Addis Ababa University

School of Graduate Studies

Addis Ababa Institute of Technology

The Impact of Existing and Proposed Irrigation scheme on Hydrology of lake Ziway

A thesis Submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Master of Science in Civil & Environmental Engineering

(Major in Hydraulic Engineering)

By

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Approval by Board of Examiners

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Advisor	Signature
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Internal Examiner	Signature
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External Examiner	Signature
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Chairman (Department of Graduate Committee)	Signature

ABSTRACT

Lake Ziway is located in Oromia Regional State near the Town of Ziway some 150 km south of Addis Ababa at the northern end of the southern Rift Valley. The lake covers an area of some 450 km^2 at its average surface level of 1,636.12 m and has a maximum depth of 8 m. The two major rivers flowing to the lake are Meki and Katar Rivers and there is Bulbula river as an outflow from the lake. The Lake is important water resource in the study area beside its importance; the level of the lake has changed dramatically over the past decades due to the rapid change of inputs and output components of the lake water balance.

To alleviate the existing development constraints, the national government of Ethiopia has designed region based irrigation development polices and strategies, from this development the one which needs more attention is the Ziway-meki pressurized irrigation development project which planned to irrigate a gross area of 15500 hectare (net 14657.2 ha) land.

This study is conducted to determine **water balance** of Ziway lake based on the available water balance components and by considering existing and proposed **irrigation** scheme of the Ziway-Meki irrigation project by creating different scenario to reflect the different stage of irrigation development and variation in the river flow patterns that flow to and out of the Ziway Lake and the rainfall pattern within the Ziway Lake basin. The water balance was formed on the basis of excel spreadsheet which handles all the inflow (from rivers and runoff alongside the lake shore) and outflow patterns from the lake (irrigation and water supply need and Bulbula river).

The water balance was basically seen via the lake water level by applying existing abstraction and proposed irrigation scheme of 14657.2 ha land. From the result of water balance model the lake drops its level from the full level (1638m) by 0.568m from September to august of which 0.33m is by the existing irrigation scheme and 0.238 m drop is due to inflow rivers variation. From model result the existing abstraction and the total irrigation area of 14657.2 ha decreases Bulbula outflow by 20 m3/s of which 17.51 m3/s due to the proposed scheme. Such yearly variation would result in a drastic decrease in Lake water level and Bulbula river flow in upcoming years.

DECLARATION

I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a Thesis entitled: Impact of existing and proposed irrigation scheme on hydrology of lake Ziway and here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements of the degree of Masters of Science in Hydraulic Engineering.

Name: Daniel Fekadu

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Date: _______________

Place: Addis Ababa Institute of Technology, School of civil and Environmental Engineering,

Addis Ababa University

DEDICATION

This Thesis is dedicated to my Father

Fekadu Tesfa

And

My Mather

Tikikil Tesfa

ACKNOWLEDGEMENT

First of all, I would like to thank the almighty God for giving me the strength to complete my thesis and passed every challenge of life.

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ABBREVIATIONS

a.m.s.l	above mean sea level
WWDSE	Water Works Deign Supervision Enterprise
C	Runoff Coefficient
EMA	Ethiopian Mapping Authority
ETo	Potential reference evapotranspiration
FAO	Food and Agricultural Organization
ha	hectare
hr	hour
min	minute
km	kilometer
km^2	Kilometer square
kWh	Kilowatt hour
m	meter
mm	millimeter
MMC	Million m^3
MWR	Ministry of Water Resources
m^3/s	cubic meters per second
NMA	National Meteorological Agency
USBR	United States Bureau of Reclamation

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Lakes plays a vital function at various times and for different purposes such as water for hydropower generation, irrigation, water supply, mitigating disastrous environmental effects and impacts, as well as ensuring flood mitigation and as an insurance during periods of drought etc.

Ethiopia is gifted with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance. However, this resource is unevenly distributed both in space and time.

The uneven distribution of water makes it finite and scarce resource. So water must be managed in a sustainable way to meet human as well as ecological needs. In the absence of proper water resources management, it is inevitable that the existence of the resource will be questioned by shortage, and then by the depletion.

The Ethiopian Rift is part of the Great East African Rift Valley, which extends from Jordan in the Middle East, through Eastern Africa to Mozambique in Southern Africa dividing the highland of central Ethiopia.

This study has been conducted on the lake Ziway catchment located within the central main Ethiopian rift valley. Lake Ziway (7°55'N and 38°43'E) is a turbid freshwater lake situated in the most northern section of the Central Ethiopian Rift Valley. The area is found in semi-arid climatic region, which is characterized by scarce precipitation and associated shortages of water resources. Even though the area is found in the water stressed region, water availability was not an issue before couple of decades. During those decades, much of the area was covered with natural vegetation and the lakes were protected from large-scale human interferences. However, the fast growing population has since induced the expansion of farmlands, increased deforestation, overgrazing, irrigation and fishing activities. This trend is intensively continuing.

Lake Ziway is fed principally by the Katar & Meki Rivers. Katar river and its tributaries drain the highland area of Chilalo to the south and east of the Lake. From the north- west

Lake Ziway receives the flow of Meki River, which may in some years be intermittent. The Meki drains the Gurage Mountains & swamps to the south of Butagira including Lake Tufa. Lake Ziway overflows into Bulbula River and flows to Lake Abiyata

The majority of population of Ethiopia is dependent on rain fed agricultural production for its livelihood. However, estimated crop production is not close to fulfill the food requirements of the country (Lambisso,R, 2005).

Irrigated agriculture is a common practice around Lake Ziway, by pumping and diverting water from the Lake and from the rivers that flow into the lake. Previously water abstraction from Lake Ziway Was mainly by state farms, cooperatives and individuals. The intermittent rainfall in the Lake Region and the increasing population with increasing demand for water use undoubtedly Increase the pressure on the lake. Recently there are different agricultural activities in the vicinity of the lake shore going on which solely depend on irrigation by lake and river water abstraction with higher efficiencies than before. The blooming floriculture in Ethiopia mainly in the Rift Valley area is also a major concern to the lakes water level and water budget in the area. The previous irrigated state farm near the shore of Lake Ziway is currently running a large scale horticulture and floriculture greenhouse complex (before (2007) 35 greenhouses with an area of 315-420 ha) by a private farm (Tibebu, 2007).

1.2. Statement of the Problem

A large-scale irrigation development project is proposed around Lake Ziway for a gross area of 15,500 ha by abstracting water from the lake (ziway-meki agronomy report). The method of irrigation system to be developed is pressurized and surface irrigation system. The design strategy is on the basis of triangular model approach. That is, optimization of the engineering, the agronomy and the economic aspects.

The existing and proposed irrigation area is found on the lower terraces along the Western, North East sides of the lake and the lower lying parts of the Meki river delta. It is geographically situated at latitude of 888,000-905,000E and longitude of 474,000-498,000N UTMs. The altitude of the project area lies between 1636m and 1690m a. s. l.

According to the calculated crop water requirement data, from the total proposed irrigation scheme the net scheme covers area of 14657.2 ha land which will need water demand of 154.4MCM per year which is very huge and has great change on the water balance of the lake.

The practical problem related to the drying up of River meki and ketar and the shrinkage of the terminal Lake Ziway is a burning issue for local people. The underlying reason for deterioration of the basin is the water abstraction, does exceed the sustainable use. The annual flow volume series of Meki River are depicted although there is a substantial increase in the exploitation of Meki River tributaries for Irrigation,

According to ziway-langano-abiyata hydrology report (2007) total sum of surface water abstraction from the Ketar River and Meki River was in the order of 14.52MCM per year, which is used for irrigation and the existing abstraction from the lake was in the order of 19.43 MCM per year. This irrigational practice has an effect on the water level and budget of the lake.

From the Recorded data, Clearly understand the previous design assumption for the proposed irrigation scheme with respect to the two river flow distribution will not correspond to the reality after the design was completed.so this study will uses the latest data (2006-2014) to calculate the response of lake water balance and change in Bulbula River to monthly varying existing and proposed irrigation water demand.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this study is:

- To determine water balance of Ziway Lake based on the available data and by considering irrigation (Existing and proposed) scheme, so as to come up with defined cause of lake level fluctuation on monthly mean basis.

1.3.2. Specific Objectives

The specific objectives of this study are to:

- To quantify the various water balance components of the lake
- To assess the effect of water abstraction for irrigation (existing and proposed) scheme and other development project on the lake future hydrologic behavior.
- To assess how the impact on Lake Ziway affect the flow of Bulbula River.

- To recommend on the measures taken on the lake and river that protect from drying (to do not became below from the expected mean flow).

1.4. Research Questions

The detail research questions are as follows:

- How much of water used for irrigation purpose and for other development project that abstracted from the lake? And how irrigation abstractions affect the lake water level?
- How the lake water level variations affect Bulbula River flow?
- What Recommendations taken to use the water appropriately and to protect both the lake and the river from drying?

1.5. Significance of the Study

This research paper focuses on the determination of the water balance of Lake Ziway and lake level by considering different input and output of the lake. Especially the research focus on the current existing and proposed irrigation scheme which abstract huge amount of water from the lake that influence the water budget and level of the lake.so this information is must be updated and give real probability forecast for future depend on the latest data. Then the study used for the decision maker, investors as well as for the community to use the water properly by knowing the level.

1.6. Scope of the study

In this study the water balance is done in two different input and output data those recorded previously for long period (years) and currently for short period (years). But this research focus on mean monthly water balance of the lake based on latest data. There may be difference in considering long term mean and short term mean hydro metrological data. Since there is a significant difference between the two data system, observing the irrigation impact with the current data is necessary to have correct information about the lake and Bulbula River.

In this study the impact of irrigation will assess by assuming the climate change will remain the same at future time horizons. However, in real world the climates change.

CHAPTER TWO

2. DESCRIPTION OF THE STUDY AREA

2.1. Location

Lake Ziway is located in Oromia Regional State near the Town of Ziway some 150 km south of Addis Ababa at the northern end of the southern Rift Valley. The lake covers an area of some 450 km^2 at its average surface level of 1,636 m and has a maximum depth of 8 m. The two major rivers flowing to the lake are Meki and Katar Rivers. Meki River originates from Gurage Mountain at an altitude of about 3000m drains a total area 2,300 km^2 while Katar originates from Arussie highlands at an altitude of some 4000m drains a total area of 3,400 km^2. Apart from the Meki and Katar, Lake Ziway has its own Catchment covering about 1,700 km^2.

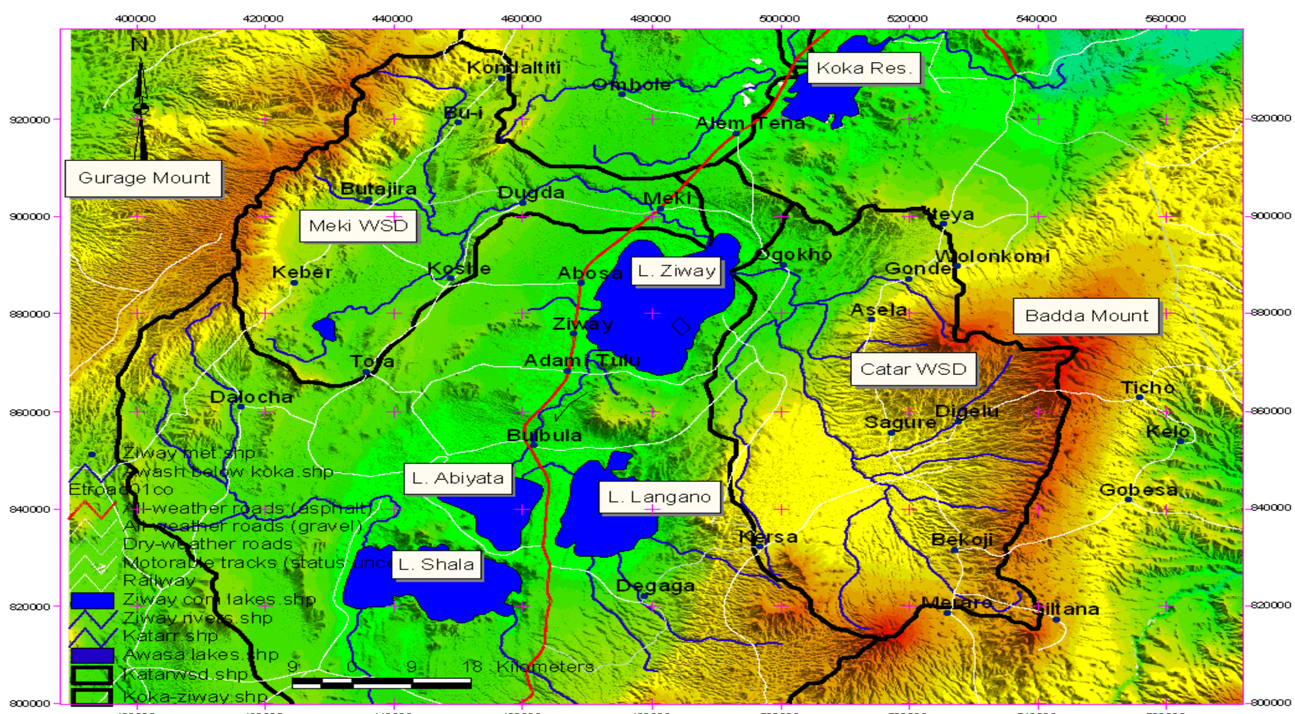


Figure 2.1 the location of the lake and the project area

2.2. Climate

Generally, the study area around the Lake is characterized with semi-arid climate where, in most of the cases rainfall doesn't exceed evaporation. The Lake Catchment has a wet season from July to September, a dry season from October to January and a season of highly variable rainfall from February to June.

2.2.1. Rain fall

The area receives bi-modal rainfall with erratic distribution and therefore, the bi-modal pattern of the rainfall is not consistent. The mean monthly rainfall of the area varies from a minimum of 3.6 mm in December to a maximum of 150 mm in July. The main rainy season (meher) lasts from end June to September and the highest amount of rain is recorded in July & August whereas the short rainy season starts in February and ends in end May.

2.2.2. Land Use

Appropriate land use policy and system of its practical application is an essential part of land use management. However, the study woredas have no systematic and technically supported land use system. According to the data taken from each woreda rural development and agriculture office, the land use pattern for Ziway Dugda includes: - cultivated land, 30,689ha, grazing land, 26,958ha, forest, 1800ha, water bodies 33,758ha, waste land 3,920ha, road &construction 2,343ha that makes the total area of the woreda125, 100ha and for Dugda bora woreda cultivated land 65,874ha, grazing, 36,700ha, forest land 20,191ha, water bodies 13,038ha that makes the total area of the woreda 146,800ha. Currently Dugda bora woreda is divided in to bora and Dugda woredas and the land use for each woreda is not yet specified.

2.2.3. Temperature

The mean daily temperature at Ziway is 20.3 ^{0}C. The highest temperature occurs between March and June prior to the start of the main rainy season. The minimum temperature in the dry season is 11.4 ^{0}C falling in December, though seasonal variation in daily temperature is relatively slight. Spatial variations in temperature are largely results of differences in altitude. Mean daily temperatures fall with increasing altitude at a rate estimated to be within the range 0.55 – 0.65oC per 100 m, though the lapse rates are not uniform and actual temperature variations depend on exposure and seasonal weather characteristics.

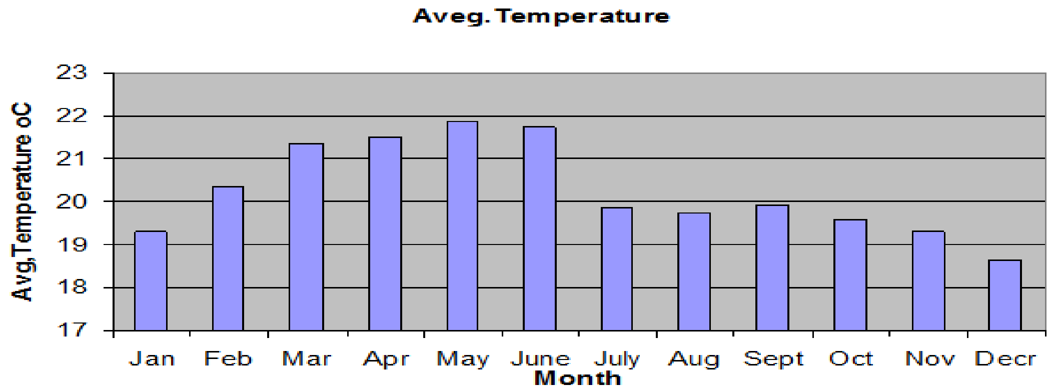


Figure 2.2 Average temperature at the study area

2.2.4. Relative Humidity

The highest humidity occurs in the wet season, and the least in February and March. Throughout the dry season and generally between 12:00 and 15:00 hours, the relative humidity falls below 64.2%. When there is also marked diurnal variation. The Ziway data seems to overestimate the natural relative humidity due to the fact that the meteorology station is located near the lake.

2.2.5. Wind

Strong and persistent daytime winds are significant feature of the lake Ziway area. During the afternoon in the dry season, the prevailing northeasterly winds are reinforced to the west and south of the lake by local on-shore airflow. Wind speeds are measured in the study area at Bui, Meraro and Ziway. The mean wind speed is relatively high, averaging 1.19 m/s throughout the year (measures by cup-counter anemometer at 1m above the ground level). The windiest periods are November-January and immediately preceding the main rains in June.

Table 2.1 Average monthly climatic data in the area

Climatic data	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	15.8	35.9	52.8	72.7	68.8	76.6	150.9	132.6	88.8	35.8	8.1	3.6
Mean max. tem(c^o)	26.2	27.4	28.2	28.2	28.6	28.7	25	25	25.9	26.7	26.3	25.9
Mean min. tem(c^o)	12.4	13.3	14.5	14.8	15.1	14.8	14.7	14.5	13.9	12.8	12.3	11.4

Humidity(%)	67.4	65.7	66.1	67	68.3	69.5	76	77.1	74.7	66.6	64.2	65.8
Mean daily Wind speed (km/hr)	6.5	6.8	6.1	6.1	7.2	9.3	8.6	7.6	5.4	5.7	6.5	6.8
Sunshine(hrs)	9.5	9.4	8.4	8.4	9.1	8.4	6.4	6.7	7.1	9.1	10.2	10.1

2.3. Population

Based on the 1994 population and housing census Report of the central statistics Authority on Oromia, the estimated population of the wordea in 2003 was 104,093. The urban populations constitute 3.2% and the rest rural population was showing small urbanization of the woreda. Among the total population, female population shares 50.28% and the remaining percent goes to male population. The crude density of the population to the woreda area in average was 83 persons per km2. The woreda sex ratio is estimated to be 99 males per 100 females. In its age group of 0-14 the ratio is 103 males per 100 females and it is 92 males per 100 females. The household size average is 5.2 per family. The dependency ratio of the woreda is 106.

Table 2.2 Population projection from 2006 to 2020 GR is the national average for both urban and rural, 1994 CSA.

