the boundary.

2.2.3. The hydrologic cycle of a watershed

The physical processes controlling the distribution and movement of water are best understood in terms of hydrologic cycle. It is the global mechanism that transfers water from the oceans to the atmosphere and from the atmosphere to the subsurface environment, and from plants to the atmosphere that surrounds our planet. Although there is no real beginning or ending point of the hydrologic cycle however, for understanding purpose hydrologic cycle start from precipitation (Rechard, 1998).

There are different approaches to assess the water balance for any given hydrological unity; for a watershed, water balance can be assessed using soil water balance or catchment water balance model whereas for lake and reservoir continuity equation and storage equation is more appropriate (Garg, 2005). Yemane (2004), assessed Hawassa lake water balance using storage equation while Melkamu (2005), was used continuity equation to evaluate Tana lake water balance.

The water cycle consists of four distinct stages: storage, evaporation, precipitation, and runoff. Water may be stored temporarily in the ground, in oceans, lakes, and rivers, and in ice caps and glaciers. It evaporates from the earth's surface, condenses in clouds, falls back to the earth as precipitation (rain or snow), and eventually either runs into the seas or re-evaporates into the atmosphere. Almost all the water on the earth has passed through the water cycle countless times. Those processes are stimulated by solar energy. They take place simultaneously and, except for precipitation, continuously.

Precipitation plays a key role in renewing our natural water resources, particularly those used to supply natural ecosystems and rain fed crops. Either precipitation, in three relatively diverse climatic zones, generally returns by evaporation or evapo transpiration back into the atmosphere, becomes surface water through runoff, or recharges groundwater. Evaporation from surface water bodies such as lakes, rivers, wetlands and reservoirs is also an important component of the hydrological cycle and integral to basin development and regional water management.

The hydrologic cycle of a natural environment is static. As the population of the world has increased changes to the land have often been significant and result on disturbing the natural path of the hydrologic cycle. Human activities (settlements and urbanization, agricultural developments, industry) can disturb the pathways and components of the natural cycle through land use changes, the use, reuse and discharge of wastes into the natural surface water and groundwater.

In CRV of Ethiopia specifically in case of Lake Zeway watershed, this phenomenon has been take places. The rapidly growing population has led to an increased claim on natural resources. A large part of the area is heavily deforested for charcoal production and agricultural activities. The agricultural area has increased considerably which further increases pressure on the natural resources. Irrigation, fertilizers and agrochemicals have been introduced to the area. The immense cattle population has led to overgrazing and is a threat to the biodiversity for which the CRV is known (Tesfaye, 2003; Dagnachew *et al*., 2007 and Scholten, 2007). Annual water abstraction from lake Zeway and its watershed is about 215 MCM (Dagnachew *et al*., 2007). All these human induced activities in the hydrological areas have a significant effect on the hydrologic cycle and availabilities on the water resources of the region.

Evaporation is the process by which the phase of water is changed from a liquid to a vapor. Evaporation and transpiration represent a significant portion of the water movement through the hydrologic cycle. Approximately 70% of the precipitation in a temperate climate returns to the atmosphere directly by way of evaporation or transpiration losses (Rechard, 1989).

Evaporation losses are considered in the design of large water storage reservoirs. Where heat storage within the water body is significant, evaporation may be much greater. Even in the humid eastern part of the United States, more than 0.6096 m of evaporation losses can be expected from a free-water surface during a 1 year period. Free water evaporation can be as much as 2.54 m per year in the more arid parts of the United States (Rechard, 1989).

In areas where annual rainfall is low, evaporation losses can represent a significant part of the water budget for a lake, and evaporation losses may contribute significantly to the lowering of the water surface elevation. This may have consequences in terms of water quality, recreational use of the lake, allocation of water for irrigation demand, and power generation. Monthly, seasonal, or annual evaporation losses may have to be considered in the design of the reservoir and the retarding structure and it is therefore; its accurate determination is crucial for a reasonable estimate of the water budget of the reservoir.

Evaporation and Evapo-transpiration estimation models range from the complex as Penman method to the simple Pan method. Complex models require many meteorological measured and estimated input parameters which incur high monitoring cost. The error in measurement and estimation of input parameters increase the error in E_o and ET_o estimation. The adaptability of simpler methods, especially in geographical areas where there is limited resource for monitoring is worth investigation. Traditional methods for point E or (ET) estimation include the pan, pitche, Cropwat, and Penman's aerodynamic techniques.

It has been found that these methods are costly, time consuming, and require elaborate and sensitive measurement equipment (Assafa *et al*., 2009; Yemane 2009). For land surfaces, a root zone soil water balance approach based on water budget is also a technique used to estimate ET as a residual variable. Quantifying each component of the soil water balance is less appealing in terms of time, labor and money requirements. The lysimeter instrumentations are relatively simpler but are usually limited to research applications. While these traditional methods of estimating E or ET at a point, recent methods have found success using remotely-sensed imagery for estimates at various spatial scales.

Unlike the above point measurements, remote sensing has the capacity to instantaneously acquire spectral signatures for large areas of the watershed and infer land-cover, vegetation cover, emissivity, albedo, surface temperature and energy flux information. Remote sensing approach has also proven to have regional applications and allows for greater spatial coverage than possible with in-situ methods (Tom, 2008; Assefa *et al*., 2009).

Estimation of evaporation from free water surface is not easy as compared with land ET. Evaporation from free water bodies (lake or reservoir) depends on the availability of energy and the mechanism of mass transfer, depth, and surface area of the lake. It is a function of solar radiation, temperature, wind speed, humidity, atmospheric pressure, and the surrounding environment (Yihun, 2009).

Monthly and annual average Lake Zeway evaporation estimated have been varied from method to method of evaporation estimation which could be due to the variation of input data and other estimated variables. Annual lake evaporation were 1,777, 1,875 and 1,728 mm, respectively estimated with the Energy balance, Penman and Complementary Relationship Lake Evaporation (CRLE) methods (Coulomb *et al*., 2001) and 2,022, 1,599 and 1,769 mm respectively, estimated with the Penman, Radiation and Pan Methods (Tenalem, 2003) respectively.

2.2.1.4. Uncertainty in lake water balance

A report from a comprehensive analysis made by winter (1981) about uncertainties in estimating the water balance of a lake indicated that, estimation of precipitation may have a wide range of errors, depending on gauge placement, gauge spacing, and aerial averaging technique. The amount of rainwater collected and measured by a rain-gauge may not always represent the exact amount, which would have been caught. For example, there may be instrumental errors in the gauges, or in their recording or measuring arrangements; some rainwater may get lost due to splash from the collector; some water from an initial rain may got lost in moistening the gauge funnel and other inside surfaces; blowing winds may tilt the rains from vertical, thus bringing lesser catch in the vertical gauge; dents in the collector rim may change its receiving area; vertical upward air currents may impart upward acceleration to precipitation this bringing lesser catch in the gauge; etc. All such factors might be introducing errors in the measured catches. Some of them may increases catch, and some of them may decrease the catch. However, in general, it can be stated that almost all the errors that are introduced in the rain catch measurements have a tendency to yield measurements which are too low. In other words, the observed rain catch needs to be increased for the likely errors introduced in its measurement. Of all the possible errors the most serious errors is introduced by wind, which may result in a vertical acceleration of air, forced upward over the gauge.

Higher the gauge, greater will be the wind errors, and hence more deficient will be the rain catch.

Errors in estimating of evaporation can also vary widely depending on the instrumentation and methodology. The energy budget is the most accurate method of calculating evaporation with errors of the orders of 5% when applied to periods less than a week. If pans are used that are located at a distance from the lake of interest, errors can be considerable. Annual pan-to-lake coefficient should be used for monthly estimating of evaporation (Maidment, 1993).

The same is also true for other components of water budget such as surface runoff (inflow and outflow recording gauge), quantifying of water abstraction from the lake for different uses, groundwater inflow and outflow estimation techniques that contribute errors on estimation of water balance.

2.2.1.5. Scientific studies on lakes water balance: Ethiopian lakes

Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. Most of the lakes except Zeway, Tana, Langano, Abbaya and Chamo have no surface water outlets, *i.e.*, they are endoriec. Lakes Shala and Abiyata have high concentrations of chemicals and Abiyata is currently exploited for production of soda ash (MoWR, 2004; Aster *et al.*, 2007).

Lake Tana, with an area of 3,600 km^2, is the largest lake on Ethiopian territory. It is situated in the western highlands at an elevation of 1800 m.a.s.l. More than 60 tributaries pour in to the lake and the Blue Nile does emanate (Chronowicz *et al.*, 1998). A study of Mercier *et al.* (2002) showed little inter annual fluctuation for 1993-1999, since the Tisiat Falls seem to limit the upper level of the lake.

All other major Ethiopian lakes are confined to the rift floor. Most of the lakes are fed by perennial rivers originating from the highlands (Tenalem, 2004) with the annual maximum in October/November (Mercier *et al.*, 2002). The effect of recent tectonic activity on the hydrological regimes of the lakes is not thoroughly investigated, but some changes in lake level may be attributed to the opening or reactivation of rift faults (Tenalem, 2004). For example, changes in the discharge of springs around Lake Langano have been observed after recent seismic activity led to the formation of new faults (Tenalem, 1998).

The main purposes of large-scale anthropogenic water-withdrawals are irrigation and soda (NaCO3) production. Due to a lack of records and controls the abstraction rates can only be estimated (Tenalem, 2004). The endorheic ones of the rift lakes prove to be especially susceptible to level height alternations. According to a study of Tenalem (2004) carried out on monthly averaged stage records, the terminal lakes showed the most drastic changes. From 1976 to 2000, the water level of Lake Abijata dropped by 4.3 m, the mean depth being only 8 m. Tenalem (2004) proposes that the sharp decrease in lake level can be ascribed to upstream water abstraction for irrigation purposes and water withdrawal for soda ash production. On the contrary Lake Beseka and Lake Awassa have expanded since the beginnings of measurements in the 1970s. The non-endorheic lakes (i.e. Lake Langano) show little or no change for the same period of time (Tenalem, 2004).

According to Schütt *et al.* (2002), population pressure, deforestation and a change in cultivation manners led to an increased sediment yield of the Lake Abaya's tributaries, thus influencing basin bathymetry and volume. Moreover, geotectonic seem to have caused an uplift of the sill departing the basins of Lake Abaya and Lake Chamo, hence controlling Lake Abaya's outflow. Due to a combination of those two factors a water level increase of roughly 2 m has been observed since 1987(Schütt *et al*., 2002).

The climatic change has also significant influences on the level and area of Lake Zeway. Because of increase in surface temperature and declining of rainy seasons, result in decrease of Rivers inflow to the lake, the lake level decline and might reach up to 62 cm at next 90 years, consequently, the water surface area might also shrink up to 25 km^2 (Dilnesaw *et al.*, 2007).

Generally, Lakes situated in the Main Ethiopian Rift are subject to climatic factors, such as seasonal rainfall, which might change on a regional or global scale and anthropological activities that modifies hydrologic circulation processes. Their hydrological regime is also strongly influenced by the geologic phenomena associated with the rupturing of the African tectonic plate (Anna, 2005).

Eyasu *et al*. (2013) conducted the research on water balance assessment of topographically closed highland lake, the case of Lake Hashange. From their analysis they revealed that direct precipitation and stream flow were the major inflow components contributing 66.7% and 33.3% respectively. On the other hand most of the outflow components were in the form of non productive loss with evaporation constituting the highest portion (83.55%) followed by net ground water flux of (16.19%). The water withdrawn for productive purposes including irrigation, livestock and house hold consumption were only 0.26% of the total. The change in volume of the lake during the observation period was -4.64 Mm^3, indicating large amount of water going out than that comes in.

Yemane (2004**) c**onducted the research on assessment of the water balance of Lake Hawassa catchment using spread sheet model. Based on the simulation results it is found that evaporation, rainfall, surface runoff and constant ground water outflow from the lake constitutes 131 Mm^3, 106 Mm^3, 83 Mm^3 and 43 Mm^3 of the annual average lake water balance respectively. The freshness of the lake water is attributed to the constant ground water out flow from the lake.

Tesfaye (2003); Dagnachew *et al*. (2007) and Scholten(2007) studied human activities (settlements and urbanization, agricultural developments, industry) can disturb the pathways and components of the natural cycle through land use changes, the use, reuse and discharge of wastes into the natural surface water and groundwater. In CRV of Ethiopia specifically in case of Lake Zeway watershed, this phenomenon has been taken places. The rapidly growing population has led to an increased claim on natural resources. A large part of the area is heavily deforested for charcoal production and agricultural activities. The agricultural area has increased considerably which further increases pressure on the natural resources. Irrigation, fertilizers and agrochemicals have been introduced to the area. The immense cattle population has led to overgrazing and is a threat to the biodiversity for which the CRV is known.

Dagnachew *et al*. (2007) conducted the impact of abstraction on availability of the water resources of Lake Zeway and its watershed. Based on the study the annual water abstraction from Lake Zeway and its watershed is about 215 MCM all these human induced activities in the hydrological areas have a significant effect on the hydrologic cycle and availabilities on the water resources of the region.

Coulomb *et al*. (2001) conducted estimation of evaporation from free water surface of Lake Zeway using different methods. Evaporation from free water bodies (lake or reservoir) depends on the availability of energy and the mechanism of mass transfer, depth, and surface area of the lake. It is a function of solar radiation, temperature, wind speed, humidity, atmospheric pressure, and the surrounding environment. According to the studies monthly and annual average Lake Zeway evaporation estimated have been vary from method to method of evaporation estimation. Annual lake evaporation was 1,777, 1,875 and 1,728 mm, respectively estimated with the Energy balance, Penman and Complementary Relationship Lake Evaporation (CRLE) methods.

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Abu (2010) conducted the study to assess water balance of Lake Zeway and its temporal variation due to water abstraction using continuity equation of water balance model. Average rainfall over the lake surface was computed using simple arithmetic mean method and evaporation from the lake surface was assessed using penman method while abstraction due to irrigation was computed using cropwat software. The mean total inflow and outflow of the lake were estimated to be 1096.83 Mm^3 and 1114.30 Mm^3. Evaporation shared about 74.04% of the total inflow, while annual water abstraction consumed about 11.72% of inflow. But Bulbula river outflow shared about 15.84% of the total inflow components of the water budget of the lake. Finally, it is recommended to look a solution for minimization of the extent of outflow components (rate of evaporation, over utilization of the water) for its future sustainability.

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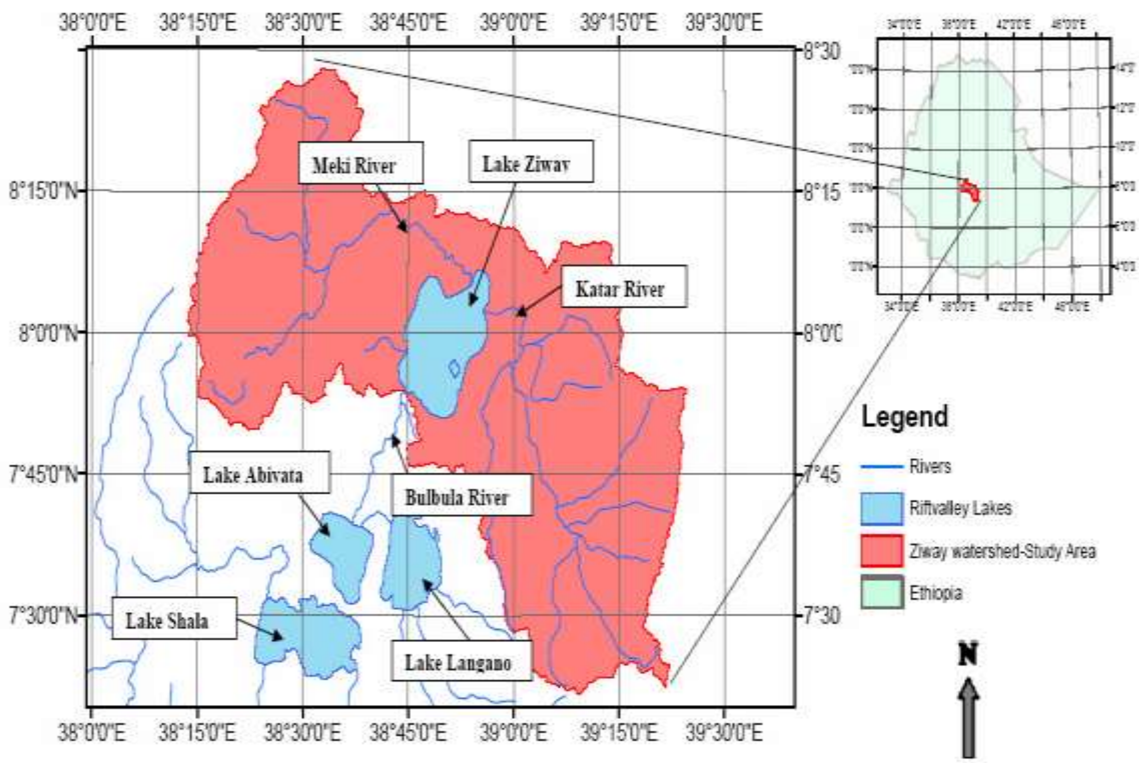
3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study area, Lake Zeway and its catchment is located in the CRV Ethiopia sub-catchment. Lake Zeway is shallowest among other lake of the country and drains to Lake Abijata (Dagnachew *et al.*, 2005). The watershed of this lake is situated between latitude of $7^0$18’ to $8^0$25’ N and longitude of $38^0$15” to $38^0$22’E in the northern part of Ethiopia CRV catchment; partly in Oromia and partly in South People Nations and Nationalities (SPNN) regional states with elevation variations from 1636 to 4167 m above sea level (m.a.s.l) at Rift floor and Kakka mountain at the eastern part respectively. It extends from Gurage Mountain in the west via main Ethiopian rift valley to Mountains Chilalo, Galema and Kakka of Arsi on its eastern side. The total catchment area is about 7444 km^2 where the watershed runoff is gauged before it joins Lake Zeway.



(Source: Shape file from Ethiopia Mapping Agency, Processed by Arc Map)
Figure 1: Location map of the study area

The study area has been accessed through one of the following routes: Addis Ababa-Modjo-Zeway-Adami Tullu, Addis Ababa-Alem Gena-Butajira-Zeway or Addis Ababa-Assella asphalt roads. Intra-catchment areas are interconnected by numerous gravel and dry weather roads.

Batu town, the capital of Adami Tullu Jiddo Kombolch (ATJK) district is located on western shore of the lake Zeway. The existence and protection of the Lake is, therefore, very critical to the town and the population residing within the entire catchment. The Lake has a total catchment area of about 7444 km^2, an open water area of 440 km^2 and average depth of 2.5 m. The lake catchment is drained with two main annual rivers (Ketar and Meki) which are flowing to the lake. Bulbula River is the outflow from the lake and drains to Lake Abijata in the south west direction (Abu, 2010).

The area is characterized by semi-arid at the rift floor to sub-humid climate at the highland areas. Climate is the function of the location (latitude, altitude, angle of the sun, distance from water bodies, terrain and the like). The different combination of these factors resulted in the prevalence of diverse climatic conditions in the area. The lake catchment has mean annual precipitation varying from 700 to 800 mm around rift floor and high land areas receives up to 1200 mm in the highland areas and mean daily temperature ranges from 12 to 22^0C in the highland and low land areas, respectively. This Lake is one of the most economic and social important lake, that located in the CRV of Ethiopia. It is Exoreic Lake (which drained by out flowing river) and fresh water playing an important roles and benefits for lives of the regions people in specifically, for the country in particular and global in general. It is one of the lakes in the CRV used for multi purposes such as agriculture, fishing, domestic water supply, transport, recreation and feeding fresh water to the lake Abijata through Bulbula River.

According to statistical abstract prepared by Central Statistical Agency, the total population of the study area is estimated to be 1,479,451 as of July 30, 2005, with population growth rate 2.4%. Livestock population of the area was estimated using statistical report of Central Agricultural Census Commission. Based on the data, total population of cattle, sheep, goat, horse, asses, mule, poultry and beehives residing in the area are 452791, 164707, 93637, 30361, 44799, 3633, 481579 and 26107 respectively.

3.2. Materials and Software Used

Excel spreadsheet was used for data arranging and analyzing. High precision GPS was used to collect geographical location. Graduated plastic tape meter and Plumb Boob was used to measure the depth of the lake. Boat was also used for transportation on the lake. Cropwat and Arc GIS software used to calculate irrigation water requirements and contour map and determination of lake parameters using linear interpolation respectively. Penman-Montheith equation was used to estimate evaporation from the lake surface. The summary of material used is described in table 1 below.

Table 1: Material used

R.No	Materials/Software	Used for	Remark
1	Boat	For Transportation	
2	Graduated Plastic Tape Meter	To measure depth of the lake	
3	GPS	To collect Geographical location	
4	Plumb Boob	To give weight for tape meter to reach ground	
5	Arc GIS Software	To interpolate Contour ,Area, perimeter Length and width Calculation	

3.3. Data Description and Sources

Table 2: Data description and sources

Data Used		Purpose	Sources
Bathymetric Surveying Data	Geographic Coordinate Points	To Establish Under Water Contour & to Estimate Lake Morphological Parameters	Field Measurement
	Depth of the lake	To Establish Under Water Contour & to Estimate Lake Morphological Parameters	Field Measurement
Metrological Data	Rainfall Data	To Analyze Precipitation	Agency National Meteorological Service
	Temperature(Max & Min)	To Analyze Evaporation and Irrigation Water Abstraction	National Meteorological Service Agency
	Relative Humidity	To Analyze Evaporation and Irrigation Water Abstraction	National Meteorological Service Agency
	Sun shine Duration	To Analyze Evaporation and Irrigation Water Abstraction	National Meteorological Service Agency
	Wind Speed	To Analyze Evaporation and Irrigation Water Abstraction	National Meteorological Service Agency
Hydrological Data	Katar River Runoff	To Estimate Water Balance	Ministry of Water Resources
	Meki River Runoff	To Estimate Water Balance	Ministry of Water Resources
	Bulbula River Runoff	To Estimate Water Balance	Ministry of Water Resources
	Un gauged Rivers Runoff	To Estimate Water Balance	Computed using Area ratio Method
	Zeway Lake Water Level	To Estimate Water Balance	Ministry of Water Resources
Others	Crop Type	To Estimate Irrigation Water Abstraction	Agriculture and Natural Resources Office
	Area of land under Irrigation	To Estimate Irrigation Water Abstraction	Agriculture and Natural Resources Office
	Live Stock Water Consumption	To Estimate Livestock Water Abstraction	Agriculture and Natural Resources Office

Table 3: Metrological data used for cropwat analyses from Zeway station (1982-2018)

Month	Temperature		Humidity (%)	Wind (km/day)	Sun Hour (hr)	Rainfall (mm)
	Min (^{0}C)	Max (^{0}C)				
Jan	12.41	26.97	48.67	1.50	9.63	13.47
Feb	13.69	28.11	43.34	1.54	9.53	29.99
Mar	14.96	29.22	42.10	1.48	8.94	50.22
Apr	15.68	28.99	47.88	1.50	8.46	75.35
May	16.09	29.14	50.09	1.63	8.38	79.10
Jun	15.55	27.92	54.49	2.11	7.98	83.60
Jul	15.02	25.38	67.72	1.87	5.98	168.39
Aug	14.97	25.55	63.79	1.64	6.50	115.11
Sep	14.43	26.57	58.89	1.23	6.54	77.37
Oct	13.01	27.51	43.82	1.37	8.61	34.70
Nov	12.04	27.21	44.23	1.55	9.44	5.99
Dec	11.36	26.53	45.64	1.54	9.96	4.41

3.4. Methodologies and Data Analysis

Field bathymetric survey was carried out over the lake area. The geographical location co-ordinate points were collected using high precision GPS. Depth of the lake was measured by crossing the lake in grid manner using graduated tape meter. Then after, Arc GIS software was used to analyze the underwater contour of the lake and estimate other lake morphological parameters (Area, Volume, Perimeter, Length, Width and average depth).

3.4.1. Establishment of Bathymetric Map

The map was established using Arc GIS Software using a three dimensional XYZ data file. These data was creating in a worksheet and grid file was produced using point kriging method and finally a series of maps were formed.

3.4.1.1. Determination of Lake Morphology

Bathymetric survey was used to quantify different parameters of lake morphology (depth, area, volume, Length, width and perimeter) of the lake. About 652 different points of geographical coordinate data was collected using GPS and analyzed by Arc GIS software through linear interpolation to establish Lake Zeway contour map, area, perimeter, length and width. However; the depth of the lake was directly measured using plastic tape meter during field survey for each geographic coordinate point.

3.4.1.2. Lake volume – area – elevation curves

On the basis of the bathymetric survey by Ministry of Over Land and Sea Resources Development (MoLRD, 1976) and Ministry of Water Resource (MoWR, 2005/2006) the Volume-Area-Elevation relationships of the lake were established. Using these Volume-Area-Elevation relationships, the lake reservoir volume was estimated and associated curves were established. The measuring staff gauge (zero water levels) of the Lake Zeway is located at 1635.10 m.a.s.l. and the outflow discharge at Bulbula River is controlled by the height of the rock sill level of 1635.56 m.a.s.l. or 0.46 m above the staff gauge at Zeway town is used in both Bathymetry study. The dead storage of the Lake Zeway is the volume below the elevation 1635.56 m.

The volume can be estimated from area and average depth of the lake or using the Volume-Area-Elevation relationships by curve fitting techniques by Ministry of Water Resource 2005/2006. Accordingly, the equation of the curve fitting used is polynomial:-

$$V = 0.1289x^5 + 2.202x^4 + 7.7764x^3 + 3.1549x^2 + 13.673x - 2.3472 - - - 3.1$$

(R^2= 0.9996 for (Elevation-Volume) (MoWR, 2005/2006)

Where, V= Lake Volume, X= Lake Water Level

3.4.1.3. Sediment deposition

Since there is no data about the rate of increase of erosion on a particular catchment of Lake Zeway, there was no sediment transportation and deposition data available. Therefore; the siltation (sedimentation) rate of the Lake was estimated by using the bathymetry survey made for different periods. The volume and area of sediment deposited during the two periods has been computed using curve fitting polynomial equation set by (LRD, 1976; MoWR 2005/2006). The time gaps between the two bathymetric surveys were 31 years. The Volume-Area-Elevation relationships are established for both bathymetry surveys by the curve fitting techniques. Accordingly, the equation of the curve fitting used is polynomial Equation:-

$$A = -0.074x^4 - 0.4169x^3 + 19.682x^2 - 36.599x - 8.042 - - - 3.2$$

(With R^2 = 0.9915, for (Elevation-Area), (LRD, 1976)

$$V = -0.6527x^4 + 9.6516x^3 - 4.4095x^2 + 6.0865x + 13.023 - - - 3.3$$

(With R^2= 0.9998 for (Elevation-Volume) (LRD, 1976)

$$A = 0.0727x^6 - 1.7613x^5 + 14.953^4 - 51.945x^3 + 72.74x^2 - 27.401 - 0.6012 — 3.4$$

(WithR^2= 0.9973 for (Elevation-Area), 2005/2006)

$$V = 0.1289x^5 + 2.202x^4 + 7.6764^3 + 3.1549x^2 + 13.673x - 2.3472 - - - 3.5$$

(With R^2= 0.9996 for (Elevation-Volume), (MoWR, 2005/2006)

Where, V= Lake Volume, A= Area of the lake, X= Lake Water Level

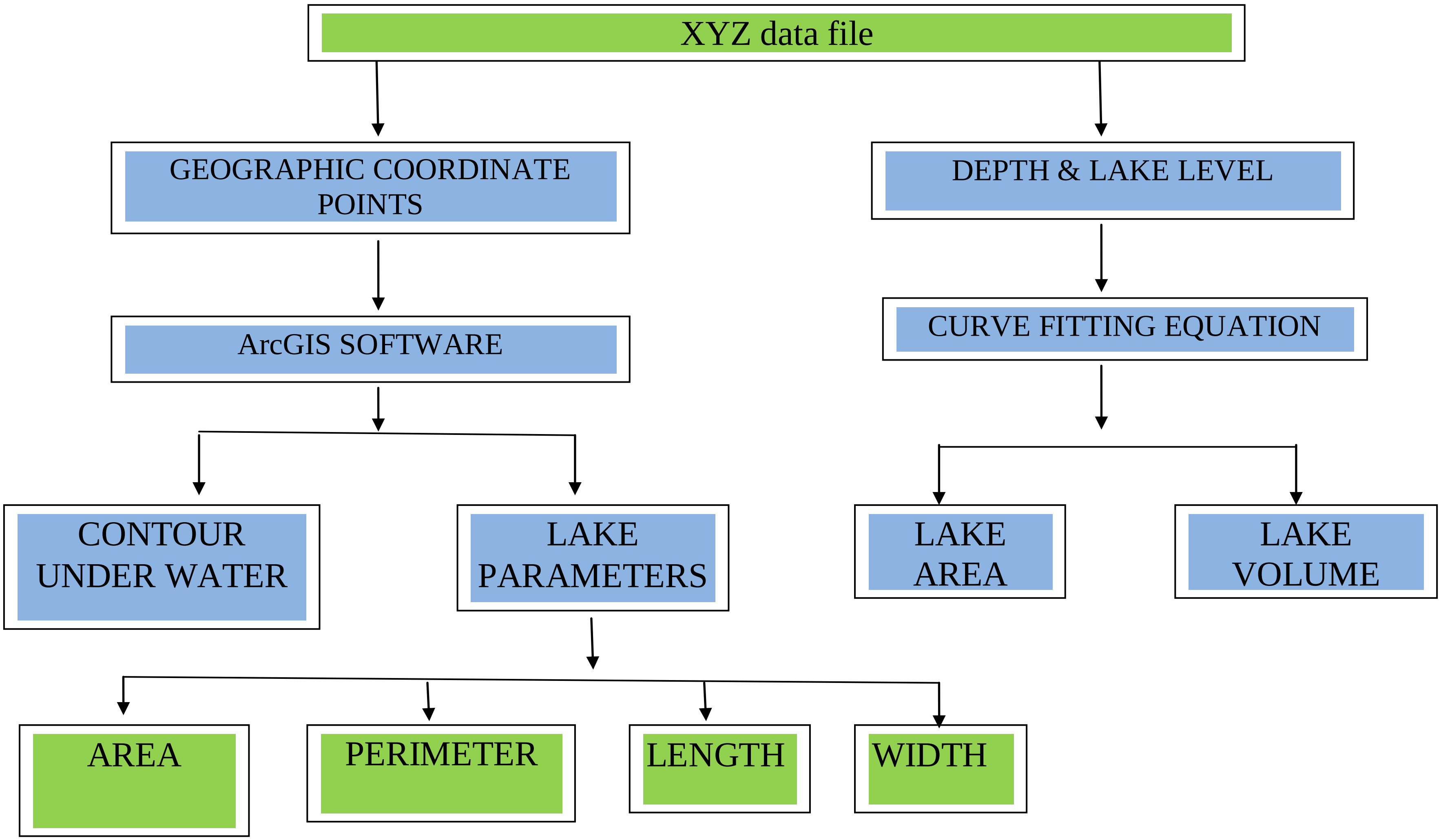


Figure 2: Flow chart of bathymetric analyses

3.4.2. Determination of water balance components

Literature was reviewed throughout the analysis of each step. Collected data from different sources such as hydro-meteorological data (rainfall, evaporation, temperature, wind speed, relative humidity, river discharge, lake level and water abstractions) from respective offices were arranged using Excel spread Sheet. Daily River gauged data of Katar, Meki, and Bulbula, at Abura, Meki and Karkarsitu gauging station respectively were arranged on Excel spread Sheet and converted to monthly and annually bases. Missed data of these hydro-metrological data was filled using correlation and regression and as well as normal average method for further analysis. Daily metrological data such as rainfall, minimum and maximum temperature, wind speed, sunshine hour, relative humidity, Pitche evaporation collected from NMSA were also arranged and converted to monthly and annually and the mean value of each was indicated on Appendix Table 18 and used to show annual trend.