Ziway Dugda Woreda				
Woreda population				
	Total		95,830	
	Male		47,179	
	Female		48,651	
Urban			Rural	
Total	3,188		Total	92,642
Male	1,568		Male	45,611
Female	1,620		Female	47,031
Year	Urban	Rural	Total	
2006	3,188	92,642	95,830	
2007	3,319	94,708	98,027	
2008	3,455	96,820	100,275	
2009	3,597	98,979	102,576	
2010	3,745	101,186	104,932	

2011	3,899	103,443	107,342	
2012	4,060	105,749	109,809	
2013	4,226	108,108	112,334	
2014	4,400	110,518	114,919	
2015	4,581	112,983	117,564	
2016	4,769	115,503	120,272	
2017	4,965	118,078	123,043	
2018	5,169	120,711	125,881	
2019	5,382	123,403	128,785	
2020	5,603	126,155	131,758	

2.4. Water Resource

The surface water resources in the project area mainly depend on perennial rivers, which originate from the highland areas. The rivers are characterized by lower and medium dry season flow, so it is possible for small/medium/large scale irrigation through small storage, reservoir or diversion weirs in conjugation. The typical example for this irrigation is Katar River.

2.5. Soil

The common soil types exposed in the project area are fine to coarse sand, silty clay and silty sand/silt to fine sand/fine sand. These soils are intercalating each other with variable thickness and lateral continuity. Some of thin layers are pinch out with in a short distance. Moreover, there is no general pattern of fining/coarsening upward sequence.

2.6. Irrigation Development in the area

There are many irrigation systems developed and to be developed by project level and under study and design level in all over the country. Raya and Ziway irrigation projects are examples of such irrigation projects under study in the country. Raya and Ziway irrigation projects are found in two distinct places, but carried under Ziway and Raya project office under WWDSE in A.A.

Ziway project is located in Oromia Region in East Shoa and Arsi Zones. The water source is Lake Ziway. The total command area is 18,000 ha, but divided into two sites. Site one being in Dugda woreda in East shoa Zone.Site two is located in Ziway Dugda Woreda in Arsi zone.

2.6.1. Existing Development

Dugda is one of the 11 woredas of East Shoa Zone in Oromia Regional state. The woreda is found in the South western part of Dugda- Bora woreda, which has split into two different woredas known as Dugda and Bora in September 2007.

Dugda woreda lies relatively in plainly area favorable for agricultural practice. The woreda encompass south western part of Dugda-Bora where there is relatively no wide area of land occupied by mountains and hills.

In Dugda woreda irrigated agriculture under taken is dominantly small scale irrigation. It is performed mainly in 15 kebels of the woreda Covering total area of about 3, 685 ha. Out of the total area used for irrigation 500 ha (13.57%) is used for modern irrigation system and the number of beneficiary in this category are 1,385 and the number of modern pumps they use count 74. On the other hand 3,158 ha of land is used for traditional irrigation system and the number of households benefiting from this sort of irrigation practice are 2,331hhs. And the traditional pumps used for the traditional irrigation number 605.

According to Dugda woreda Irrigation Development Office, there are 774 households using the lake with 131 pumps to irrigate 597 ha of land.

About 289 house hold use rivers with 42 pumps to irrigate 388 ha of land. But the majority /2,653/ of the households use ground water to irrigate 2670 hectare of land.

The people using irrigation system have about 55 water users associations though they are usually weak in management and unlikely to benefit members to the level expected.

Irrigation practice in the woreda can be described as at lower stage as compared to the potential of the area. It is practiced mostly by using lower level local technology and effective and efficient utilization of the land and water sources is not undertaken based on proper studies.

In Ziway Dugda woreda there are numerous traditional irrigation schemes that irrigate a total of 5268ha of land with 959 pumps. Half of them (2800ha with 505 pumps) are found in the Lake Ziway water system.

The Woreda has a potential of 3326ha irrigable land. Currently, 894.25ha land has been developed through modern and traditional irrigations. According to the data obtained from the agricultural office, schemes that irrigate 175ha modern and 189.25ha traditional irrigations found in the project area are given in tables below.

Table 2.3 Existing Irrigation Developments (Source: Ziway Dugda Rural Woreda Agricultural Development Office).

S.No	Water source	Irrigable Area (ha)	Irrigation Type	Owner	Remark
1	Catar River	75	Gravity	Community	Modern
2	Catar River	32	Pump	Community	Traditional
3	Catar River	40	Pump	Private	Modern
4	Catar River*	65	Pump	Community	Modern
5	Chufa	100	Gravity	Community	Modern
6	Chufa	28	Pump	Community	Traditional
7	Goto/Bulbula	69	Pump	Community	Modern
8	Goto/Bulbula	70	Pump	Community	Modern
9	Goto/Bulbyla	40	Pump	Private	Modern
10	L.Ziway	81.25	Pump	Community	Traditional
11	L.Ziway*	170	Pump	Community	Modern
12	L.Ziway	76	Pump	Private	Modern
13	Ground water	48		Community	Traditional
Total		894.25	* To be operational		

2.6.2. Planed Development

As parts of the designed polices and strategies, Ministry of water resource has planned to undertake large-scale pressurized irrigation feasibility study in and around Lake Ziway of oromia region. Water works design and supervision enterprise (WWDSE), which is the leading consultant, in association with Concert Engineering and Consulting Enterprises PLC, has been commissioned to undertake the study. The planned Ziway irrigation is (sprinkler and/or drip) based system, which required less water per hectare of irrigated land (except greenhouse).

The proposed irrigation development is located in these two woredas, viz. Ziway Dugda and Dugda, as it is justified by the previous studies and field verification. Out of the total proposed irrigable land, 75% is found in Dugda woreda and the rest in Ziway Dugda Woreda.

The main objective of the planed irrigation project is to ensure food security at local level and to produce industrial raw material and export crops through development of sustainable irrigation systems using water from Lake Ziway.

CHAPTER THREE

3. LITERATURE REVIEW

3.1. General

3.1.1. Water balance and lake level

The level of water losses, both real and apparent, is one of the most important efficiency issues for water Utilities across the world. One would assume that accurate performance indicators are used for benchmarking, international performance comparison, or target setting for internationally funded projects. But unfortunately this is widely not the case - utility managers, consultants and the International Lending Institutions continue to use a very inappropriate indicator when talking about water losses.

In the mid-nineties the IWA Operations and Maintenance group has started its work on best practice Performance indicators. Part of these efforts was a standard water balance - a very important issue as only an accurate quantification of water losses, both real and apparent, can form the basis for the calculation of appropriate performance indicators.

According to Steven Hostetler (March 27, 1999) the hydrologic budget of a lake reflects interactions between processes acting on many spatial and temporal scales. Understanding the interactions between these processes and identifying which processes exert the greatest influence on the water balance of lakes is essential for interpreting the detailed record of terrestrial paleo-climate change preserved in lacustrine sediments. In addition, understanding lake-atmosphere interactions is useful for anticipating the response of lake systems to various anthropogenic forcing, including enhanced atmospheric greenhouse gases and decreased lake inflow resulting from diversions of natural fiver water. Observational studies of lake systems provide important information about Lake Hydrology [e.g., Changnon and Jones, 1972]. However, a modeling approach is useful for Understanding interactions between lake and atmosphere processes and to assess how lake systems may respond to various forcing. Physically based models are only useful if they accurately portray the various climatic and hydrologic processes that influence lake systems.

Sharon E. Nicholson (et al) stated the numerous lakes of East Africa are important indicators of climatic and environmental change. Sediment cores bear evidence of changes over geological time and historical witness of the lakes provides a wealth of information about fluctuations on time scales of centuries. Because the lakes' fluctuations register the pulse of rainfall variability in the equatorial tropics.

The interpretation of the past history of the lakes in terms of climate is a complex problem. The lakes integrate conditions over large and diverse regions and, together with the surrounding topography, they produce regional-scale climates that are superimposed upon and interact with the large-scale patterns. Also, the conversion of lake level changes to rainfall depends on the relative magnitude of the water balance terms, as well as on lake geometry and basin characteristics. Thus, the climatic interpretation of the lakes' histories requires a rigorous understanding of the water balance of each lake.

Increased demand for water associated with population growth has heightened the importance of proper Management of limited water resources. Most of groundwater aquifers and surface water reservoirs are connected to one another; therefore, the use of one can affect the quantity and quality of the other. It is perhaps because of this reason that water resource managers have taken considerable interest in quantification of the interaction of surface water and ground water (Moench and Barlow, 2000). Incorporating the role of bank storage flow is important for gaining insight into the surface water quantity and quality dynamics through a water body system.

3.2. Diversion

According to Brian P. Neff and J.R. Nicholas in their study of great lake level fluctuation, diversion of a lake is two types. The first is diverting water body from other source by using different conveyance structure to the studied lake body (inflow to the lake), and the second is diversion from the lake to other area by using diverted structure or by using pumps (outflow from the lake) for different purpose such as water supply, irrigation, hydropower etc. This amount of diverted water has great influence to determine the lake level fluctuation and water budget.

3.3. Types of water balance model

3.3.1. Simple water balance for a lake

The water balance equation for lakes at any time interval is a continuity equation. According to the law of conservation of matter, there is equilibrium between inflow components, outflow components and the change of water volume for each interval of time. This equilibrium is described by the water balance equation (UNSECO, 1974):

$$IS + IG + PL - EL - OS - OG \pm A = \Delta S \quad \text{(3.1)}$$

Where

IS= Surface inflow into the lake (ISg and ISug)

IG = Ground water inflow

PL = precipitation on the surface of the lake

EL = evaporation from the lake

OS = surface out flow from the lake

OG = Ground water outflow from the lake

± A = Abstraction (agricultural, industrial etc.)

ΔS = change in the water storage in the lake for the balanced period.

Water balance formulation is a multi-step process that results in the identification and quantification of the model's components. Thus, the forecast model is formulated through a quantitative assessment of the inflows (precipitation on Lake Surface and runoff - gauged and un-gauged), outflows (evaporation and groundwater outflow) and storage changes within the lake. The steps should include the specification of the water balance "free-body," time interval, and base period (Hayes et al., 1980 and Peters, 1972) so that the components are properly identified (Winter, 1981).

3.4. Existed and proposed irrigation scheme

From agronomy report in most developing countries including Ethiopia, agriculture is the basis of economy for the people. However, this occupation is largely dependent on natural rainfall that usually varies from year to year and from place to place, depending on whether conditions, sometimes there is a high rain fall, while at other time there is a shortage which has direct impact on rain fed agricultural production.

As parts of the nation, Oromia Region shares equally this production failure. Farmers in the region practices mixed farming where they raise crops and rear animals. In general the annual GDP/ gross domestic product/ and export earnings are based on crop sector. However the production capacity of these sectors is lagging behind the actual demand of the nation.

On the other hand, the natural resources potential (water resources, land resources, animal resources, etc) in most part of the region particularly in the study area is comparatively immense. If properly developed, managed and optimally utilized, these resources can possibly bring rapid and sustainable development to the region and subsequently better economic contribution to the national economy. To realize this, therefore, transformation from the present highly subsistence, unproductive and extensive based farming culture to more intensified, diversified, modernized, and integrated socio-economic system is now timely and crucial. To alleviate the existing development constraints, the national government of Ethiopia has designed region based irrigation development polices and strategies from this development the one which needs more attention is the meki-Ziway irrigation development project which planned to irrigate a gross area of 15500 hectare land.

3.4.1. Water abstraction / demands/

To determine the irrigation requirement that abstracted from the lake computing crop water requirement is necessary. The method adopted for computing the crop evapotranspiration is the procedure outlined in the revised version of cropwat window 4.3 methods. Using this method and climatic data of Ziway station, the estimation of E_{TC} (crop water requirement) for each crop is undertaken first by taking the reference crop evapotranspiration /ET_O/ then applying suitable crop coefficient /Kc/. The crop water requirement of the pattern of crops of this project was calculated by considering the following basic formula.

$$ET_C = K_C . ET_O$$

Where: - ET_C: - crop water requirement mm/day

K_C: - Relating coefficient of ET_C and ET_O

ET_O: - Reference crop evapotranspiration mm/day

Crop Coefficient /K_C/

The effect of plant characteristics on crop water requirement is accounted by crop coefficient (K_C). The K_C values relate to the evapotranspiration of disease free crops grown in a large field under optimum soil water and fertility condition, achieving full production potential under a given growing environment (FAO irrigation and drainage paper Vol. 24). Thus the correct estimation of ET_{crop} from reference evapotranspiration /ET_O/ depends on the accuracy of K_C values adopted. For this project all K_C values are taken by considering ET_O of the study area and referring FAO irrigation and drainage paper Vol. 24 and 46.

Table 3.1 proposed K_C values of proposed crops

Crop Type	K_C Values			
	1st	2nd	3rd	4th
Maize	0.30	-	1.1	0.8
Sweet corn	0.30	-	1.1	1.05
Chick pea	0.4	-	1.1	0.95
Green beans	0.35	-	1	0.85
Broccoli	0.4	-	1	0.8
Papaya	0.65	-	1	0.8
Tomato	0.45	-	1.05	0.8
Onion	0.45	-	1	0.85
Pepper	0.4	-	1.05	0.8
Eggplant	0.45	-	1.05	0.8
Watermelon	0.45	-	0.98	0.8

Table 3.2 crop water requirement

Season	Month	ETc(mm/d)
Dry	January	5.5
	February	3.7
	March	2.3
	April	2.8
Wet	May	1.7

	June	2.2
	July	1.5
	August	1.0
	September	1.4
Dry	October	3.7
	November	3.6
	December	4.0

According to Butajera-Ziway area development project by ministry of water resource (2008) the project area has a wet season from July to September, dry season from October to January, and a season of highly variable rainfall from February to June. The climate of the area around Lake Ziway has arid characteristics for most of the year. However, the climate becomes more humid with increasing altitude on the rift valley flanks constituting the catchments of rivers draining into Lake Ziway. Over 50% of the annual rainfall is received during the 3-month wet season, rainfall distribution is variable and long dry periods are common. The wet season winds are generally southeasterly or south-westerly, depending on the location of low pressure convergence zone towards the north of the country.

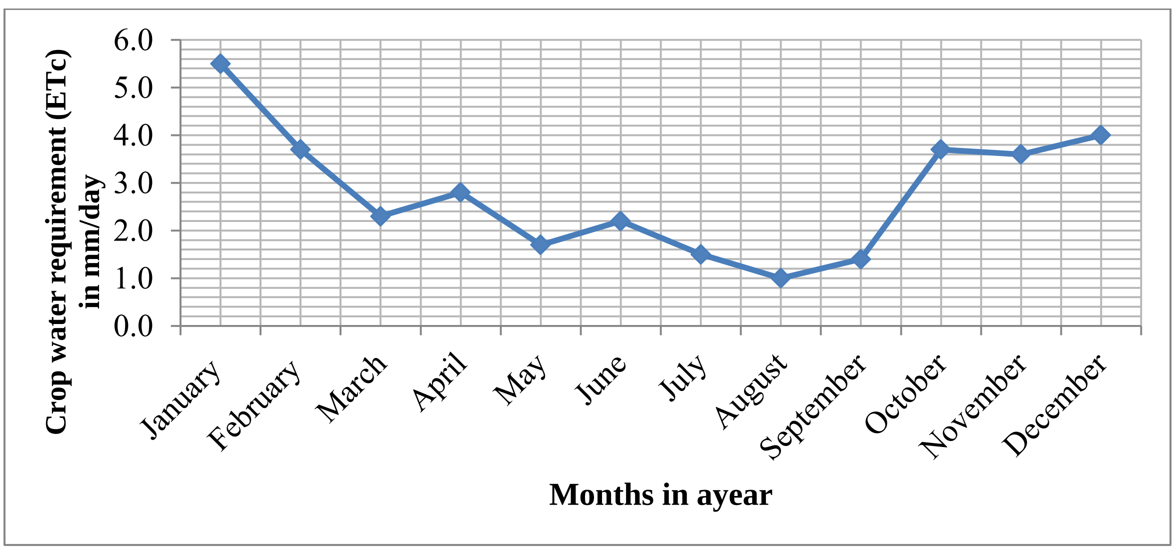


Figure 3.1 Monthly Crop water requirement of the irrigation area in (mm/day)

The water demand is one of the important engineering design data. The maximum daily water demand or maximum daily deficit data provided by the agronomists (from agronomic report) was adopted by the engineering design group for irrigation system designs.

The irrigation application efficiency (E) is very important factor for calculation of the application of the gross irrigation portion (G.I.P).

$$D = G.I.P = \frac{N.I.P}{E}$$

Where:

G.I.P= Gross daily irrigation portion or gross daily depth of application, D (mm)

N.I.P= Maximum daily deficit or net daily irrigation portion (mm)

E = Irrigation efficiency of the system (fraction)

E=0.8 -0.9 ---→pressurized systems

E=0.6 ---→surface systems (furrow)

For all hydraulic computation, the water demand of each plot is estimated and determined based on the following formula.

$$Q = 10\frac{AD}{\Delta T}$$

Where,

Q = Discharge to each plot (m^3/hr)

A = Plot area (ha)

D = Maximum daily crop water requirement (mm)

ΔT=maximum daily pumping hour

The total maximum water to be withdrawn from Lake Ziway is a limiting factor for the design of the whole irrigation system. The value of this limiting factor has not been changed when a decision is made to shift from pressurized irrigation system to furrow irrigation system. Only the total irrigable land area is adjusted for the furrow irrigation system (Phase-I) for total irrigation efficiency of 60. Then the adjusted maximum discharge (Q_m) values of the sub-sub-areas at the critical operation points are summed up to determine the maximum pumping capacities of each pumping points. The computation has been done by accounting the revised plot area (A), the maximum daily deficit (D), and maximum daily pumping hours at the critical irrigation day, T. In revised phase-I project, the maximum irrigation water demand values have been estimated for a maximum daily deficit value of 5.50mm, a maximum of 18 hours pumping, and total irrigation efficiency of 60%.

According to the Hydrological Study carried out in previous Phase I following an assessment on the lake water balance, the proposed irrigation area is the same as in Phase-I Pressurized, Known as A-3. It is situated on the lower terraces along the Northern side of the lake and the lower lying parts of the Meki river delta. Geographically, it is located at 893,000-902,000 latitude and 481,000-490,000 longitude. The altitude of the project area lies between 1636m and 1670m a s l

The project area encompasses plots in Kebele 2, Kebele 3, Kebele 4 and Kebele 9. It consists of totally 45 plots. During the first phase gross area of 3870 ha (excluding swampy areas) and net 2635ha in the design was designed considering fully pressurized irrigation system. Now in furrow irrigation application keeping the stated application efficiency, this net 2635 ha irrigable area becomes reduced to 1900 ha. Therefore the assignment of revising the pressurized detail design (Phase-I) shall be carried out on this area, 1999.7 ha.

In addition to 1999.7 ha of furrow irrigation system additional 1775 ha of land is cultivated based on pressurized system (both by sprinklers and drip system).Finally in first phase irrigation scheme a total of 3774.7 ha land will cultivated and the water demand is determined.

In second phase and third phase of the proposed irrigation scheme 4668.5 and 6214 ha of land will cultivated, this land division is based on the capacity of the adjusted pump system of the plot, operational time of the pump, crop water requirement, the amount of the plot (area) to be irrigated and taking efficiency of irrigation system as (0.8-0.9) the water demand of the area is determined and applied for the water balance system.

In addition From Meki and Katar river about 4.7 Mm^3/year and 9.8 Mm^3/year are diverted to irrigate 388 ha and 856 ha respectively but this irrigation area is found at upstream side from the gaging stations of the rivers so the water balance only take the data that recorded at the station. Water supply demand of Ziway town and Ziway shere flower pumped irrigation is also taken into account.

3.5. Previous work

These basins are extensively and separately studied by different researchers. Among the works, Climate Change Impact on Lake Ziway Watershed Water Availability of Ethiopia Lijalem Zeray (et al 2007),management of lake Ziway fisheries in Ethiopia Felegeselam Yohannes (2003) ,ground water flow system and hydrochemistry of Ziway corroder in the main Ethiopian rift Abiyu Kebede(2007), Effects of Irrigation Practices and Lacustrine Aquifer Development on Water Availability in Ziway-Abijata Corridor Tibebu Terefe (2007), Zooplankton community structure, population dynamics and production and its relation to abiotic and biotic factors in Lake Ziway Ethiopia Adamneh Dagne (2010).

In addition to the above researchers, more valuable works related to the Ziway Lake and its contributing rivers were studied in depth by different researchers as follow

According to ziway-abiyata-langano hydrology study (2007) the major study regarding Lake Ziway development was made in 1976 by Land Resources Division, Ministry of Overseas Development, entitled "Prospects for irrigation development around Lake Ziway, Ethiopia". The second significant study on the water resources of the Rift Valley was made by Halcrow & ULG in 1992 as part of the Reconnaissance Master Plan for the Development of the Natural Resources of the Rift Valley Lakes Basin.

3.5.1. Land Resources Divisions (1976)

According to this study observed that the headwater of **Meki river** starts at an altitude about 3 000 m, and rapidly descends the rift valley escarpment to below 2 000 m before being joined by several major tributaries, including the Lebu, the Akomoja and the Weja. Downstream of its confluence with the Weja, the Meki is incised in a steep-sided valley until it reaches Meki Town at the head of its delta. Thereafter, the Meki river meanders for 15 km between slightly raised natural levees through deltaic alluvium before entering Lake Ziway at an average elevation of 1636 m.

According to this study In an average year, the contributions to the Lake from the Meki and Katar rivers and from rainfall on the Lake surface amounts to 1500 million m^3, while the outflow through the Bulbula river to Lake Abiyata is 210 million m^3. About 940 million m^3 of flow is lost by evaporation from the Lake Ziway.

3.5.2. HALCROW and ULG (1992) Reconnaissance Master Plan for the Development of the Natural Resources of the Rift Valley Lakes

HALCROW and ULG (1992) indicated that in terms of the potential for water resources exploitation, Meki-Ziway-Abiyata sub-basin is considered a most important area in the Rift Valley. A water balance model showed that the estimated median inflow (or 50% exceedance probability flow) into Lake Ziway is 297 Mm^3 and 405 Mm^3 annually from Meki and Katar rivers respectively totaling 702 Mm^3 each year compared with an annual average of 721 Mm^3; median spill to Lake Abiyata is estimated at 82 Mm^3, the corresponding average annual volume is 121 Mm^3 and the annual surface water evaporation rate in the Ziway-Abiyata area is estimated at 2350 mm.

3.5.3. Meki irrigation and rural development Project in Oromia Region, Ethiopia by JICA and OIDA (2000)

According to ziway-abiyata-langano hydrology study (2007) This study was a comprehensive study on Meki irrigation and rural development by constructing a dam (about 40 m high) located 48 km upstream from Lake Ziway or a diversion weir on Meki river upstream of Meki town (alternative one 2.5 km upstream of Meki town and alternative two is about 2 km upstream of the confluence point of the Meki river and Deki river).

The water balance study linked with the Meki-Ziway-Abiyata system was carried out under alternative cases (i) proposed dam and (ii) diversion dam on the Meki river. The model was calibrated based on 1979-1999 data.

The result showed that Ziway lake storage will reduce by 2.3% with diversion scheme, and by 25.3% with dam of 40 m height. The study concluded that there is possibility of development of 3200 ha area with gravity for 110% cropping intensity on the Meki river (diverting about 23 Mm^3/year), and ruled out Meki dam based irrigation development.

3.5.4. Lake Abiyata study by Dagnachew and et al (2004)

Dagnachew et al (2004) made an analysis of the hydrological response of a tropical terminal lake, Lake Abiyata (Main Ethiopian Rift Valley) to changes in climate and human activities. The objectives of this paper were (i) to study the natural variability of lake level and salinity using dynamic lake water and chemical mass balance models coupled with catchment-scale hydrological modeling and (ii) to investigate the impacts of climate change and human activity on lake level and salinity by using sensitivity analysis. Lake Abiyata belongs to the Ziway–Shala basin (14,120 km2), which contains four lakes of decreasing elevation and increasing salinity (Lakes Ziway: 1636 m a.s.l., 9 m deep, 0.4 g /L; Langano: 1585 m a.s.l., 46 m deep, 1.8 g/; L Abiyata: 1577 m a.s.l., 10 m deep, 18 g /L; Shala: 1558 m a.s.l., 256 m deep, 19 g/L).

3.5.5. Assessment of Lake Ziway water balance by Amare (2008)

Amare (2008) made an assessment of water balance for lake ziway which is found in the main Ethiopian rift valley. According to this study In a year, the contributions to the Lake from the Meki river was about 277.8 MCM, the contributions to the Lake from Katar rivers was about 401.3 MCM, the contributions to the Lake from the runoff from the ungauged catchments considered in this study is only in the rainy seasons and the estimated amount is about 106.8MCM, lake Ziway areal rainfall was about 737.41mm while the outflow through the Bulbula river to Lake Abiyata is 161.3MCM and About 2019.2mm of flow is lost by evaporation from the Lake Ziway.

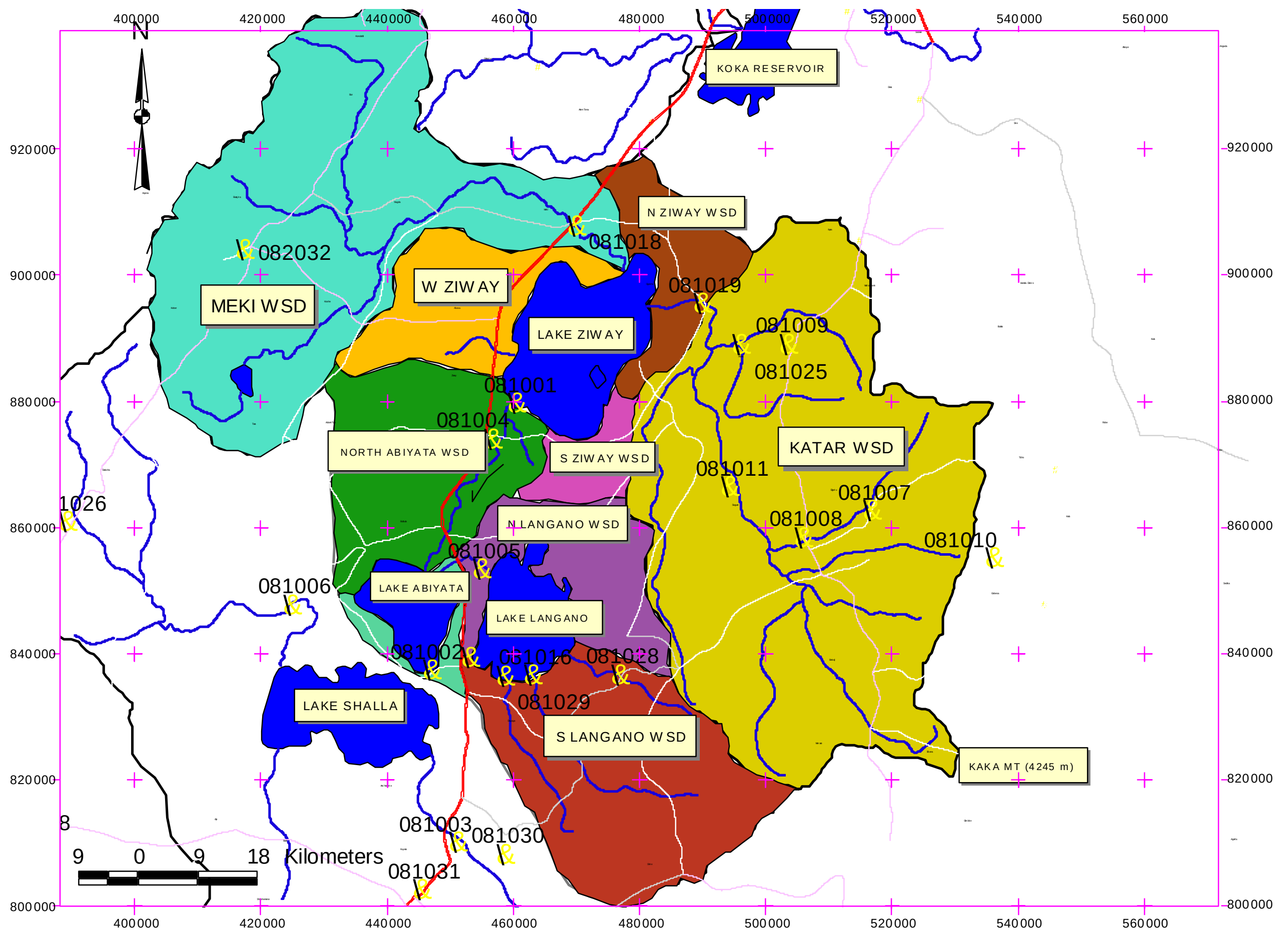
CHAPTER FOUR

4. HYDRO METEOROLOGICAL DATA ANALYSIS

4.1. Metrological data

4.1.1. Rainfall data analysis

The Ziway-Langano-Abiyata sub-basin (northern part of the Rift Valley Basin) is relatively well gauged as compared to middle and southern part. Figure 4.1- shows the location of these gauging stations with their corresponding delineated catchment area



Legends……………. X-metrological stations….. and……… O-discharge stations

Figure 4.1 Discharge and lake level gauging locations (ziway-langano-abiyata hydrology study))

Rainfall data from 27 stations in and around Ziway-Langano-Abiyata lakes sub-basin have been collected by national meteorological agency to make the irrigation scheme consistent. Their record length varies and nearly all stations have missing data(see figure 3.2).It must be necessary to fill this missing data by using appropriate method.to prepare the rainfalls data for further application of the lake and catchment water balance estimate.

The consistency of point rainfall measurement on the station is checked. Encoded data have been examined for obvious outlier (often caused by encoding error) using time series plot and some outliers have been removed after checking with original hard copy data(Ziway-meki hydrology report). Time series plot also used to identify non-stationarity of data, which are not found.

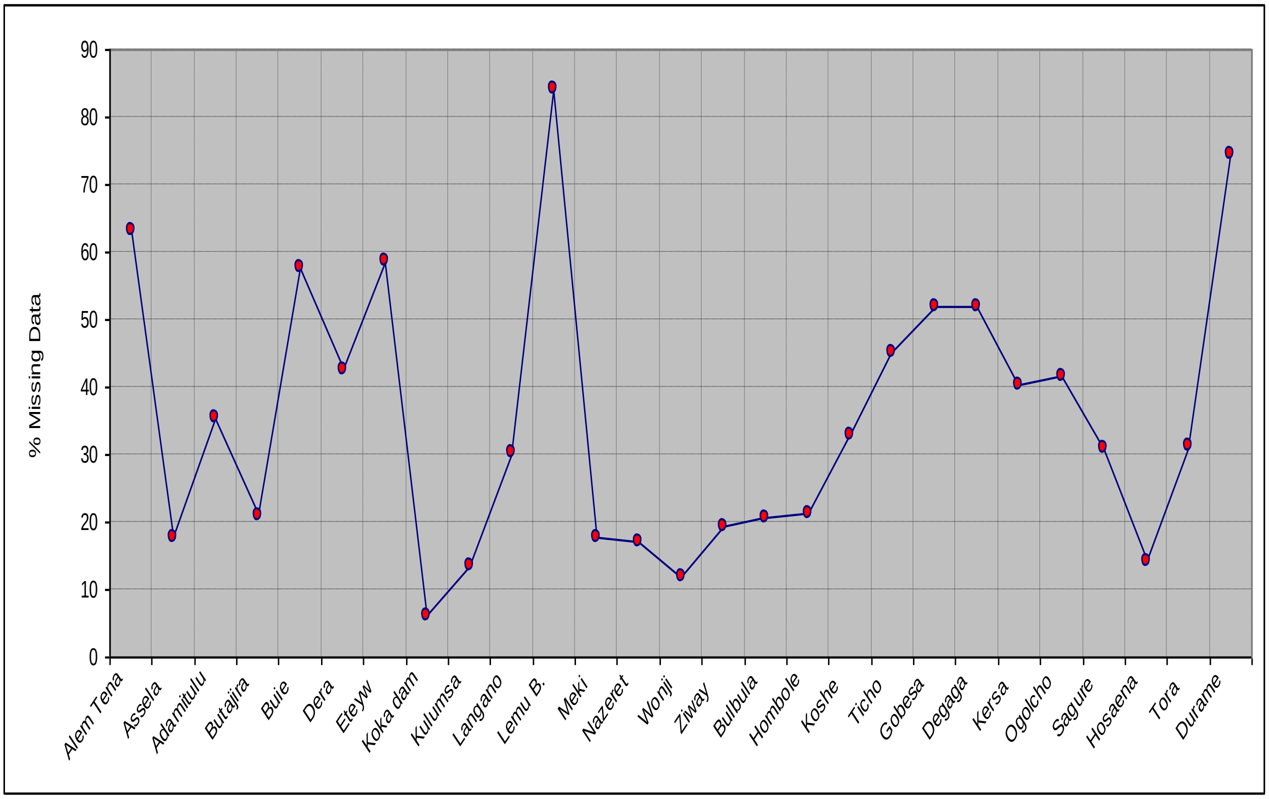


Figure 4.2 Percent of missing monthly data over the period 1963-2005(From Ziway-langano-abiyata hydrology report).

4.1.1.1. *Estimating Missing Data*

The rainfall amounts at a certain rain gauges for a certain months may be missing due to the absence of some observer, instrumental failures and mis-location of gauge station. In such cases, it is needed to estimate the missing rainfall amount by appropriate method.

There are different approach for estimating missing rainfall data this difference is based on the effect of orography on rainfall, distance between the rainfall station and the variation of rainfall recorded in the station.

The method adopted for computing the missing rainfall data for Ziway catchment is the Normal Ratio method which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10%. This method is used to fill in missing data on rainfall station in the study area since the difference in annual rainfall between most of the station exceeds 10% due to large elevation difference between the stations.

This method enables to estimate missing data by weighting the observation at G gauge number by their respective annual average rainfall value as expressed by equations

$$po = \frac{1}{G} * \sum \frac{Po}{Pg} * pg$$

Where po =the missing data

Po =the annual average precipitation at the gage with missing data

Pg =annual average of neighbouring station ,g

Pg =monthly rainfall data in station for the same month of the missing station

G =the total number of gages under consideration

After filling missing rainfall data checking consistency of data is done by double mass curve method. The double –mass analysis is a consistency check used to detect whether the data at a site have been subjected to a significant change in magnitude or not. If the data are consistent, the plot will be a straight line. On the other hand, inconsistent data will exhibit a change in slope or break at the point where the inconsistency occurred.

4.1.1.2. *Estimation of Areal Rainfall*

Rainfall is the lowest in the vicinity of the Lake. On the valley flanks and on hill masses, rainfall rises steadily with elevation. The rainfall characteristics show the symmetry of annual rainfall at the escarpments and rainfall decreases in the rift valley. The rift valley appears to be a rain shadow area.

The aerial depth of precipitation was estimated using arithmetic mean, Theissen Polygon and isohyetal methods.

If the rain gage station is uniformly distributed over an area, then a simple arithmetic mean of the point rainfall for each station could be sufficient to determine the areal rainfall over the Ziway lake but the rainfall station at assela is foun in higher elevation than other station, so rather than adapting arithmetic mean theissen polygon and isohyetal methods are adopted to determine the areal rainfall over the lake.

According to Amare (2008) uses theissen polygon method to determine the areal rainfall over lake Ziway, there are five rainfalls gauging station in the surrounding shore of the lake are selected. This are the rainfall station located at Ziway Town, Meki, Adamitulu, Arata and Ogelcho have been selected by virtue of their location with the lake, class and long period of observation consistency of the data base.by using the following equation

$P = (A_1P_1 + A_2P_2 + A_3P_3 + \ldots\ldots\ldots\ldots + A_nP_n)/A$

Where

$P_1, P_2, P_3 \ldots P_n$ represent rainfalls at the respective stations, and the

Surrounding polygons have areas $A_1, A_2, A_3 \ldots A_n$

Table 4.1 Thessien vs Isohyetes rainfall distribution over the project area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Thessien Rainfall(mm)	16.9	35.9	61.1	74.2	67.2	76.7	143	128.3	86.51	35.7	6.92	5.11
Isohyetes Rainfall(mm)	15.8	35.9	52.8	72.7	68.8	76.6	150.9	132.6	88.8	35.8	8.1	3.6

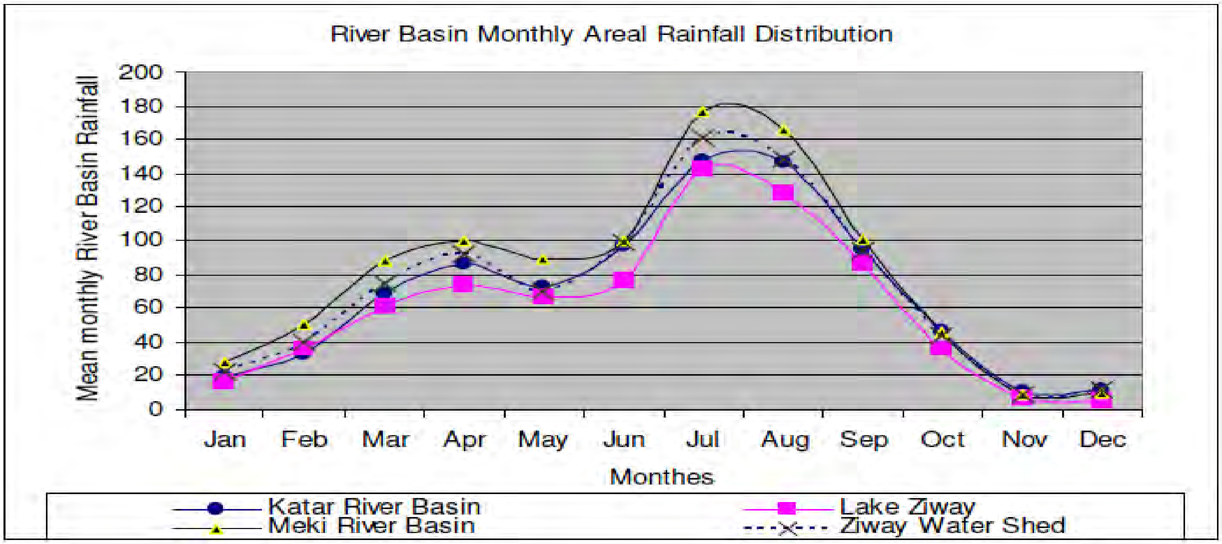


Figure 4.3 River Basin Monthly Areal Rainfall Distributions (from amare (2008)

But during studying the Ziway-meki irrigation scheme of the area the ministry of water resource consider the isohyetal determination of the areal rainfall over the lake by considering time series plot of monthly and annual rainfall for Key stations: Meki, Ziway, Bulbula, Assela, and Butajira. When low rainfall (1971, 1980, and 2002) and wet (1970, 1972, 1979, and 2001) years occur, this stations cover nearly the whole sub-basin (mountainous part to the lake and project area).