3.4.2.1. Determination of precipitation

In order to evaluate the rainfall component of the water balance which was falling on the lake, gauging stations on the shore of the lakes were required. The number depends on climatic condition, relative importance of gauging stations, accuracy of measurements and other factors. For lake Zeway, four rainfall gauging stations (Zeway, Meki, Adami-Tulu, and Ogelcho) was selected for estimation of areal rainfall over lake Zeway by virtue of their close proximity to the lake, sufficient length of record, consistency of their records and similarity of topography and same rainfall patterns using double mass curve.

Melaku (2005) adopted Arithmetic or station average method for Lake Tana which was used to compute precipitation from the record of rain gages within the area. Since the stations are homognous and found in the same ecology, adopted Arithmetic or station average method was used to determine precipitation.

$$\frac{(\mathrm{P1} + \mathrm{P2} + \mathrm{P3} - - - \mathrm{Pn})}{\mathrm{N}} - 3.6$$

Where, P = the mean precipitation of over the lake (mm), P1, P_2, P_3, Pn = the respective precipitations (mm) at the stations and N = is total number of the stations

3.4.2.2. Determination of evaporation

Evaporation (E) is also one of the hydrologic parameters that have least variation on annual basis. Variation of E at smaller time scales can be also very high. It is a major component of the water cycle and important in water resource development and management. Measurement and estimation of this parameter usually provides different results for the same hydro-climatic zone with adoption of different methodologies.

Evaporation from the lakes is often the largest percentage component of the water budget (Garg, 2005). The rate of evaporation is a function of climatic variables, such as incoming solar radiation, air and water temperature, wind speed, soil moisture content, surface area of water exposed, barometric pressure, water quality, vegetation cover and saturation vapor pressure deficit. Knowledge of evaporation is a major importance in water resources assessment among others to determine the amount of water lost through the process of evaporation in the water balance computations of land, rivers, lakes and reservoirs.

The rate of evaporation from large water surfaces such as rivers, ponds, reservoirs, lakes etc is estimated from different methods, such as, Dalton Law, Water budget, Pan Evaporation, Penman-Monteith, aerodynamic and energy budget. However, for these studies Penman-Monteith method was used.

Penman-Monteith method was developed to predict evaporation from an open water surface rather than PET from a vegetation surface (Richard, 1989, Hans ., *et al*., 1991 and Kebede *et al*., 2005). The equation was used to compute the evaporation from an open water surface using standard climatic data. This method was based on a combination of aerodynamic and heat balance approaches and requires knowledge of mean air temperature, RH, wind speed and solar radiation. The basic Penmen formula for open water evaporation to evaluate evaporation from Lake Zeway is depicted as follow(Garg, 2005):

$$E_t = \frac{A * H_n + E_a * r}{A + r} \qquad (3.7)$$

Where,

E_t = Open Water Evaporation

A = Slope of saturation Vapor pressure Vs temperature curve at mean air temperature

H_n = Net incoming solar radiation evaporable water per day (mm)

E_a = Parameter including wind velocity and saturation deficit (mm/day)

P = pschromatic constant = 0.49 mm of Hg/^{0}c

$$H_n = H_c(1-r)\left(\alpha + b * \frac{n}{P}\right) - \sigma * T_a{}^4\left(0.56 - 0.092\sqrt{e_a}\right) * \left(0.1 + 0.9\frac{n}{N}\right) \ldots\ldots\ldots\ldots\ldots (3.8)$$

Where, H_c = mean incident solar radiation at top face (mm), r = reflection coefficient (albedo) = 0.05 for water surface, α = constant depend upon the latitude = 0.29cos, b = constant = 0.52, n = actual duration of bright sunshine (hrs), N = maximum possible hours of bright sunshine, function of latitude = Stefan-Bolzman constant = 2.01*10^{-9} mm/day, T_a = mean air temperature in ^{0}K, e_a = actual mean vapour pressure in air in mm of Hg

$$E_a = 0.35\left(1 + \frac{V_2}{160}\right)(e_s - e_a) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Where, V_2 = mean wind speed at 2 m above ground in km/day, e_a = actual vapour pressure at mean air temperature in mm of Hg, e_s = saturation mean vapour pressure of air in mm of Hg (from table).

Using this method, to calculate the quantity of water outflows from the lake due to evaporation, climatic parameters such as temperature, RH, sunshine duration and wind speed of Zeway meteorological station data of last 37 years (1982-2018) were employed.

3.4.2.3. Determination of water abstraction

The main water abstraction from this lake is irrigation water consumption. By now this lake is not serving for house hold drinking water supply consumption except for Livestock. Data from Dugda, ATJK, and Zeway Dugda wereda showed that, 11618.57 ha of land is under irrigation. Even though there are different vegetables that are produced by irrigation at the study area, Tomato, Onion, Cabbages, Maize and Pepper were selected as dominant vegetables under irrigation. CropWat software was used to calculate water abstracted from the lake for irrigable land.

Table 4: Land used under irrigation and water sources

District	Lake(ha)	Katar river(ha)	Meki river(ha)	Bulbula river(ha)	Ground Water(ha)	Total Area(ha)
A/T/J/K	3242.78	-	-	350	547	4139.78
Dugda	3278.5	-	840	-	-	4118.5
Z/Dugda	1869.3	1150.47	-	-	340.52	3360.29
Total	8390.58	1150.47	840	350	887.52	11618.57

Source: Arsi and East Shawa Zones ANR office

The livestock that exist around the lake are cattle, sheep, goat, horse, donkey and mule. Data from Agriculture and Natural Resource office of weredas showed that, there are, 450,790 Cattles, 150, 000 Sheep, 93,600 Goats, 30,350 Horses, 45100 Donkeys and 3500 Mules. The livestock water consumption was based on the type and number of livestock daily water consumption and time duration the animals depend on the lake for water consumption. According to tropical livestock Unit (2008), the average consumption of Cattle is 68 l/day, Horse, Donkey and Mule is 46 l/day, Sheep and Goat 9 l/day.

3.4.2.4. Determination of runoff from gauged station

Gauged runoff was collected from MoWR for Katar, Meki and Bulbula Rivers. Both Katar and Meki contribute inflow while Bulbula is for out flow from Lake Zeway.

3.4.2.5. Determination of runoff from un-gauged sub-catchments

The runoff in the un-gauged watershed was converted into runoff applying the area ratio method between the two watersheds located in similar rainfall regimes and runoff was expressed using following equation (Garg, 2005).

$$\frac{Qg}{Ag} + \frac{Qun}{Aun} \text{--} 3.10$$

Where, Q_g and Q_{un} = Seasonal discharge from gauged and un-gauged sub-catchment respectively and, A_g and A_{un} = Area of gauged and un-gauged of sub-catchments respectively.

Based on this fact, Habura and Meki gauging stations of Katar and Meki rivers were used respectively to estimate runoff from un-gauged sub-catchments of Lake Zeway.

3.4.2.5. Determination of water balance of Lake Zeway

The water balance model was established, after all components were estimated using Continuity equation. The next step was calculating the change in storage of the lake which was significant to know the behavior of the lake.

$$\sum \text{Inflow} - \sum \text{Outflow} = \Delta S \text{--} 3.11$$

Where, ΔS= Change in storage,

In order to understand the basic hydrological process, water balance computation of the lake is made using excel spread model. This model approach stems on solving the lake water balance equations.

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and during any period of time, the difference between total input and output was balanced by the change of water storage within the volume.

$$\Delta S = P + R - E + G_{in} - G_{out} - Abs - Q_o \text{-----------------------------------} (3.12)$$

Where, P= direct precipitation on the lake (mm), E= Evaporation from the lake surface (mm), R= Surface runoff into the lake (mm), G_{in}= Ground water inflow to the lake (mm), G_o= Ground water outflow from the lake (mm), Q_o = Surface water out flow from the lake (mm), Abs = Abstraction from the lake (mm), ΔG =Net ground water flow (mm), ΔS =Change in lake storage (mm)

3.4.2.6. Determination of net ground water flux (ΔG)

As quantification of G_{in} and G_{out} is difficult with luck of available data, the net ground water flux (G_{in}- G_{out}) was estimated as residual to the model output using Recursive equation 3.12 above.

$$\Delta G = (E + Abs + Qo + \Delta S) - (P + R + Qi) - - - - - - - - - - - - - - 3.13$$

Where, P= direct precipitation on the lake (mm), E= Evaporation from the lake surface (mm), R= Surface runoff into the lake (mm), Qo = Surface water out flow from the lake (mm), Abs = Abstraction from the lake (mm), ΔG =Net ground water flow (mm), ΔS =Change in lake storage (mm).

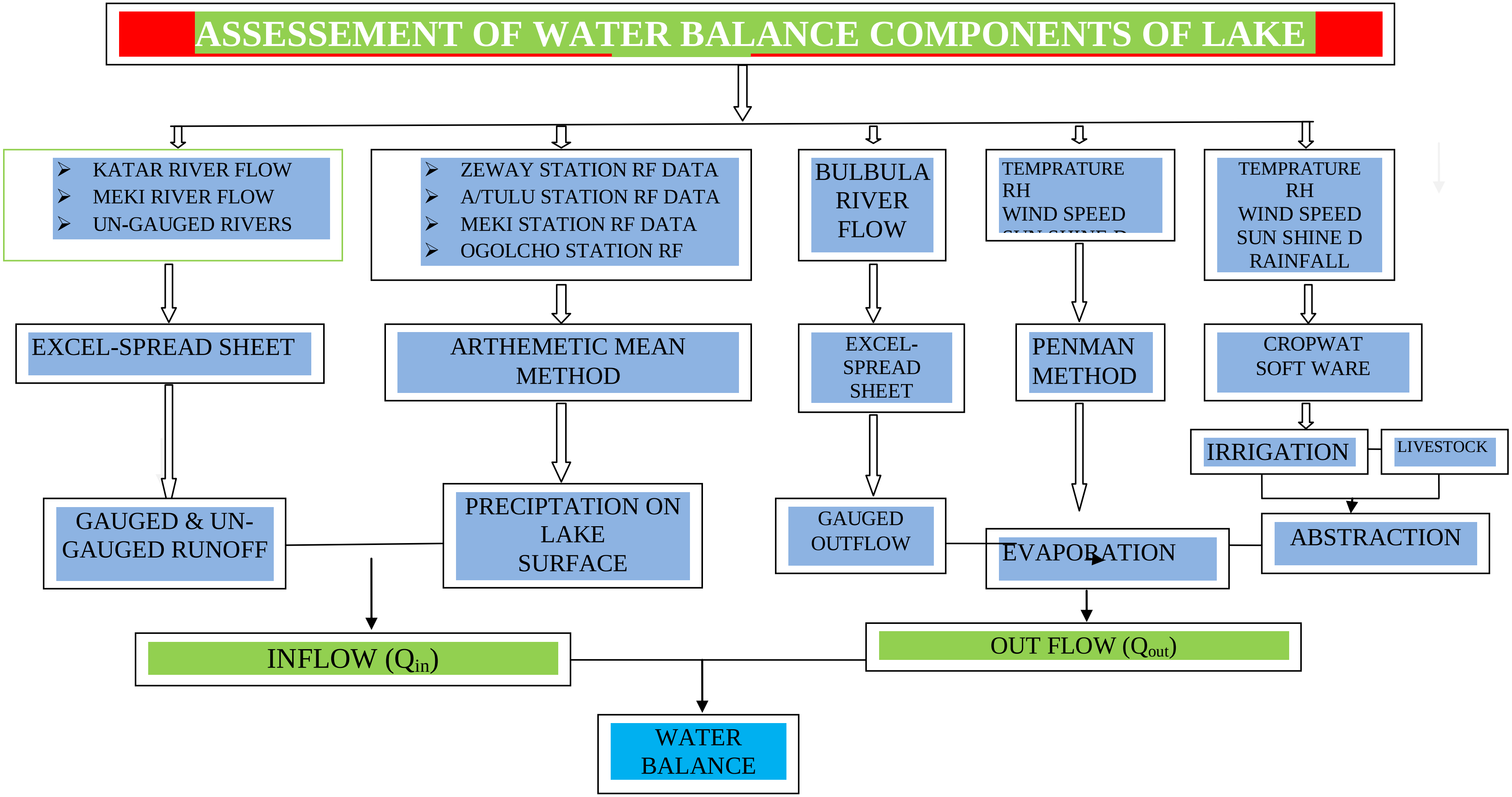


Figure 3: Flow chart of water balance analyses

4. RESULTS AND DISCUSION

4.1. Bathymetric Map of Lake Zeway

Greater than six hundred geographical coordinate points for which the water depth has been measured using plastic graduated tape meter were collected using GPS during the Bathymetric surveying as indicated on Table 29 arranged in the Appendix Table 28 and highlighted on figure 4 were used to develop under water contour using Arc GIS software with the contour interval of 0.5 m as indicated on figure 5. From the result, the top and the bottom level of the lake was found to be 1636 and 1630.4 m.a.s.l. respectively. Similarly, the border of the lake was identified visually and the location was collected as specified in Table 28 in the appendix. Using this border points, the area of the lake was estimated to be 469 km^2. The depth of the lake was measured using plastic tape meter. The maximum depth, of the Lake was 6.2 m and average depth was estimated to be 2.5 m from field data measurement.

The dimension of other lake parameters namely maximum length, maximum width, lake perimeter, and area were 31.74 m, 20.05 m, 95.91 m, and 469 km^2 respectively using the data collected from field measurement in the month of Oct. 01, 2020 up to Oct. 30, 2020 using Arc GIS software. From figure 4 below the green and the red line depicted the maximum length and the maximum width of Lake Zeway respectively. Based on the best fit equation developed by MoWR 2005/2006, the long term mean annual Lake Zeway surface area has been 461 km^2 which was slightly different with 1.74% increment in area compared to this study (469 km^2).

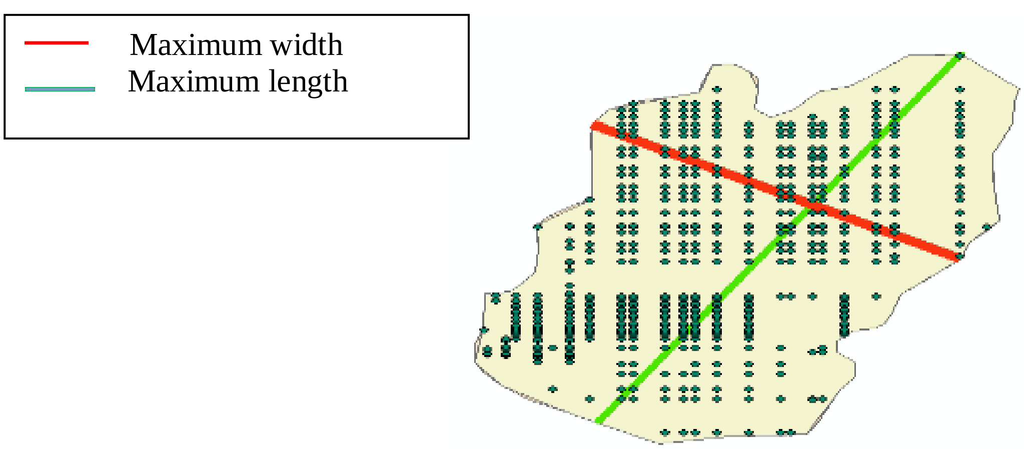


Figure 4: Sampling points, length and width of the lake

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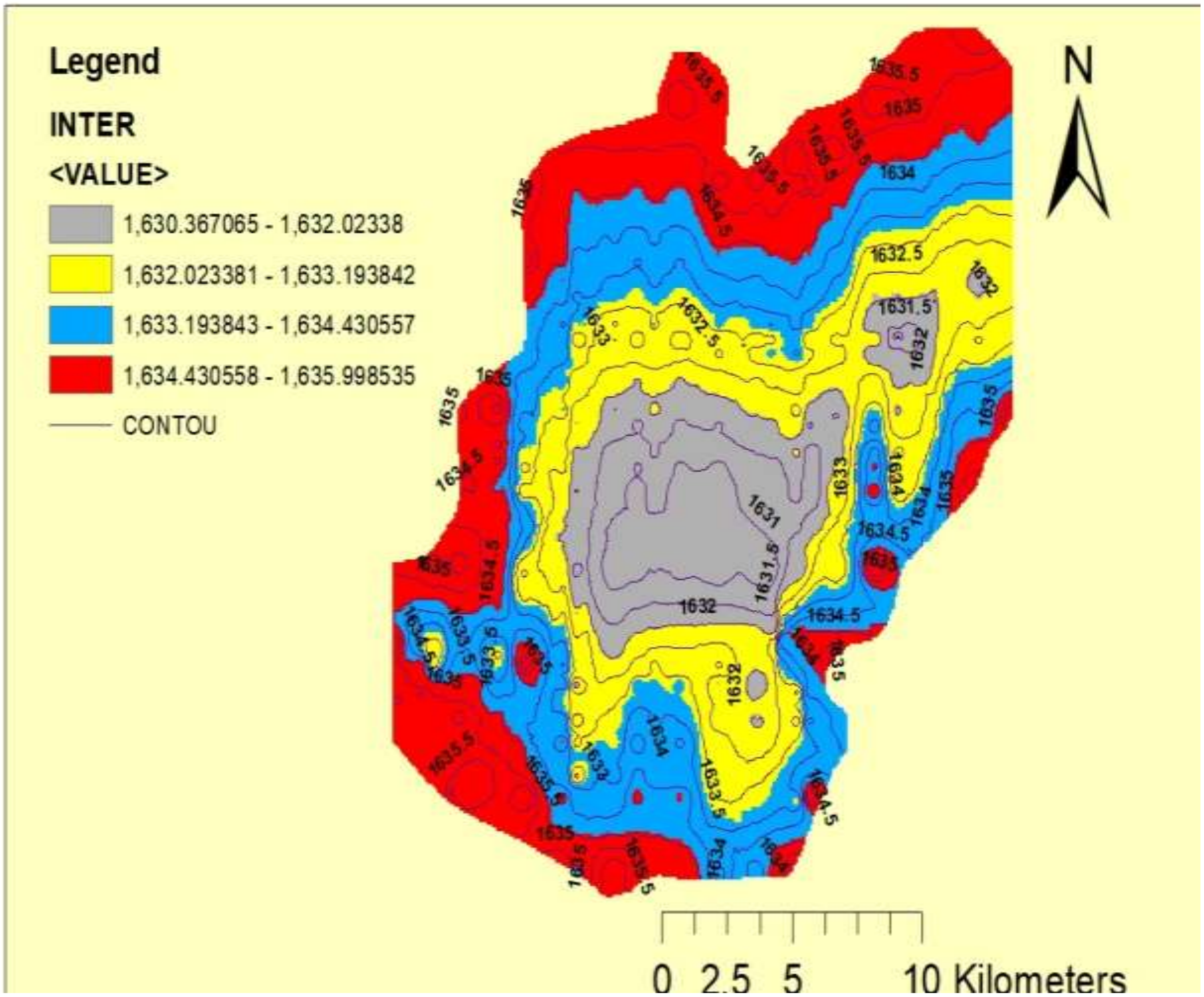

Figure 5: Bathymetric survey (Contour Map) of Lake Zeway

4.2. Computation of Sediment Depositions

As indicated on figure 6, the gap between the two graphs plotted using the curve fitting of polynomial equation of bathymetric survey by (MoLRD, 1976 and MoWR, 2005/2006) was the accumulation of the silt within 31 years period. The total volume of sediment deposited for the last 31 years which was indicated in table 6 is 873.44 MCM which means that the depth of the lake reduced by 1.9 m. Therefore; the siltation (sedimentation) rate of Lake Zeway was 28

MCM/Year in terms of volume and 6 cm/year in terms of depth. So that Lake Zeway will dry out after 42 years like Abjata and Haromaya Lakes if there will not any amendments carried out in terms of water resource and catchment management policy and if the other parameters becomes constant. The Clear volume of the lake is 1174.23 MCM based on the best fit equation developed by MoWR 2005/2006 using water level data which is 8m with reference elevation of 1628. However, the volume of the lake was 2047.23 MCM based on the best fit equation developed by MoLRD in 1976.

Total Siltation within 31 Years was 873.44 MCM which was obtained by subtracting the clear volume of water in 2005 (1174.23 MCM) from 1976(2047.67 MCM). Therefore, siltation rate was 28 MCM/year.

Table 5: Lake level elevation (m.a.s.l) and lake volume (MCM)

Elevation	Water level(m)	Lake Volume(MCM) IN 1976	Lake Volume(MCM) IN 2005/2006	Siltation Volume(MCM)	Siltation Depth(cm)
1628	0	13.02	-2.35	15.37	3.28
1629	1	23.70	8.88	14.82	3.16
1630	2	74.33	7.31	67.01	14.29
1631	3	199.32	6.84	192.48	41.04
1632	4	417.43	43.25	374.18	79.78
1633	5	731.73	158.78	572.95	122.16
1634	6	1129.65	386.63	743.02	158.43
1635	7	1582.93	735.53	847.40	180.68
1636	8	2047.67	1174.23	873.44	186.23
1637	9	2464.28	1616.07	848.22	180.86

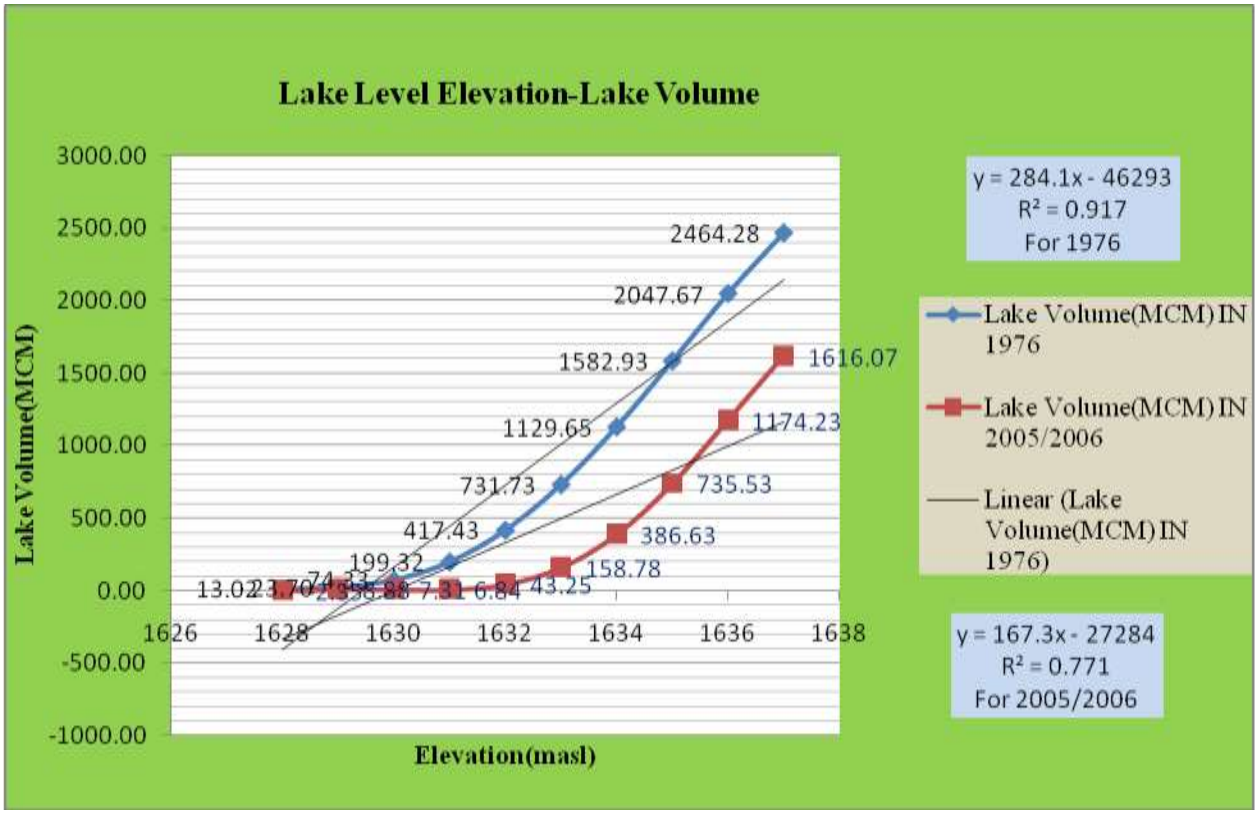

Figure 6: Lake level elevation-volume curve of Lake Zeway (1976 and 2005/2006)

Table 6: Comparison of previous and current study lake parameters

Year of Study	Lake Area (km^2)	Lake Storage Volume(Mm^3)
Previous Study(Oct,1976) by Ministry of Over land and Seas Development	447.83	1891
Previous Study(Oct,2005) by Ministry of Water Resources	463.05	1603.67
This Study(Oct, 2020) by Abdo Bedasso	469	1603

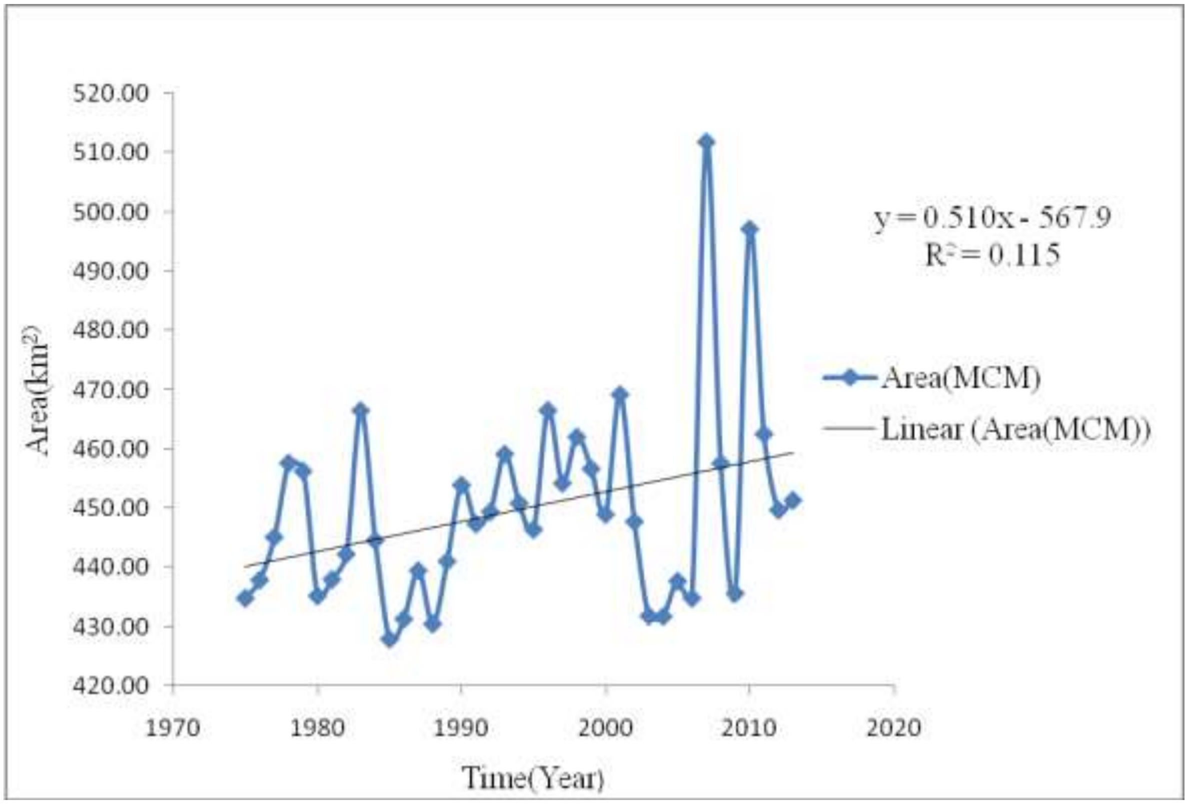

Figure 7: Mean annual area of Lake Zeway (km^2)