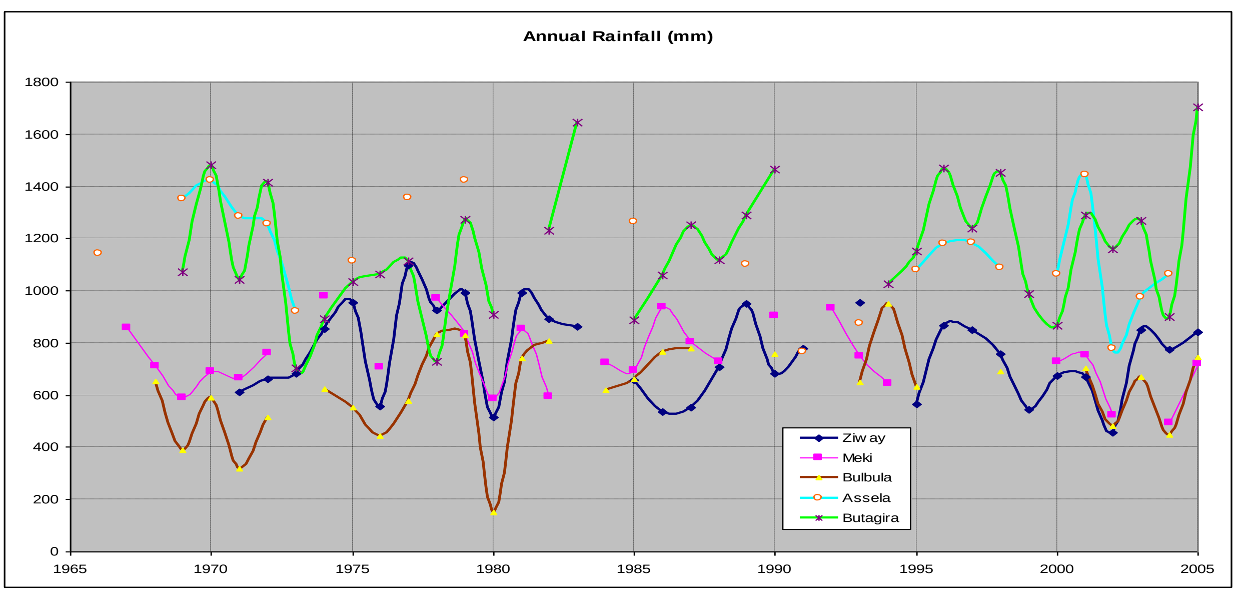


Figure 4.4 Time series of annual rainfall at Ziway, Meki, Bulbula, Assela and Butajira stations (from Ziway-langano-abiyata hydrology report)

Isohyets of annual, July, August and 75% dependable rainfall over the project area are given.

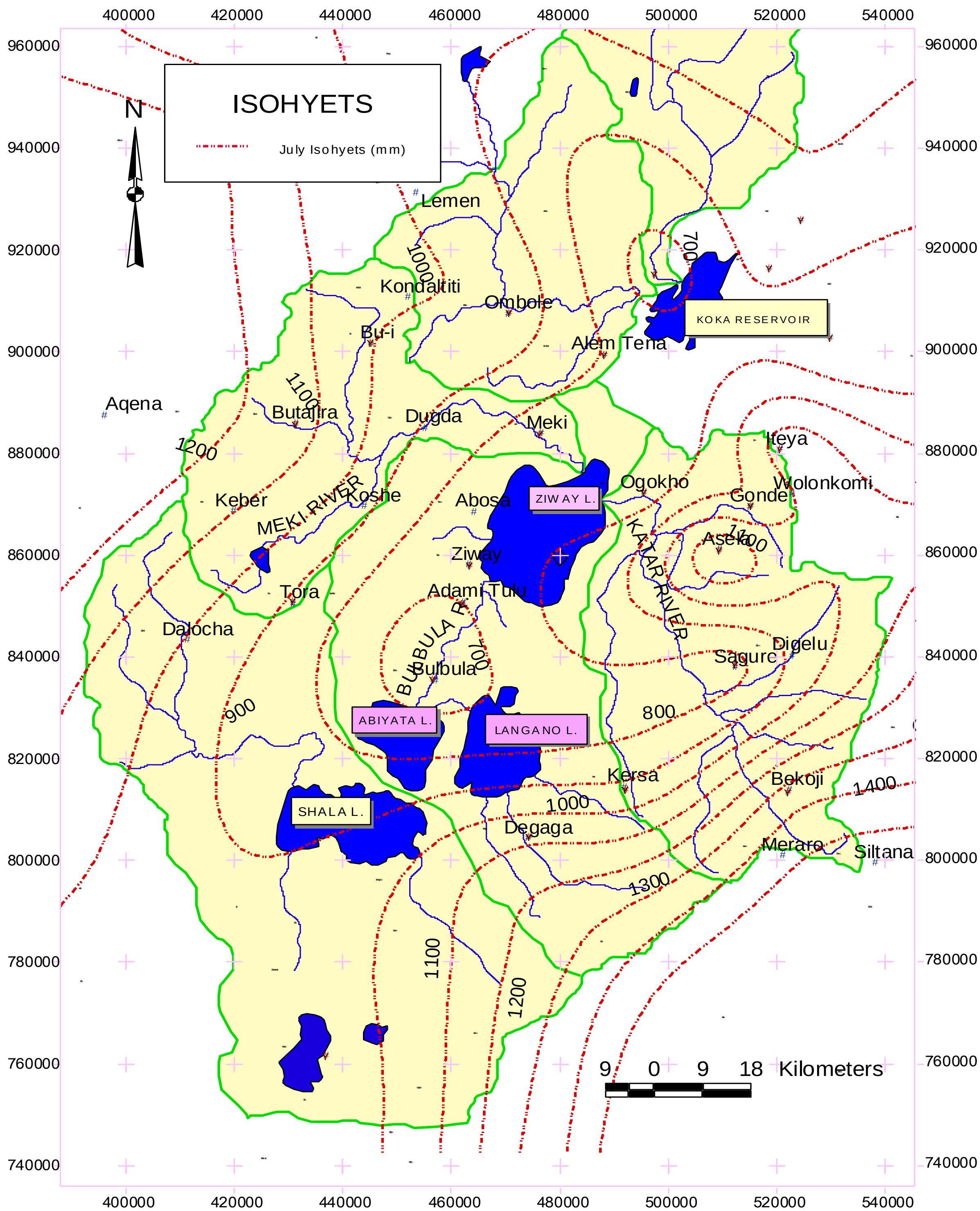


Figure 4.5 Annual Ishoyets over the project area (from Ziway-langano-abiyata hydrology repot)

Mean Areal rainfall data over the lake that used for this research

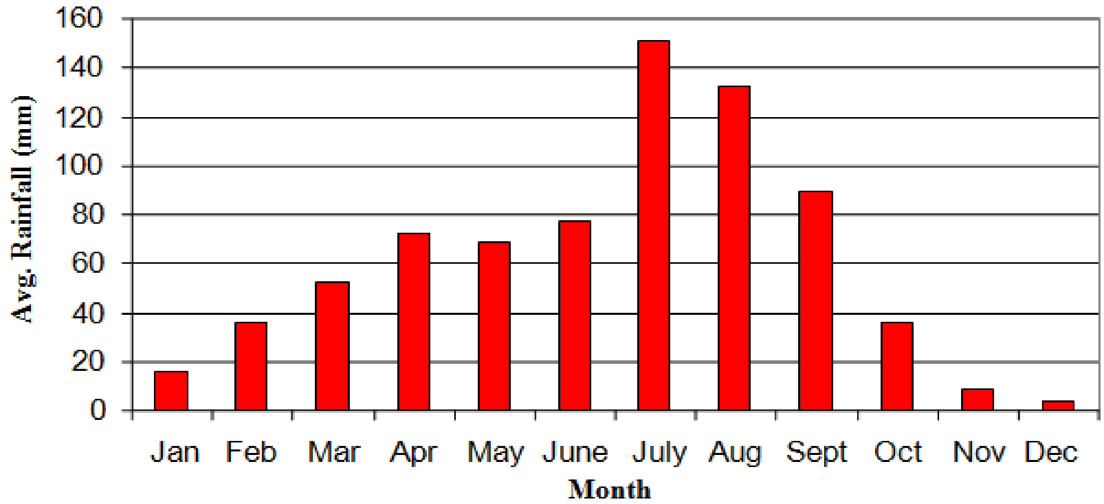


Figure 4.6 average rainfall over Ziway lake from isohyet result

4.1.2. Evaporation

Evaporation is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface (vapor removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

Energy is required to change the state of the molecules of water from liquid to vapor. Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapor from the evaporating surface is the difference between the water vapor pressure at the evaporating surface and that of the surrounding atmosphere. As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed.

There are many ways of calculating evaporation from large water bodies, the following are the methods.

- ✓ Water balance approach
- ✓ Mass transfer approach
- ✓ Energy balance approach and
- ✓ Penman combination approach and pan evaporation approach

Due to its demand of usually an available data from most of meteorological station like surface water temperature, most of the approaches are less applicable to data scarce area. Penman (combination approach) is an approach which does not require surface water temperature and is recommended for estimating free water evaporation. The penman equation is as follow.

$$Ep = \frac{\Delta}{\Delta + \gamma} * (Rn + Ah) + \frac{\gamma}{\Delta + \gamma} * \frac{6.43 * (1 + 0.536U2) * (es - ea)}{0.1555\partial}$$

Where Ep =potential evaporation that occurs from free water evaporation…. (mm/day)

Rn=net radiation exchange for the free water surface………………… (mm/day)

Ah=energy advected to the water body……………………………... (mm/day)

U2=wind speed measured at 2m……………………………………… (m/s)

es-ea= vapour pressure deficit……………………………………………(kpa)

ə=latent heat of vaporization……………………………………………. (MJ/kg)

ɣ = psychometric constant…………………………………………… (kpa/c^o)

Δ=slop of saturation vapour pressure curve at air temperature…………. (kpa/c^o)

4.1.2.1. *Climatic Factors Affecting Evaporation and used for cropwat 4.3-window program*

Computing the water demand of crops requires commonly available climatic, water, soil and crop data. Therefore, more than 15 years analyzed climatic data from Ziway station has been taken and adopted to calculate crop water requirement of the project (Ziway-meki hydrology report). Crop water requirement is calculated using modified cropwat 4.3-window program. Moreover, proper soil and crop data are also considered. This computer program also generates evaporation and evapotranspiration data.

The climatic information is computed in computer program of crop water requirement developed by FAO version cropwat 4.3 windows. The climatic information is prepared in the following ways.

- Mean monthly maxi. Tem (^oc)
- Mean monthly mini. Tem (^oc)
- Relative humidity (%)

- Latitude and longitude of the area
- Altitude to the study area
- Wind velocity at 2m height in m/s and km/day
- Duration of sun shine in hrs
- Mean monthly and effective rain fall in mm/month

Country: - Ethiopia Meteo. Station Ziway

Table 4.2 Average Monthly climatic data

Climatic data	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	15.8	35.9	52.8	72.7	68.8	76.6	150.9	132.6	88.8	35.8	8.1	3.6
Mean max.tem c^o	26.2	27.4	28.2	28.2	28.6	28.7	25	25	25.9	26.7	26.3	25.9
Mean min. tem c^o	12.4	13.3	14.5	14.8	15.1	14.8	14.7	14.5	13.9	12.8	12.3	11.4
Humidity %	67.4	65.7	66.1	67	68.3	69.5	76	77.1	74.7	66.6	64.2	65.8
Wind speed km/day	155.5	164.2	146.9	146.9	172.8	224.6	207.4	181.4	129.6	138.2	155.5	164.2
Sunshine (hrs)	9.5	9.4	8.4	8.4	9.1	8.4	6.4	6.7	7.1	9.1	10.2	10.1

- Data source: - hydrology report

For Ziway pressurized irrigation project mean monthly reference crop evapotranspiration (ETo) are estimated based on FAO-CROPWAT 4 program which is based on the Penman Monteith model. The result is given in Appendices

Table 4.3 Mean Climate in Ziway Project area (1963-2005)

Month	Rainfall (mm)			Max Temp	Min Temp	Relative Humidity	Wind speed	Sun Shine	FAO ETo	FAO ETo
	Mean	75% Dependab	85% Dependable.	(Deg. C)	(Deg C)	(%)	(m/s)	(Hours)	mm /day	mm /month

		le								
Jan	15.8	0.0	0.0	26.2	12.4	67.4	1.8	9.5	4.26	132
Feb	35.9	2.7	0.0	27.4	13.3	65.7	1.9	9.4	4.72	132
Mar	52.8	20.5	3.2	28.2	14.5	66.1	1.7	8.4	4.77	148
Apr	72.7	40.4	23.2	28.2	14.8	67.0	1.7	8.4	4.80	144
May	68.8	32.4	12.8	28.6	15.1	68.3	2.0	9.1	4.97	154
Jun	76.6	47.4	31.7	28.7	14.8	69.5	2.6	8.4	5.00	150
Jul	150.9	116.1	97.3	25.0	14.7	76.0	2.4	6.4	3.92	122
Aug	132.6	101.1	84.2	25.0	14.5	77.1	2.1	6.7	3.97	123
Sep	88.8	62.5	48.4	25.9	13.9	74.7	1.5	7.1	4.05	122
Oct	35.8	4.0	0.0	26.7	12.8	66.6	1.6	9.1	4.50	140
Nov	8.1	0.0	0.0	26.3	12.3	64.2	1.8	10.2	4.47	134
Dec	3.6	0.0	0.0	25.9	11.4	65.8	1.9	10.1	4.27	132
Average				**26.8**	**13.7**	**69.0**	**1.9**	**8.6**		
Total	**742.5**	**427.0**	**300.7**							**1632**

In general, December is the driest month, the coolest month is December (11.4 ^{o}C), the warmest and windiest month is June corresponding to the highest ET0.

Open water evaporation is about 10 – 20% higher than evapotranspiration. The Ziway lake evaporation is estimated by multiplying the Ziway evapotranspiration by 1.15(source from butajira Ziway area development project by ministry of water resource January 2008).

As monthly evaporation is much higher than rainfall, direct recharge from rainfall to the Lake is small and considered in rainy season.

4.2. Hydrological data analysis

The main water source for the lake is the flow of the Katar and Meki Rivers. The mean annual flows of these rivers are 412.18 MCM and 287.34 MCM respectively. The total catchment area of Lake Ziway is 7,380 Km2. The remaining catchment that is surrounding the lake passing through swamps contributes little as the large part of the water evaporating before it contributes to the lake effectively and there is also an outflow river from the lake known Bulbula river. Therefore, the total annual average inflow in the lake can be safely estimated by the sum of the Katar and Meki river flows and an outflow Bulbula river which drains to lake abiyata.

4.2.1. Meki River

Land Resources Divisions (1976) study observed that the headwater of meki river starts at an altitude about 3 000 m, and rapidly descends the rift valley escarpment to below 2 000 m before being joined by several major tributaries, including the Lebu, the Akomoja and the Weja. Downstream of its confluence with the Weja, the Meki is incised in a steep-sided valley until it reaches Meki Town at the head of its delta. Thereafter, the Meki river meanders for 15 km between slightly raised natural levees through deltaic alluvium before entering Lake Ziway at an average elevation of 1636 m.

In Meki River catchment there are only two stations. The station on the main Meki River; at Meki Town, which is the gauge station before the river enters the lake and the second station is situated at the Irinzaf stream, which is tributary of Meki River. This station (Irinzaf stream) is at Butajira Town; currently it is disrupted by a pipeline crossing the river and requires recalibration.

The catchment area of Meki River has two distinctive features:

a) Upstream of the Addis Ababa - Butajira - Hosaina Road, the catchment area has generally steep slope and has good vegetation cover; and

b) Downstream of the above-mentioned road, the catchment area becomes flat. This part of the catchment area is typically characterized by marshy area and a land setup that is suitable for crop cultivation.

A lot of irrigation activity is also taking place in the catchment area of Meki River. In fact, water Deficiency is occurring at some places. The high discharge occurs during the months of August and September while minimum flow occurs generally during the dry season from December to February. The river discharge sometimes becomes zero during these months. Current irrigation practices in the area fully utilize Dobena river, Akamuja and Lebu streams and some of the springs as a result none of the tributaries contribute to main Meki river during the dry seasons. Meki gauging stations is characterized by highly shifting river bed (deposition/aggradations) and rating equations had to be rated nearly every two years by the Hydrology Department Daily instantaneous flow of Meki River is recorded for various year interval, . It is seen that the river is highly seasonal (high flows in rainy months of July and August.

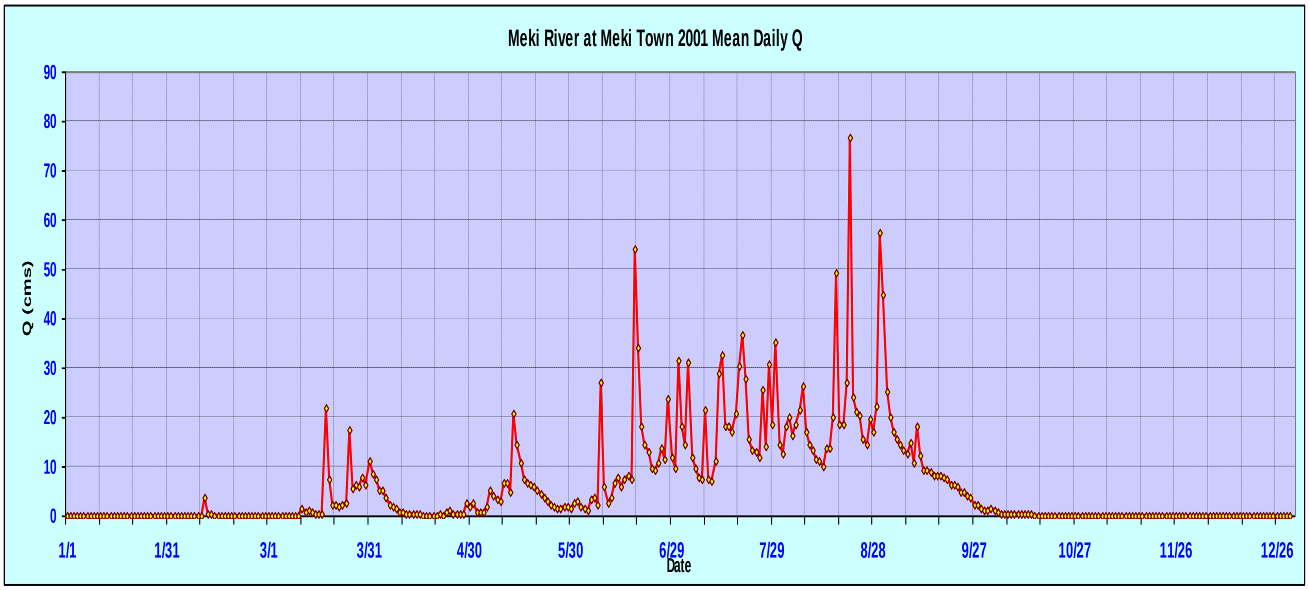


Figure 4.7 Mean daily flow of Meki River at Meki in 2001(from ziway-langano-abiyata hydrology study).

The total annual mean contribution of the Meki River to the Lake Ziway is 283.34 MCM. On the average (using the data from 1963-2005 years) on monthly basis, maximum flows occurs in August with a minor secondary peak in April and minimum flows between December and January.

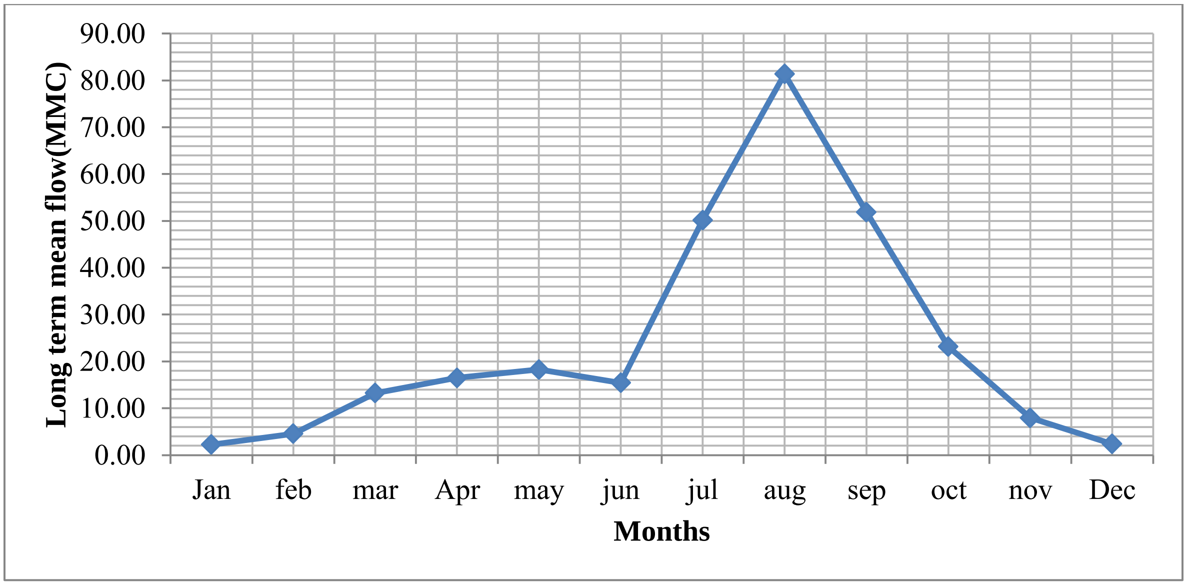


Figure 4.8 mean monthly Meki river discharge (1963-2005)

4.2.2. Katar River

The catchment of Katar river ascends to over 4 000 m on the summits of Mounts Badda and Cacca. The gradient of the river is generally steep throughout its course to Lake Ziway, and it is often deeply incised up to 50 m below the surrounding countryside. The overall pattern of flow is similar to that of the Meki. However, the base flows in the dry season are rather higher. Ketar river is seasonal like meki river,it has high flow during july and august.to show its seasonality daily recorded flow data in the year 2001 is ploted as follows

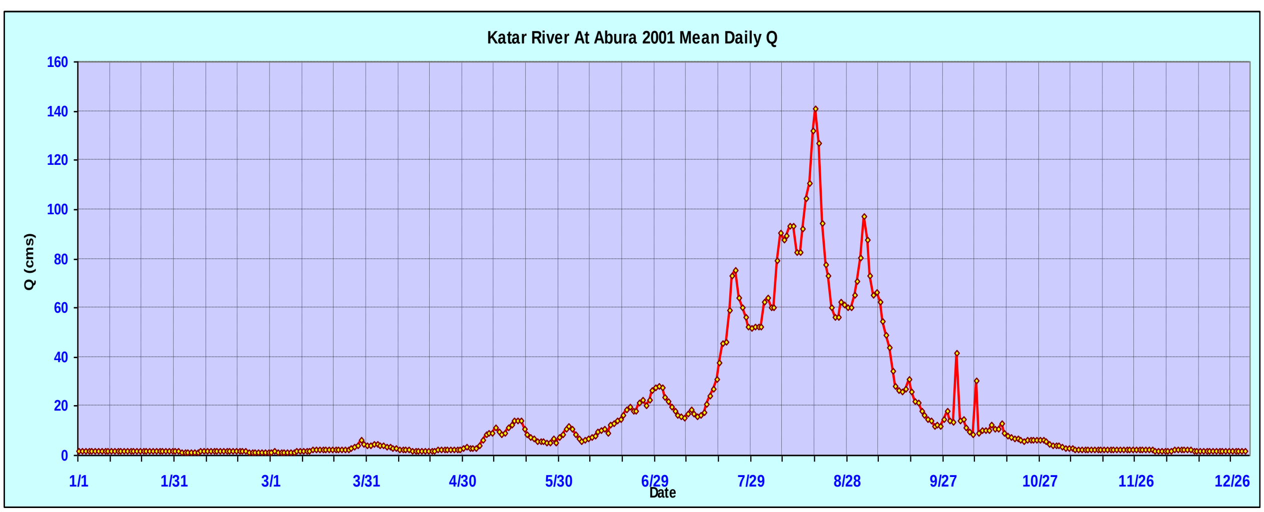


Figure 4.9 Mean daily flow of Katar River at Abura in 2001(ziway-langano-abiyata hydrology)

The total annual mean contribution of the Ketar River to the Lake Ziway is 412.18 MCM. On the average (using the data from 1963-2005 years) on monthly basis, maximum flows occurs in August with a minor secondary peak in April and minimum flows between December and January.

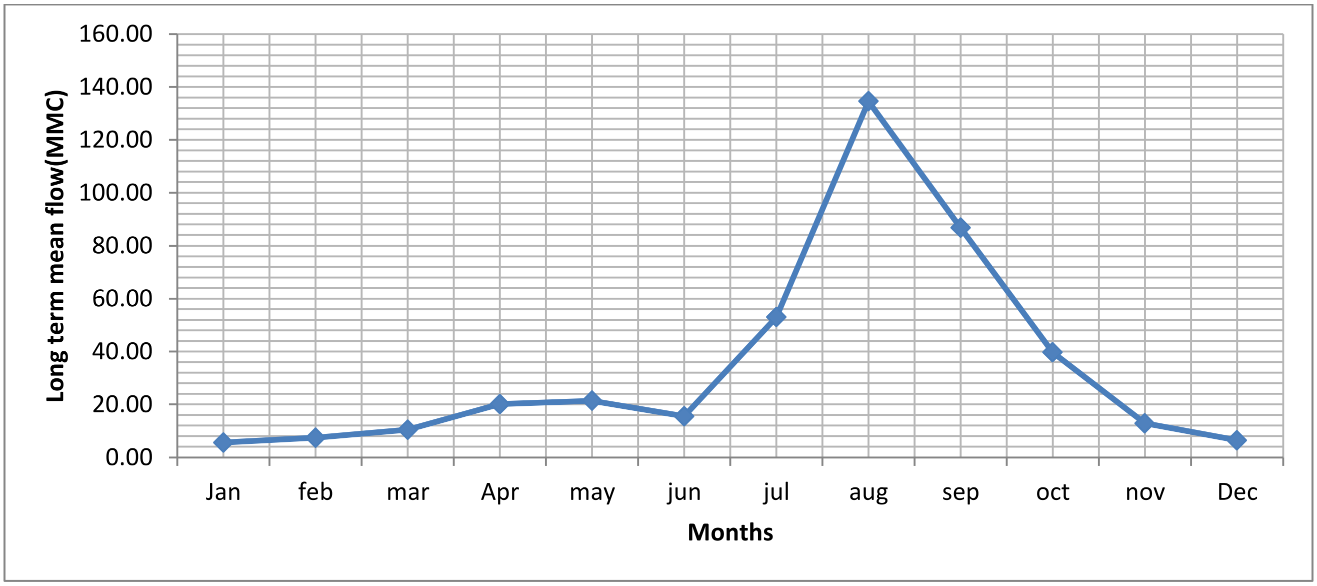


Figure 4.10 mean monthly Ketar river discharge(1963-2005)

4.2.3. Bulbula River

The water level of Lake Ziway, which is controlled by the natural basalt bar at some 6 km downstream from the outflow of the lake, influences the Bulbula River flow. The upper part of Bulbula River is also known as Kekeristu River. Bulbula River drains annually about 180 MCM of water on average from Lake Ziway into Lake Abijata.

The Bulbula River descends some 58 m over a distance of 30 km between Lakes Ziway and Abiyata. The level of this river for the first 6 km of its length is virtually the same as that of Lake Ziway due to a lava rock sill that effectively controls the level of the lake. Below the sill, there are a series of minor falls over further banks of lava, before the Bulbula River becomes incised to over 50 m in a steep-sided gorge within poorly consolidated ash deposits. The gorge continues almost to Lake Abiyata, into which the Bulbula flows over a shallow beach. Except periodically during wet season, the flow in the Bulbula usually derives entirely from Lake Ziway. However, the Bulbula does have a significant catchment of its own with ephemeral tributaries from the east occasionally contributing to the flow.

Table 3.4 relates the average water level of Lake Ziway and the monthly discharge of the river recorded at the station near Adami Tulu Town. (This is recorded previously).

Table 4.4 Relation between water level of Lake Ziway and outflow to Bulbula River

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
L.Ziway water level (m)	1.06	0.95	0.85	0.80	0.76	0.74	0.83	1.19	1.50	1.53	1.34	1.23	1.07
Q (m3/s)	4.07	2.56	1.23	1.34	1.27	1.38	1.98	6.16	13.68	15.09	11.84	7.50	5.70

Rather than taking daily instant or monthly recorded flow data as an outflow from the lake,inter relating the rating curve at the exit point of the lake to the river is preferable because there is irrigation scheme between the exit point and the recorded station point

The discharge at Bulbula town should greater than the discharge at Kakarsitu during the rainy seasons due to many ephemeral rivers between the two stations which drains the runoff to the river from the catchments of Bulbula river. However discharge observed at Kakaritu station is greater than measurements taken at Bulbula town throughout the observed years. This is due to the river loss, abstraction, along the stretch of the river and evaporation even during the rainy seasons.

4.2.4. Flow from un gauged area (un gauged inflow) to the lake

There are different ideas about the area of Ziway lake ungagged inflow in to the lake.

According to Butajera Ziway development project the area outside of Ziway lake is covered by swamp so almost all of the rainfall evaporates due to high temperature rather than contributing to the lake. But this research considers the relation between rainfall and runoff which is declared by hydrology study for semi-arid catchments adjacent to Ziway-Langano-Abiyata lakes to estimate ungagged flow.

Table 4.5: Rainfall-Runoff relationship for semi-arid catchments adjacent to Ziway-Langano-Abiyata lakes

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moisture Factor(mm)	100	100	100	100	100	50	45	80	100	100	100	100
Runoff Coefficients(c)	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.2	0.15	0.1	0.1	0.1

The runoff from the un gauged catchments considered in this study is only in the rainy seasons and the estimated amount is about 64.6 MMC per year (source from ziway-Langano-Abiyata hydrology report).

4.2.5. Ground water

The occurrence of groundwater is due to the hydrological and hydrogeological conditions in the western and eastern escarpments and the hydrological condition within different geomorphological units and Lake Ziway are studied and determined by ministry of water resource under their study of the area (butajira Ziway area development project), so this research uses this calculated result to calculate the water balance of lake Ziway.

According to their result from the drilling and testing and from the hydrogeological conditions in the area, ground water inflow and ground water out flow of the lake calculated by considering the following assumption:-

- The two major perennial rivers are Ketar and Meki., these rivers are not connected to the groundwater, except at the inlet to the lake
- Lake Ziway is connected to the groundwater. The lake receives groundwater from the eastern and its north-eastern side and groundwater output from the lake takes place at its south-western side.
- From the result the ground water inflow and outflow are the same

$$\text{Inflow}=\text{outflow}$$

$$2.8M^3/s=2.8M^3/s$$

4.2.6. Bathymetry Survey of the Lake

The bathymetric map digitized from the softcopy data obtained from ministry of water resource is used to calculate the corresponding lake level, area and volume parameter of the lake. Two different bathymetry data were developed, the first was in 1967 by LRD and the second was in 2006 by ministry of water resource. The latest bathymetry relates the outflow (stage) through Bulbula River with the lake area, stage and volume.

Table 4.6 Lake Ziway Elevation-Area-Capacity Data from previous bathymetry (1967)

Elevation(m a.s.l)	Lake Area(km2)	Lake Volume(MCM)
1628	0	0
1629	6	10
1630	18	30
1631	40	80
1632	104	180
1633	250	420
1634	320	750
1635	394	1120
1636	440	1580
1637	492	2050

The water balance computation in this thesis work is done using the recent bathymetry survey prepared in 2006 by ministry of water resource which relates the outflow through Bulbula river. According to this bathymetry the result of lake Level, lake area, lake water volume and Bulbula river outflow is given as follow.

Table 4.7 Lake Ziway Elevation-Area-Capacity and outflow Data from latest bathymetry (ziway-langano-abiyata hydrology)

Lake Level(M)	Area(1000M2)	Volume(1000M3)	Outlate capacity(M3/s)
1627	0	0	0
1628	490	95	0
1629	3827	2082	0
1630	7814	7849	0
1631	15909	19356	0
1632	33457	42293	0
1633	171031	138942	0
1634	325416	394283	0
1635	386184	755341	0
1635.5	419266	952684	0.27
1636	427812	1159385	2.56
1636.5	462103	1388907	9.11
1637	491569	1624228	22.16
1637.5	494149	1866862	43.96
1638	508668	2123656	76.73

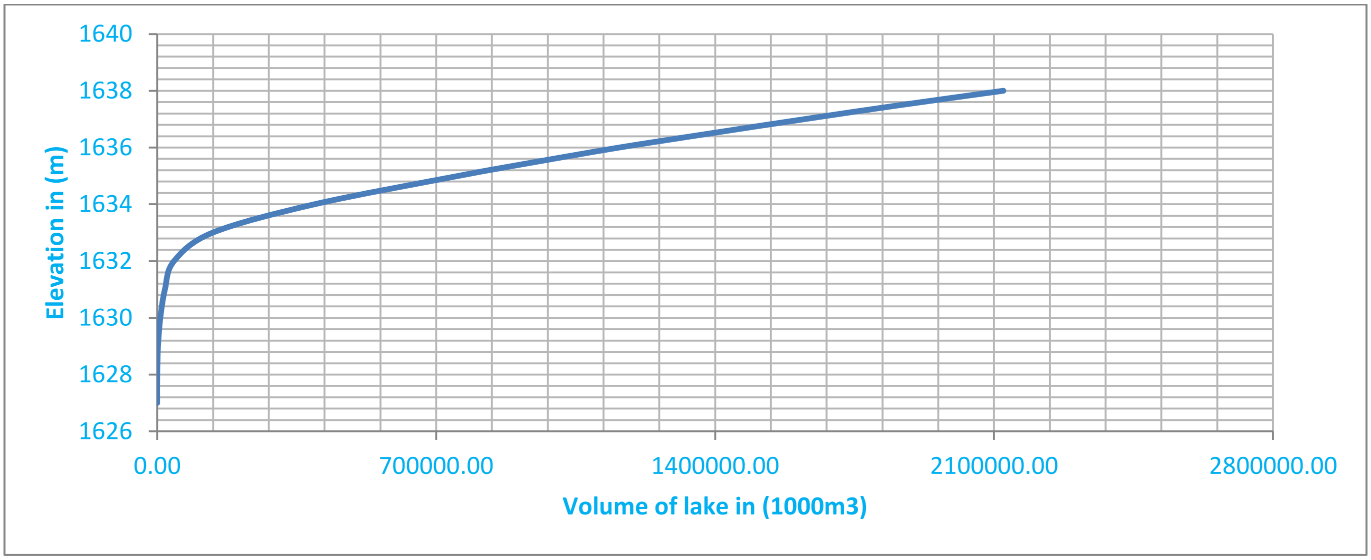


Figure 4.7 lake volume-elevation graph

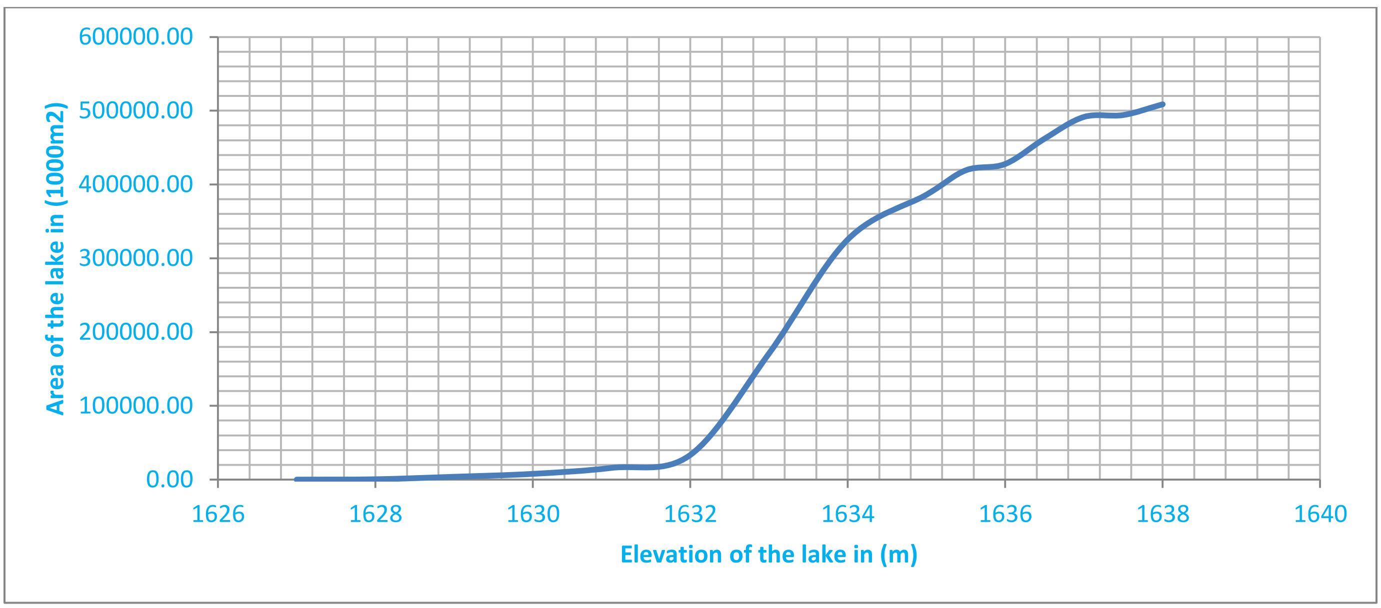


Figure 4.8 lake Area-elevation graph

CHAPTER FIVE

5. MATERIALS AND METHODOLOGY

5.1. Methodology

Water resources management mainly deals with hydrological forecasting. In hydrological forecast mainly forecast of water balance or level of lake is done which is useful for various purposes. Forecasting techniques may be different as per the purpose of system, data availability for the system and physical characteristics. Uncertainty is there in hydrological parameters, and to deal with this, a proper forecasting method is needed. Since The objective of the study is to carry out to determine and analysis mean monthly water level fluctuation of lake Ziway by considering different abstraction from the lake catchment specially the existing and proposed irrigation scheme, so to satisfies and came up to the planed objective appropriate methodology must be adopted.