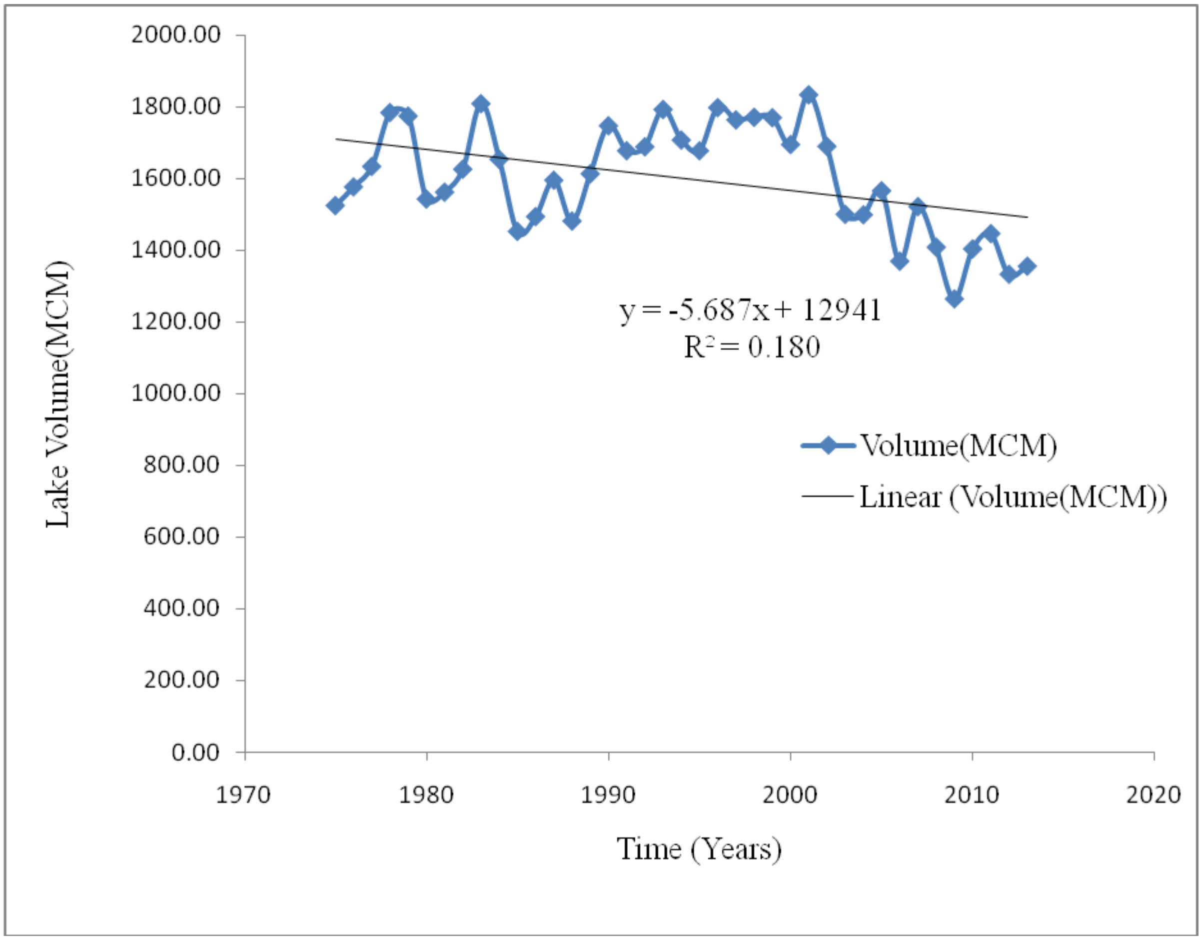

Figure 8: Mean annual volume of Lake Zeway (MCM))

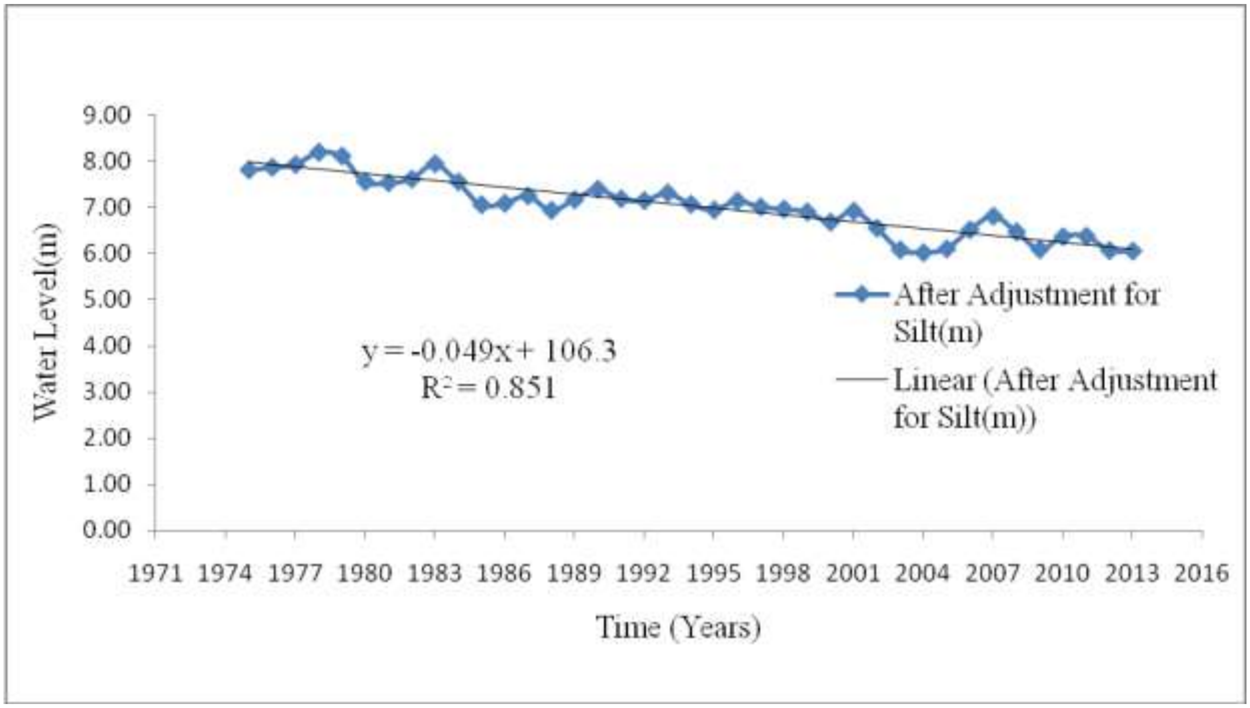

Figure 9: Time (Year) versus mean annual lake level adjusted for sediment

According to this study using bathymetric best fit equation model the mean monthly area and volume for October month were 469 km^2 and 1603 MCM respectively. Based on previous study by MoWR 2005/2006 to estimate mean monthly area and volume using curve fitting equation for the same period was 463.05 km^2 and 1603.67 MCM respectively.

As indicated in the table 6, figure 7, figure8 and figure 9 above the morphological parameters of Lake Zeway concerning to the lake area, lake volume and lake water level were indicating the increasing and decreasing trend of the lake area and volume at monthly bases respectively. This trend of the results of both studies above was attributed to the time to time siltation of the lake due to Buffer area degradation and poor management of the catchment.

4.3. Determination of Water Balance Components

4.3.1. Determination of precipitation

In order to evaluate the rainfall component of the water balance which was falling on the lake, gauging stations on the shore of the lakes are required. For this study four rainfall gauging stations (Zeway, Meki, Adami-Tulu, and Ogelcho) was selected for estimation of areal rainfall over lake Zeway by virtue of their close proximity to the lake, sufficient length of record, consistency of their records and similarity of topography and the same rainfall patterns (homogenous), and simple arithmetic mean method was used and quantified as 760.15 mm or 356.51MCM as indicated in table 8 below.When we compare this result with previous study by Abu Eresso (2010) which was estimated to be 326.74 MCM which was in lined with this study. But it shows slight difference which could be attributed to climatic changes and data processing techniques.

Table 7: Zeway sub-basin mean monthly areal rainfall (1982-2014)

Months	Katar Sub-basin(mm)	Meki Sub-basin(mm)	Zeway Lake(mm)	Average(mm)
Jan	19.55	21.79	11.04	17.46
Feb	35.60	44.00	30.64	36.75
Mar	72.57	77.90	54.74	68.40
Apr	88.60	94.36	72.89	85.28
May	82.76	86.65	75.81	81.74
Jun	94.18	96.78	85.15	92.04
Jul	155.26	167.69	170.93	164.63
Aug	151.83	151.94	127.73	143.84
Sep	101.28	99.45	86.10	95.61
Oct	48.17	40.96	32.86	40.66
Nov	13.72	7.98	7.51	9.73
Dec	10.62	7.52	4.76	7.63
Annual(mm)	874.15	897.03	760.15	843.78

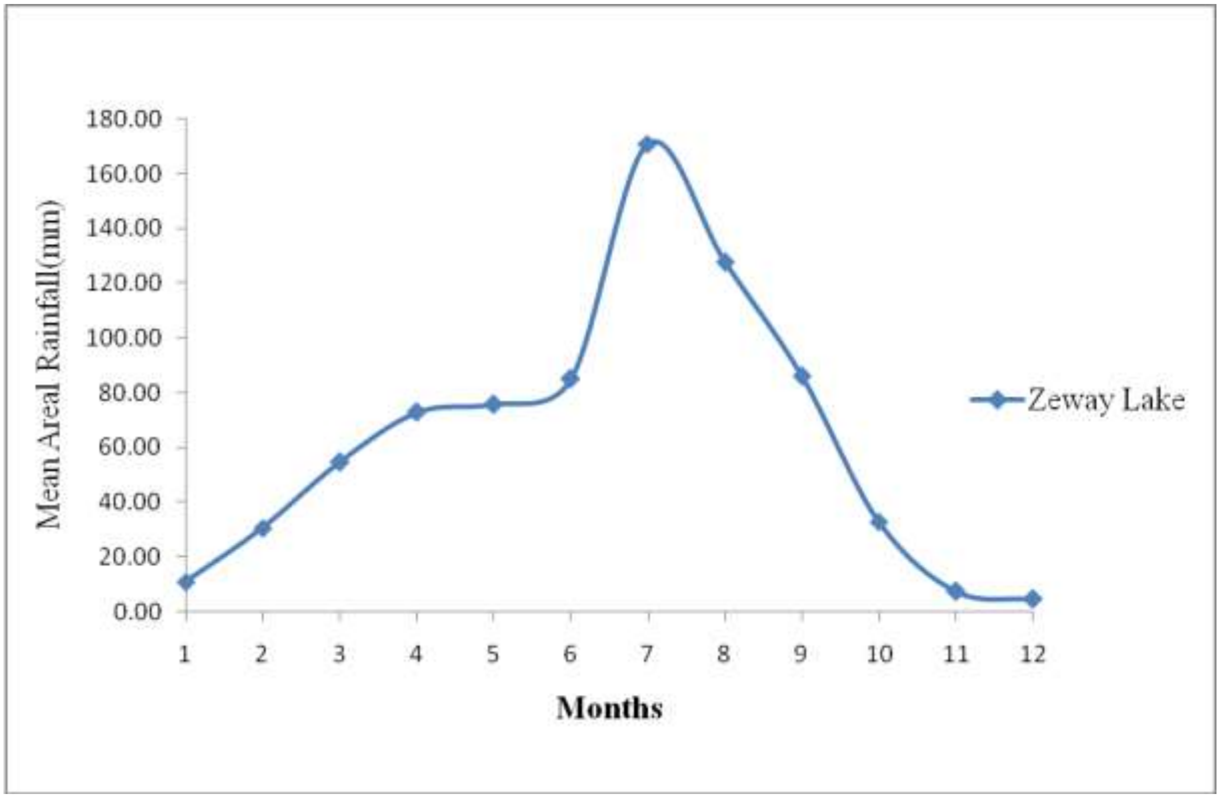

Figure 10: Lake Zeway mean monthly areal rainfall (mm) (1982-2014)

From figure 10 above it can be concluded that the maximum precipitation was observed in the months of July and August and on the other side, the minimum precipitation has been observed from October up to January during which the inflow Rivers experiencing only the base flow.

4.3.2. Determination of evaporation

Using Penman Montheith method, to calculate the quantity of water outflows from the lake due to evaporation, climatic parameters such as temperature, RH, sunshine duration and wind speed of Zeway meteorological station data of last 36 years (1982-2018) were employed and the estimated long term mean annual evaporation from lake surface was 1989.9 mm or 933.23 MCM, with the maximum in the month of April which was 187.20 mm as indicated in Table 8 below. This result was in lined with the results of previous studies by different scholars on lake Zeway using Penman method, such as; Coulomb, C.V et al (2001); Yihun (2009) and Abu(2010) which were quantified as 1875 mm, 1875 mm and 812 MCM respectively. Similarly, when we compare this result with previous studies it shows slight difference and an increasing trend**.** Therefore**,** such increase in the rate of evaporation would have a negative impact on Lake Zeway water level and storage volume that in turns responsible for Bulbula river discharge minimization which has significant impact on Abijata lake level. The increasing of evaporation was originating from increasing of temperature as indicated on figure11 below, may seem to be generally accepted with the status of global warming (Robock *et al*., 2000). Such magnitude of evaporation increment as indicated on figure 12 could affect the water budget of the lake (Lantersa *et al*., 2005); hence it is the most important losses in many water resources management studies (Salim *et al*., 2017).

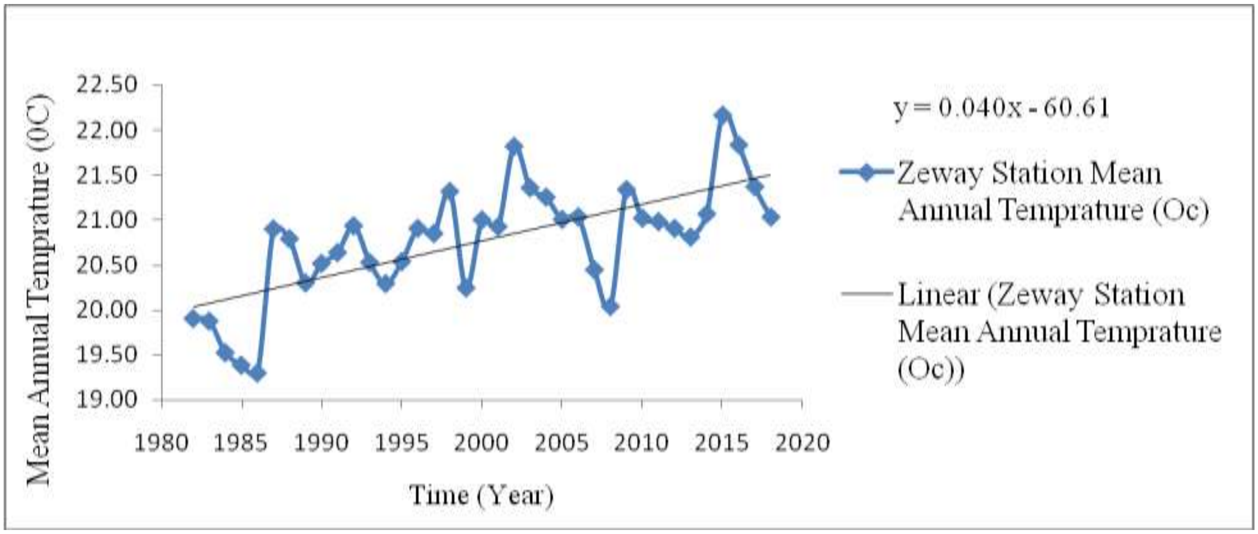

Figure 11: Mean annual temperature of Lake Zeway(^{o}C)(1982- 2018)

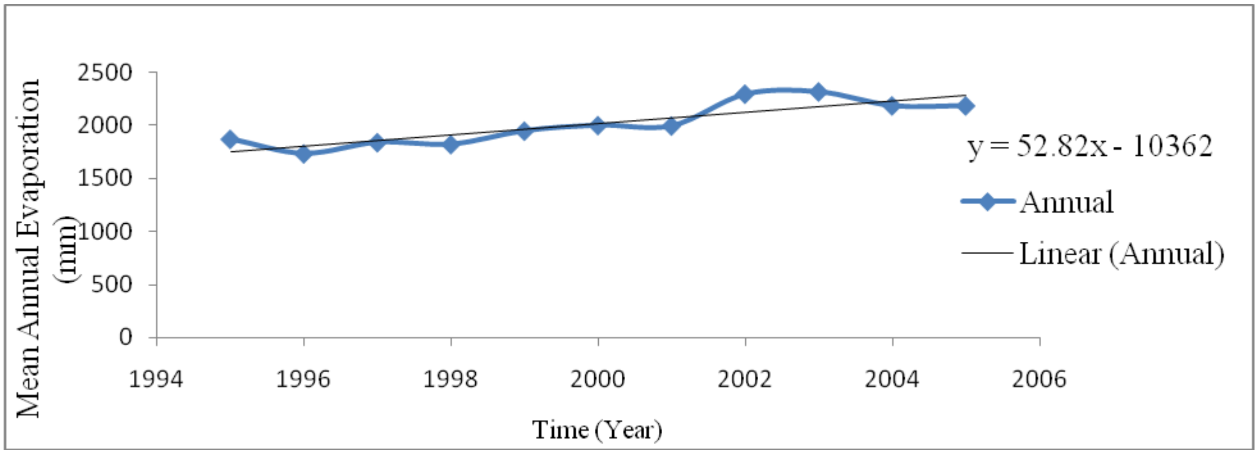

Figure 12: Mean annual evaporation of Lake Zeway (mm) (1995- 2005)

Table 8: Mean monthly evaporation from lake body

Months	A	H_n	E_a	ϒ	E_t (mm/month)	E_t (Mm^3/month)
Jan	1.05	5.14	3.18	0.05	156.49	73.39
Feb	1.24	5.83	4.09	0.05	167.00	78.32
Mar	1.24	6.10	4.18	0.05	186.70	87.56
Apr	1.24	6.34	3.76	0.05	187.20	87.80
May	1.24	6.21	3.61	0.05	183.38	86.00
Jun	1.24	6.12	3.30	0.05	180.29	84.55
Jul	1.05	5.65	2.00	0.05	169.90	79.68
Aug	1.05	5.87	2.25	0.05	176.98	83.00
Sep	1.05	5.64	2.54	0.05	165.06	77.41
Oct	1.05	5.52	3.48	0.05	168.19	78.88
Nov	1.05	5.13	3.46	0.05	151.65	71.12
Dec	0.95	3.14	2.88	0.05	97.07	45.52
Annual					1989.90	933.23

4.3.3. Water abstraction

Besides other water balance components, there is anthropogenic water loss from Lake Zeway. For example, different pumps of different capacities owned by individual farmers, farmers association, and private companies and livestock consumption are in operation of abstracting millions of litters of water per day from Lake Zeway (Desta, 2016).The main water abstraction from this lake is irrigation water use. Since this lake is not used by human, domestic consumptive considers only that is used by Livestock only. Data from Dugda, ATJK, and Zeway Dugda wereda showed that, 11618.57ha of land is under irrigation as indicated on table 14. Even though there are different vegetables that are produced by irrigation at the study area, Tomato, Onion, Cabbage, Maize and Pepper were selected as dominant vegetables under this irrigation. CropWat software was used to calculate water abstracted from the lake for irrigable land. Metrological data of Zeway station, which is nearer to the Lake, was arranged as needed by Cropwat soft ware. Hence, the total consumption by irrigation of the study area was 69.11 MCM as indicated on table 10.

The livestock that exist around the lake are cattle, sheep, goat, horse, donkey and mule. Data from Agriculture and Natural Resource office of weredas showed that, there are, 450,790 Cattles, 150, 000 Sheep, 93,600 Goats, 30,350 Horses, 45100 Donkeys and 3500 Mules. The livestock water consumption was based on the type and number of livestock daily water consumption and time duration the animals depend on the lake for water consumption. According tropical livestock Unit (2008), the average consumption of Cattle is 68 l/day, Horse, Donkey and Mule is 46 l/day, Sheep and Goat 9 l/day .Hence, the total consumption by live stock of the study area was 13.08 MCM as indicated on table 10. The total abstraction was estimated to be 82.19 MCM. When we compare this result with previous study by Abu (2010) which was estimated to be 128.5 MCM, our finding indicated the decreasing trend because the source of house hold potable drinking water for Batu/Zeway Town has been changed from Lake Zeway to Lake Langano. Such water withdrawal is affecting the water budget and lowering the water level and storage volume of Lake Zeway (Tamiru *et al*., 2006; Scholten, 2007). Such lake water level reduction in Lake Zeway could in turn affect the water level of Lake Abijata which gets its water supply from Lake Zeway through Bulbula River.

Table 9: Total water abstraction (mm)

month	Livestock Abstraction	Irrigation Abstraction	Total (Mm3/month)
Jan	1.09	6.83	7.92
Feb	1.09	2.15	3.24
Ma	1.09	5.40	6.49
Apr	1.09	6.75	7.84
Mar	1.09	9.41	10.50
Jun	1.09	6.13	7.22
Jul	1.09	0.17	1.26
Au	1.09	0.13	1.22
Se	1.09	2.36	3.45
Oc	1.09	8.06	9.15
Nov	1.09	11.57	12.66
Dec	1.09	10.13	11.22
Annual	13.08	69.11	82.19

4.3.4. Inflow rivers discharge

The Water balance analysis depicted that Katar showed higher discharge of water yield to Lake Zeway as compared with Meki River. Despite their similar high land originate of annual rainfall amount of these watershed , their response are different and that makes different in their amount of water contribution whose flows determine the hydrology of Lake Zeway in which they ends up. This variation might be caused by the different distribution of rainfall of their respective sub-watershed.

The long term mean annual discharge of both rivers have showed a decreasing trend as indicated on figure 13 below for the years (1982-2004).This could likely to be due to land cover and climate change (Merz and Bloschu,2009; Zhang *et al*.,2009; Desta,2016) and human and livestock population pressure(CSA,2013; Tsegaye *et al*.,2013). The agriculture and disturbed vegetation cover also decreases the runoff (Wang *et al*., 2014).

Besides the climatic phenomenon and land cover change, anthropologic factors such as, direct human induced activities have negatively affect the water balance system (Femiglietti *et al*., 2011; Rodell *et al*., 2009). Thus Katar and Meki Rivers are likely to cease to exist, if the water abstraction, land cover change, and other human impact continue as is in the watershed.

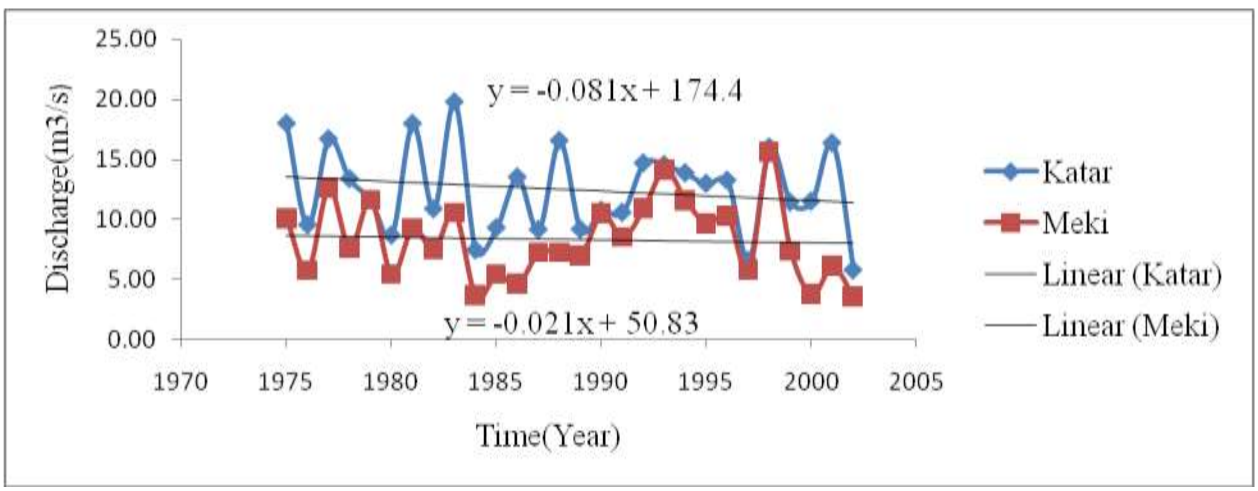

Figure 13: Mean annual discharge of inflow rivers discharge (m3/s)

4.3.4.1. Determination of katar river runoff

Gauges were installed at two stations; one at Fite on the middle reaches of the Katar, and the second near Ogelcho. The discharge measured at Katar Fite is greater than the discharge at Katar

Abura as indicated on figure 14and the difference was very pronounced during the high rainfall months of the country i.e. August. This might be due to abstraction losses either through faults, evapo-transpiration and storage in large natural pond which is namely “Shetamata” between the two observation stations and equal discharge measurements observed at the two stations in the month of October & November after covering the above demands.

Using 36 year data (1975-2010), the mean annual inflow of the Lake Zeway from the Katar River was 423.24 MCM gauged at Abura (confluence to Lake Zeway) and 553.95 MCM gauged at Katar fite (sagure) at mid stream of Kata River. In lined with this study, Abu (2010) also estimated the Katar river runoff to be 401.57 MCM. But it shows slight difference that could be attributed to climatic change. The long term mean annual discharge of Katar River shows a decreasing trend for the year between (1975-2004) as indicated on figure 15 below which might be attributed to climatic change, anthropologic factors and land use change.

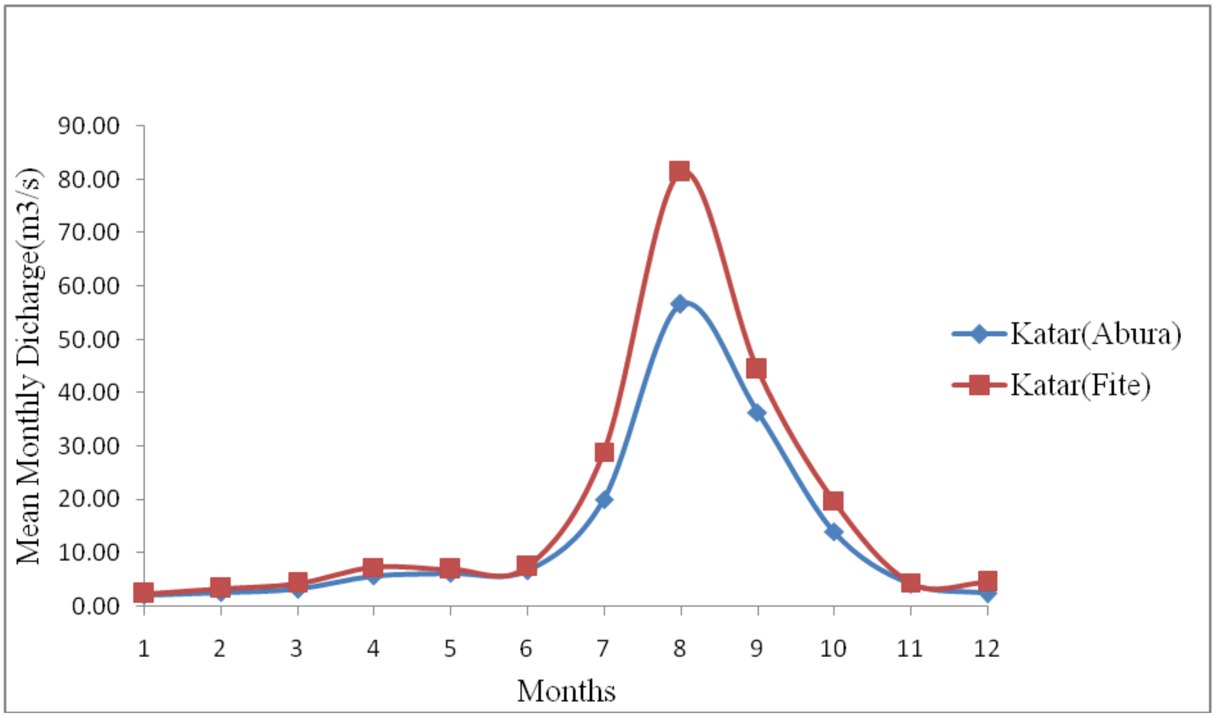

Figure 14: Mean monthly discharge of Katar at Abura and Fite (MCM)

As it has been indicated on figure 15, there was a drought years when there were low mean Annual Discharge recoded for Katar River. For instance; 1983, 1998, 2002 and 2003 were the years at which low discharge had been recorded. The mean annual discharge of Katar River is showing a decreasing trend as indicated on figure 15 below which is attributed to climatic change, land cover change and anthropogenic factors.