The methodology adopted for the research is as follow:-

- Studying and assessing the previous study on different sub basins of the lake.
- Data collection from relevant secondary sources (institutions) such as Ministry of water resource, national meteorological agency, Ethiopian mapping agency.

  The materials (data) collected that used for this research are:-

  - Lake Bathometer which include the rating curve of Bulbul River.
  - Agronomy data of Ziway-meki irrigation development project.
  - Different map data that show the project area
  - Hydrological data of the lake and its catchment.
  - Meteorological data.
  - Pump operation schedule data.
- Collect Primary data from the local people to know when and how the lake became full and to know the state of contributing rivers.

- Data organization, data pre-processing, producing necessary map from relevant hard copy information.
- Application of excel (spread sheet software) to estimate the water balance component of the lake by using relevant formula. Specially estimate irrigation requirement by considering pump operation schedule, crop irrigation requirement and area to be irrigated.
- Pick out and understand which components of the water balance priory affect the lake level fluctuation and creating different scenario for the data and for the proposed irrigation area that affect the lake
- Determine the water balance of the lake based on previous long term and current mean monthly hydro meteorological data and asses the magnitude of the effect of existed and proposed irrigation scheme on the lake level fluctuation and on Bulbula River depend on latest data (2006-2014).
- Finally understand the impact of irrigation by assuming future development scheme and provide limit in irrigation scheme to safe the lake and flow through Bulbula River.

5.2. Lake Water Balance Model

As described in the literature review, the water balance equation for lakes at any time interval is a continuity equation. According to the law of conservation of matter, there is equilibrium between inflow components, outflow components and the change of water volume for each interval of time. This equilibrium is described by simple water balance equation (Excel spread sheet model) (UNSECO, 1974):

$$\frac{\Delta S}{\Delta t} = P - Ev + Gin - Gout - Abs + Qin - Qout$$

Where

P=Direct precipitation over the lake

E=Evaporation from the lake

Gin=Ground water inflow in to the lake

Gout=Ground water outflow from the lake

Qin=Inflow to the lake

Abs= Abstraction from the lake

Qout=Outflow from the lake

Since Water balance formulation is a multi-step process that results in the identification and quantification of the model's components. Thus, the forecast model is formulated through a Quantitative assessment of the inflows (precipitation on Lake Surface, ground water inflow to the lake and runoff – gauged and ungagged), outflows (evaporation, river outflow, abstraction and groundwater outflow from the lake) and storage changes within the lake.

This research focus and apply the simple water balance model (excel spreadsheet model) to determine the water balance and lake level of Ziway lake. This model is applied after quantification of each components of the water balance. But from those the main component is knowing the estimated discharge for all type of irrigation scheme in the area(from agronomy report and from the design).the other all components of the water balance is quantified according to the data and the available model type.

Water balance techniques are used in several disciplines to model surface hydrology and in any water related field. Typically water budget are constructed by using graph and tables or by using conventional computer programme.in this paper water balance is constructed using spreadsheet software such an approach has at least two advantages over other method.

First the programming is streamlined when compared to conventional language: that is less code is required and the process of typing in the necessary code is simplified.

Second spreadsheet programmed has the ability to recalculate rapidly all affected dependent variables as the user changes any independent variable.

5.3. Water Balance Recursive Formula and Formulation of the spreadsheet

Depend on the primarily data collected from the local people and from data collected from hydrology, the lake became full at the end of month august so this thesis start calculating the water balance of the lake from September by considering (elevation, area and volume of the lake) is maximum at the end of august is the same with that of first date of September.

From the drilling and testing and from the hydrogeological conditions in the area that is studied by ministry of water resource, ground water inflow and ground water out flow of the lake is the same (2.8m3/s) so it doesn’t affect the water balance recursive formula.

From the bathymetry data which is obtained by surveying in 2006, the maximum amount of lake elevation, lake area, lake volume and Bulbula out flow is the starting point for the water balance in this study. This data is seen in table 4.1 below

Table 5.1 Lake Level, lake area, lake volume and Bulbula outflow at the end of August

Row 1	Volume in august (1000m3)=	2123656.00
Row 2	lake level in august(m)=	1638
Row 3	Area of lake in august(1000m2)=	508668.00
Row 4	out late capacity(m3/s)=	76.73

The recursive continuity equation is formulated as:

St =St-1+ Q in + P lake – E lake – Q abs………………………….. (5.1)

Where

St = Storage at the current month (1000m3),

St-1 = Storage at the end of the preceding month (1000m3),

Q in = inflow to the lake at the current month (Katar,Meki river & flow from ungauged in 1000m3),

P lake = is the mean areal precipitation on the lake at the current month (mm),

Q abs = is the abstraction of water at the current month (1000m3), and

E lake = evaporation loss from lake at the current month (mm).

The following excel formation shows how this research done.

From the lake bathymeter, the lake stage, lake area, volume of lake and out late capacity of bulbula river is arranged in column for interpolation purpose to determine the lake water balance parameters.

Column A	Column B	Column C	Column D
Lake Level(m)	Area(1000m^2)	Volume(1000m^3)	Out late capacity(m^3/s)

The following shows how the inflow and outflow data of the lake arranged in excel application in column and rows (**the whole flow chart is putted on annex part**)

	Inflow Data to the lake			Column I
Column E	Column F	Column G	Column H	Sum of inflow(1000m^3)
Rainfall(mm)	meki	ketar	ungauged	Col F + Col G + Col

	river(1000m^3)	river(1000m^3)	flow(1000m^3)	H

Out flow data from the lake

	Column K	
Column J	net Evaporation(mm)	Column L
Evaporation(mm)	Col J -Col E	Abstraction(1000m^3)

Months	Total inflow from river(1000m3)	Abstraction(1000m3)	Net evaporation(mm)
September	Column I	Column L	Column K
October			
August			

Finally by applying the above equation (5.1) the following water balance parameters are determined in this research and the detail spreadsheet data were located on annex part.

Column M	Column N	Column O	Column P	Column Q
Net evaporation(1000m3)	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
Col K * Row 3/1000	Row 1+Col I-Col L-Col M	interpolate Col N on Col A	interpolate Col O on COL B	interpolate Col P on Col D

5.4. Scenario development

In this spreadsheet water balance model the monthly mean Lake storage change in a year is the calculated sum of all the inflows, outflows and storage changes in the lake. In order to use the model for forecasting purposes it is required to know the value of the Lake storage(Volume, lake level and lake water covered area from lake bathymetry data.as one of the objective of the research is to understand the lake level fluctuation of lake Ziway for recent year so only the lake level or lake storage data that is at the time the lake became full is taken as starting point for water balance recursive formula by keeping other input and output components. every model has its own assumption and base scenario for other scenario.

According to the time series data described in different year clearly show the 1963-2005 (42 years) flow series will not represent the present 2006-2014(9years) and the future (planning period). Thus the following four scenarios with base scenario are created to get the water balance situation there by the effect of the existing and planned irrigation schemes.

1. **Base scenario** considering Ziway lake inflow, outflow and lake change storage data (without any abstraction) from the lake for the year from (2006-2014).
2. Scenario -1 by analyzing the above base scenarios, considering Ziway lake inflow, outflow, lake storage data and the existing abstraction that will continue in present (Ziway lake pumped irrigation and Ziway lake pumped water supply) depend on the latest data for the year (2006-2014).
3. Scenario 2 considering Ziway lake inflow, outflow, lake storage data, the existing abstraction and water demand for 3774.7 ha land from the proposed scheme. For the year from (2006-2014).
4. Scenario 3 considering Ziway lake inflow, outflow, lake storage data, the existing abstraction and water demand for total of 8443.2 ha land from the proposed scheme(additional of 4668.5 ha land on scenario-4).
5. Scenario 4 considering Ziway lake inflow, outflow, lake storage data, the existing abstraction and water demand for total proposed irrigation scheme of 14657.2 ha land (additional of 6214 ha land on scenario-5).

In this study application of spreadsheet water balance is applied to forecast the lake water balance and to assess the impact of irrigation scheme. This model is selected due to the resin discussed in the above .but the model has its own assumption to determine and forecast the water balance.

Assumption of the model

1. From primarily and collected data the lake became full at the end of august month so start the water balance in the starting date of September by considering.

   Lake storage at the end of august = Lake storage at the start of September
2. From study done by ministry of water resource about ground water, the result obtained was 2.8 m^3/s for both ground water inflow and outflow (from Butajera Ziway development study by ministry of water resource) so this thesis consider this value and it doesn’t affect the water balance.
3. The latest climate data (2006-2014) will continue in the future).
4. The mean boundery lake level is 1636.12m and the Bulbula outflow is considerd (from Ziway-langano-Abiyata hydrology report), so every result of the water balance is compare and contrasted with this amount.

5. The previous existed irrigation(water abstracted from the lake) which studied in (2007) by Ziway-langano-abiyata hydrology report will continue to the present
6. For Bulbula river this research considers (relates) measured lake level and measured outflow (discharge) to the river at the exit point of the lake.

CHAPTER SIX

6. MODEL RESULT AND DISCUSION

6.1. Analyzing water balance components

The water balance simulation is done by analyzing the water balance components those recorded in different year interval separately. This separation is due to the rapid change of the inflow and outflow components of the lake which affect the lake water balance remarkably. The year interval this research focus on previous data (1963-2005) and specially on the latest data (2006-2014).the research formulate different scenario, specially depend on the existed and proposed irrigation scheme that developed by pumping the lake water.

6.1.1. Areal rainfall over the lake

During study the irrigation area, ministry of water resource select isohyet determination of the areal rainfall over the lake rather than thissen polygon method by considering time series plot of monthly rainfall for Key stations: Meki gauging station at the confluence of Meki river basin to the Ziway Lake, Ziway town gauging station near the lake and sub-basin of the lake , Bulbula, Assela, and Butajira were selected to represent precipitation on the lake. This method is selected due to all station cover nearly the whole sub-basin (mountainous part to the lake area). The difference in areal rainfall in previous and latest data happen due to the change occurs in the recorded data on different stations those considered in determination of areal rainfall on the lake by isohyet method.

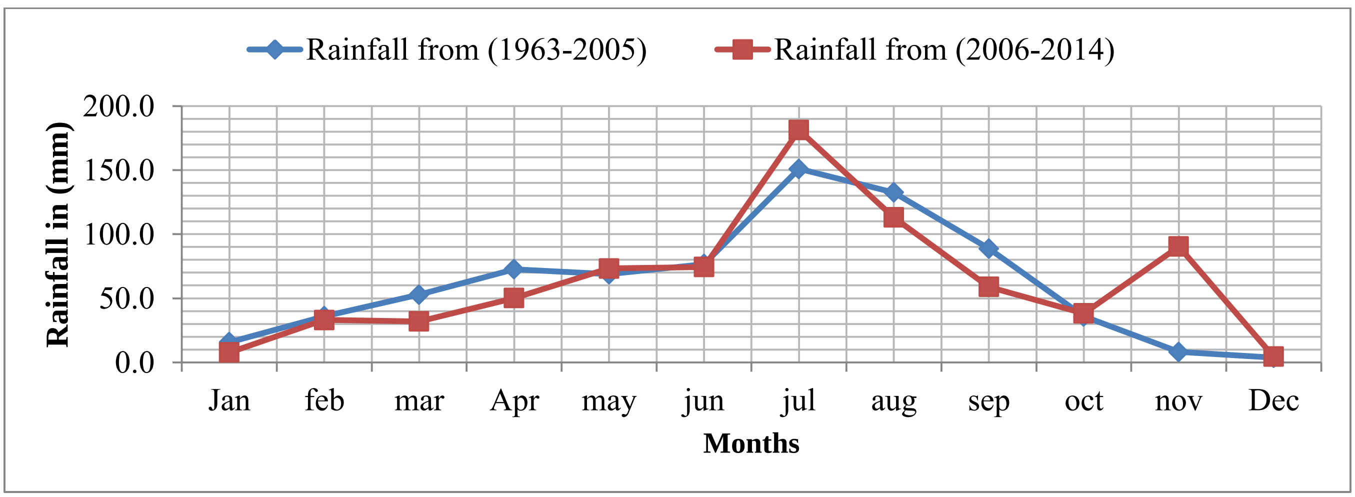


Figure 6.1 Rainfall distribution for the year (1963-2005) and (2006-2014)

Table 6.1 Areal rainfall over the lake

	From (1963-2005)	From (2006-2014)
Months	Mean Areal Rainfall(mm)	Mean Areal Rainfall(mm)
Jan	15.8	7.7
feb	35.9	33.0
mar	52.8	32.0
Apr	72.7	50.2
may	68.8	73.3
jun	76.6	74.4
jul	150.9	181.2
aug	132.6	113.2
sep	88.8	58.9
oct	35.8	38.2
nov	8.1	90.4
Dec	3.6	4.5

Since this research focus to show the data gape that happen due to the contributing rivers(Meki and Ketar) due to irrigation abstraction from the rivers, so to determine(forecast) the water balance of the lake considering areal rainfall that happen currently(2006-2014) is necessary as a base scenario.

6.1.2. Inflow Rivers and ungauged runoff

Ziway lake has two rivers to flow in to the lake, flow from ungagged runoff and outflow through Bulbula river. Since Meki and Ketar rivers are inflow to the lake, the recorded data is taken for water balance simulation after filling the missed flow data and taking the whole abstraction data from the rivers are at upstream side from the gaging station.

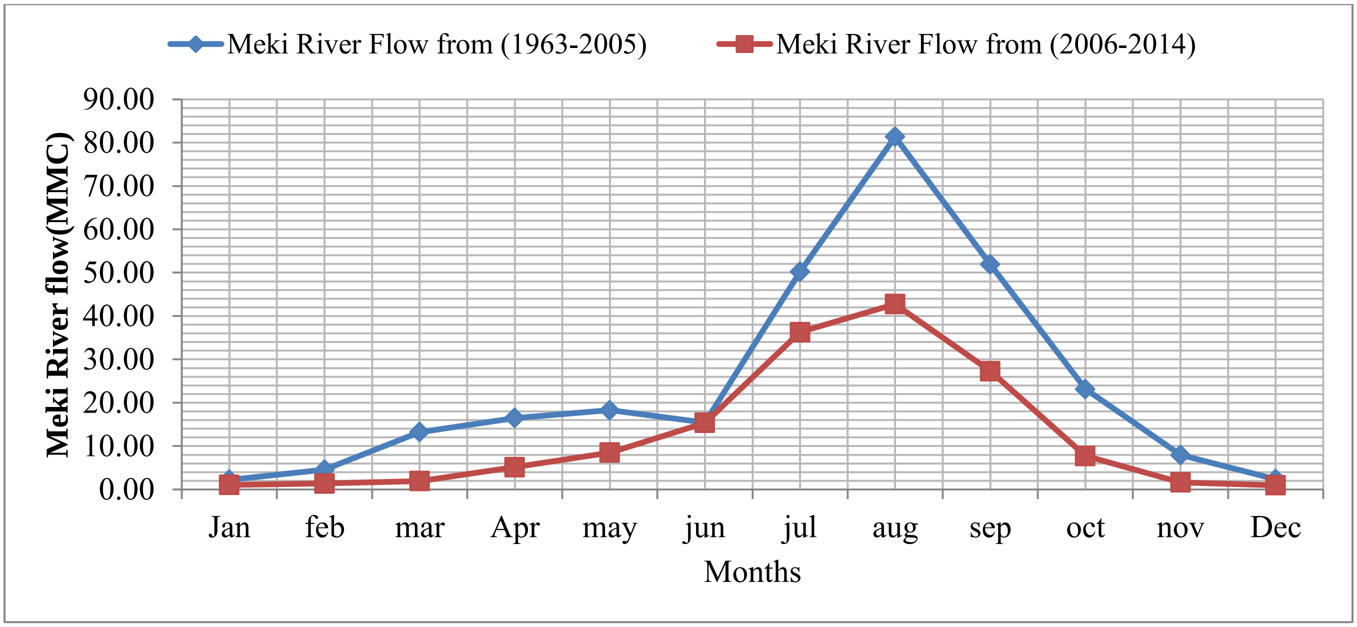


Figure 6.2Meki River Mean flow (MMC)

According to ziway-langano-Abiyata hydrology report(2007),there is increasing amount of irrigation development area in (2007) by abstracting water demand from the two contributing rivers (Meki and Ketar) so observing this change on the water balance of the lake depend on latest recorded rivers data is necessary

Table 6.2 Irrigation area by abstracting water from Meki and Ketar River (2007)

River / Lake		Irrigated area 2007 Survey (Ha)
MEKI RIVER	MEKI Small pumps irrigation (owned by private farmers),Dugda bora woreda	388
	Sub Total	388
KATAR RIVER	Katar up stream	464
	(Katar Genet,Golja & Hamsa Gasha)	
	Shalad irrigation scheme(Katar d/s)	75
	Unshete (using pump)*	65
	Small pump irr. Zeway Dugda wrd	252
	Sub Total	856

Table 6.3Meki river flow(MMC)

	for the year (1963-2005)	for the year (2006-2014)
Months	Mean meki river(MMC)	Mean meki river(MMC)
Jan	2.23	1.036333
feb	4.56	1.375939
mar	13.24	1.946616
Apr	16.49	5.133222
may	18.27	8.486
jun	15.43	15.3762
jul	50.19	36.27911
aug	81.35	42.74167
sep	51.88	27.29644
oct	23.16	7.742989
nov	7.94	1.654136
Dec	2.38	0.981111

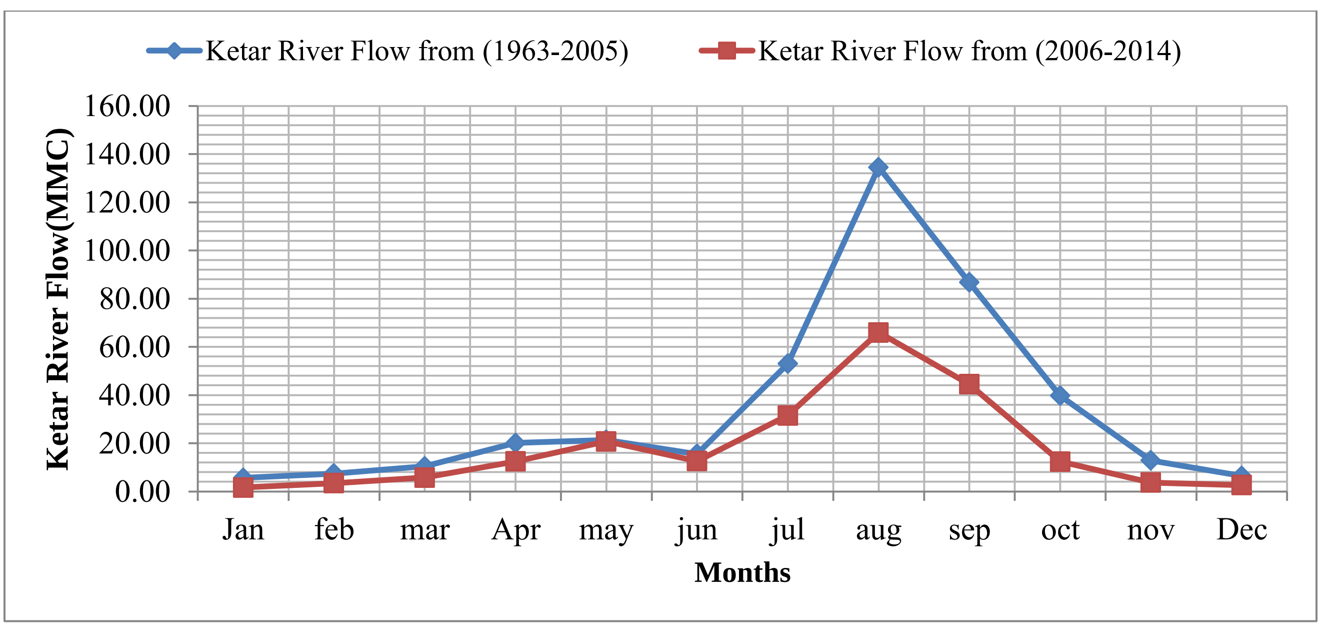


Figure 6.3 Ketar River Mean flow(MMC)

Table 6.4 Ketar river flow (MMC)

	From(1963-2005)	From 2006-2014
Months	Mean ketar river(MMC)	Mean ketar river(MMC)
Jan	5.62	1.6653
feb	7.41	3.427409
mar	10.42	5.783628
Apr	20.12	12.49324
may	21.38	20.77694
jun	15.55	12.62936
jul	52.98	31.50347
aug	134.53	65.93827
sep	86.75	44.50667
oct	39.67	12.43018
nov	12.85	3.726061
Dec	6.44	2.610517

From the above two data (table 5.2-5.3) we clearly understand the previous design assumption (consideration) for proposed irrigation scheme is depend on the river flow data from (1963-2005) will not correspond to the reality after the design is completed because the river flow data is changed rapidly from (2006-2014).

In case of Bulbula River rather than taking the recorded flow data, taking the data that determine the relation of lake level and outflow at the exit point of the lake which is surveyed in 2006 is preferable. This is because of there is a lot of abstraction between the lake exit and the river gaging station point.

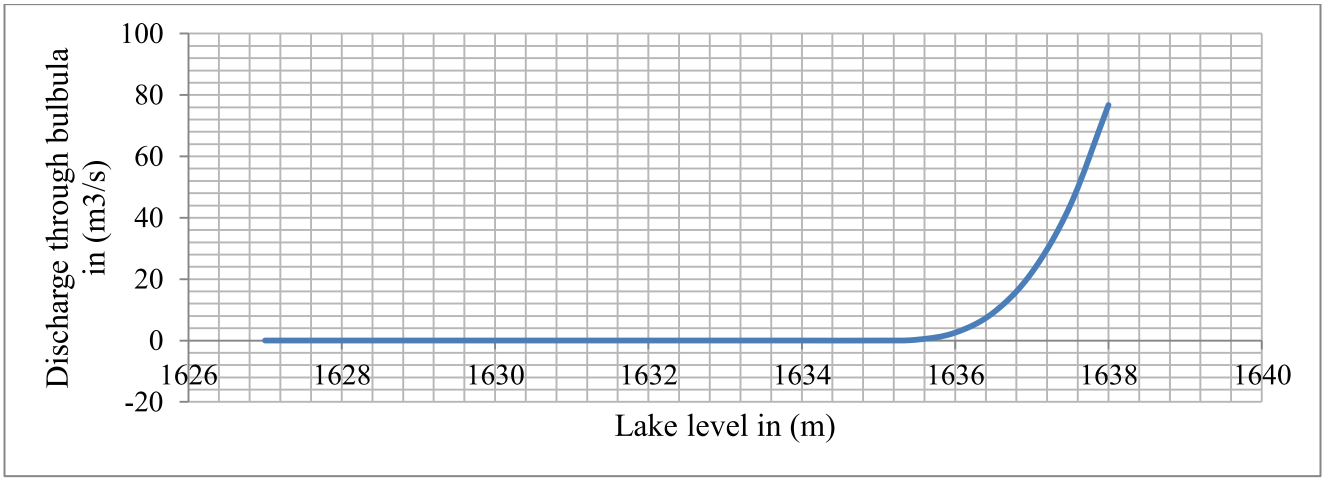


Figure 6.4 Ziway lake level and bulbula river outflow relation at the exit point

Outflow through Bulbula River is start at the lake level of 1635.5m which has a flow of 0.27m^3/s up to full lake level(1638m) which has a flow of 76.73m3/s.

For un gauged runoff –data is taken and calculated from Rainfall-Runoff relationship for semi-arid catchments adjacent to Ziway-Langano-Abiyata lakes so according to this relation (From Ziway-Langano-Abiyata Hydrology report).since (2007) there is abstraction of water demand from the two contributing rivers and from the lake by using pump for irrigation purpose adjacent to the lake catchment, so there is change in ungauged flow due to change of land use and land cover in the catchment.

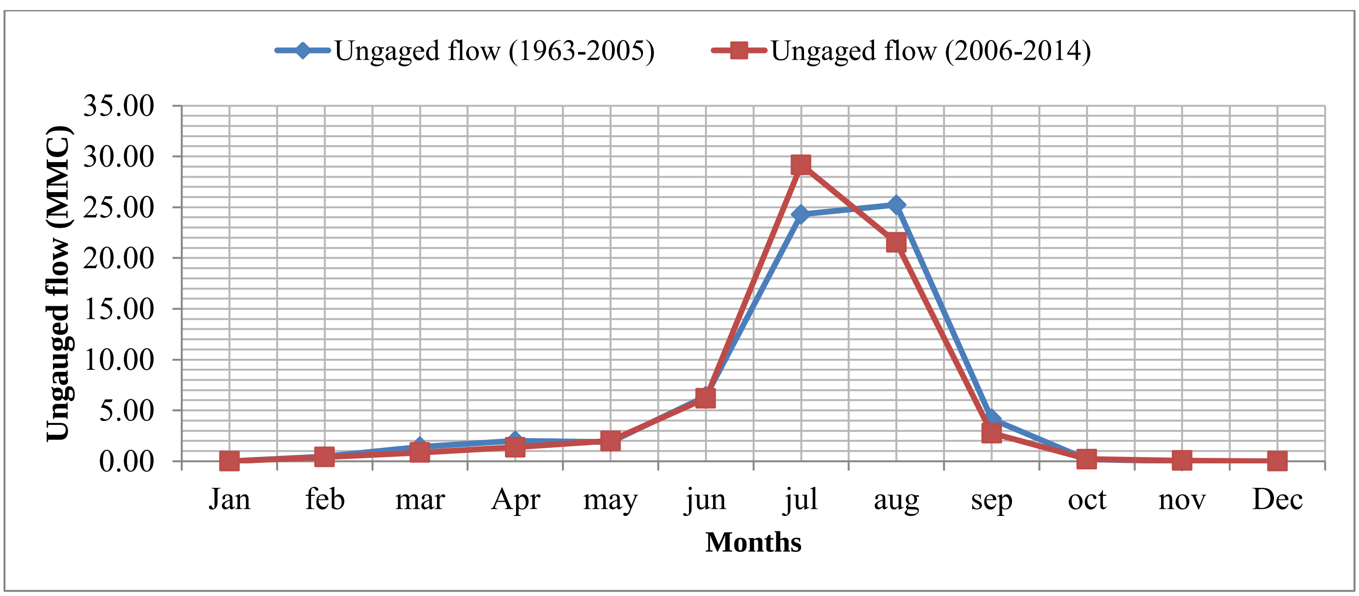


Figure 6.5 Un gauged mean flow (MMC)

6.1.3. Evaporation

For this research evaporation is taken from modified cropwat 4.3-window program. This program is applied to calculate crop water requirement depend on penman monteith model.in addition the program generate evapotranspiration data.

Table 6.5 Evaporation of Lake Ziway from cropwat 4.3 window programe

Months	Monthly Evaporation(mm)
Jan	145.30
feb	145.40
mar	162.70
Apr	158.40
may	169.50
jun	165.00
jul	133.70
aug	135.40
sep	133.70
oct	153.50
nov	147.50
Dec	145.60

6.1.4. Abstraction (existing and proposed irrigation scheme)

6.1.4.1. *Existing Abstraction*

From the hydrology report of Ziway-langano-Abiyata done in (2007)- water abstraction from Lake Ziway–Langano-Abiyata system is amounts to 73.35 Mm^3/year constituting (1) Ziway + Bulbula irrigation totaling 4267 ha –53.84 Mm^3/year, (2) Ziway Town Water Supply 40000 people, 90 lpcd – 1.31 Mm^3/year, (3) Bulbula Town Water Supply 5000 people, 90 lpcd – 0.16 Mm^3/year, (4) Langano tributary river diversion of 830 ha – 10.53 Mm^3/year and (6) Soda Ash pump from Lake Abiyata (for 50000 ton soda ash /year, expansion considered) ~ 7.5 Mm^3 /year. According to the data approximately 5000 ha of existing irrigation area (2007) (two vegetable crops per year) can be expanded to 10000 ha irrigated land which is part of the planed irrigation scheme in first phase. Currently Since irrigation is a daily rapid process and every farmers can cultivate different crops by abstracting water from the contributing rivers and the lake, this research consider the studied and quantified data which is studied previously. From the table below this thesis consider abstraction for Ziway lake pumped irrigation and Ziway lake pumped water supply from the lake.

Table 6.6 Irrigation water demand abstracted from the lake for proposed scheme (MCM)

Abstraction Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
Meki River Irrigation Diversion	0.52	0.62	0.68	0.75	0.49	0.07	0.00	0.00	0.01	0.50	0.52	0.52	**4.69**
Katar River Irrigation Diversion	1.10	1.30	1.43	1.57	1.02	0.15	0.00	0.00	0.02	1.04	1.10	1.10	**9.83**
ZIWAY Lake Pumped Irrigation	2.02	2.40	2.64	2.89	1.89	0.27	0.00	0.00	0.04	1.92	2.03	2.03	**18.12**
Ziway Shere Flower Pumped Irrigation	0.81	0.97	1.06	1.16	0.76	0.11	0.00	0.00	0.01	0.77	0.82	0.82	**7.30**
Ziway Lake Pumped Water Supply	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.11	0.11	0.11	0.11	**1.31**
Bulbula River Diversion Irrigation	1.55	1.84	2.02	2.22	1.45	0.21	0.00	0.00	0.03	1.47	1.56	1.56	**13.90**
Bulbula Town Water Supply	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.16**
Langano Tributaries Diversion Irrigation	1.17	1.39	1.53	1.68	1.10	0.16	0.00	0.00	0.02	1.12	1.18	1.18	**10.53**
Lake Abiyata Soda Ash Diversion for producing 50000 tonnes/year	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	**7.50**
Sum	**7.93**	**9.27**	**10.12**	**11.02**	**7.46**	**1.72**	**0.74**	**0.74**	**0.88**	**7.57**	**7.95**	**7.95**	**73.35**

6.1.4.2. *Planed (Proposed) Irrigation scheme*

From Ziway Lake water abstracted for different purposes specially for existed and proposed irrigation scheme is assumed to be maximum from agronomy report. In this thesis total amount of 14657.2 ha of land is considered for irrigation in three different scenarios (for the irrigation area) but the study has four scenarios depend on the data. For each plot area(1 ha land) average of 1.7 l/s for furrow irrigation and 1.2 l/s for pressurized system is considered as water demand respectively. Water supply demand of Ziway town and Ziway Lake pumped irrigation is also taken into account as existing abstraction for water balance of the lake. All water balance data is done by changing the whole data multiplied by 1000 m^3 this is to make the same with Lake Bathymetry volume data because its result is kept in this unit.

Table 6.7 Irrigation water demand abstracted from the lake for proposed scheme

		From proposed scheme	From proposed scheme	From proposed scheme
Season	Month	Volume(1000m3) for 3774.7ha	Volume(1000m3) for 4668.5ha)	Volume(1000m3) for 6214ha
Dry	January	9245.12	8947.72	11851.09
	February	4920.65	4861.22	6438.59
	March	2920.58	2826.63	3743.81
	April	3476.45	3364.63	4456.38
Wet	May	2652.41	2567.09	3400.06
	June	2863.01	2770.91	3670.01
	July	2065.02	1998.59	2647.10
	August	917.79	888.26	1176.49
	September	1740.84	1684.83	2231.54
Dry	October	5022.79	4861.22	6438.59
	November	5746.79	5561.93	7366.67
	December	5870.32	5681.49	7525.02

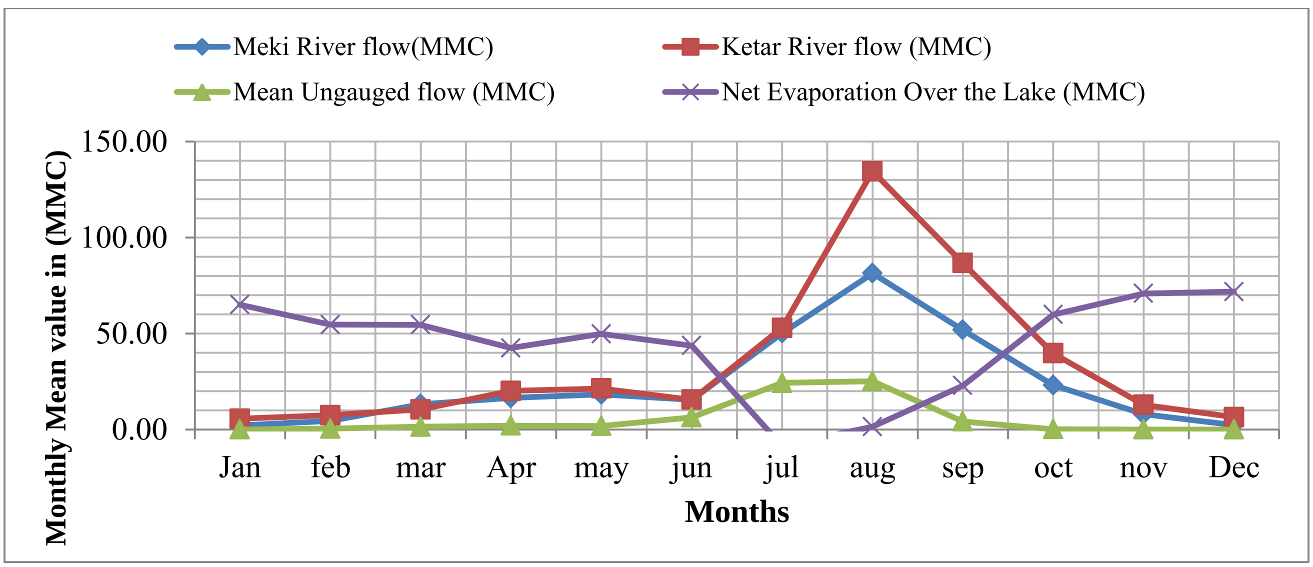


Figure 6.6 components of the water balance for scenario one (1963-2005)

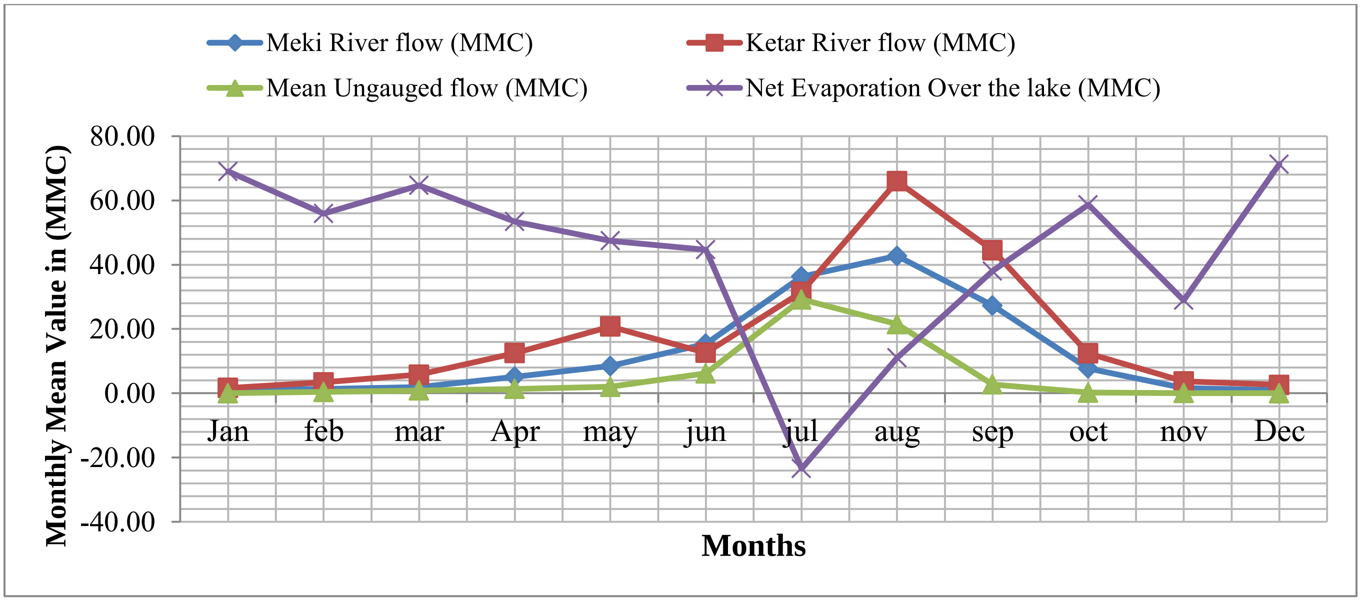


Figure 6.7 components of the water balance for scenario two (2006-2014)

6.2. Model Scenarios Results and Discussions

6.2.1. Water balance that considers data from (1963-2005)

Consider Ziway lake inflow, outflow and lake storage at the end of august for the year from (1963-2005) without existing and proposed irrigation scheme.

The purpose of this application is to calculate the response of lake and Bulbula river to monthly variation of hydro metrological data only. The application is based on the previous data (1963-2005). Since the aim of the research is to generate level, area, volume of Ziway lake and such variation on Bulbula outflow. The analysis assumes the lake is full at the end of the rainy season which in this study case is august.

Table 6.8 lake level, area, volume and Bulbula out flow at the end of august

Lake Level(m)	Area(1000m2)	Volume(1000m3)	Out let capacity(m^3/s)
1638	508668	2123656	76.73

Results and discussion

From the result water balance (monthly mean):-Lake Ziway Mean lake level remain the same from (1963-2005) years. There is (1.37 m rise from the mean 1936.12 m asl) which means the lake drops its level from the full level by 0.507 m from October to June then gain its level in July and august then it became full.