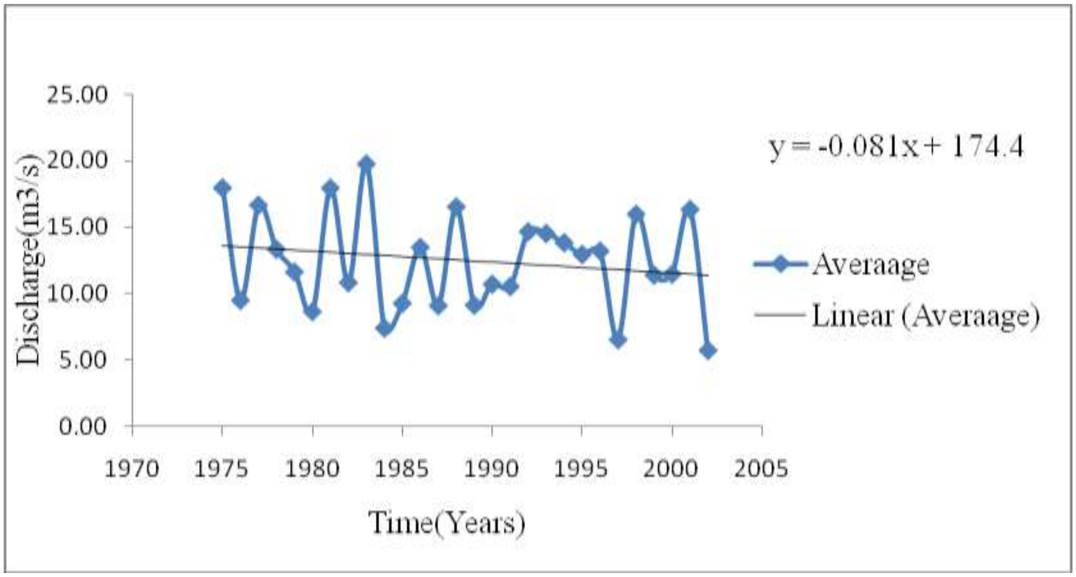

Figure 15: Katar river mean annual runoff (m^3/s)

4.3.5.2. Determination of meki river discharge

On 37 years average using the data from 1975-2011 on monthly basis, maximum flows occurs in August and minimum flows between December and Feb as it was observed from the hydrograph of the Meki River on figure 16.The discharge of Meki river during dry season Dec-Jan may dry. It can be said that the base flow of the river has been dry out during the dry years which is a good indication not to depend on runoff of the river throughout the year for irrigation and domestic water supply. The total annual contribution of Meki River to the Lake Zeway is 275.85 MCM. This result was in lined with previous study by Abu Eresso (2010) which was estimated to be 270.19 MCM. But it shows slight difference which could be attributed to climatic change. The mean annual discharge of Meki River was showing a decreasing trend as indicated on figure 17 below which is attributed to climatic change, land cover change and anthropogenic factors.

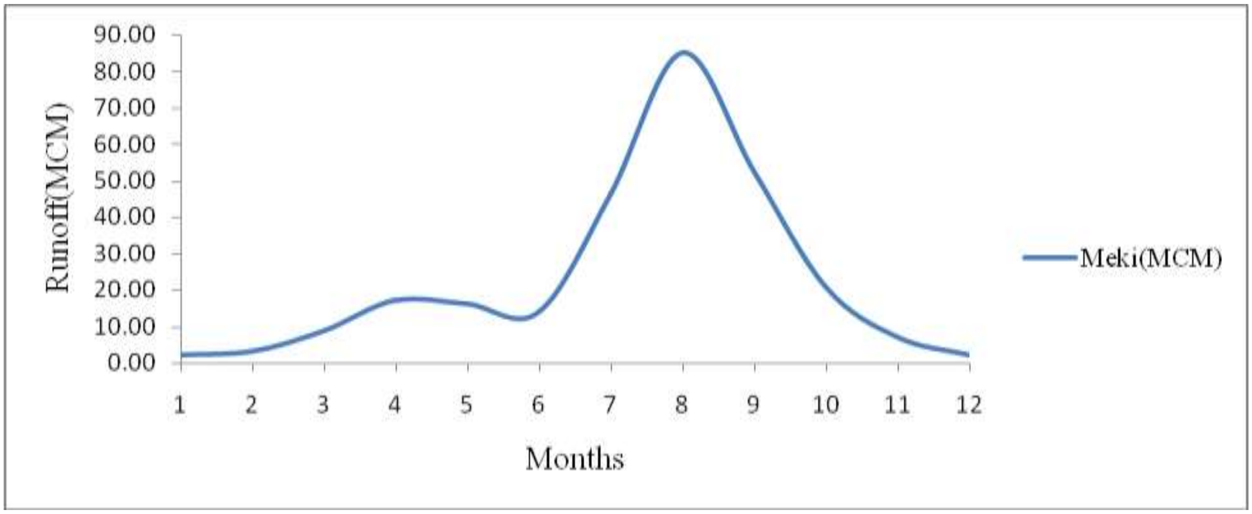

Figure 16: Mean monthly discharge of Meki River (MCM)

As it has been indicated on figure 17, there was a drought years when there were low mean Annual Discharge recoded. For instance; 1983, 2001 and 2010 were the years at which low discharge had been recorded. The mean annual discharge of Meki River is showing a decreasing trend as indicated on figure 17 below which is attributed to climatic change, land cover change and anthropogenic factors.

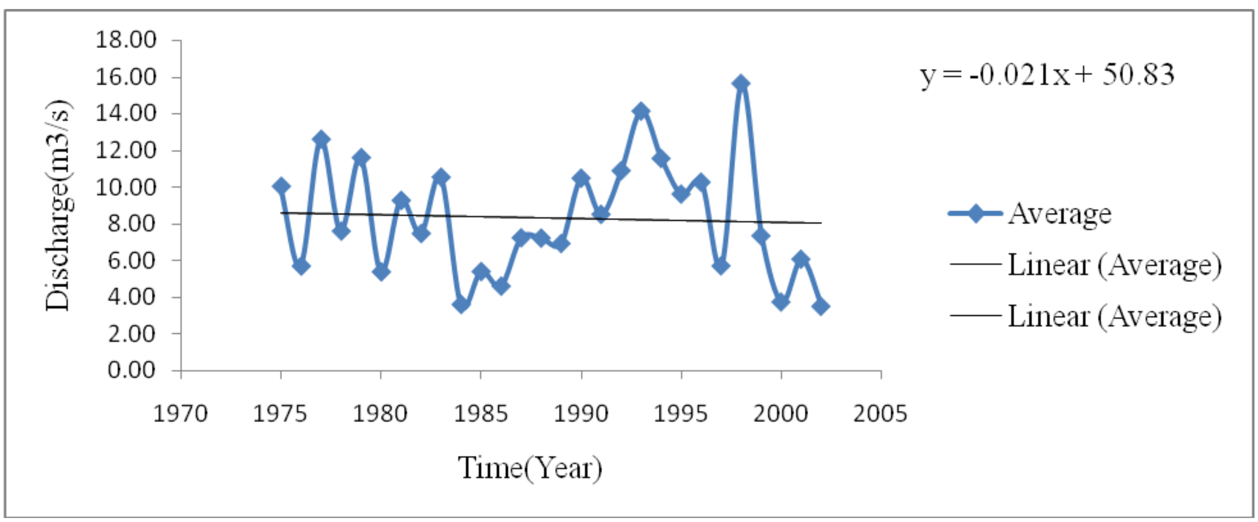

Figure 17: Meki river mean annual runoff (m^3/s)

4.3.6. Determination of discharge from un-gauged sub-catchment

Apart from Meki and Katar River, Lake Zeway has its own catchment which is part of the lake catchment referred to as un-gauged. The un-gauged area covers a sub-catchment adjoined to Lake Zeway almost on all sides. The gauged Katar and the Meki sub-river basin for which their runoff is directly entered to the Lake Zeway are used to estimate the runoff from the un-gauged sub-catchments using the Area Ratio Method. The runoff from the un gauged catchments considered in this study is only in the rainy season (June to September) and the estimated amount is about 121.33 MCM for which its distribution is indicated on figure 18.When we compare this result with previous study by Abu Eresso (2010) which was estimated to be 98.33 MCM which was in lined with this study. But it shows slight difference which could attributed to uncertainties in water balance component data processing technique and due to climatic change, anthropologic factors and land use change which was responsible for slight decrement as it indicated for the case of Katar and Meki river discharge which is indicated on figure 15 and figure 17 since it was estimated from these rivers discharge using the area ratio method.

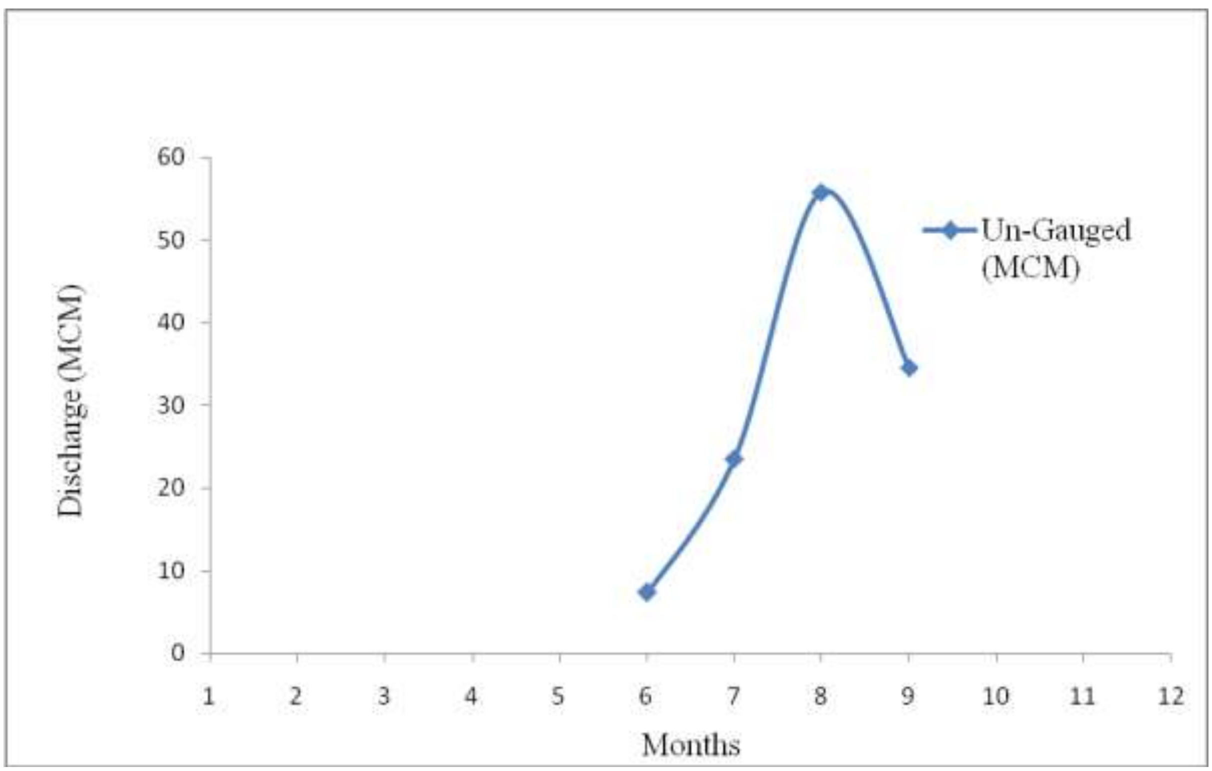

Figure 18: Mean monthly runoff of un-gauged rivers (MCM)

4.3.7. Determination of Bulbula river out flow discharge

The discharge of outflow from the Zeway Lake was controlled by the height of the rock sill in the Bulbula channel, near Adami Tulu. Outflow ceases when the lake falls to this level which is 1635.56 m.a.s.l or 0.46 m on the staff gauge at Zeway town. Using 34 years data the total mean annual outflow from the Lake Zeway measured at Kakarsitu was 173.45 MCM and its distribution depicted on figure 19below.When we compare this result with previous study by Abu Eresso (2010) which was estimated to be 173.71 MCM which was in lined with this study.

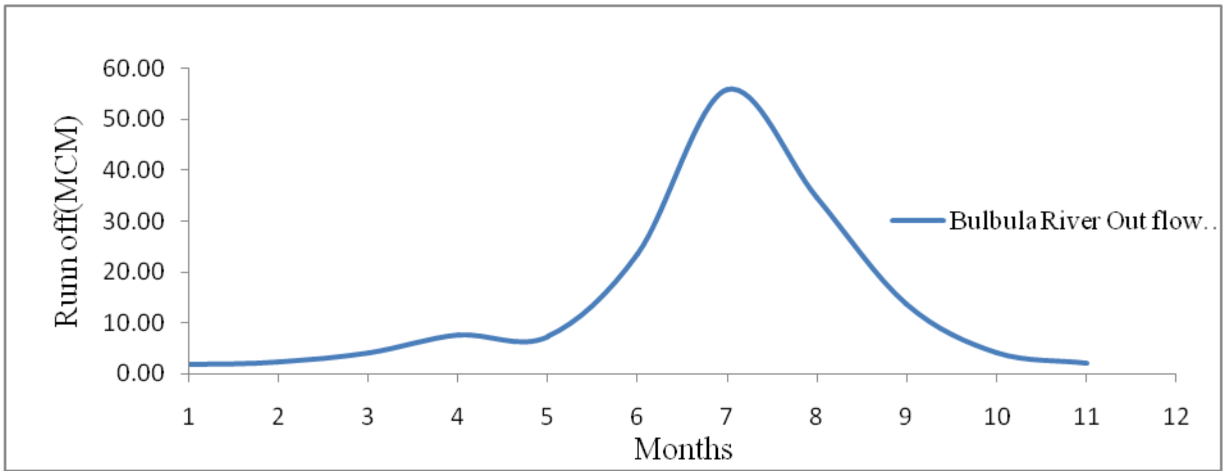

Figure 19: Bulbula river mean monthly discharge (m^3/s)

As it has been indicated on figure 20, there was a drought years when there were low mean Annual Discharge recoded. For instance; 1980, 1984 and 2002 -2005 were the years at which low discharge had been recorded. In contrast to these years, 1993 and 2008 were the years with maximum mean Annual discharge had been recorded which was attributed to climatic changes such as annual rainfall distribution on both sub-watershed and on the lake surface as well.

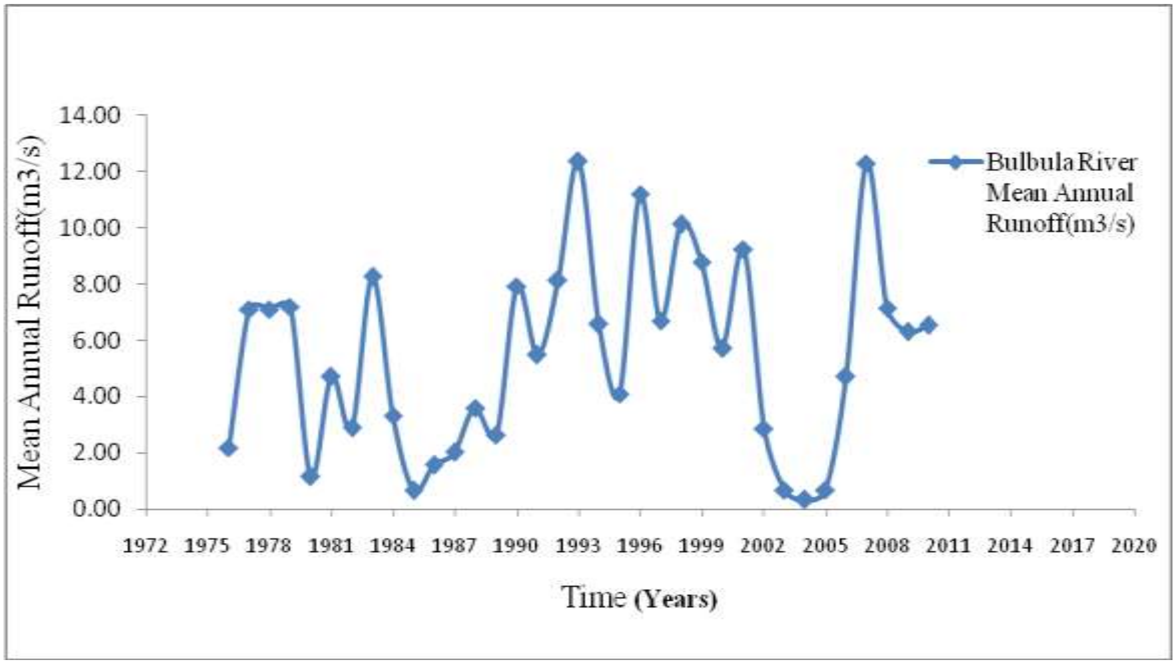

Figure 20: Bulbula river mean annual runoff (m^3/s)

4.3.8. Determination of net ground water flux (ΔG)

From recursive equation 3-13in the methodology, monthly net ground water Flux was computed as the residual of other water balance components and lake storage. Long term monthly water balance of Lake Zeway and the influence of ground water were summarized as shown in Table 11. The ground water contributed the water budget about +11.95 MCM to the lake which is 1.01% of total annual out flow components. The net ground water flux (ΔG) was positive which is indicating that the ground water inflow was substantial to contribute the flow to the lake having a positive impact to the storage of the reservoir system. From Table 11 it can be observed that, Lake Zeway contributes the water to the ground during the months of July – September and received the water from ground during months of October – June. From this occasion we can justifies that, the rainfall distribution of lake Zeway watershed which was having the maximum pick rainfall during months of August and releases immediately the water in the form of base flow to lake Zeway after one month, which started in the month of October. This result is in line with the previous study by Abu Eresso (2010), which was estimated to be +17.47 MCM. But it shows slightly decreasing of change in ground water (ΔG) which might be attributed to land cover and climate change (Merz and Bloschu,2009; Zhang *et al*.,2009; Desta,2016)

Besides the climatic phenomenon and land cover change, anthropologic factors such as, direct human induced activities have negatively affect the water balance system (Femiglietti *et al*., 2011; Rodell *et al*., 2009).

Table 10: Mean annual total inflow, outflow, change in storage and ∆G

Months	Inflow (MCM)	Outflow (MCM)	Storage(∆S) (MCM)	∆G MCM	Lake Level m	∆s m
Jan	12.92	94.98	-75.86	157.92	1.13	-0.16
Feb	23.89	90.07	-57.34	123.52	1.01	-0.12
Mar	43.23	99.61	-50.70	107.08	0.90	-0.11
Apr	66	99.61	-23.44	57.05	0.85	-0.05
May	68.19	99.95	-19.30	51.06	0.81	-0.04
Jun	78.64	94.53	-17.31	33.20	0.77	-0.04
Jul	203.92	85.83	44.70	-162.79	0.87	0.10
Aug	352.67	100.5	171.43	-423.60	1.23	0.37
Sep	221.76	115.05	157.28	-263.99	1.57	0.34
Oct	73.52	123.21	14.04	35.65	1.60	0.03
Nov	21.36	110.21	-63.34	152.19	1.47	-0.14
Dec	10.84	75.34	-80.17	144.67	1.29	-0.17
Mean Annual	1176.93	1188.88	0.00	+11.95		

4.3.9. Determination of water balance of Lake Zeway

The Monthly and annual water balance components of lake Zeway was presented in table 12 and figure 21 revealed that, the contribution of direct precipitation, Katar river, Meki river and Runoff from the un gauged sub-watershed to the annual inflow components to the lake were about 35.96%, 23.44% , 10.31% and 30.29% respectively. Whereas, evaporation loss, outflow to Bulbula river and water abstraction contributed about 79.29%, 14.74% and 6.98% respectively of the total annual inflow to the lake and the outflow components (evaporation) is highly responsible for the depletion of lake Zeway and showed increasing trend.

When we compare this result with previous study by Abu Eresso (2010) the contribution of direct rainfall (Precipitation), Katar River, Meki River and runoff from un-gauged sub watershed from the annual inflow components to lake Zeway were about 29.79%, 36.61%, 24.63%, and 8.96%respectively.Whereas, the outflow from Bulbula river, the water abstraction and evaporation loss which was the dominant water balance components of lake Zeway were contributed about 15.84%, 11.72% and 74.04% respectively which is in lined with this study. But it shows slight difference.

The results of the annual water balance assessments revealed that an inflow and outflow was 1176.93 MCM and 1188.88 MCM respectively, which means that, the change in storage (ΔS) of the lake during the observation period was -11.93 MCM, indicating that large amount of water going out than water comes in, which means that an annual flow deficit of 11.93 MCM. The previous study by Abu Eresso (2010) which was estimated to be -17.47 MCM was in lined with this study, but it shows slight difference. This deficit was attributed to climate change due to global warming and land cover change (Merz and Bloschu, 2009; Zhang *et al.*, 2009; Desta, 2016). Besides, the climatic phenomenon and land cover change, anthropologic factors such as, direct human induced activities have negatively affect the water balance system (Femiglietti *et al.*, 2011; Rodell *et al.*, 2009).Studies in other part of Ethiopia have also revealed that there was a significance of climate change on lake water balance. Tenalem *et al*. (2007) indicated that 10% change in evaporation in Lake Hawasa causes up to an average of 43cm rise or fall in the water level. Therefore; the results of this study also agree with that of Tenalem (2007).

Finally, the decline of water balance of lake Zeway leads to the declining effect of the out flow of Bulbula River from this lake As well as; it becomes changing this lake to endoergic lake in near future and will attain the fate of Lake Haromaya and Abijata in the long run if no any mechanisms to mitigate these problems will be carried out soon. Therefore, it is recommended to look a solution for minimization of the extent of the dominant component (rate of evaporation) for the depletion of the water balance as well as applying important catchment development strategy to minimize siltation for future sustainability of Lake Zeway.

Table 12 and figure 19 below presents the summary of the water balance components of Lake Zeway for the observation period.

Table 11: Summary of water balance components of Lake Zeway (MCM)

Inflow Data					Outflow Data			ΔS (MCM)	
Month	Katar	Meki	Un-Gauged Runoff (MCM)	Precipitation on the Lake (MCM)	River Outflow (MCM)	Evaporation (MCM)	Abstraction (MCM)	MCM	mm
Jan	5.57	2.17		5.18	13.67	73.39	4.93	-79.07	-168.59
Feb	6.28	3.24		14.37	8.50	78.32	2.30	-65.23	-139.08
Ma	8.68	8.88		25.67	5.55	87.56	4.13	-54.02	-115.18
Apr	14.73	17.08		34.18	3.97	87.80	4.89	-30.66	-65.38
Mar	16.56	16.07		35.56	3.45	86.00	6.38	-27.64	-58.93
Jun	17.33	13.99	7.38	39.94	2.75	84.55	4.54	-13.21	-28.16
Jul	53.62	46.55	23.59	80.17	4.88	79.68	1.19	118.17	251.96
Au	151.67	85.29	55.80	59.91	16.28	83.00	1.16	252.23	537.80
Se	94.23	52.58	34.57	40.38	34.19	77.41	2.42	107.74	229.72
Oc	37.45	20.67		15.41	35.18	78.88	5.63	-46.17	-98.44
Nov	10.79	7.05		3.52	26.43	71.12	7.60	-83.79	-178.65
Dec	6.34	2.27		2.23	18.60	45.52	6.79	-60.07	-128.07
Annual (MCM)	423.24	275.85	121.33	356.51	173.45	933.23	82.19	-11.95	-25.45
Annual (mm)	902.42	588.16	258.71	760.15	369.82	1989.83	175.24	-25.45	

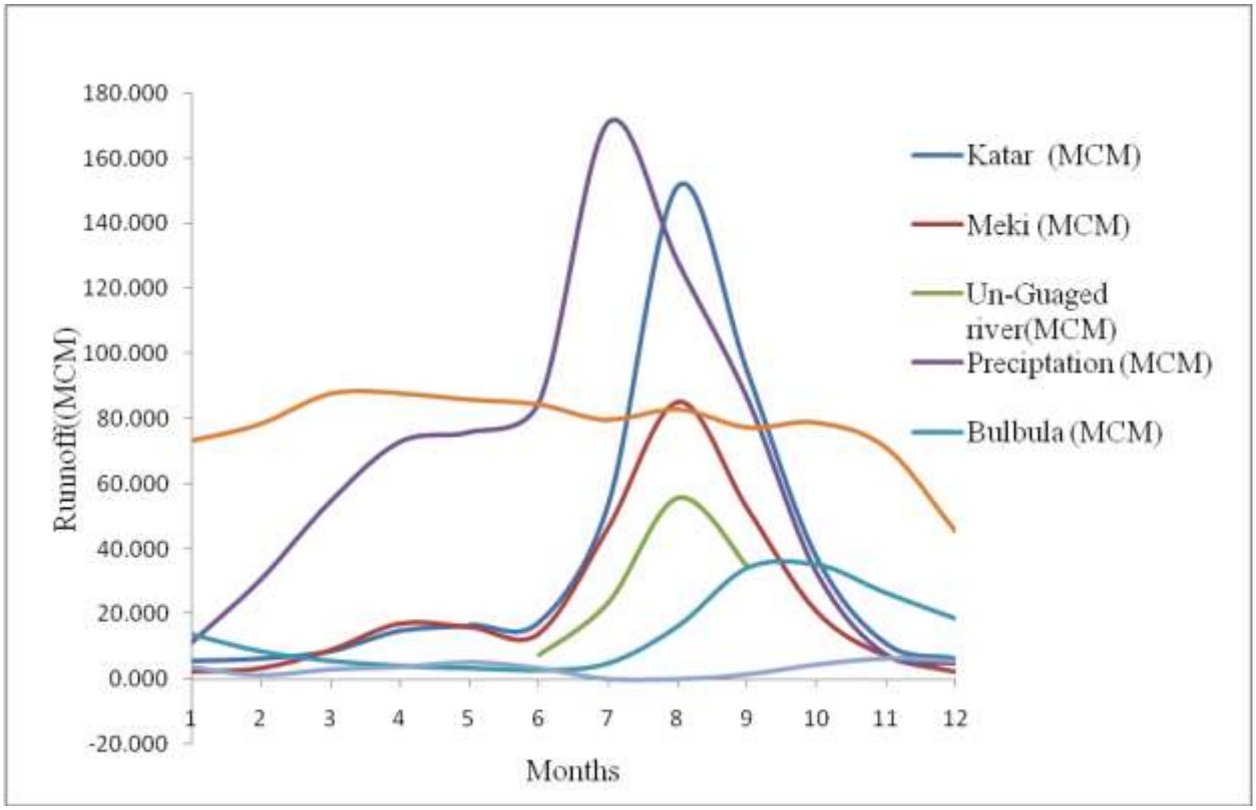

Figure 21: Water balance components of Lake Zeway

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Six hundred fifty two geographical coordinate points for which the water depth has been measured using plastic graduated tape meter were collected using GPS during the Bathymetric surveying. The depth of the lake was measured using plastic tape meter. This bathymetric data collected during field survey were used to develop under water contour using Arc GIS software with the contour interval of 0.5 m. The maximum depth, of the Lake was 6.2 m and average depth was estimated to be 2.5 m from field data measurement. The dimension of other Lake Parameters, Maximum Length, Maximum Width, Lake Perimeter, and Area were 31.74 m, 20.05 m, 95.91 m, and 469 Km^2 respectively using the data collected from field measurement during the month of Oct. 01, 2020 up to Oct. 30, 2020 using Arc GIS software.

According to this study using bathymetric best fit equation model the mean monthly area and volume for October month were 469 km^2 and 1603 MCM respectively. Based on previous study by MoWR 2005/2006 to estimate mean monthly area and volume using curve fitting equation for the same period was 463.05 km^2 and 1603.67 MCM respectively. From the results of bathymetric survey, the morphological parameters of Lake Zeway concerning to the lake area and lake volume were indicating the increasing and decreasing trend respectively.

According to the water balance estimated using the spread sheet, the hydrologic component that plays an important role in the lake level fluctuation was known to be evaporation**.** It comprises about 79.29% of the total inflow component of the lake water balance. The contribution of Katar river, Meki river Un gauged sub catchment, lake surface precipitation, bulbula river, Evaporation from lake surface and abstraction were 423.24 Mm3, 275.85 Mm3, 121.33 Mm3, 356.51 Mm3, 173.45 Mm3, 933.23 Mm3, 82.19 Mm3 respectively. The total annual average inflow to the lake can be safely estimated by the sum of the Katar, Meki River and runoff water from the un-gauged Sub-catchment and precipitations on the lake and the outflow from the lake has been estimated from evaporation, livestock and irrigation abstraction and Bulbula River outflow. The ground water contributed the water budget of about +11.95 MCM to the lake which is 1.01% of total annual out flow components. The positive result was indicating that the ground water inflow was substantial to contribute the flow to the lake having a positive impact to the storage of the reservoir system.

The results of the annual water balance assessments revealed that the long term mean annual inflow and outflow was 1176.93 MCM and 1188.88 MCM respectively, which means that, the change in storage (ΔS) of the lake during the observation period was -11.93 MCM, indicating that large amount of water going out than water comes in, which means that an annual flow deficit of 11.93MCM.

Although, the lake level, storage volume and lake surface area fluctuation was experienced in Lake Zeway, it was not concluded either land use change, climate change or anthropologic factors alone was the cause, but it was attributed to the combined effect of all these factors. Eventually, according to this study the lake may change in to Endorehic Lake and will dry out in the long run. If this will happened, the local communities who depend on the lake water for livestock consumption, irrigation watering and fishing production will be affected.

5.2. Recommendations

Based on the results found and challenges faced during this piece of work, the following recommendations are forwarded:

- ❖ Obviously, water is an excellent resource of a nation, as it can be serve various functions, therefore; proper watershed management so as to minimize siltation is absolutely necessary, in order to obtain maximum benefits and employing integrated water use approach to sustain future development activities on the lake water resources.
- ❖ Measures should be taken to reduce loss of water due to evaporation which was the dominant component for the depletion of the water balance, since the large trees are almost cleared out for the fuel woods and charcoal production, which was serving as a wind breakers. Therefore; growing tall trees on the windward side of the reservoir is recommended and hence reduce evaporation. Moreover, As the lake periphery and inside the lake is recently affected by newly emerged broad leave plant, locally named that" Emboch" which is responsible to increase the rate of evaporation, so it should be removed
- ❖ Program of erosion control measures in the basin such as forestation, terracing, prevention of overgrazing and poor farming practice and applying water use management interventions in order to mitigate siltation.

- ❖ Investigations of groundwater flux and directions should be very important to improve the results of water balance obtained.
- ❖ Proper irrigation scheduling, focusing on high value crops and under taking detail crop-water requirements study in irrigation fields to avoid the over utilization and optimum use of water resource.

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APPENDIXES

Appendix 1: List of tables

Appendix Table 1: Meki river runoff gauged at Meki town (m^3/sc)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	0.11	0.24	0.01	0.60	0.44	4.47	27.20	28.11	44.90	12.07	1.96	0.49	10.05
1976	0.26	0.09	2.39	2.04	5.87	2.08	14.80	18.86	13.90	2.04	5.43	0.74	5.71
1977	2.50	3.94	0.66	3.52	9.95	6.45	31.50	28.75	18.80	17.92	24.50	2.84	12.61
1978	0.46	1.30	5.27	1.20	0.74	3.86	13.20	29.34	16.00	14.27	3.32	2.37	7.61
1979	2.97	5.86	7.91	20.89	13.20	2.98	23.40	30.57	14.00	12.85	3.53	1.16	11.61
1980	0.81	0.96	1.27	2.19	1.54	4.95	16.70	21.07	9.53	4.35	0.82	0.53	5.39
1981	0.40	0.49	13.70	20.03	6.00	2.10	9.43	30.14	22.20	5.11	0.62	1.14	9.28
1982	0.92	1.77	1.49	7.03	7.12	2.53	8.26	30.07	9.64	16.62	2.58	1.74	7.48
1983	0.53	2.76	4.62	11.87	18.00	14.00	9.92	33.42	21.40	7.53	1.61	0.89	10.55
1984	0.62	0.49	0.45	0.32	2.60	4.58	9.81	9.82	13.00	1.08	0.35	0.29	3.62
1985	0.22	0.18	0.13	1.53	6.65	1.25	8.96	27.42	15.30	2.77	0.34	0.17	5.41
1986	0.09	0.52	0.87	4.89	2.56	7.94	8.24	16.84	11.30	1.90	0.20	0.04	4.62
1987	0.01	0.28	7.70	18.25	17.30	14.60	7.52	6.26	7.31	7.26	0.41	0.04	7.24
1988	0.04	0.41	0.15	3.07	2.22	2.85	15.80	23.26	22.50	12.62	2.91	0.92	7.23
1989	0.14	2.43	3.30	9.65	2.93	3.90	15.20	15.77	17.60	9.72	1.65	0.89	6.93
1990	0.31	11.30	20.20	21.69	5.28	5.82	17.10	19.81	15.20	6.42	1.86	0.87	10.49
1991	0.50	2.60	7.17	2.84	0.89	3.76	24.50	34.90	20.10	3.48	0.87	0.66	8.52
1992	1.50	1.83	1.30	2.26	2.27	2.40	6.07	48.97	40.10	18.61	3.38	2.10	10.90
1993	4.92	0.98	0.98	13.44	17.50	12.30	25.20	57.52	19.90	11.61	4.45	0.89	14.14

1994	0.80	1.42	0.60	1.16	1.50	3.17	17.00	60.03	47.10	4.39	0.98	0.62	11.56
1995	1.16	1.18	5.89	5.36	4.04	1.88	9.35	35.93	44.00	3.41	1.74	1.57	9.63
1996	1.84	1.26	2.12	2.92	5.00	13.30	16.00	47.58	24.50	5.55	1.99	1.21	10.27
1997	0.32	0.27	0.99	9.95	2.89	4.36	16.60	16.60	5.40	4.14	6.18	0.92	5.72
1998	1.60	0.74	12.10	3.27	11.80	5.23	27.60	70.11	29.20	23.12	2.55	0.42	15.65
1999	0.09	0.07	2.84	0.12	0.51	2.84	20.60	22.42	10.20	23.55	4.73	0.28	7.35
2000	0.02	0.00	0.00	0.05	0.83	0.64	6.31	14.02	11.00	8.25	2.96	0.94	3.75
2001	0.01	0.18	3.06	1.91	4.61	10.90	19.30	21.76	10.90	0.32	0.00	0.00	6.08
2002	1.05	0.55	0.13	1.55	2.07	2.55	5.41	11.60	12.00	2.16	1.69	1.42	3.51
2003	0.86	0.51	7.85	6.23	1.96	4.61	42.10	46.95	20.90	3.67	0.33	0.73	11.39
2004	0.84	0.26	0.62	19.13	0.65	2.00	18.50	56.20	21.30	8.72	0.39	0.11	10.73
2005	0.33	0.08	1.15	5.98	23.60	12.90	24.00	87.29	50.50	8.62	1.76	1.16	18.11
2006	1.97	1.01	1.19	26.89	26.25	8.86	37.77	48.48	21.31	5.07	1.37	1.02	15.10
2007	0.77	1.95	1.23	0.48	1.78	14.83	40.91	41.66	23.37	5.55	0.69	0.51	11.14
2008	0.43	0.32	0.21	0.32	1.18	3.17	9.76	20.76	15.24	1.03	10.47	0.36	5.27
2009	0.64	0.12	0.12	0.56	0.52	0.25	3.26	6.49	5.42	5.05	0.62	0.00	1.92
2010	0.00	0.96	2.59	10.69	7.73	1.39	25.08	31.70	18.55	1.86	0.04	0.00	8.38
2011	0.00	0.00	0.30	0.01	2.05	4.07	10.66	27.78	26.99	2.83	0.33	0.00	6.25

Appendix Table 2: Katar river runoff gauged at Abura town (m^3/sc)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	1.92	1.72	1.32	2.03	1.98	4.59	24.55	90.35	67.31	14.33	3.25	2.52	17.99
1976	2.16	1.95	1.92	2.54	4.02	2.72	13.46	46.42	26.51	4.65	4.54	3.31	9.52
1977	3.28	3.22	2.59	5.69	5.06	4.92	20.56	50.21	43.07	32.90	24.70	4.10	16.69
1978	2.73	2.98	5.71	2.78	3.59	3.64	34.69	57.95	21.49	17.18	4.48	3.19	13.37
1979	4.48	8.58	4.02	2.58	3.03	3.77	25.83	48.41	20.08	12.55	3.67	2.82	11.65
1980	2.57	2.59	2.33	2.37	2.47	3.89	16.96	38.87	18.67	7.91	2.86	2.46	8.66
1981	2.24	2.20	4.11	21.90	8.08	2.83	12.71	64.24	57.12	33.90	3.60	2.75	17.97
1982	2.72	2.60	2.46	5.41	5.47	3.97	12.48	50.53	20.19	15.39	4.55	4.43	10.85
1983	1.13	1.61	2.33	9.67	16.50	23.80	11.91	99.98	41.71	23.61	3.21	1.97	19.79
1984	1.75	1.49	1.30	1.30	3.15	6.28	17.37	25.52	22.66	3.56	2.37	2.28	7.42
1985	2.00	1.77	1.71	3.26	7.95	3.23	16.76	34.02	28.57	8.35	1.94	1.82	9.28
1986	1.85	2.79	3.41	5.10	5.74	9.90	28.18	51.54	34.52	13.13	3.39	2.51	13.51
1987	1.84	1.81	4.87	18.10	9.79	14.80	10.02	19.34	17.06	7.37	2.37	2.01	9.12
1988	1.85	2.12	2.02	2.30	2.52	2.73	22.99	99.43	34.52	20.32	5.17	2.69	16.56
1989	2.40	2.35	2.33	6.39	5.80	3.93	12.84	25.06	29.16	12.10	3.43	4.01	9.15
1990	1.39	10.90	20.00	21.30	5.30	4.31	11.95	27.67	18.71	3.76	1.06	2.39	10.73
1991	2.16	2.24	3.76	5.39	2.77	3.44	14.05	45.78	36.07	6.14	2.56	2.31	10.56
1992	2.02	2.46	1.76	3.04	3.07	3.23	8.18	65.98	53.99	25.08	4.56	2.83	14.68
1993	2.71	6.55	2.19	5.10	11.50	11.60	16.41	52.83	35.71	20.12	7.17	2.70	14.55
1994	2.14	1.92	1.64	1.56	2.02	4.27	22.93	68.87	49.09	7.02	2.81	2.04	13.86

1995	1.56	1.58	7.94	7.23	5.44	2.54	12.60	48.41	59.32	4.59	2.35	2.11	12.97
1996	2.48	1.69	2.86	3.93	6.74	17.90	21.50	64.12	24.38	8.54	2.44	2.16	13.23
1997	2.91	1.67	1.57	6.00	2.60	2.74	13.57	20.98	11.05	5.58	6.96	2.94	6.55
1998	2.19	3.45	5.01	2.38	5.99	3.66	13.40	69.19	49.60	28.12	6.76	2.36	16.01
1999	1.99	0.43	1.71	1.65	1.69	3.19	17.00	33.86	21.21	44.47	7.45	2.34	11.42
2000	1.58	1.58	1.56	1.49	4.67	2.75	9.73	49.31	28.69	25.27	8.71	2.51	11.49
2001	1.76	1.55	2.17	2.57	7.57	13.80	34.32	80.06	37.86	10.45	2.45	1.79	16.36
2002	1.84	1.90	2.77	2.08	2.80	3.43	7.29	26.57	13.45	3.33	1.48	1.92	5.74
2003	2.44	1.39	1.55	3.93	3.80	2.44	16.62	51.94	28.99	7.50	1.84	1.85	10.36
2004	1.47	1.34	1.35	8.71	3.52	3.32	20.04	38.03	26.83	13.57	2.22	1.41	10.15
2005	1.51	1.39	2.29	2.74	13.90	19.30	35.78	130.20	75.26	12.86	2.62	1.73	24.97
2006	1.64	1.64	2.15	11.56	7.50	4.70	38.20	79.89	41.37	8.34	3.01	1.79	16.82
2007	1.16	1.89	1.01	3.62	3.85	11.76	28.83	67.17	58.43	12.16	2.26	1.09	16.10
2008	1.37	1.58	0.89	2.70	2.46	8.23	33.51	73.53	49.90	10.25	2.64	1.44	15.71
2009	1.32	1.27	0.77	1.78	1.06	9.99	31.17	70.35	54.16	11.21	2.45	1.26	15.57
2010	2.28	5.25	9.22	14.39	39.14	9.11	32.34	71.94	52.03	7.68	2.54	1.35	20.61
Mean	2.08	2.60	3.24	5.68	6.18	6.69	20.02	56.63	36.35	13.98	4.16	2.37	13.33
MCM	5.57	6.28	8.68	14.73	16.56	17.33	53.62	151.67	94.23	37.45	10.79	6.34	35.27

Appendix Table 3: Bulbula river runoff gauged at Karkarsitu (m^3/sc)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1976	3.4	0.91	0.55	0.35	0.31	0.15	0.2	1.54	7.09	5.85	4.38	1.53	2.19
1977	8.66	5.78	6.21	3.4	1.35	0.66	2.29	8.88	14	14.7	11.2	8.13	7.11
1978	8.66	5.78	6.21	3.4	1.35	0.66	2.29	8.88	14	14.7	11.2	8.13	7.11
1979	5.14	4.3	3.69	3.04	1.74	1.56	3.97	12.4	15	15.2	12	8.25	7.19
1980	3.99	2.21	0.9	0.2	0	0.18	0.19	0.84	2.04	2.03	0.92	0.38	1.16
1981	0.21	0.19	0.21	0.2	1.38	0.2	0.22	2.39	12.7	18	13.1	7.81	4.72
1982	3.21	1.77	1	0.62	0.54	0.31	0.26	2.1	6.89	7.99	5.95	4.11	2.90
1983	1.97	1.31	0	1.3	3.14	6.49	7.11	21.2	43.9	6.24	4.06	2.52	8.27
1984	11	6.25	3.17	1.42	0.68	0.56	0.67	2.94	5.64	4.48	2.17	0.92	3.33
1985	0.39	0.32	0.25	0.19	0.18	0.18	0.18	0.32	2.02	2.58	0.99	0.48	0.67
1986	0.25	0.24	0.22	0.22	0.22	0.19	0.23	1.27	4.25	6.24	3.84	1.68	1.57
1987	0.66	0.27	0.23	0.59	0.81	2.44	1.64	2.43	4.2	5.66	3.33	1.95	2.02
1988	1.19	0.87	0.65	0.68	0.64	0.66	0.66	1.5	5.19	14.2	10.8	6.16	3.60
1989	3.36	1.98	1.13	1.46	0.77	0.82	1.03	2.8	6.55	7.01	3.3	1.46	2.64
1990	3.41	0.46	1.39	3.35	2.72	0.79	1.21	10.1	26	23.6	14.5	7.47	7.92
1991	3.46	1.36	0.68	0.27	0.31	0.13	0.41	4.59	19.4	17	11.4	6.78	5.48
1992	3.45	4.08	0.65	0.4	0.14	0.08	0.21	5.66	23.6	25.5	20.4	13.2	8.11
1993	8.48	6.8	3.35	1.99	4.85	7.42	10.3	21.2	27.9	24.7	18.6	12.8	12.37
1994	7.94	5.01	3.32	1.19	0.05	0.04	0.03	3.94	15	18.1	14	10.2	6.57
1995	5.21	2.31	1.5	0.47	1.79	1	1.07	3.8	9.34	11.5	7.97	3.12	4.09
1996	1.84	4.54	0.28	0.32	0.86	2.7	7.19	20.9	35.8	28.8	18.7	12.5	11.20
1997	8.59	6.78	3.76	7.26	5.75	3.16	5.39	9.01	10.1	8.49	7.39	4.71	6.70

1998	2.7	1.48	1.19	0.36	0.44	0.57	0.76	9.14	24.4	31.9	27.8	20.7	10.12
1999	14.7	10.1	7.75	4.39	1.2	0.35	0.74	3.48	7.33	17.2	22.5	15.7	8.79
2000	10.7	5.8	1.66	0.67	0.51	0.23	0.63	1.7	6.2	14	15.1	11.5	5.73
2001	8.43	7.1	3.63	2.87	1.18	0.53	3.99	7.47	25.1	23.8	14.5	12.2	9.23
2002	9.63	6.73	4.01	2.26	1.07	1.12	1.53	1.86	2.7	1.43	1.1	0.98	2.87
2003	0.63	0.28	0.18	0.19	0.27	0.34	0.27	0.73	1.93	1.76	1.13	0.59	0.69
2004	0.19	0.09	0.03	0.05	0.04	0.08	0.1	0.36	1.04	0.99	0.58	0.45	0.33
2005	0.43	0.27	0.2	0.11	0.2	0.21	0.26	1.21	1.89	1.39	0.94	1.19	0.69
2006	1.18	0.41	0.39	1.29	2.24	1.11	0.00	3.65	9.99	13.17	12.57	10.56	4.71
2007	5.78	6.19	4.11	1.71	1.34	1.57	6.25	18.82	32.68	32.03	22.70	14.29	12.29
2008	9.54	7.01	3.76	0.13	0.00	0.70	2.53	8.31	17.84	13.17	12.57	10.19	7.15
2009	10.11	7.01	3.22	4.06	1.61	0.00	0.00	3.65	9.99	13.17	12.57	10.19	6.30
2010	10.11	7.01	3.09	3.19	5.34	0.00	0.00	3.65	9.99	13.17	12.57	10.19	6.52
Mean	5.10	3.51	2.07	1.53	1.29	1.06	1.82	6.08	13.19	13.14	10.20	6.94	5.49
(MCM)	13.67	8.50	5.55	3.97	3.45	2.75	4.88	16.28	34.19	35.18	26.43	18.60	14.45

Appendix Table 4: Katar river runoff gauged at Fite (m^3/sc)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	2.55	2.27	1.75	2.69	2.62	6.09	32.56	119.80	89.26	19.00	4.31	3.34	23.85
1976	2.86	2.59	2.55	3.36	5.33	3.60	17.85	61.56	35.15	6.17	6.02	4.39	12.62
1977	4.35	4.27	3.44	7.54	6.71	6.53	27.26	66.59	57.12	43.60	32.80	5.43	22.14
1978	3.62	3.95	7.57	3.69	4.75	4.82	46.01	76.86	28.50	22.80	5.94	4.23	17.73
1979	5.94	11.40	5.33	3.42	4.01	4.99	34.25	64.20	26.63	16.60	4.87	3.74	15.45
1980	3.41	3.43	3.09	3.14	3.27	5.16	22.49	51.55	24.75	10.50	3.79	3.26	11.49
1981	2.97	2.92	5.45	29.10	10.72	3.75	16.86	85.19	75.75	45.00	4.77	3.65	23.84
1982	3.61	3.44	3.26	7.18	7.26	5.26	16.55	46.74	11.49	3.93	3.25	3.09	9.59
1983	1.49	2.12	3.08	6.54	27.36	41.90	31.61	171.60	36.97	33.40	4.23	2.61	30.24
1984	2.32	1.96	1.72	1.72	2.19	5.56	33.31	21.02	28.10	2.79	1.64	1.64	8.66
1985	1.57	1.41	1.50	2.41	7.40	2.45	50.98	65.23	27.73	5.66	1.72	1.41	14.12
1986	1.27	1.67	2.05	3.43	3.50	2.34	46.27	50.63	41.92	18.80	2.47	1.49	14.65
1987	1.41	1.50	7.77	24.90	17.66	10.90	8.96	34.50	17.62	13.50	1.72	1.64	11.84
1988	1.41	2.45	1.81	2.64	2.35	2.35	42.72	85.42	35.14	56.30	5.73	3.12	20.12
1989	2.50	2.73	2.73	8.61	6.13	4.54	18.88	32.48	43.05	7.86	3.52	4.12	11.43
1990	2.57	24.20	41.01	32.50	8.23	3.74	22.14	51.24	34.64	6.97	1.96	1.64	19.24
1991	1.41	2.81	3.50	4.62	2.27	1.92	15.60	81.28	42.72	3.42	1.41	1.27	13.52
1992	1.67	1.74	1.22	4.21	1.92	1.99	10.47	70.01	38.37	28.20	2.76	1.96	13.71
1993	2.41	5.84	1.70	6.02	14.22	23.40	21.02	88.04	35.04	52.50	5.75	2.13	21.51
1994	1.96	1.71	2.07	2.16	3.75	3.75	30.42	91.34	65.10	9.31	3.72	2.48	18.15
1995	2.32	2.23	2.88	10.60	10.60	4.13	39.50	77.56	80.30	7.08	2.25	2.45	20.16
1996	2.73	0.24	3.57	1.53	11.53	17.00	42.87	178.20	29.41	10.80	0.73	70.50	30.76

1997	1.92	1.09	2.36	5.91	2.96	2.44	16.36	23.69	7.71	4.39	4.71	1.70	6.27
1998	2.22	4.56	5.91	12.20	5.19	3.33	40.40	136.30	76.90	57.20	6.40	1.49	29.34
1999	1.68	3.20	4.22	7.95	3.90	2.38	26.62	100.80	53.11	40.40	4.52	1.39	20.85
2000	1.75	3.37	4.43	8.48	4.07	2.50	28.34	105.20	56.09	42.50	4.75	1.40	21.91
2001	2.33	2.05	2.88	3.41	10.04	18.30	45.52	106.20	50.21	13.90	3.24	2.37	21.70
2002	2.44	2.52	3.67	2.76	3.71	4.55	9.67	35.24	17.83	4.42	1.96	2.55	7.61
2003	3.23	1.84	2.06	5.21	5.03	3.23	22.04	68.88	38.45	9.94	2.44	2.46	13.73
2004	1.95	1.78	1.79	11.60	4.67	4.40	26.57	50.44	35.58	18.00	2.95	1.87	13.47
2005	2.00	1.84	3.04	3.63	18.39	25.60	47.45	172.60	99.81	17.10	3.47	2.30	33.10
2006	0.27	0.58	1.31	4.78	5.09	3.07	36.31	129.33	74.65	17.10	3.47	1.87	23.15
2007	1.03	1.45	0.88	2.50	2.58	8.01	25.18	86.07	49.48	3.10	1.96	2.30	15.38
Mean	2.34	3.37	4.29	7.29	6.95	7.39	28.88	81.39	44.38	19.76	4.40	4.58	17.92
MCM	6.26	8.15	11.49	18.89	18.62	19.16	75.49	210.16	110.88	51.80	10.98	12.07	46.16

Appendix Table 5: Mean monthly gauge height of Lake Zeway

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	0.73	0.62	0.46	0.32	0.22	0.13	0.28	0.78	1.46	1.65	1.45	1.23	0.78
1976	1.07	0.92	0.81	0.72	0.68	0.60	0.65	0.95	1.23	1.16	1.04	0.92	0.89
1977	0.83	0.77	0.63	0.55	0.55	0.51	0.73	1.12	1.48	1.56	1.77	1.68	1.01
1978	1.53	1.37	1.36	1.19	1.01	0.86	1.00	1.40	1.68	1.74	1.55	1.37	1.34
1979	1.24	1.20	1.13	1.16	1.09	1.06	1.18	1.49	1.72	1.66	1.53	1.37	1.32
1980	1.18	1.05	0.91	0.76	0.61	0.52	0.56	0.80	1.00	1.01	0.83	0.65	0.82
1981	0.54	0.43	0.40	0.60	0.64	0.50	0.49	0.99	1.45	1.64	1.42	1.24	0.86
1982	1.11	0.98	0.86	0.79	0.77	0.68	0.67	0.99	1.29	1.38	1.31	1.17	1.00
1983	1.02	0.91	0.81	0.89	0.97	1.21	1.24	1.65	2.17	2.18	1.96	1.69	1.39
1984	1.44	1.31	1.09	0.90	0.80	0.77	0.81	1.14	1.31	1.24	1.04	0.87	1.06
1985	0.72	0.60	0.46	0.36	0.35	0.26	0.27	0.68	1.04	1.07	0.91	0.78	0.62
1986	0.58	0.52	0.48	0.41	0.39	0.36	0.63	0.89	1.12	1.11	1.10	0.99	0.71
1987	0.85	0.72	0.69	0.69	0.78	1.06	1.08	1.16	1.21	1.15	1.00	0.85	0.94
1988	0.66	0.53	0.39	0.25	0.20	0.19	0.28	0.67	1.13	1.40	1.33	1.19	0.68
1989	1.02	0.92	0.81	0.82	0.78	0.70	0.77	0.99	1.26	1.36	1.22	1.05	0.97
1990	0.92	0.88	1.10	1.22	1.19	1.08	1.12	1.46	1.74	1.68	1.48	1.27	1.26
1991	1.12	1.00	0.98	0.93	0.82	0.69	0.79	1.25	1.65	1.57	1.35	1.18	1.11
1992	1.07	0.98	0.88	0.74	0.67	0.66	0.89	1.28	1.71	1.74	1.57	1.41	1.13
1993	1.30	1.21	1.07	0.95	1.05	1.13	1.25	1.60	1.81	1.80	1.65	1.47	1.36
1994	1.30	1.15	0.96	0.84	0.72	0.71	0.82	1.33	1.71	1.76	1.46	1.34	1.17
1995	1.21	1.09	0.95	0.90	1.01	0.93	0.91	1.20	1.47	1.41	1.20	1.06	1.11
1996	0.97	0.83	0.72	0.76	0.89	1.07	1.35	1.84	2.24	2.16	1.89	1.68	1.37

1997	1.53	1.40	1.24	1.24	1.22	1.11	1.20	1.36	1.42	1.34	1.31	1.18	1.30
1998	1.06	0.97	0.93	0.87	0.83	0.79	0.90	1.44	1.97	2.13	2.05	1.78	1.31
1999	1.57	1.37	1.23	1.09	0.96	0.82	0.94	1.23	1.43	1.65	1.81	1.60	1.31
2000	1.41	1.22	1.03	0.82	0.79	0.74	0.80	1.03	1.40	1.59	1.55	1.41	1.15
2001	1.27	1.12	1.03	1.00	0.94	0.97	1.21	1.70	2.25	2.15	1.93	1.75	1.44
2002	1.57	1.41	1.30	1.20	1.08	0.99	0.93	1.03	1.22	1.15	0.97	0.81	1.14
2003	0.69	0.58	0.45	0.87	0.36	0.24	0.37	0.86	1.17	1.19	1.03	0.93	0.73
2004	0.84	0.76	0.57	0.55	0.52	0.40	0.37	0.74	0.95	1.11	1.01	0.90	0.73
2005	0.74	0.60	0.53	0.41	0.56	0.62	0.63	0.99	1.38	1.47	1.33	1.16	0.87
2006	1.02	0.89	0.79	0.92	1.06	1.00	1.17	1.80	2.19	1.90	1.87	1.48	1.34
2007	1.61	1.51	1.34	1.28	1.18	1.28	1.49	1.91	2.32	2.41	2.14	1.87	1.70
2008	1.62	1.45	1.28	1.11	1.02	0.95	1.07	1.47	1.83	1.79	1.80	1.64	1.42
2009	1.51	1.39	1.22	1.13	0.95	0.82	0.77	0.99	1.14	1.16	1.09	0.97	1.10
2010	0.86	0.79	0.84	0.83	0.99	1.13	1.27	1.74	2.25	2.35	2.17	1.98	1.43
2011	1.73	1.59	1.45	1.30	1.15	1.10	1.22	1.47	1.86	1.89	1.71	1.58	1.50
2012	1.44	1.20	1.03	0.94	0.84	0.67	0.80	1.33	1.77	1.85	1.66	1.49	1.25
2013	1.30	1.15	1.00	0.97	1.00	0.89	1.01	1.40	1.81	1.87	1.69	1.53	1.30
Mean	1.13	1.01	0.90	0.85	0.81	0.77	0.87	1.23	1.57	1.60	1.47	1.29	1.13

Appendix Table 6: Mean monthly gauge height of Lake Zeway

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
975	7.83	7.72	7.56	7.42	7.32	7.23	7.38	7.88	8.56	8.75	8.55	8.33	7.88
1976	8.17	8.02	7.91	7.82	7.78	7.70	7.75	8.05	8.33	8.26	8.14	8.02	7.99
1977	7.93	7.87	7.73	7.65	7.65	7.61	7.83	8.22	8.58	8.66	8.87	8.78	8.11
1978	8.63	8.47	8.46	8.29	8.11	7.96	8.10	8.50	8.78	8.84	8.65	8.47	8.44
1979	8.34	8.30	8.23	8.26	8.19	8.16	8.28	8.59	8.82	8.76	8.63	8.47	8.42
1980	8.28	8.15	8.01	7.86	7.71	7.62	7.66	7.90	8.10	8.11	7.93	7.75	7.92
1981	7.64	7.53	7.50	7.70	7.74	7.60	7.59	8.09	8.55	8.74	8.52	8.34	7.96
1982	8.21	8.08	7.96	7.89	7.87	7.78	7.77	8.09	8.39	8.48	8.41	8.27	8.10
1983	8.12	8.01	7.91	7.99	8.07	8.31	8.34	8.75	9.27	9.28	9.06	8.79	8.49
1984	8.54	8.41	8.19	8.00	7.90	7.87	7.91	8.24	8.41	8.34	8.14	7.97	8.16
1985	7.82	7.70	7.56	7.46	7.45	7.36	7.37	7.78	8.14	8.17	8.01	7.88	7.72
1986	7.68	7.62	7.58	7.51	7.49	7.46	7.73	7.99	8.22	8.21	8.20	8.09	7.81
1987	7.95	7.82	7.79	7.79	7.88	8.16	8.18	8.26	8.31	8.25	8.10	7.95	8.04
1988	7.76	7.63	7.49	7.35	7.30	7.29	7.38	7.77	8.23	8.50	8.43	8.29	7.78
1989	8.12	8.02	7.91	7.92	7.88	7.80	7.87	8.09	8.36	8.46	8.32	8.15	8.07
1990	8.02	7.98	8.20	8.32	8.29	8.18	8.22	8.56	8.84	8.78	8.58	8.37	8.36
1991	8.22	8.10	8.08	8.03	7.92	7.79	7.89	8.35	8.75	8.67	8.45	8.28	8.21
1992	8.17	8.08	7.98	7.84	7.77	7.76	7.99	8.38	8.81	8.84	8.67	8.51	8.23
1993	8.40	8.31	8.17	8.05	8.15	8.23	8.35	8.70	8.91	8.90	8.75	8.57	8.46
1994	8.40	8.25	8.06	7.94	7.82	7.81	7.92	8.43	8.81	8.86	8.56	8.44	8.27

1995	8.31	8.19	8.05	8.00	8.11	8.03	8.01	8.30	8.57	8.51	8.30	8.16	8.21
1996	8.07	7.93	7.82	7.86	7.99	8.17	8.45	8.94	9.34	9.26	8.99	8.78	8.47
1997	8.63	8.50	8.34	8.34	8.32	8.21	8.30	8.46	8.52	8.44	8.41	8.28	8.40
1998	8.16	8.07	8.03	7.97	7.93	7.89	8.00	8.54	9.07	9.23	9.15	8.88	8.41
1999	8.67	8.47	8.33	8.19	8.06	7.92	8.04	8.33	8.53	8.75	8.91	8.70	8.41
2000	8.51	8.32	8.13	7.92	7.89	7.84	7.90	8.13	8.50	8.69	8.65	8.51	8.25
2001	8.37	8.22	8.13	8.10	8.04	8.07	8.31	8.80	9.35	9.25	9.03	8.85	8.54
2002	8.67	8.51	8.40	8.30	8.18	8.09	8.03	8.13	8.32	8.25	8.07	7.91	8.24
2003	7.79	7.68	7.55	7.97	7.46	7.34	7.47	7.96	8.27	8.29	8.13	8.03	7.83
2004	7.94	7.86	7.67	7.65	7.62	7.50	7.47	7.84	8.05	8.21	8.11	8.00	7.83
2005	7.84	7.70	7.63	7.51	7.66	7.72	7.73	8.09	8.48	8.57	8.43	8.26	7.97
2006	8.12	7.99	7.89	8.02	8.16	8.10	8.27	8.90	9.29	9.00	8.97	8.58	8.44
2007	8.71	8.61	8.44	8.38	8.28	8.38	8.59	9.01	9.42	9.51	9.24	8.97	8.80
2008	8.72	8.55	8.38	8.21	8.12	8.05	8.17	8.57	8.93	8.89	8.90	8.74	8.52
2009	8.61	8.49	8.32	8.23	8.05	7.92	7.87	8.09	8.24	8.26	8.19	8.07	8.20
2010	7.96	7.89	7.94	7.93	8.09	8.23	8.37	8.84	9.35	9.45	9.27	9.08	8.53
2011	8.83	8.69	8.55	8.40	8.25	8.20	8.32	8.57	8.96	8.99	8.81	8.68	8.60
2012	8.54	8.30	8.13	8.04	7.94	7.77	7.90	8.43	8.87	8.95	8.76	8.59	8.35
2013	8.40	8.25	8.10	8.07	8.10	7.99	8.11	8.50	8.91	8.97	8.79	8.63	8.40
Mean	8.23	8.11	8.00	7.95	7.91	7.87	7.97	8.33	8.67	8.70	8.57	8.39	8.23

Appendix Table 7: Area of the Lake Zeway with bathymetry best fit equation (Km^2)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	431.80	428.00	422.00	416.80	412.50	408.90	415.26	433.66	462.50	473.95	461.82	450.80	434.83
1976	444.30	438.00	434.80	431.40	430.10	427.10	428.93	439.65	451.10	447.83	443.26	438.44	437.91
1977	435.50	433.00	428.30	425.50	425.30	424.00	431.68	446.43	463.30	468.57	483.46	476.45	445.12
1978	466.50	457.00	456.90	449.20	441.80	436.50	441.62	459.02	476.70	481.29	467.82	457.37	457.64
1979	451.40	450.00	446.50	447.90	445.10	443.80	448.67	464.03	479.30	475.01	466.16	457.37	456.27
1980	448.50	443.00	438.30	433.00	427.70	424.30	425.65	434.43	441.40	442.04	435.21	429.18	435.23
1981	425.00	421.00	419.70	427.20	428.50	423.60	423.32	441.09	461.90	473.26	460.08	451.29	438.00
1982	445.90	441.00	436.60	433.80	433.40	430.20	429.60	441.28	453.90	458.14	454.76	448.42	442.25
1983	442.40	438.00	434.70	437.50	440.60	450.10	451.15	474.23	525.20	526.23	500.31	477.25	466.47
1984	461.50	455.00	445.20	437.80	434.40	433.20	434.64	447.04	454.50	451.33	442.95	436.89	444.54
1985	431.50	427.00	422.00	418.20	418.10	414.40	414.69	430.10	443.10	444.08	438.33	433.62	427.93
1986	426.50	424.00	423.10	420.20	419.40	418.40	428.40	437.46	446.40	445.72	445.42	441.02	431.34
1987	436.00	432.00	430.40	430.30	433.70	443.70	444.78	448.00	450.00	447.42	441.54	435.92	439.48
1988	429.20	425.00	419.40	413.70	411.90	411.30	415.18	429.82	446.80	458.91	455.68	449.14	430.50
1989	442.30	439.00	434.80	434.90	433.50	430.80	433.13	441.09	452.20	457.12	450.40	443.38	441.05
1990	438.70	437.00	445.30	450.30	449.30	444.60	446.07	462.38	481.10	476.08	463.63	452.55	453.92
1991	446.40	442.00	440.80	439.10	434.90	430.60	433.97	451.65	474.50	469.21	456.57	448.55	447.35
1992	444.40	441.00	437.00	432.10	429.90	429.50	437.68	453.25	478.40	481.29	468.70	459.81	449.42
1993	454.00	450.00	444.30	439.80	443.40	446.60	451.74	470.90	486.30	485.53	474.23	462.88	459.14
1994	453.90	447.00	440.10	435.60	431.50	431.00	434.93	455.53	479.00	482.89	462.55	456.12	450.84
1995	450.10	445.00	439.90	437.80	441.80	438.80	438.40	449.66	462.70	459.49	449.70	444.00	446.45
1996	440.40	435.00	431.40	432.80	437.50	444.20	456.77	489.60	535.60	524.76	493.44	476.45	466.49
1997	466.20	459.00	451.50	451.20	450.60	445.70	449.79	457.07	460.30	456.02	454.52	448.80	454.23
1998	444.00	440.00	438.90	436.70	435.30	434.10	437.75	461.49	501.70	520.60	510.07	484.03	462.05
1999	468.60	458.00	450.70	445.20	440.00	435.20	439.21	451.11	460.70	474.02	486.29	470.96	456.67
2000	459.40	451.00	442.80	435.00	434.00	432.10	434.40	442.53	459.00	469.92	467.69	459.65	448.96
2001	452.90	446.00	442.70	441.60	439.40	440.60	450.09	477.62	536.80	523.44	497.49	481.53	469.18

2002	468.80	460.00	453.90	449.60	444.80	441.00	438.84	442.72	450.70	447.54	440.53	434.50	447.74
2003	430.30	427.00	421.80	436.90	418.30	413.30	418.90	436.39	448.30	449.36	442.80	438.80	431.85
2004	435.80	433.00	426.10	425.30	424.50	419.80	418.87	432.32	439.80	445.70	442.00	437.79	431.75
2005	432.30	427.00	424.70	420.40	425.80	428.00	428.47	441.36	458.20	463.05	455.43	447.79	437.71
2006	448.878	440.674	469.568	474.104	479.977	477.12	485.659	567.921	700.5346	592.414	584.332	512.055	519.44
2007	465.456	454.347	442.398	439.032	435.573	439.162	452.908	519.377	673.2397	721.788	588.165	510.144	511.80
2008	466.572	449.592	439.118	433.775	432.172	431.305	432.912	450.871	499.5872	492.34	494.624	468.36	457.60
2009	453.981	445.258	436.756	434.14	431.252	430.178	429.874	431.795	434.4811	435.115	433.373	431.545	435.65
2010	430.495	429.991	430.339	430.254	431.68	434.332	438.651	483.47	635.2167	684.48	599.869	536.524	497.11
2011	482.144	462.953	449.515	440.017	434.79	433.623	436.722	450.627	506.7924	512.672	479.411	461.027	462.52
2012	448.226	436.159	432.277	431.199	430.31	429.203	430.056	441.753	488.1315	505.482	471.166	452.471	449.70
2013	440.347	434.711	431.875	431.498	431.808	430.683	431.992	445.714	496.9719	509.015	475.146	456.487	451.35

Appendix Table 8: Volume of the Lake Zeway with bathymetry best fit equation (MCM)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1975	1499.00	1450.00	1375.00	1314.00	1267.00	1230.00	1296.50	1523.30	1843.00	1929.30	1837.10	1731.80	1524.67
1976	1658.00	1586.00	1539.00	1494.00	1476.00	1438.00	1461.60	1600.90	1735.00	1699.30	1645.80	1585.50	1576.59
1977	1547.00	1517.00	1453.00	1418.00	1415.00	1399.00	1497.40	1683.30	1850.00	1891.00	1988.90	1945.90	1633.79
1978	1875.00	1798.00	1793.00	1715.00	1628.00	1561.00	1625.60	1812.50	1947.00	1976.10	1885.30	1797.40	1784.49
1979	1738.00	1720.00	1684.00	1700.00	1668.00	1652.00	1708.70	1855.50	1964.00	1936.40	1872.50	1797.40	1774.71
1980	1707.00	1647.00	1583.00	1514.00	1446.00	1402.00	1419.50	1533.50	1623.00	1630.80	1543.70	1464.80	1542.86
1981	1412.00	1364.00	1347.00	1440.00	1456.00	1394.00	1390.40	1619.10	1838.00	1924.60	1821.90	1737.00	1562.00
1982	1677.00	1614.00	1561.00	1526.00	1520.00	1478.00	1470.30	1621.40	1763.00	1804.50	1772.30	1705.90	1626.12
1983	1635.00	1583.00	1537.00	1573.00	1613.00	1724.00	1735.50	1931.20	2175.00	2178.60	2075.60	1951.10	1809.33
1984	1834.00	1772.00	1669.00	1578.00	1533.00	1518.00	1536.20	1690.40	1770.00	1737.40	1642.00	1565.50	1653.79
1985	1495.00	1440.00	1375.00	1329.00	1328.00	1288.00	1290.20	1476.70	1643.00	1655.60	1584.10	1522.80	1452.28
1986	1431.00	1404.00	1387.00	1352.00	1343.00	1332.00	1454.70	1572.90	1683.00	1675.10	1671.60	1618.20	1493.71
1987	1553.00	1497.00	1480.00	1480.00	1524.00	1651.00	1664.10	1701.20	1723.00	1694.60	1624.70	1552.90	1595.46
1988	1465.00	1409.00	1343.00	1280.00	1261.00	1254.00	1295.60	1473.00	1688.00	1811.50	1781.30	1713.90	1481.28
1989	1634.00	1589.00	1538.00	1540.00	1521.00	1486.00	1516.40	1619.10	1746.00	1795.00	1727.50	1647.20	1613.27
1990	1589.00	1567.00	1670.00	1727.00	1716.00	1662.00	1679.10	1841.80	1975.00	1943.50	1852.20	1750.20	1747.73
1991	1683.00	1626.00	1615.00	1594.00	1539.00	1483.00	1527.50	1740.70	1933.00	1895.70	1789.80	1707.30	1677.83
1992	1659.00	1617.00	1567.00	1503.00	1473.00	1468.00	1575.70	1757.20	1958.00	1976.10	1891.90	1819.60	1688.79
1993	1765.00	1726.00	1658.00	1603.00	1648.00	1685.00	1741.70	1908.00	2005.00	2000.70	1931.20	1846.10	1793.14
1994	1764.00	1695.00	1606.00	1548.00	1495.00	1489.00	1540.00	1779.90	1962.00	1985.50	1843.20	1785.60	1707.77
1995	1724.00	1667.00	1604.00	1577.00	1628.00	1591.00	1585.00	1719.50	1845.00	1816.70	1720.00	1654.70	1677.66
1996	1611.00	1546.00	1494.00	1512.00	1574.00	1657.00	1791.70	2022.80	2210.00	2173.50	2042.60	1945.90	1798.38
1997	1873.00	1812.00	1739.00	1736.00	1730.00	1675.00	1720.90	1794.50	1824.00	1784.60	1770.00	1710.10	1764.09
1998	1655.00	1609.00	1592.00	1564.00	1545.00	1529.00	1576.70	1834.20	2082.00	2158.50	2117.80	1992.20	1771.28
1999	1891.00	1799.00	1731.00	1669.00	1606.00	1543.00	1595.30	1735.10	1828.00	1929.80	2004.90	1908.50	1770.05
2000	1816.00	1730.00	1640.00	1540.00	1527.00	1503.00	1533.00	1636.90	1812.00	1900.90	1884.40	1818.20	1695.12
2001	1754.00	1683.00	1639.00	1625.00	1597.00	1613.00	1724.20	1953.40	2214.00	2168.80	2062.40	1977.50	1834.28

2002	1893.00	1819.00	1764.00	1719.00	1665.00	1618.00	1590.60	1639.20	1730.00	1696.00	1612.10	1534.40	1690.03
2003	1479.00	1432.00	1372.00	1566.00	1331.00	1276.00	1337.60	1559.00	1705.00	1716.20	1640.20	1590.20	1500.35
2004	1552.00	1512.00	1425.00	1415.00	1405.00	1348.00	1337.20	1505.70	1602.00	1674.90	1630.30	1577.10	1498.68
2005	1505.00	1442.00	1408.00	1355.00	1422.00	1450.00	1455.60	1622.40	1805.00	1847.50	1778.90	1698.80	1565.85
2006	1229.01	1169.17	1121.407	1183.43	1249.26	1219.35	1298.84	1576.84	1724.69	1615.27	1603.47	1437.76	1369.04
2007	1496.65	1451.24	1377.567	1346.31	1302.51	1347.67	1444.18	1621.22	1768.78	1795.08	1704.99	1605.68	1521.82
2008	1500.54	1426.44	1347.217	1270.4	1229.93	1198.63	1250.64	1433.55	1585.85	1570.66	1575.61	1506.57	1408.00
2009	1449.48	1399.17	1319.424	1277.75	1196.32	1137.46	1116.37	1217.5	1284.18	1295.18	1261.67	1208.29	1263.57
2010	1157.67	1124.62	1148.023	1142.51	1213.36	1281.42	1342.21	1549.87	1743.73	1775.37	1715.62	1646.61	1403.42
2011	1546.51	1487.56	1425.991	1356.3	1289.68	1267.19	1318.97	1432.21	1599.65	1610.09	1539.36	1480.17	1446.14
2012	1418.42	1311.2	1233.156	1194.02	1146.19	1070.24	1129.2	1372.15	1561.13	1597.22	1515.57	1441.97	1332.54
2013	1359.47	1288.3	1220.266	1206.45	1217.96	1168.48	1224.18	1402.31	1580.53	1603.67	1527.51	1461.14	1355.02

Appendix Table 9: Katar river sub-basin means monthly point rainfall (mm)

Months	Asella	Kulumsa	Arata	Ogelcho	Merero	Bokoji	Kersa	Digalu	Sagure	Average
Jan	15.55	16.68	15.07	10.65	19.10	30.50	25.70	29.20	13.50	19.55
Feb	36.56	40.18	24.66	30.97	37.56	42.37	40.70	39.11	28.31	35.60
Mar	89.49	74.68	59.14	65.91	65.46	88.41	73.60	75.23	61.23	72.57
Apr	109.97	87.22	71.56	67.77	73.47	107.00	103.90	97.58	78.92	88.60
May	110.19	92.48	67.70	66.24	50.80	99.12	90.25	84.11	83.95	82.76
Jun	118.55	88.48	87.33	78.43	76.79	112.90	84.01	104.00	97.18	94.18
Jul	188.93	126.06	145.79	162.83	145.13	178.84	118.26	177.41	154.09	155.26
Aug	194.06	132.82	120.48	109.33	168.08	193.85	125.47	178.57	143.82	151.83
Sep	152.31	107.92	106.06	102.45	75.76	89.18	107.80	96.83	73.20	101.28
Oct	60.24	45.42	42.97	35.84	43.50	57.40	56.30	52.10	39.80	48.17
Nov	17.20	11.07	11.50	10.38	15.70	17.40	17.70	13.70	8.80	13.72
Dec	14.39	10.87	3.77	3.73	17.97	13.89	12.78	11.78	6.41	10.62
Annual	1107.43	833.89	756.04	744.52	789.32	1030.86	856.47	959.62	789.21	874.15

Appendix Table 10: Zeway Lake mean monthly point rainfall (mm)

Months	Ogelcho	Zeway	A/Tulu	Meki
Jan	10.65	13.47	14.22	5.81
Feb	30.97	29.99	28.45	33.14
Mar	65.91	50.22	47.46	55.34
Apr	67.77	75.35	82.62	65.81
May	66.24	79.10	90.00	67.92
Jun	78.43	83.60	104.20	74.39
Jul	162.83	168.39	189.49	163.01
Aug	109.33	115.11	148.36	138.13
Sep	102.45	77.37	83.80	80.77
Oct	35.84	34.70	37.67	23.21
Nov	10.38	5.99	7.85	5.81
Dec	3.73	4.41	7.40	3.51
Annual	744.52	737.72	841.51	716.86

Appendix Table 11: Katar river sub-basin mean monthly point rainfall(mm)

Months	Katar.Ge	Butajira	Bui	Tora	Koshe	Ejersalale	Meki	Average
Jan	11.20	44.60	27.60	24.90	23.00	15.40	5.81	21.79
Feb	30.32	65.57	51.62	47.50	48.42	31.42	33.14	44.00
Mar	58.57	124.30	90.92	78.20	80.22	57.77	55.34	77.90
Apr	71.94	136.60	90.34	126.70	98.06	71.10	65.81	94.36
May	92.87	111.31	87.15	91.94	90.97	64.36	67.92	86.65
Jun	92.60	119.80	123.00	92.48	94.21	81.01	74.39	96.78
Jul	140.05	186.18	202.89	129.35	163.85	188.53	163.01	167.69
Aug	126.37	168.54	178.81	126.57	165.04	160.13	138.13	151.94
Sep	100.80	120.40	92.58	111.70	104.50	85.39	80.77	99.45
Oct	38.50	53.90	40.30	51.10	47.40	32.30	23.21	40.96
Nov	6.23	13.60	11.50	8.27	5.46	4.99	5.81	7.98
Dec	4.66	13.96	10.47	6.01	7.72	6.29	3.51	7.52
Average	64.51	96.56	83.93	74.56	77.40	66.56	59.74	74.75

Appendix Table 12: Zeway basins mean monthly areal rainfall (mm)

Months	Katar Sub-basin	Meki Sub-basin	Zeway Lake	Average
Jan	19.55	21.79	11.04	17.46
Feb	35.60	44.00	30.64	36.75
Mar	72.57	77.90	54.74	68.40
Apr	88.60	94.36	72.89	85.28
May	82.76	86.65	75.81	81.74
Jun	94.18	96.78	85.15	92.04
Jul	155.26	167.69	170.93	164.63
Aug	151.83	151.94	127.73	143.84
Sep	101.28	99.45	86.10	95.61
Oct	48.17	40.96	32.86	40.66
Nov	13.72	7.98	7.51	9.73
Dec	10.62	7.52	4.76	7.63
Annual(mm)	874.15	897.03	760.15	843.78

Appendix Table 13: Zeway basin stations non dimensional values for homogeneity test (mm)

Months	Ziway	Meki	Adami Tulu	Ogolcho	Arata	Asala	Kulumsa
Jan	0.22	0.10	0.20	0.17	0.24	0.17	0.24
Feb	0.49	0.55	0.41	0.50	0.39	0.40	0.58
Mar	0.82	0.93	0.68	1.06	0.94	0.97	1.07
Apr	1.23	1.10	1.18	1.09	1.14	1.19	1.26
May	1.29	1.14	1.28	1.07	1.07	1.19	1.33
Jun	1.36	1.25	1.49	1.26	1.39	1.28	1.27
Jul	2.74	2.73	2.70	2.62	2.31	2.05	1.81
Aug	1.87	2.31	2.12	1.76	1.91	2.10	1.91
Sep	1.26	1.35	1.20	1.65	1.68	1.65	1.55
Oct	0.56	0.39	0.54	0.58	0.68	0.65	0.65
Nov	0.10	0.10	0.11	0.17	0.18	0.19	0.16
Dec	0.07	0.06	0.11	0.06	0.06	0.16	0.16

Appendix Table 14: Meki river sub-basin non dimensional values for homogeneity test(mm)

Months	Katar.Ge	Butajira	Bui	Tora	Koshe	Ejersalale	Meki
Jan	0.17	0.46	0.33	0.33	0.30	0.23	0.10
Feb	0.47	0.68	0.62	0.64	0.63	0.47	0.55
Mar	0.91	1.29	1.08	1.05	1.04	0.87	0.93
Apr	1.12	1.41	1.08	1.70	1.27	1.07	1.10
May	1.44	1.15	1.04	1.23	1.18	0.97	1.14
Jun	1.44	1.24	1.47	1.24	1.22	1.22	1.25
Jul	2.17	1.93	2.42	1.73	2.12	2.83	2.73
Aug	1.96	1.75	2.13	1.70	2.13	2.41	2.31
Sep	1.56	1.25	1.10	1.50	1.35	1.28	1.35
Oct	0.60	0.56	0.48	0.69	0.61	0.49	0.39
Nov	0.10	0.14	0.14	0.11	0.07	0.07	0.10
Dec	0.07	0.14	0.12	0.08	0.10	0.09	0.06

Appendix Table 15: Mean monthly evaporation from Zeway Lake surface (mm)

Months	A	H_n	E_a	Υ	E_t (mm/month)	E_t (Mm^3/month)
Jan	1.05	5.14	3.18	0.05	156.49	73.39
Feb	1.24	5.83	4.09	0.05	167.00	78.32
Mar	1.24	6.10	4.18	0.05	186.70	87.56
Apr	1.24	6.34	3.76	0.05	187.20	87.80
May	1.24	6.21	3.61	0.05	183.38	86.00
Jun	1.24	6.12	3.30	0.05	180.29	84.55
Jul	1.05	5.65	2.00	0.05	169.90	79.68
Aug	1.05	5.87	2.25	0.05	176.98	83.00
Sep	1.05	5.64	2.54	0.05	165.06	77.41
Oct	1.05	5.52	3.48	0.05	168.19	78.88
Nov	1.05	5.13	3.46	0.05	151.65	71.12
Dec	0.95	3.14	2.88	0.05	97.07	45.52
Annual					1989.90	933.26

Appendix Table 16: Mean monthly metrological data for evaporation calculation

month	Mean T	humid	wind	sun	rf	Hc	r	α	b	n	N	σ
Jan	19.7	0.49	2	9.6	13.47	12.8	0.05	0.29	0.52	9.6	11.6	2E-09
Feb	20.9	0.43	2	9.5	29.99	13.9	0.05	0.29	0.52	9.5	11.8	2E-09
Mar	22.1	0.42	1	8.9	50.22	14.8	0.05	0.29	0.52	8.9	12.1	2E-09
Apr	22.3	0.48	1	8.5	75.35	15.2	0.05	0.29	0.52	8.5	12.4	2E-09
May	22.6	0.50	2	8.4	79.10	15	0.05	0.29	0.52	8.4	12.6	2E-09
Jun	21.7	0.54	2	8.0	83.60	14.8	0.05	0.29	0.52	8.0	12.7	2E-09
Jul	20.2	0.68	2	6.0	168.39	14.8	0.05	0.29	0.52	6.0	12.6	2E-09
Aug	20.3	0.64	2	6.5	115.11	15	0.05	0.29	0.52	6.5	12.4	2E-09
Sep	20.5	0.59	1	6.5	77.37	14.9	0.05	0.29	0.52	6.5	12.9	2E-09
Oct	20.3	0.44	1	8.6	34.70	14.1	0.05	0.29	0.52	8.6	11.9	2E-09
Nov	19.6	0.44	2	9.4	5.99	13.1	0.05	0.29	0.52	9.4	11.7	2E-09
Dec	18.9	0.46	2	10.0	4.41	10.3	0.05	0.29	0.52	10.0	11.5	2E-09

Appendix Table 17: Mean monthly metrological data for evaporation calculation

T	es	ϒ	A	Hc(1-r)	(α+b*n/N)	σ*T^4(0.56-0.092*ea^0.5)*(0.1+0.9*n/N)	Hn	ea =RH*es)	Ea =0.35(1+V2/160)(es-ea)	Et/Cu = (A*Hn+Ea*ϒ)/(A+ϒ) (mm/day)	No of days/Month	Et/CU (mm/month)
292.7	17.54	0.05	1.05	12.16	0.72	3.64	5.14	8.54	3.18	5.05	31	156.48698
293.9	20.44	0.05	1.24	13.21	0.71	3.55	5.83	8.86	4.09	5.76	29	167.00388
295.1	20.44	0.05	1.24	14.06	0.67	3.38	6.10	8.61	4.18	6.02	31	186.70153
295.3	20.44	0.05	1.24	14.44	0.64	2.97	6.34	9.79	3.76	6.24	30	187.19915
295.6	20.44	0.05	1.24	14.25	0.64	2.85	6.21	10.24	3.61	6.11	30	183.37848
294.7	20.44	0.05	1.24	14.06	0.62	2.55	6.12	11.14	3.30	6.01	30	180.28583
293.2	17.54	0.05	1.05	14.06	0.54	1.90	5.65	11.88	2.00	5.48	31	169.898
293.3	17.54	0.05	1.05	14.25	0.56	2.15	5.87	11.19	2.25	5.71	31	176.97523
293.5	17.54	0.05	1.05	14.16	0.55	2.19	5.64	10.33	2.54	5.50	30	165.06143
293.3	17.54	0.05	1.05	13.4	0.67	3.40	5.52	7.69	3.48	5.43	31	168.19354
292.6	17.54	0.05	1.05	12.45	0.71	3.70	5.13	7.76	3.46	5.05	30	151.6494
291.9	15	0.05	0.95	9.785	0.74	4.10	3.14	6.85	2.88	3.13	31	97.067053
												1,989.90

Appendix Table 18: Monthly pitche evaporation from Zeway gauging station(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	148.5	172	167.9	125	172	148.3	104.1	96.9	102.9	234.4	219.7	182	1872.5
1996	147.5	229	174.9	154	122.5	84.8	92.9	77	81.7	195.2	179.1	197	1735.2
1997	144.9	229	203.8	139	174.5	126.7	100.4	103.1	136.7	159.8	141.5	181	1841
1998	143.5	152	180.8	208	167.9	167.6	102.5	73.4	83.5	116.4	215.2	212	1822.8
1999	211.1	256	68.4	199	210.6	187.1	116.5	115.9	126.3	93.1	182.4	184	1949.9
2000	200.1	243	269.2	190	162	190.6	120.5	107.6	107.8	131.5	137.1	143	2002.5
2001	163	136	128.5	208	165.7	164.9	142	129.9	117	190.4	239.6	213	1997.7
2002	169.1	194	164	221	190	204.8	179.4	146.6	161.3	264.3	218.8	184	2297.3
2003	203	238	245.7	197	241.2	182.9	120.1	119.9	125.6	234.3	215.4	196	2318.5
2004	160.3	217	242.9	143	249.9	187.5	136.9	131.8	120	195.5	209	193	2187.1
2005	181	228	189.8	213	124.8	162.2	139.7	145.1	138.3	213.3	222.6	230	2187.2
Mean	170.2	209	185.1	181	180.1	164.3	123.2	113.4	118.3	184.4	198.2	192	2019.2

Appendix Table 19: Mean monthly max. temperature of Zeway stations

Staion	Years Of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Ziway	1982-2018	26.97	28.11	29.22	28.99	29.14	27.92	25.38	25.55	26.57	27.51	27.21	26.53	27.42
Asella	1974-2014	21.77	22.68	23.13	22.87	22.86	21.58	19.74	19.57	19.82	21.00	21.17	21.14	21.44
Kulumsa	1918-2014	23.13	24.34	25.11	24.74	24.71	23.49	21.29	20.93	21.49	22.57	22.82	22.39	23.08
Butajira	1972-2006	25.7	26.1	26.4	26.1	26	25.2	23.7	23.9	25.1	25.6	25.8	25.6	25.43
Sagure	1981-2006	23.4	23.9	24.3	22.8	22.8	21.3	19.5	19.4	20.5	21.9	22.8	22.9	22.13
Merero	1983-2006	18.7	19.2	19.1	18	18.6	18.4	16.3	16.3	16.7	16.4	17.4	18	17.76
Bui	1990-2005	25.5	26.4	27	26.6	27.3	25.9	23.3	23.3	24.6	25	25.3	25.2	25.45
Mean		23.60	24.39	24.89	24.30	24.49	23.40	21.32	21.28	22.11	22.86	23.21	23.11	23.25

Appendix Table 20: Mean monthly max. temperature of Zeway stations

Staion	Years Of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Ziway	1982-2018	12.41	13.69	14.96	15.68	16.09	15.55	15.02	14.97	14.43	13.01	12.04	11.36	14.10
Asella	1974-2014	7.21	8.14	9.59	10.41	10.45	10.31	10.29	10.33	9.76	9.26	7.36	6.52	9.14
Kulumsa	1982-2018	8. 08	9.27	10.35	11.42	11.13	10.56	10.64	10.51	10.08	10.31	8.80	7.93	9.92
Butajira	1972-2006	10.80	11.20	12.10	12.50	12.20	11.80	11.80	11.80	11.80	11.40	10.90	10.30	11.55
Sagure	1981-2006	5.04	6.73	7.76	9.18	8.64	8.49	9.09	8.63	8.15	6.59	4.41	4.39	7.26
Merero	1983-2006	4.54	5.28	6.24	7.53	6.88	6.27	6.82	6.81	6.24	5.91	4.92	4.93	6.03
Bui	1990-205	7.92	8.63	10.00	10.80	10.50	9.53	9.49	9.73	9.37	8.08	6.56	6.83	8.95
Mean		8.00	8.99	10.14	11.07	10.84	10.36	10.45	10.40	9.98	9.22	7.86	7.47	9.56

Appendix Table 21: Monthly average temperature of 7 stations

Staion	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
Ziway	1982-2018	19.69	20.90	22.09	22.33	22.61	21.74	20.20	20.26	20.50	20.26	19.62	18.94	20.76
Asella	1974-2014	14.49	15.41	16.36	16.64	16.66	15.95	15.01	14.95	14.79	15.13	14.27	13.83	15.29
Kulumsa	1982-2018	15.61	16.80	17.73	18.08	17.92	17.02	15.97	15.72	15.78	16.44	15.81	15.16	16.50
Butajira	1972-2006	18.25	18.65	19.25	19.30	19.10	18.50	17.75	17.85	18.45	18.50	18.35	17.95	18.49
Sagure	1981-2006	14.22	15.32	16.03	15.99	15.72	14.90	14.30	14.02	14.33	14.25	13.61	13.65	14.69
Merero	1983-2006	11.62	12.24	12.67	12.77	12.74	12.34	11.56	11.56	11.47	11.16	11.16	11.47	11.89
Bui	1990-2005	16.71	17.52	18.50	18.70	18.90	17.72	16.40	16.52	16.99	16.54	15.93	16.02	17.20
Mean		15.80	16.69	17.52	17.69	17.66	16.88	15.88	15.84	16.04	16.04	15.54	15.29	16.41

Appendix Table 22: Mean annual relative humidity of Zeway stations (%)

Years	Ziway	Bui	Kulumsa	Merero
1991	62.42	83.56	61.89	68.94
1992	87.31	83.11	65.97	67.75
1993	77.24	79.75	67.50	71.06
1994	64.67	58.21	62.15	65.07
1995	61.19	57.43	64.86	67.91
1996	65.64	62.19	67.36	70.53
1997	63.03	61.96	67.78	70.96
1998	63.28	61.17	68.00	71.20
1999	58.86	56.90	61.44	64.33
2000	54.31	58.94	61.36	64.25
2001	61.83	61.90	65.61	69.86
2002	60.53	59.09	61.22	68.53
2003	59.36	59.15	63.28	68.36
2004	59.08	60.53	62.76	59.56
2005	57.86	59.31	61.89	68.94
2006	51.48	58.21	65.97	67.75
2007	51.66	57.43	67.50	71.06
2008	50.66	62.19	62.15	65.07
2009	50.27	61.96	64.86	67.91
2010	52.90	61.17	67.36	70.53
2011	49.09	56.90	67.78	70.96
2012	50.78	58.94	68.00	71.20
2013	52.26	61.90	61.44	64.33
2014	51.16	59.09	61.36	64.25
2015	45.06	59.15	65.61	69.86
2016	52.14	60.53	61.22	68.53
2017	52.21	59.31	63.28	68.36
2018	53.61	59.31	62.76	59.56
Mean	57.85	62.12	64.37	67.74
Elevation	1640	2020	2200	2940

Appendix Table 23: Mean annual wind speed of Zeway stations (m/s)

Years	Ziway	Bui	Kulumsa	Merero	Average
1991	1.950	2.125	2.683	2.908	2.417
1992	1.910	1.983	2.442	2.800	2.283
1993	1.890	1.883	2.275	2.708	2.190
1994	2.060	1.783	2.750	2.506	2.274
1995	1.930	1.875	2.458	2.634	2.223
1996	1.800	1.950	2.258	2.740	2.187
1997	1.840	1.936	2.292	2.720	2.197
1998	1.840	1.774	2.100	2.493	2.052
1999	1.910	1.809	2.142	2.542	2.100
2000	1.880	1.892	2.142	2.342	2.065
2001	1.730	1.717	1.875	2.143	1.867
2002	1.950	1.817	1.883	2.167	1.954
2003	1.780	2.558	2.892	2.142	2.344
2004	1.780	1.633	1.829	1.926	1.793
2005	1.740	1.517		2.131	1.347
Mean	1.870	1.884	2.287	2.460	
Elevation	1640	2020	2200	2940	

Appendix Table 24: Mean monthly sun shine hour huration of Zeway stations (hours)

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2003	9.34	9.90	8.68	7.41	9.87	7.71	4.87	5.41	6.60	10.15	9.77	9.29	8.25
2004	8.58	9.52	8.57	10.66	9.78	7.75	6.55	6.84	6.86	8.82	10.17	10.07	8.68
2005	9.55	10.24	9.09	8.46	7.24	7.87	5.80	7.75	7.19	9.24	9.48	10.64	8.55
2006	9.75	9.39	7.89	7.95	8.93	8.00	5.94	5.18	5.90	8.61	10.29	9.15	8.08
2007	8.99	8.96	9.56	8.43	8.95	7.54	5.98	5.33	6.66	9.52	9.88	10.61	8.37
2008	9.90	9.91	10.00	8.69	7.45	8.30	5.48	5.52	6.32	8.69	9.62	10.25	8.34
2009	9.12	9.86	9.34	8.33	9.42	8.79	7.26	6.86	7.78	8.80	10.38	7.62	8.63
2010	9.45	6.53	8.31	7.65	7.58	7.88	5.59	7.11	6.00	10.02	10.25	9.53	7.99
2011	9.95	10.19	9.01	9.04	7.95	7.65	6.45	7.11	6.08	10.01	8.72	10.77	8.58
2012	10.52	10.35	9.15	7.36	8.81	7.65	4.71	5.36	6.20	9.31	8.72	10.15	8.19
2013	9.93	10.18	8.26	8.64	8.05	7.89	4.78	5.54	6.73	8.08	8.72	10.67	8.12
2014	9.90	9.00	8.80	9.11	7.98	8.93	6.22	6.26	6.07	8.08	8.72	10.67	8.31
2015	10.36	9.96	9.11	9.26	7.66	7.23	8.45	7.76	7.38	8.65	9.43	9.32	8.71
2016	8.51	9.56	8.97	6.70	8.27	7.48	6.35	7.76	6.85	9.89	8.69	10.34	8.28
2017	10.62	9.38	9.38	9.28	7.84	9.07	5.32	7.76	5.46	1.24	8.69	10.34	7.86
Mean	9.63	9.53	8.94	8.46	8.38	7.98	5.98	6.50	6.54	8.61	9.44	9.96	8.33

Appendix Table 25: Area of Lake Zeway using curve fit equation (km^2)

Elevation	Water level(m)	Lake Area(Km2) IN 1976	Lake Area(km^2) IN 2005/2006
1628	0	8.04	-0.60
1629	1	-9.37	6.06
1630	2	9.05	7.54
1631	3	58.13	5.54
1632	4	130.93	51.33
1633	5	218.73	165.27
1634	6	311.05	308.62
1635	7	395.60	407.78
1636	8	458.34	430.79
1637	9	483.46	516.21

Appendix Table 26: Abijata Lake level (m)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1989	2.12	2.06	2.075	2.079	2.022	2.21	2.331	2.269	2.28	2.418	2.44	2.451	2.23
1990	2.4	2.373	2.388	2.359	2.312	2.29	2.244	2.27	2.4	2.877	3.13	3.119	2.513
1991	2.97	2.95	2.996	2.98	2.76	2.61	2.596	2.649	2.66	2.898	2.96	2.871	2.825
1992	2.84	2.917	2.677	2.443	2.43	2.38	2.476	2.556	2.66	3.065	3.3	3.58	2.777
1993	3.6	3.595	3.543	3.437	3.435	3.5	3.519	3.621	3.82	4.197	4.39	4.364	3.752
1994	4.3	4.303	4.114	3.217	3.128	2.94	2.901	2.964	3.22	3.444	3.47	3.484	3.457
1995	3.45	3.454	3.4	3.438	3.425	3.3	3.219	3.225	3.25	3.509	3.69	3.532	3.407
1996	3.54	3.418	3.236	3.173	3.11	3.14	3.291	3.57	4.08	4.525	4.72	4.792	3.717
1997	4.72	4.652	4.521	3.596	3.505	3.48	4.216	4.272	4.42	4.42	4.49	4.393	4.224
1998	4.3	4.225	4.158	4.018	3.899	3.82	3.736	3.806	3.88	3.473	3.56	3.666	3.878
1999	3.7	3.648	3.65	3.62	3.481	3.39	3.364	3.338	3.33	3.546	3.76	3.83	3.555
2000	3.85	3.764	3.588	3.427	3.366	3.25	3.203	3.173	3.17	3.306	3.43	3.458	3.415
2001	3.46	3.362	3.276	3.174	3.101	3.06	3.03	3.062	3.32	3.6	3.72	3.773	3.328
2002	3.79	3.724	3.678	3.591	3.459	3.32	3.245	3.215	3.18	3.053	2.85	2.688	3.316
2003	2.61	2.497	2.37	2.166	2.104	1.98	1.97	1.968	1.96	1.879	1.69	1.535	2.061
2004	1.41	1.297	1.086	1.052	0.897	0.88	0.829	0.796	0.75	0.728	0.57	0.404	0.891
2005	0.22	0.412	0.53	0.507	0.675	0.67	0.607	0.599	0.54	0.531	0.5	0.426	0.518
mean	3.13	3.097	3.017	2.84	2.771	2.72	2.752	2.785	2.88	3.028	3.1	3.0804	2.933

Appendix Table 27: Volume of Lake Zeway using curve fit equation (MCM)

Elevation	Water level(m)	Lake Volume(MCM) IN 1976	Lake Volume(MCM) IN 2005/2006	Siltation Volume(MCM)	Siltation Depth(cm)
1628	0	13.02	-2.35	15.37	3.28
1629	1	23.70	8.88	14.82	3.16
1630	2	74.33	7.31	67.01	14.29
1631	3	199.32	6.84	192.48	41.04
1632	4	417.43	43.25	374.18	79.78
1633	5	731.73	158.78	572.95	122.16
1634	6	1129.65	386.63	743.02	158.43
1635	7	1582.93	735.53	847.40	180.68
1636	8	2047.67	1174.23	873.44	186.23
1637	9	2464.28	1616.07	848.22	180.86
		Average		454.89	96.99

Appendix Table 28: Geographic co-ordinate points of lake periphery

S/NO	Easting(Longitude)	Northing(Latitude)	Depth(m)	Elevation
1	470000	875000	0	1636
2	480000	870000	0	1636
3	490000	880000	0	1636
4	495000	887000	0	1636
5	470000	880000	0	1636
6	480000	897500	0	1636
7	490000	897500	0	1636
8	495000	894000	0	1636
9	486576	876187	0	1636
10	479390	868732	0	1636
11	473181	873204	0	1636
12	470115	875764	0	1636
13	485000	894000	0	1636
14	492500	897500	0	1636
15	495000	895000	0	1636
16	490000	895000	0	1636
17	480000	895000	0	1636
18	486000	895000	0	1636
19	495000	892500	0	1636
20	475000	892500	0	1636
21	494000	890000	0	1636
22	475000	890000	0	1636
23	495000	892500	0	1636
24	485000	892500	0	1636
25	475000	892500	0	1636
26	482500	892500	0	1636
27	494000	887500	0	1636
28	475000	887500	0	1636
29	493800	885000	0	1636
30	472500	885000	0	1636
31	492500	882500	0	1636
32	472500	882500	0	1636

33	471500	880000	0	1636
34	488500	877500	0	1636
35	470000	877500	0	1636
36	487500	875000	0	1636
37	471000	875000	0	1636
38	486500	872500	0	1636
39	472500	872500	0	1636
40	485000	870000	0	1636
41	477000	870000	0	1636
42	482500	862500	0	1636

Appendix Table 29: Geographic co-ordinate points of Lake Zeway

S/NO	E	N	Depth	Surface Elevation	Bottom Elevation
1	470000	877500	0.0	1636	1636.0
2	470115	875764	0.0	1636	1636.0
3	470115	875830	1.0	1636	1635.0
4	470115	876162	0.9	1636	1635.1
5	470500	879648	1.0	1636	1635.0
6	470500	880000	0.9	1636	1635.1
7	470500	879648	1.0	1636	1635.0
8	470500	880000	0.9	1636	1635.1
9	471000	875664	1.0	1636	1635.0
10	471000	875764	1.0	1636	1635.0
11	471000	875830	0.0	1636	1636.0
12	471000	876162	1.1	1636	1634.9
13	471000	876328	1.2	1636	1634.8
14	471000	876660	1.2	1636	1634.8
15	471000	876826	1.1	1636	1634.9
16	471500	876826	3.3	1636	1632.7
17	471500	877158	3.4	1636	1632.6
18	471500	877324	3.5	1636	1632.5

19	471500	877500	3.3	1636	1632.7
20	471500	877656	3.0	1636	1633.0
21	471500	877822	2.8	1636	1633.2
22	471500	878154	2.6	1636	1633.4
23	471500	878320	2.4	1636	1633.6
24	471500	882500	2.1	1636	1633.9
25	471500	878652	1.9	1636	1634.1
26	471500	878818	1.7	1636	1634.3
27	471500	879150	1.4	1636	1634.6
28	471500	885000	1.2	1636	1634.8
29	471500	879316	1.0	1636	1635.0
30	471500	879648	0.7	1636	1635.3
31	471500	880000	0.0	1636	1636.0
32	472500	875166	0.0	1636	1636.0
33	472500	875498	0.8	1636	1635.2
34	472500	875664	1.0	1636	1635.0
35	472500	875764	1.1	1636	1634.9
36	472500	875830	1.2	1636	1634.8
37	472500	876162	1.4	1636	1634.6
38	472500	876328	1.5	1636	1634.5
39	472500	876660	1.7	1636	1634.3
40	472500	876826	1.8	1636	1634.2
41	472500	877158	1.9	1636	1634.1
42	472500	877324	2.1	1636	1633.9
43	472500	877500	2.2	1636	1633.8
44	472500	877656	2.1	1636	1633.9
45	472500	877822	1.9	1636	1634.1
46	472500	878154	1.8	1636	1634.2
47	472500	878320	1.6	1636	1634.4
48	472500	882500	1.5	1636	1634.5
49	472500	878652	1.4	1636	1634.6

50	472500	878818	1.2	1636	1634.8
51	472500	879150	1.1	1636	1634.9
52	472500	885000	0.9	1636	1635.1
53	472500	879316	0.8	1636	1635.2
54	472500	879648	0.8	1636	1635.2
55	472500	880000	0.0	1636	1636.0
56	473181	873204	0.0	1636	1636.0
57	473181	875000	0.9	1636	1635.1
58	473181	876187	1.1	1636	1634.9
59	474000	875166	1.3	1636	1634.7
60	474000	875498	1.5	1636	1634.5
61	474000	875664	1.8	1636	1634.2
62	474000	875764	2.0	1636	1634.0
63	474000	875830	2.2	1636	1633.8
64	474000	876162	2.4	1636	1633.6
65	474000	876328	2.6	1636	1633.4
66	474000	876660	2.8	1636	1633.2
67	474000	876826	3.0	1636	1633.0
68	474000	877158	3.2	1636	1632.8
69	474000	877324	3.0	1636	1633.0
70	474000	877500	2.8	1636	1633.2
71	474000	877656	2.6	1636	1633.4
72	474000	877822	2.4	1636	1633.6
73	474000	878154	2.2	1636	1633.8
74	474000	878320	1.9	1636	1634.1
75	474000	882500	1.7	1636	1634.3
76	474000	878652	1.5	1636	1634.5
77	474000	878818	1.4	1636	1634.6
78	474000	879150	1.4	1636	1634.6
79	474000	885000	1.3	1636	1634.7
80	474000	879316	1.3	1636	1634.7

81	474000	879648	1.2	1636	1634.8
82	474000	880000	1.2	1636	1634.8
83	474000	880175	1.0	1636	1635.0
84	474000	887500	1.1	1636	1634.9
85	474000	887000	1.1	1636	1634.9
86	474000	880725	1.0	1636	1635.0
87	474000	881825	1.0	1636	1635.0
88	474000	882375	1.0	1636	1635.0
89	474000	882500	1.0	1636	1635.0
90	474000	883475	0.9	1636	1635.1
91	474000	884025	0.9	1636	1635.1
92	474000	885000	0.8	1636	1635.2
93	474000	885125	0.0	1636	1636.0
94	475000	876826	0.0	1636	1636.0
95	475000	877158	1.0	1636	1635.0
96	475000	877324	1.2	1636	1634.8
97	475000	877490	1.5	1636	1634.5
98	475000	877822	1.8	1636	1634.2
99	475000	877988	2.1	1636	1633.9
100	475000	878320	2.3	1636	1633.7
101	475000	878486	2.6	1636	1633.4
102	475000	878818	2.9	1636	1633.1
103	475000	878984	3.1	1636	1632.9
104	475000	879316	3.3	1636	1632.7
105	475000	879482	3.5	1636	1632.5
106	475000	879814	3.7	1636	1632.3
107	475000	879980	3.5	1636	1632.5
108	475000	882500	3.3	1636	1632.7
109	475000	883262	3.1	1636	1632.9
110	475000	883728	3.0	1636	1633.0
111	475000	884660	2.8	1636	1633.2

112	475000	885000	2.6	1636	1633.4
113	475000	885126	2.4	1636	1633.6
114	475000	886058	2.3	1636	1633.7
115	475000	887456	2.1	1636	1633.9
116	475000	887500	1.9	1636	1634.1
117	475000	887000	1.7	1636	1634.3
118	475000	887922	1.6	1636	1634.4
119	475000	888854	1.4	1636	1634.6
120	475000	889320	1.2	1636	1634.8
121	475000	890000	0.0	1636	1636.0
122	475000	892500	0.0	1636	1636.0
123	475000	893048	1.0	1636	1635.0
124	475000	893514	1.2	1636	1634.8
125	475000	893980	1.6	1636	1634.4
126	475000	894000	2.0	1636	1634.0
127	475000	895000	2.2	1636	1633.8
128	475000	897500	1.9	1636	1634.1
129	475000	862500	1.7	1636	1634.3
130	475000	868732	1.4	1636	1634.6
131	475000	870000	1.1	1636	1634.9
132	475000	872500	0.0	1636	1636.0
133	476500	876826	1.9	1636	1634.1
134	476500	877158	2.1	1636	1633.9
135	476500	877324	2.2	1636	1633.8
136	476500	877490	2.4	1636	1633.6
137	476500	877822	2.5	1636	1633.5
138	476500	877988	2.7	1636	1633.3
139	476500	878320	2.8	1636	1633.2
140	476500	878486	3.0	1636	1633.0
141	476500	878818	3.1	1636	1632.9
142	476500	878984	3.3	1636	1632.7

143	476500	879316	3.4	1636	1632.6
144	476500	879482	3.6	1636	1632.4
145	476500	879814	3.7	1636	1632.3
146	476500	879980	3.7	1636	1632.3
147	476500	882500	3.5	1636	1632.5
148	476500	883262	3.4	1636	1632.6
149	476500	883728	3.2	1636	1632.8
150	476500	884660	3.0	1636	1633.0
151	476500	885000	2.9	1636	1633.1
152	476500	885126	2.7	1636	1633.3
153	476500	886058	2.5	1636	1633.5
154	476500	887456	2.4	1636	1633.6
155	476500	887500	2.2	1636	1633.8
156	476500	887000	2.0	1636	1634.0
157	476500	887922	1.9	1636	1634.1
158	476500	888854	1.7	1636	1634.3
159	476500	889320	1.5	1636	1634.5
160	476500	890000	1.4	1636	1634.6
161	476500	890252	1.2	1636	1634.8
162	476500	890718	1.2	1636	1634.8
163	476500	891650	1.3	1636	1634.7
164	476500	892116	1.2	1636	1634.8
165	476500	892500	1.1	1636	1634.9
166	476500	893048	1.1	1636	1634.9
167	476500	893514	1.0	1636	1635.0
168	476500	893980	0.9	1636	1635.1
169	476500	894000	0.9	1636	1635.1
170	476500	895000	0.0	1636	1636.0
171	476500	897500	0.0	1636	1636.0
172	476500	870000	0.0	1636	1636.0
173	476500	872500	1.3	1636	1634.7

174	476500	874280	1.5	1636	1634.5
175	476500	873204	2.0	1636	1634.0
176	476500	875000	2.2	1636	1633.8
177	476500	876187	2.3	1636	1633.7
178	477000	876826	3.1	1636	1632.9
179	477000	877158	3.2	1636	1632.8
180	477000	877324	3.4	1636	1632.6
181	477000	877490	3.5	1636	1632.5
182	477000	877822	3.6	1636	1632.4
183	477000	877988	3.8	1636	1632.2
184	477000	878320	3.9	1636	1632.1
185	477000	878486	4.0	1636	1632.0
186	477000	878818	4.1	1636	1631.9
187	477000	878984	4.3	1636	1631.7
188	477000	879316	4.4	1636	1631.6
189	477000	879482	4.5	1636	1631.5
190	477000	879814	4.7	1636	1631.3
191	477000	879980	4.7	1636	1631.3
192	477000	882500	4.5	1636	1631.5
193	477000	883262	4.4	1636	1631.6
194	477000	883728	4.2	1636	1631.8
195	477000	884660	4.0	1636	1632.0
196	477000	885000	3.9	1636	1632.1
197	477000	885126	3.7	1636	1632.3
198	477000	886058	3.5	1636	1632.5
199	477000	887456	3.3	1636	1632.7
200	477000	887500	3.2	1636	1632.8
201	477000	887000	3.0	1636	1633.0
202	477000	887922	2.8	1636	1633.2
203	477000	888854	2.7	1636	1633.3
204	477000	889320	2.5	1636	1633.5

205	477000	890000	2.3	1636	1633.7
206	477000	890252	2.2	1636	1633.8
207	477000	890718	2.0	1636	1634.0
208	477000	891650	1.8	1636	1634.2
209	477000	892116	1.6	1636	1634.4
210	477000	892500	1.5	1636	1634.5
211	477000	893048	1.3	1636	1634.7
212	477000	893514	1.1	1636	1634.9
213	477000	893980	1.0	1636	1635.0
214	477000	894000	0.8	1636	1635.2
215	477000	895000	0.0	1636	1636.0
216	477000	897500	0.0	1636	1636.0
217	477000	862500	0.0	1636	1636.0
218	477000	868732	0.0	1636	1636.0
219	477000	870000	1.9	1636	1634.1
220	477000	872500	2.3	1636	1633.7
221	477000	874280	3.1	1636	1632.9
222	477000	873204	3.6	1636	1632.4
223	477000	875000	3.9	1636	1632.1
224	477000	876187	4.2	1636	1631.8
225	478500	876826	3.9	1636	1632.1
226	478500	877158	4.0	1636	1632.0
227	478500	877324	4.1	1636	1631.9
228	478500	877490	4.2	1636	1631.8
229	478500	877822	4.3	1636	1631.7
230	478500	877988	4.5	1636	1631.5
231	478500	878320	4.6	1636	1631.4
232	478500	878486	4.7	1636	1631.3
233	478500	878818	4.8	1636	1631.2
234	478500	878984	4.9	1636	1631.1
235	478500	879316	5.0	1636	1631.0

236	478500	879482	5.1	1636	1630.9
237	478500	879814	5.2	1636	1630.8
238	478500	879980	5.2	1636	1630.8
239	478500	882500	5.0	1636	1631.0
240	478500	883262	4.8	1636	1631.2
241	478500	883728	4.6	1636	1631.4
242	478500	884660	4.4	1636	1631.6
243	478500	885000	4.2	1636	1631.8
244	478500	885126	4.0	1636	1632.0
245	478500	886058	3.8	1636	1632.2
246	478500	887456	3.6	1636	1632.4
247	478500	887500	3.4	1636	1632.6
248	478500	887000	3.2	1636	1632.8
249	478500	887922	2.9	1636	1633.1
250	478500	888854	2.7	1636	1633.3
251	478500	889320	2.5	1636	1633.5
252	478500	890000	2.3	1636	1633.7
253	478500	890252	2.1	1636	1633.9
254	478500	890718	1.9	1636	1634.1
255	478500	891650	1.7	1636	1634.3
256	478500	892116	1.5	1636	1634.5
257	478500	892500	1.3	1636	1634.7
258	478500	893048	1.1	1636	1634.9
259	478500	893514	1.0	1636	1635.0
260	478500	893980	1.0	1636	1635.0
261	478500	894000	0.9	1636	1635.1
262	478500	895000	0.0	1636	1636.0
263	478500	870000	0.0	1636	1636.0
264	478500	872500	2.2	1636	1633.8
265	478500	874280	2.9	1636	1633.1
266	478500	873204	2.7	1636	1633.3

267	478500	875000	3.0	1636	1633.0
268	478500	876187	3.2	1636	1632.8
269	479390	876826	3.4	1636	1632.6
270	479390	877158	3.5	1636	1632.5
271	479390	877324	3.7	1636	1632.3
272	479390	877490	3.8	1636	1632.2
273	479390	877822	4.0	1636	1632.0
274	479390	877988	4.1	1636	1631.9
275	479390	878320	4.3	1636	1631.7
276	479390	878486	4.4	1636	1631.6
277	479390	878818	4.6	1636	1631.4
278	479390	878984	4.7	1636	1631.3
279	479390	879316	4.9	1636	1631.1
280	479390	879482	5.0	1636	1631.0
281	479390	879814	5.2	1636	1630.8
282	479390	879980	5.3	1636	1630.7
283	479390	882500	5.3	1636	1630.7
284	479390	883262	5.1	1636	1630.9
285	479390	883728	4.9	1636	1631.1
286	479390	884660	4.7	1636	1631.3
287	479390	885000	4.5	1636	1631.5
288	479390	885126	4.3	1636	1631.7
289	479390	886058	4.0	1636	1632.0
290	479390	887456	3.8	1636	1632.2
291	479390	887500	3.6	1636	1632.4
292	479390	887000	3.4	1636	1632.6
293	479390	887922	3.2	1636	1632.8
294	479390	888854	3.0	1636	1633.0
295	479390	889320	2.8	1636	1633.2
296	479390	890000	2.6	1636	1633.4
297	479390	890252	2.4	1636	1633.6

298	479390	890718	2.2	1636	1633.8
299	479390	891650	1.9	1636	1634.1
300	479390	892116	1.7	1636	1634.3
301	479390	892500	1.5	1636	1634.5
302	479390	893048	1.3	1636	1634.7
303	479390	893514	1.1	1636	1634.9
304	479390	893980	0.9	1636	1635.1
305	479390	894000	0.7	1636	1635.3
306	479390	895000	0.0	1636	1636.0
307	479390	868732	0.0	1636	1636.0
308	479390	870000	1.0	1636	1635.0
309	479390	872500	1.3	1636	1634.7
310	479390	874280	1.6	1636	1634.4
311	479390	873204	1.9	1636	1634.1
312	479390	875000	2.2	1636	1633.8
313	479390	876187	2.5	1636	1633.5
314	480000	876826	2.8	1636	1633.2
315	480000	877158	3.1	1636	1632.9
316	480000	877324	3.4	1636	1632.6
317	480000	877490	3.7	1636	1632.3
318	480000	877822	3.9	1636	1632.1
319	480000	877988	4.0	1636	1632.0
320	480000	878320	4.2	1636	1631.8
321	480000	878486	4.3	1636	1631.7
322	480000	878818	4.5	1636	1631.5
323	480000	878984	4.6	1636	1631.4
324	480000	879316	4.8	1636	1631.2
325	480000	879482	4.9	1636	1631.1
326	480000	879814	5.0	1636	1631.0
327	480000	879980	5.0	1636	1631.0
328	480000	882500	4.8	1636	1631.2

329	480000	883262	4.6	1636	1631.4
330	480000	883728	4.4	1636	1631.6
331	480000	884660	4.2	1636	1631.8
332	480000	885000	4.0	1636	1632.0
333	480000	885126	3.8	1636	1632.2
334	480000	886058	3.6	1636	1632.4
335	480000	887456	3.4	1636	1632.6
336	480000	887500	3.2	1636	1632.8
337	480000	887000	3.0	1636	1633.0
338	480000	887922	2.8	1636	1633.2
339	480000	888854	2.6	1636	1633.4
340	480000	889320	2.4	1636	1633.6
341	480000	890000	2.2	1636	1633.8
342	480000	890252	2.0	1636	1634.0
343	480000	890718	1.9	1636	1634.1
344	480000	891650	1.6	1636	1634.4
345	480000	892116	1.4	1636	1634.6
346	480000	892500	1.2	1636	1634.8
347	480000	893048	1.1	1636	1634.9
348	480000	893514	1.0	1636	1635.0
349	480000	893980	1.0	1636	1635.0
350	480000	894000	0.9	1636	1635.1
351	480000	895000	0.7	1636	1635.3
352	480000	868732	0.0	1636	1636.0
353	480000	870000	1.3	1636	1634.7
354	480000	872500	1.9	1636	1634.1
355	480000	874280	2.5	1636	1633.5
356	480000	873204	2.3	1636	1633.7
357	480000	875000	2.6	1636	1633.4
358	480000	876187	2.7	1636	1633.3
359	481000	876826	3.1	1636	1632.9

360	481000	877158	3.3	1636	1632.7
361	481000	877324	3.4	1636	1632.6
362	481000	877490	3.6	1636	1632.4
363	481000	877822	3.8	1636	1632.2
364	481000	877988	4.0	1636	1632.0
365	481000	878320	4.1	1636	1631.9
366	481000	878486	4.3	1636	1631.7
367	481000	878818	4.5	1636	1631.5
368	481000	878984	4.6	1636	1631.4
369	481000	879316	4.8	1636	1631.2
370	481000	879482	5.0	1636	1631.0
371	481000	879814	5.1	1636	1630.9
372	481000	879980	5.3	1636	1630.7
373	481000	882500	5.3	1636	1630.7
374	481000	883262	5.1	1636	1630.9
375	481000	883728	4.9	1636	1631.1
376	481000	884660	4.7	1636	1631.3
377	481000	885000	4.5	1636	1631.5
378	481000	885126	4.3	1636	1631.7
379	481000	886058	4.0	1636	1632.0
380	481000	887456	3.8	1636	1632.2
381	481000	887500	3.6	1636	1632.4
382	481000	887000	3.4	1636	1632.6
383	481000	887922	3.2	1636	1632.8
384	481000	888854	3.0	1636	1633.0
385	481000	889320	2.8	1636	1633.2
386	481000	890000	2.6	1636	1633.4
387	481000	890252	2.4	1636	1633.6
388	481000	890718	2.2	1636	1633.8
389	481000	891650	1.9	1636	1634.1
390	481000	892116	1.7	1636	1634.3

391	481000	892500	1.5	1636	1634.5
392	481000	893048	1.3	1636	1634.7
393	481000	893514	1.1	1636	1634.9
394	481000	893980	1.0	1636	1635.0
395	481000	894000	0.9	1636	1635.1
396	481000	895000	0.0	1636	1636.0
397	481000	868732	0.0	1636	1636.0
398	481000	870000	1.3	1636	1634.7
399	481000	872500	1.5	1636	1634.5
400	481000	874280	1.9	1636	1634.1
401	481000	873204	2.4	1636	1633.6
402	481000	875000	2.5	1636	1633.5
403	481000	876187	2.7	1636	1633.3
404	482500	876826	2.9	1636	1633.1
405	482500	877158	3.1	1636	1632.9
406	482500	877324	3.3	1636	1632.7
407	482500	877490	3.5	1636	1632.5
408	482500	877822	3.7	1636	1632.3
409	482500	877988	3.9	1636	1632.1
410	482500	878320	4.1	1636	1631.9
411	482500	878486	4.3	1636	1631.7
412	482500	878818	4.5	1636	1631.5
413	482500	878984	4.7	1636	1631.3
414	482500	879316	4.9	1636	1631.1
415	482500	879482	5.1	1636	1630.9
416	482500	879814	5.3	1636	1630.7
417	482500	879980	5.4	1636	1630.6
418	482500	882500	5.4	1636	1630.6
419	482500	883262	5.1	1636	1630.9
420	482500	883728	4.9	1636	1631.1
421	482500	884660	4.6	1636	1631.4

422	482500	885000	4.3	1636	1631.7
423	482500	885126	4.0	1636	1632.0
424	482500	886058	3.7	1636	1632.3
425	482500	887456	3.5	1636	1632.5
426	482500	887500	3.2	1636	1632.8
427	482500	887000	2.9	1636	1633.1
428	482500	887922	2.6	1636	1633.4
429	482500	888854	2.4	1636	1633.6
430	482500	889320	2.1	1636	1633.9
431	482500	890000	1.8	1636	1634.2
432	482500	890252	1.5	1636	1634.5
433	482500	890718	1.3	1636	1634.7
434	482500	891650	1.1	1636	1634.9
435	482500	892116	1.0	1636	1635.0
436	482500	892500	0.0	1636	1636.0
437	482500	862500	0.7	1636	1635.3
438	482500	868732	0.0	1636	1636.0
439	482500	870000	2.7	1636	1633.3
440	482500	872500	3.0	1636	1633.0
441	482500	874280	3.4	1636	1632.6
442	482500	873204	3.5	1636	1632.5
443	482500	875000	3.7	1636	1632.3
444	482500	876187	4.0	1636	1632.0
445	484000	879980	5.2	1636	1630.8
446	484000	882500	5.0	1636	1631.0
447	484000	883262	4.7	1636	1631.3
448	484000	883728	4.5	1636	1631.5
449	484000	884660	4.3	1636	1631.7
450	484000	885000	4.0	1636	1632.0
451	484000	885126	3.8	1636	1632.2
452	484000	886058	3.5	1636	1632.5

453	484000	887456	3.3	1636	1632.7
454	484000	887500	3.1	1636	1632.9
455	484000	887000	2.8	1636	1633.2
456	484000	887922	2.6	1636	1633.4
457	484000	888854	2.4	1636	1633.6
458	484000	889320	2.1	1636	1633.9
459	484000	890000	1.9	1636	1634.1
460	484000	890252	1.6	1636	1634.4
461	484000	890718	1.4	1636	1634.6
462	484000	891650	1.2	1636	1634.8
463	484000	892116	0.9	1636	1635.1
464	484000	892500	0.0	1636	1636.0
465	484000	868732	0.0	1636	1636.0
466	484000	870000	2.5	1636	1633.5
467	484000	872500	2.9	1636	1633.1
468	484000	874280	3.6	1636	1632.4
469	484000	875052	3.9	1636	1632.1
470	484000	875000	4.2	1636	1631.8
471	484000	876187	4.4	1636	1631.6
472	484500	879980	5.2	1636	1630.8
473	484500	882500	5.0	1636	1631.0
474	484500	883262	4.7	1636	1631.3
475	484500	883728	4.5	1636	1631.5
476	484500	884660	4.2	1636	1631.8
477	484500	885000	4.0	1636	1632.0
478	484500	885126	3.7	1636	1632.3
479	484500	886058	3.5	1636	1632.5
480	484500	887456	3.2	1636	1632.8
481	484500	887500	3.0	1636	1633.0
482	484500	887000	2.7	1636	1633.3
483	484500	887922	2.5	1636	1633.5

484	484500	888854	2.2	1636	1633.8
485	484500	889320	2.0	1636	1634.0
486	484500	890000	1.7	1636	1634.3
487	484500	890252	1.5	1636	1634.5
488	484500	890718	1.2	1636	1634.8
489	484500	891650	1.0	1636	1635.0
490	484500	892116	0.9	1636	1635.1
491	484500	892500	0.7	1636	1635.3
492	484500	868732	0.0	1636	1636.0
493	484500	870000	1.5	1636	1634.5
494	485500	879980	4.5	1636	1631.5
495	485500	882500	4.3	1636	1631.7
496	485500	883262	4.1	1636	1631.9
497	485500	883728	3.9	1636	1632.1
498	485500	884660	3.7	1636	1632.3
499	485500	885000	3.4	1636	1632.6
500	485500	885126	3.2	1636	1632.8
501	485500	886058	3.0	1636	1633.0
502	485500	887456	2.8	1636	1633.2
503	485500	887500	2.6	1636	1633.4
504	485500	887000	2.4	1636	1633.6
505	485500	887922	2.2	1636	1633.8
506	485500	888854	2.0	1636	1634.0
507	485500	889320	1.8	1636	1634.2
508	485500	890000	1.5	1636	1634.5
509	485500	890252	1.3	1636	1634.7
510	485500	890718	1.3	1636	1634.7
511	485500	891650	1.2	1636	1634.8
512	485500	892116	1.1	1636	1634.9
513	485500	892500	1.0	1636	1635.0
514	485500	893048	0.0	1636	1636.0

515	485500	870000	0.0	1636	1636.0
516	485500	872500	2.6	1636	1633.4
517	485500	872387	3.0	1636	1633.0
518	485500	875928	3.6	1636	1632.4
519	485500	875000	3.7	1636	1632.3
520	486000	882500	5.0	1636	1631.0
521	486000	883262	4.9	1636	1631.1
522	486000	883728	4.9	1636	1631.1
523	486000	884660	4.6	1636	1631.4
524	486000	885000	4.3	1636	1631.7
525	486000	885126	4.1	1636	1631.9
526	486000	886058	3.8	1636	1632.2
527	486000	887456	3.5	1636	1632.5
528	486000	887500	3.2	1636	1632.8
529	486000	887000	2.9	1636	1633.1
530	486000	887922	2.7	1636	1633.3
531	486000	888854	2.4	1636	1633.6
532	486000	889320	2.1	1636	1633.9
533	486000	890000	1.8	1636	1634.2
534	486000	890252	1.5	1636	1634.5
535	486000	890718	1.4	1636	1634.6
536	486000	891650	1.3	1636	1634.7
537	486000	892116	1.1	1636	1634.9
538	486000	892500	0.0	1636	1636.0
539	486000	872500	0.0	1636	1636.0
540	486000	875928	1.8	1636	1634.2
541	486000	875000	1.9	1636	1634.1
542	486000	876187	1.9	1636	1634.1
543	487000	876826	0.0	1636	1636.0
544	487000	877158	0.0	1636	1636.0
545	487000	877324	0.9	1636	1635.1

546	487000	877490	1.2	1636	1634.8
547	487000	877822	1.4	1636	1634.6
548	487000	877988	1.6	1636	1634.4
549	487000	878320	1.9	1636	1634.1
550	487000	878486	2.1	1636	1633.9
551	487000	878818	2.3	1636	1633.7
552	487000	878984	2.6	1636	1633.4
553	487000	879316	2.8	1636	1633.2
554	487000	879482	3.0	1636	1633.0
555	487000	879814	3.3	1636	1632.7
556	487000	879980	3.5	1636	1632.5
557	487000	882500	3.7	1636	1632.3
558	487000	883262	4.0	1636	1632.0
559	487000	883728	4.2	1636	1631.8
560	487000	884660	4.4	1636	1631.6
561	487000	885000	4.7	1636	1631.3
562	487000	885126	4.2	1636	1631.8
563	487000	886058	4.0	1636	1632.0
564	487000	887456	3.7	1636	1632.3
565	487000	887500	3.5	1636	1632.5
566	487000	887000	3.3	1636	1632.7
567	487000	887922	3.0	1636	1633.0
568	487000	888854	2.8	1636	1633.2
569	487000	889320	2.6	1636	1633.4
570	487000	890000	2.3	1636	1633.7
571	487000	890252	2.1	1636	1633.9
572	487000	890718	1.9	1636	1634.1
573	487000	891650	1.6	1636	1634.4
574	487000	892116	1.4	1636	1634.6
575	487000	892500	1.2	1636	1634.8
576	487000	893048	0.9	1636	1635.1

577	487000	893514	0.0	1636	1636.0
578	488500	879980	0.0	1636	1636.0
579	488500	882500	1.1	1636	1634.9
580	488500	883262	1.4	1636	1634.6
581	488500	883728	1.8	1636	1634.2
582	488500	884660	2.1	1636	1633.9
583	488500	885000	2.5	1636	1633.5
584	488500	885126	2.9	1636	1633.1
585	488500	886058	3.2	1636	1632.8
586	488500	887456	3.6	1636	1632.4
587	488500	887500	3.9	1636	1632.1
588	488500	887000	4.3	1636	1631.7
589	488500	887922	4.3	1636	1631.7
590	488500	888854	4.0	1636	1632.0
591	488500	889320	3.7	1636	1632.3
592	488500	890000	3.4	1636	1632.6
593	488500	890252	3.1	1636	1632.9
594	488500	890718	2.8	1636	1633.2
595	488500	891650	2.5	1636	1633.5
596	488500	892116	2.2	1636	1633.8
597	488500	892500	1.9	1636	1634.1
598	488500	893048	1.6	1636	1634.4
599	488500	893514	1.3	1636	1634.7
600	488500	893980	1.0	1636	1635.0
601	488500	894000	1.0	1636	1635.0
602	488500	895000	0.0	1636	1636.0
603	489383	882500	3.2	1636	1632.8
604	489383	882907	3.7	1636	1632.3
605	489383	883728	3.7	1636	1632.3
606	489383	884660	3.9	1636	1632.1
607	489383	885000	4.0	1636	1632.0

608	489383	885126	4.1	1636	1631.9
609	489383	886058	4.1	1636	1631.9
610	489383	887456	4.2	1636	1631.8
611	489383	887500	6.2	1636	1629.8
612	489383	887000	4.3	1636	1631.7
613	489383	887922	4.3	1636	1631.7
614	489383	888854	4.0	1636	1632.0
615	489383	889320	3.7	1636	1632.3
616	489383	890000	3.4	1636	1632.6
617	489383	890252	3.1	1636	1632.9
618	489383	890718	2.8	1636	1633.2
619	489383	891650	2.5	1636	1633.5
620	489383	892116	2.2	1636	1633.8
621	489383	892500	1.9	1636	1634.1
622	489383	893048	1.6	1636	1634.4
623	489383	893514	1.5	1636	1634.5
624	489383	893980	1.4	1636	1634.6
625	489383	894000	1.2	1636	1634.8
626	489383	895000	0.0	1636	1636.0
627	492500	882500	0.0	1636	1636.0
628	492500	882907	1.0	1636	1635.0
629	492500	883728	1.3	1636	1634.7
630	492500	884660	1.6	1636	1634.4
631	492500	885000	1.9	1636	1634.1
632	492500	885126	2.2	1636	1633.8
633	492500	886058	2.5	1636	1633.5
634	492500	887456	2.8	1636	1633.2
635	492500	887500	3.1	1636	1632.9
636	492500	887000	3.4	1636	1632.6
637	492500	887922	3.7	1636	1632.3
638	492500	888854	4.0	1636	1632.0

639	492500	889320	4.3	1636	1631.7
640	492500	890000	4.0	1636	1632.0
641	492500	890252	3.7	1636	1632.3
642	492500	890718	3.4	1636	1632.6
643	492500	891650	3.1	1636	1632.9
644	492500	892116	2.8	1636	1633.2
645	492500	892500	2.5	1636	1633.5
646	492500	893048	2.2	1636	1633.8
647	492500	893514	1.9	1636	1634.1
648	492500	893980	1.6	1636	1634.4
649	492500	894000	1.3	1636	1634.7
650	492500	895000	1.0	1636	1635.0
651	492500	897500	0.0	1636	1636.0
652	493800	885000	0.0	1636	1636.0
	Average Depth		2.5		

Appendix Table 30: Mean annual Abjata , Zeway Lake level and Bulbula river discharge

Years	Abjata Lake Level (m)	Zeway Lake Level (m)	Bulbula River Discharge(m^3/s)
1989	2.23	0.97	2.64
1990	2.513	1.26	7.92
1991	2.825	1.11	5.48
1992	2.777	1.13	8.11
1993	3.752	1.36	12.37
1994	3.457	1.17	6.57
1995	3.407	1.11	4.09
1996	3.717	1.37	11.20
1997	4.224	1.30	6.70
1998	3.878	1.31	10.12
1999	3.555	1.31	8.79
2000	3.415	1.15	5.73
2001	3.328	1.44	9.23
2002	3.316	1.14	2.87
2003	2.061	0.73	0.69
2004	0.891	0.73	0.33
2005	0.518	0.87	0.69

Appendix Table 31: Mean annual rainfall of stations (mm)

Year	Zeway Station maen Annual RF(mm)	Arata Station maen Annual RF(mm)	Asela Station maen Annual RF(mm)
1982	890.80	816.6	1325.90
1983	864.40	578.6	1502.80
1984	551.40	502.9	1129.25
1985	659.10	1110.4	1087.00
1986	541.20	890.4	1250.95
1987	552.90	753.9	941.40
1988	700.60	707.4	908.00
1989	951.50	660.8	1162.60
1990	689.40	580.9	964.70
1991	801.60	554.9	784.00
1992	794.20	463.6	883.85
1993	958.90	660.4	1033.10
1994	517.30	981.1	1068.30
1995	564.00	655.8	1070.30
1996	912.10	717.0	1231.40
1997	848.60	658.3	1151.90
1998	756.20	753.0	1115.10
1999	545.50	756.9	857.70
2000	704.30	709.2	1061.80
2001	725.70	846.7	1443.80
2002	457.60	634.8	779.50
2003	850.80	1016.9	978.70
2004	773.60	922.4	1077.20
2005	779.10	878.6	1082.80
2006	776.50	928.3	1101.20
2007	836.50	728.6	1194.10
2008	892.60	805.2	954.10
2009	728.70	837.0	1098.80
2010	863.30	575.2	1140.10
2011	672.90	771.2	1037.70
2012	916.60	633.1	859.80
2013	747.40	785.4	1101.70
2014	725.40	723.9	1146.60

Appendix Table 32: Mean annual cumulative silt(m)

year	Cumulative Silt(m)
1975	0.06
1976	0.12
1977	0.18
1978	0.24
1979	0.3
1980	0.36
1981	0.42
1982	0.48
1983	0.54
1984	0.6
1985	0.66
1986	0.72
1987	0.78
1988	0.84
1989	0.9
1990	0.96
1991	1.02
1992	1.08
1993	1.14
1994	1.2
1995	1.26
1996	1.32
1997	1.38
1998	1.44
1999	1.5
2000	1.56
2001	1.62
2002	1.68
2003	1.74
2004	1.8
2005	1.86
2006	1.92
2007	1.98
2008	2.04
2009	2.1
2010	2.16
2011	2.22

Appendix Table 33: Katar sub basin mean annual rainfall and mean annual runoff

Year	Katar Sub-basin Mean Annual RF(mm)	Katar river Mean Rainy Season Runoff(MCM)
1985	679.7	214.05
1986	893.8	321.77
1987	635.0	158.68
1988	901.4	413.86
1989	844.0	184.01
1990	795.7	162.36
1991	671.0	257.49
1992	737.8	340.54
1993	817.8	302.10
1994	721.1	376.25
1995	825.7	318.48
1996	885.0	331.52
1997	831.1	125.30
1998	848.7	352.12
1999	680.8	195.07
2000	781.2	234.53
2001	917.2	430.38
2002	626.4	131.52
2003	741.9	259.17
2004	692.4	228.67
2005	700.1	675.32
2006	719.8	425.51
2007	847.3	430.74
2008	801.6	428.13
2009	719.9	429.43
2010	876.3	428.78

Appendix Table 34: Katar river and Meki river discharge for dry period (month of January)

Years	Katar River Dicharge for Dry Month(Jan)(m3/s)	Meki River Discharge for Dry Month(Jan)(m^3/s)
1975	1.92	0.11
1976	2.16	0.26
1977	3.28	2.50
1978	2.73	0.46
1979	4.48	2.97
1980	2.57	0.81
1981	2.24	0.40
1982	2.72	0.92
1983	1.13	0.53
1984	1.75	0.62
1985	2.00	0.22
1986	1.85	0.09
1987	1.84	0.01
1988	1.85	0.04
1989	2.40	0.14
1990	1.39	0.31
1991	2.16	0.50
1992	2.02	1.50
1993	2.71	4.92
1994	2.14	0.80
1995	1.56	1.16
1996	2.48	1.84
1997	2.91	0.32
1998	2.19	1.60
1999	1.99	0.09
2000	1.58	0.02
2001	1.76	0.01
2002	1.84	1.05
2003	2.44	0.86
2004	1.47	0.84
2005	1.51	0.33
2006	1.64	1.97
2007	1.16	0.77
2008	1.37	0.43
2009	1.32	0.64
2010	2.28	0.00

Appendix Table 35: Zeway station means annual temperature (^{o}c)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1982	19.94	20.42	20.79	20.44	20.75	20.74	19.57	19.03	19.10	18.68	19.73	19.71	19.91
1983	19.49	21.43	22.76	21.57	21.20	20.70	19.34	19.17	18.72	18.33	18.17	17.66	19.88
1984	17.44	17.86	20.36	21.82	21.12	20.09	19.80	19.31	19.25	18.82	19.84	18.64	19.53
1985	19.19	19.79	21.11	20.57	20.75	20.93	18.85	18.42	19.08	18.60	18.30	17.10	19.39
1986	17.24	19.88	20.53	20.86	21.02	19.31	18.48	19.05	19.15	19.31	18.93	17.89	19.30
1987	19.08	20.68	22.22	21.77	21.62	21.44	21.06	20.97	21.25	21.24	19.82	19.69	20.90
1988	20.20	21.89	22.74	22.65	23.02	21.69	19.75	20.34	20.53	19.80	18.22	18.70	20.79
1989	18.63	20.33	21.63	20.57	21.54	21.12	19.95	20.13	20.17	19.53	19.76	20.27	20.30
1990	19.76	20.89	20.91	21.73	22.80	21.67	19.86	19.63	20.64	19.79	19.93	18.60	20.52
1991	20.43	20.48	21.48	21.77	22.77	22.25	20.24	19.92	20.15	19.66	19.40	19.14	20.64
1992	21.00	21.46	22.13	22.46	23.09	22.28	19.37	19.90	19.98	20.30	19.50	19.79	20.94
1993	19.87	20.11	21.48	22.86	22.98	21.79	19.82	19.70	19.63	19.65	18.90	19.59	20.53
1994	19.74	19.49	20.99	21.88	22.74	21.83	20.08	19.65	19.95	19.59	19.17	18.45	20.30
1995	18.64	20.30	22.61	22.01	22.57	21.50	19.86	20.02	19.84	20.64	19.00	19.49	20.54
1996	20.75	20.96	22.36	21.98	22.62	22.60	20.36	20.26	20.49	19.85	19.72	18.96	20.91
1997	20.03	20.82	22.31	22.17	21.55	20.60	20.23	19.96	20.57	21.57	20.92	19.52	20.85
1998	21.01	22.30	23.18	22.24	23.36	22.43	20.61	20.86	21.85	20.87	18.81	18.32	21.32
1999	19.34	20.90	22.61	22.20	21.03	20.22	19.45	19.28	20.04	20.55	18.80	18.56	20.25
2000	19.17	21.03	21.74	23.67	23.39	22.06	20.36	21.01	21.34	19.73	19.68	18.88	21.00
2001	19.27	20.81	21.56	22.90	22.46	21.15	20.60	20.63	20.82	21.81	19.72	19.42	20.93
2002	19.93	21.12	22.59	23.06	23.96	22.59	21.84	21.31	21.34	22.00	20.83	21.28	21.82
2003	20.54	22.24	22.86	22.75	24.01	22.47	20.02	20.45	21.02	20.80	20.52	18.63	21.36
2004	21.23	20.92	21.91	22.20	23.79	22.24	20.55	20.78	21.09	20.35	20.17	19.85	21.26
2005	20.28	20.90	22.71	22.73	21.94	21.72	20.69	21.10	21.28	20.98	19.72	18.07	21.01
2006	20.30	22.18	22.16	21.93	22.79	22.09	20.31	19.93	20.24	21.02	19.81	19.70	21.04
2007	19.76	21.74	22.21	22.34	22.74	20.64	19.96	19.72	20.45	19.10	19.13	17.60	20.45
2008	19.54	19.74	21.22	22.52	22.14	20.86	19.32	19.51	19.99	20.00	18.07	17.60	20.04
2009	19.16	20.87	22.82	22.88	23.34	23.27	20.67	20.89	21.70	20.13	19.71	20.62	21.34
2010	20.24	21.38	21.25	22.73	23.02	22.33	20.42	20.86	20.67	20.96	19.68	18.72	21.02
2011	20.01	21.19	21.87	23.43	23.22	21.99	20.47	19.99	20.46	20.31	20.45	18.42	20.98
2012	19.76	20.29	22.47	22.57	23.83	22.49	19.55	20.05	20.14	19.77	20.45	19.55	20.91
2013	19.49	20.69	22.53	22.91	22.44	21.96	19.89	20.23	20.60	20.20	20.17	18.63	20.81
2014	19.75	21.67	22.23	22.92	22.50	22.73	21.28	20.42	20.74	19.88	20.09	18.65	21.07
2015	18.93	21.46	23.08	23.60	25.85	22.88	21.94	22.10	22.00	22.30	21.10	20.78	22.17
2016	21.60	21.83	24.87	23.67	22.78	22.24	20.90	22.10	21.65	21.06	20.26	19.10	21.84
2017	18.60	21.73	23.05	23.75	23.20	23.68	21.09	21.29	21.29	21.28	19.80	17.70	21.37
2018	19.27	21.55	22.11	22.32	22.74	21.67	21.02	21.66	21.29	21.28	19.80	17.70	21.03
Mean	19.69	20.90	22.09	22.33	22.61	21.74	20.20	20.26	20.50	20.26	19.62	18.94	20.76

Appendix 2: List of photos

Photo 1: Katar river fall at Fite

Photo 2: Zeway metrological station


Photo 3: Bathymetric data field measurement at Lake Zeway

Photo 4: Field data collection at Lake Zeway

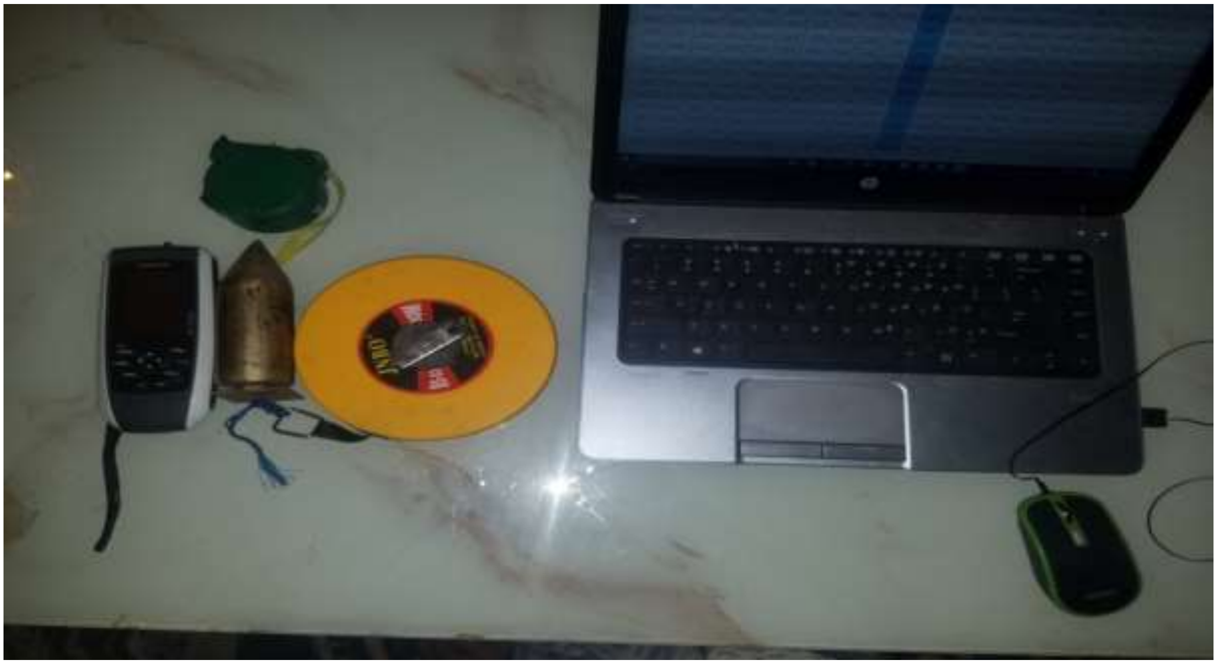
Photo 5: Bathymetric survey data collection tools

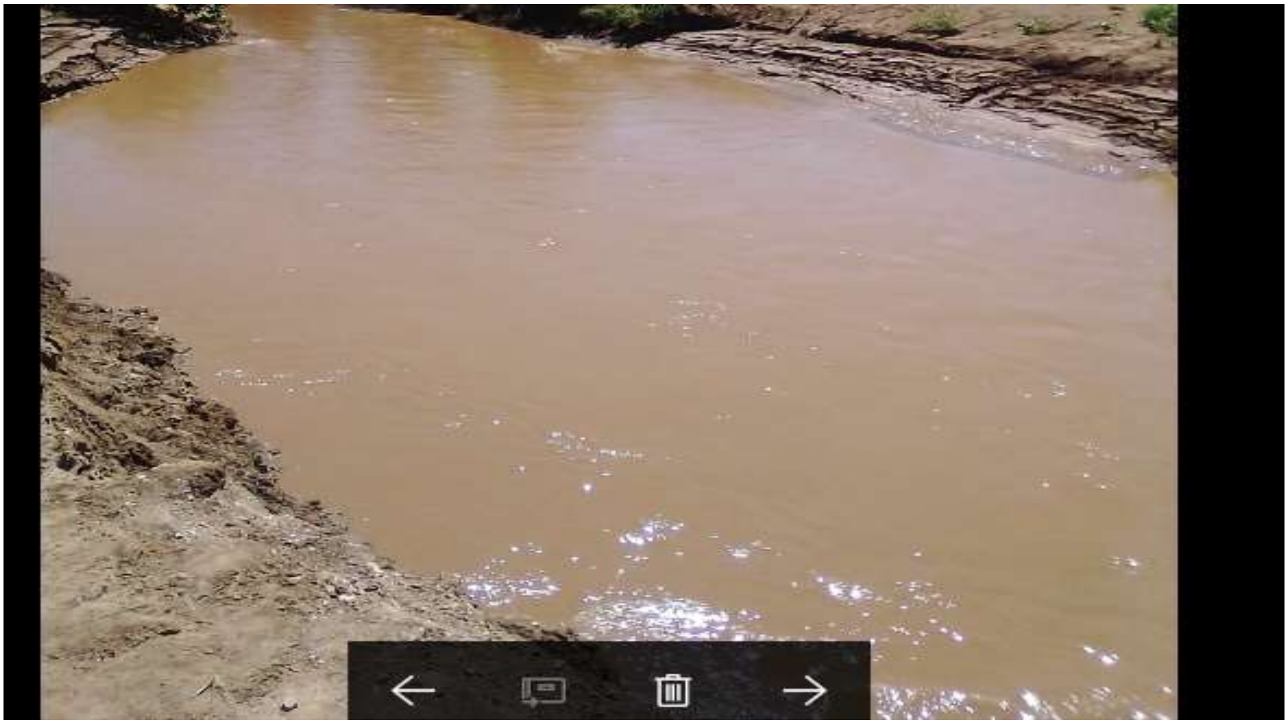

Photo 6: Maki river inflow

Photo 7: Integrated use of Lake Zeway

Photo 8: Small scale irrigation farm

Photo 9: Katar gauging station at Abura

Photo 10: Zeway Lake level gauging station at karkarsitu

Photo 11: Drainage disposal at share Ethiopia to the Lake Zeway