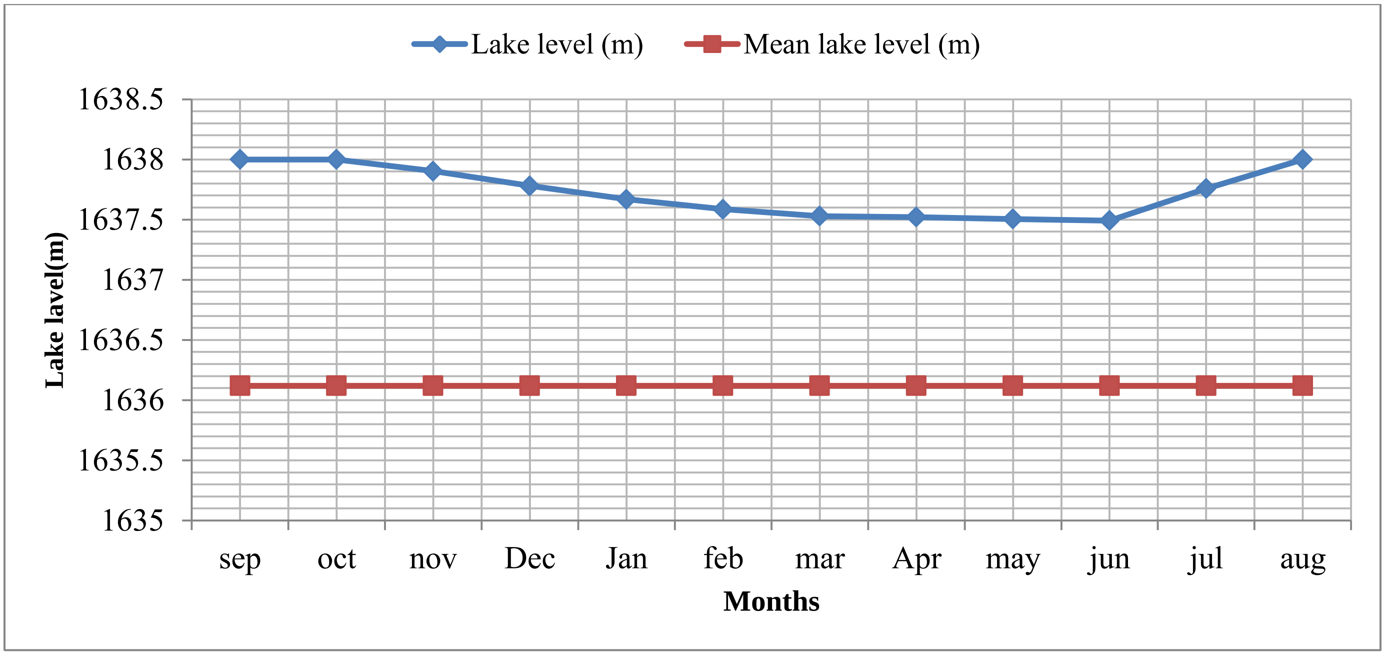


Figure 6.8 Results of Lake level (m) for (1963-2005) year data

Table 6.9 Results of the Model for (1963-2005) data

Months	volume of lake (1000m^3)	level of lake(m)	Area of lake (1000m^2)	Bulbula out flow(m^3/s)
sep	2123656	1638	508668	76.73
oct	2126802.52	1638	508668	76.73
nov	2073536.84	1637.9	505834.2886	70.334193
Dec	2010521.34	1637.78	502271.4247	62.29265772
Jan	1953326.03	1637.69	499037.6314	54.9938489
feb	1911098.86	1637.58	496650.1291	49.60515468
mar	1881594.31	1637.53	494981.9572	45.84001977
Apr	1877774.37	1637.52	494765.9799	45.35254985
may	1869488.38	1637.5	494176.9271	44.19597351
jun	1863165.37	1637.49	494109.6926	43.62786806
jul	1999126.2	1637.75	501627.1495	60.83850121
aug	2123656	1638	508668	76.73
Annual (sum)	23928936.87		6009459.18	707.2707667

Results and discussion For Bulbula River

From the result of the water balance (monthly mean):-Bulbula river Mean outflow (discharge) remain the same from (1963-2005) years. The river drops its Discharge from the full (76.73

m^3/s) by 33.1 m^3/s from October to June then gain its amount in July and august then became full.

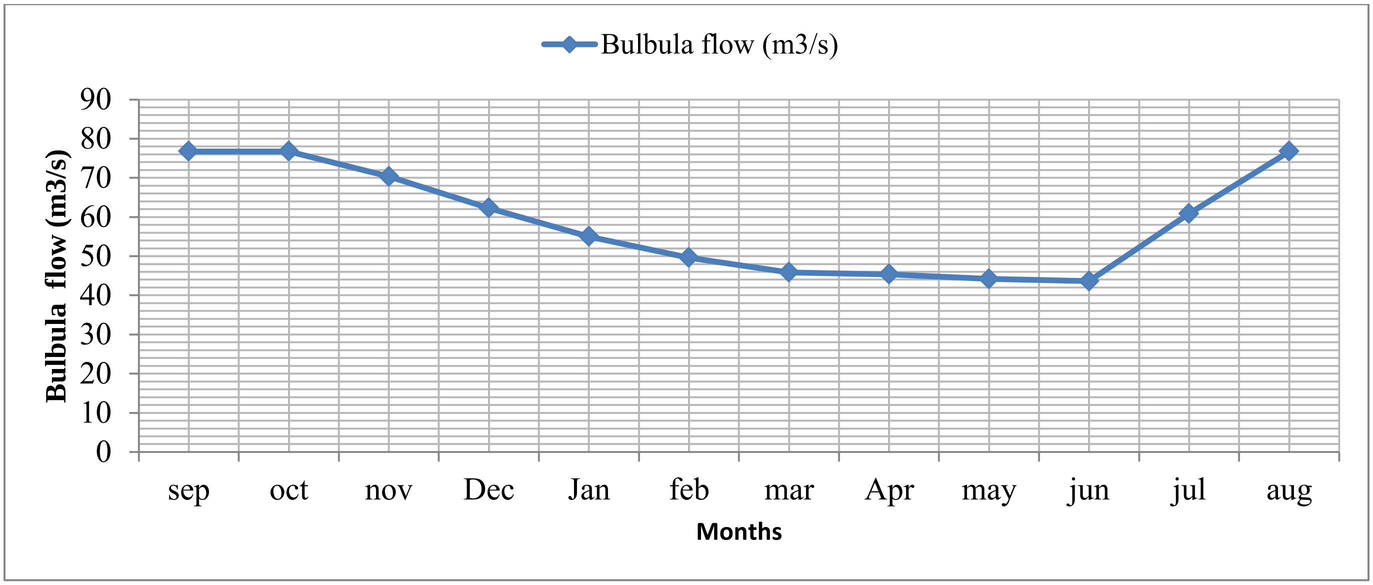


Figure 6.9 Results of Rating curve for Bulbula River outflow for (1963-2005)

6.2.2. Base Scenario that considers data from (2006-2014)

Base Scenario considers Ziway lake inflow, outflow and lake storage data for the year from (2006-2014) without existing and proposed irrigation scheme.

The purpose of this application is to calculate the response of lake and Bulbula river to monthly variation hydro metrological data without the existing and proposed irrigation scheme conditions. The application is based on the latest data (2006-2014).In addition, this scenario show the difference between previous and latest data on water balance of the lake and Bulbula outflow.

Results and discussion of base scenario for Ziway Lake:

From the result of base scenario (monthly mean):-Lake Ziway Mean lake level remain the same from (2006-2014) years. There is (1.16 m rise from the mean boundary of 1936.12 m a.s.l).in the other expression the lake drops its level from the full level by 0.72 m from September to Jun then increasing its level in July and august finally in a year the lake drops its level by 0.24m.

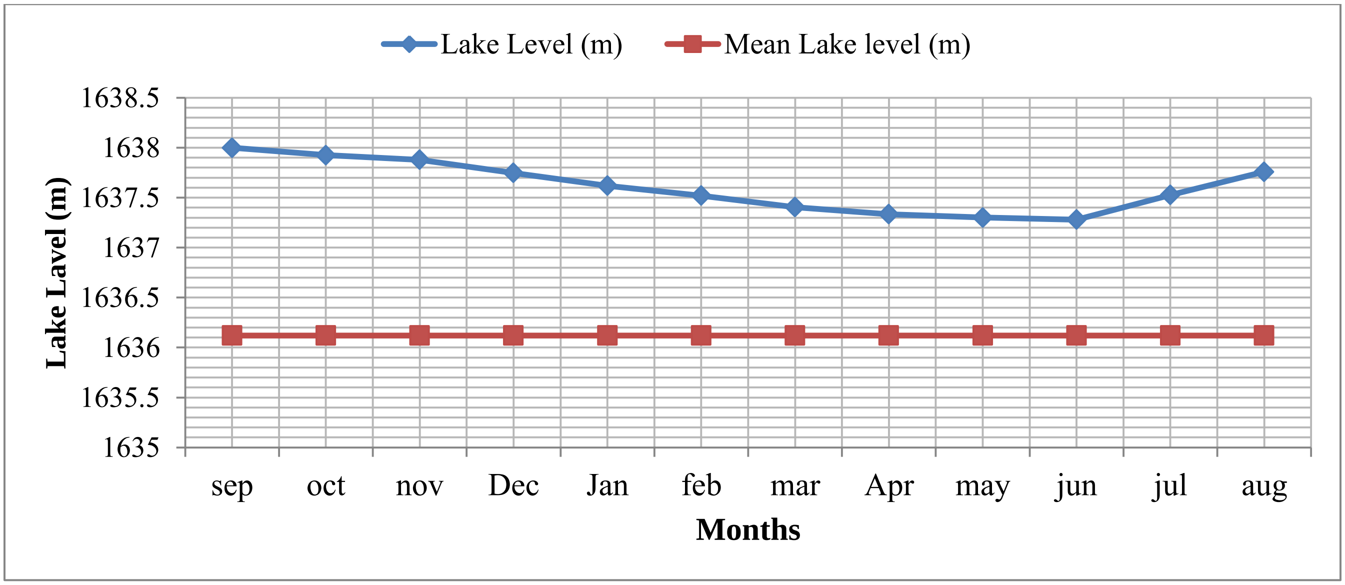


Figure 6.10 Result of Lake level for base scenario from (2006-2014)

Table 6.10 Results of the water balance model for base scenario (2006-2014)

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656	1638	508668	76.73
oct	2085397.29	1637.925507	506504.8723	71.84772894
nov	2061927.765	1637.87981	505177.9175	68.85273546
Dec	1994256.803	1637.748049	501351.8363	60.21710762
Jan	1927966.511	1637.618976	497603.8175	51.75766986
feb	1877268.732	1637.520263	494737.3912	45.28802401
mar	1821178.077	1637.405858	493663.2292	39.85542471
Apr	1786742.356	1637.334896	493297.0638	36.76146956
may	1770567.325	1637.301564	493125.0699	35.30818736
jun	1760108.748	1637.280012	493013.8607	34.36851286
jul	1880482.799	1637.526521	494919.1129	45.69817761
aug	1999693.258	1637.758634	501659.2107	60.91086466
Annual (sum)	23089245.67		5983721.382	627.5959026

Results and discussion of base scenario For Bulbula river

From the result of base scenario (monthly mean):-Bulbula river outflow (discharge) doesn't remain the same from (2006-2014) years. The river discharge drops from the full (76.73 m^3/s) by

42.36 m^3/s from September to Jun then gaining some amount of discharge in July and august to decrease by 15.81 m^3/s from the full in a year.

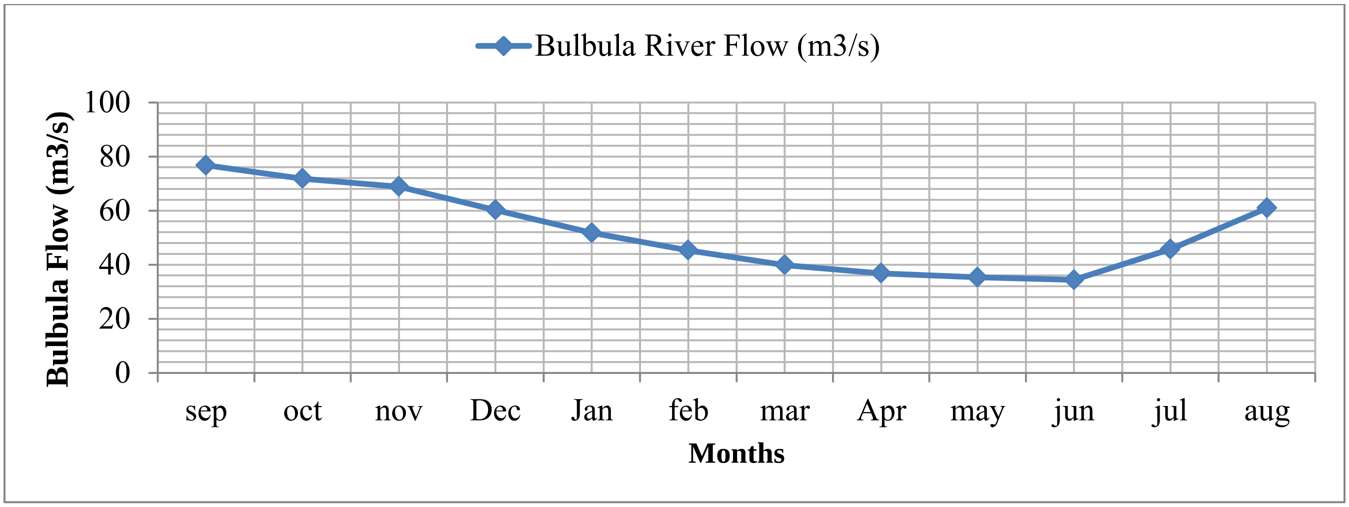


Figure 6.11 Result of rating curve for Bulbula river in base scenario from (2006-2014)

6.2.3. Scenario -1 (first scenario) by considering the existing abstraction

Scenario -1 by analyzing the above scenario, considering Ziway lake inflow, outflow, lake storage data and the existing abstraction that will continue in present (Ziway lake pumped irrigation and Ziway lake pumped water supply) depend on the latest data for the year (2006-2014).

Table 6.11 Existing abstractions water demand for scenario one (2006-2014)

Months	Ziway Lake Pumped Irrigation(1000m^3)	Ziway Lake Pumped Water Supply(1000m^3)
Jan	2020	110
Feb	2400	110
Mar	2640	110
Apr	2890	110
May	1890	110
Jun	270	110
Jul	0	100
Aug	0	100
Sep	40	110
Oct	1920	110
Nov	2030	110
Dec	2030	110
Annual	18120	1310

The purpose of this application is to calculate the response of lake and Bulbula river to monthly varying existing abstractions for total water demand of 19.430 Mm^3 in a year. The application is based on the latest data (2006-2014) by keeping the difference between the previous and latest data.

Results and discussion of scenario- 1 For Ziway lake:

From the result of first scenario (monthly mean):-Lake Ziway Mean lake level remain the same from (2006-2014) years. There is (1.12m rise from the mean boundary of 1936.12 m asl).in the other expression the lake drops its level from the full level by 0.758 m from September to Jun then increasing its level in July and august finally in a year the lake drops its level by 0.27m.in this scenario the existing abstraction makes the lake to drop in 0.04m (4cm).

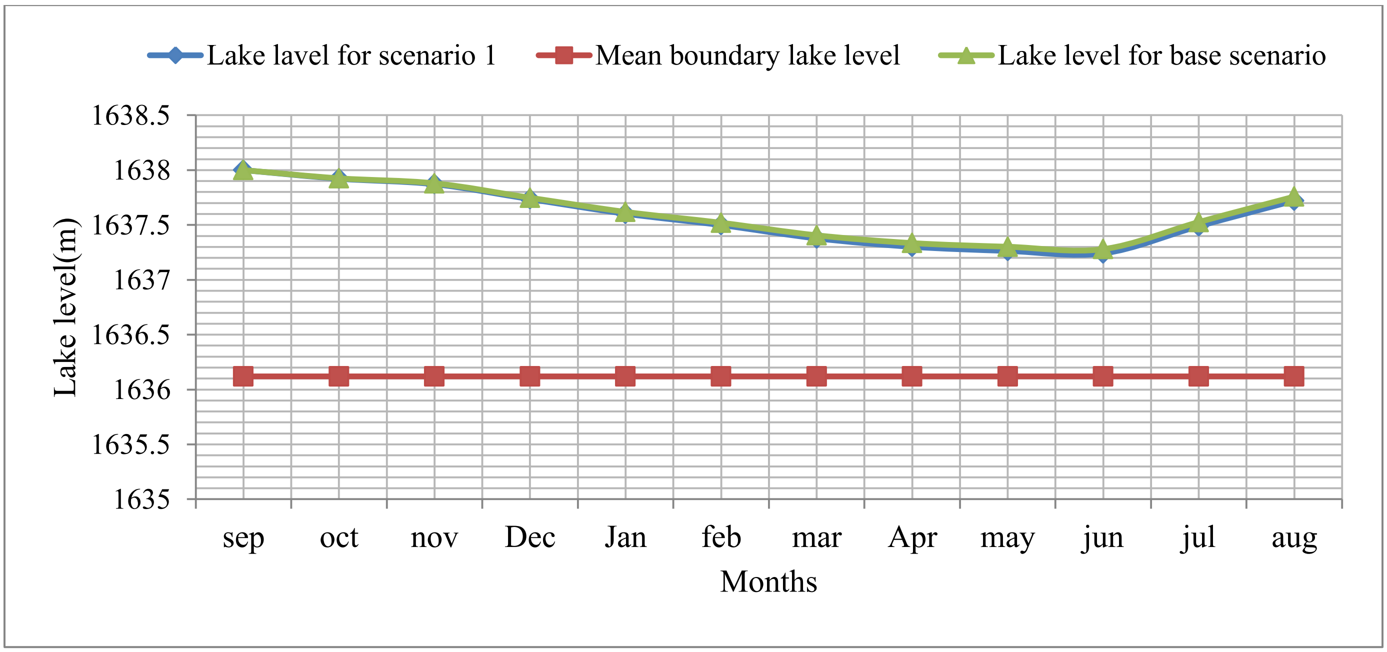


Figure 6.12 Result of Lake Level for scenario one (by considering the existing abstraction)

Table 6.12 Results of the water balance for scenario one (2006-2014)

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656	1638	508668	76.73
oct	2083367.29	1637.921554	506390.0972	71.58867654
nov	2057764.316	1637.871703	504942.5183	68.32142939
Dec	1987986.561	1637.73584	500997.3201	59.41694938

Jan	1919615.055	1637.602715	497131.6304	50.69192366
feb	1866460.335	1637.499172	494144.729	43.92391154
mar	1807697.16	1637.378078	493519.8825	38.64420126
Apr	1770276.956	1637.300966	493121.9823	35.28209851
may	1752118.766	1637.263547	492928.9008	33.65063484
jun	1741297.957	1637.241248	492813.8399	32.6784148
jul	1861562.507	1637.489079	494092.6489	43.48385508
aug	1980691.349	1637.721636	500584.8525	58.48599266
Total(Sum)	22952494.25		5979336.402	612.8980877

Results and discussion of scenario-1 For Bulbula River

From the result of first scenario (monthly mean):- Bulbula river outflow (discharge) doesn't remain the same from (2006-2014) years. The river drops Discharge from the full (76.73 m3/s) by 44.05 m3/s from September to Jun then gaining some amount of discharge in July and august to decrease by 18.24 m3/s from the full in a year. In monthly mean basis the existing abstraction decrease Bulbula outflow by 2.42 m3/s.

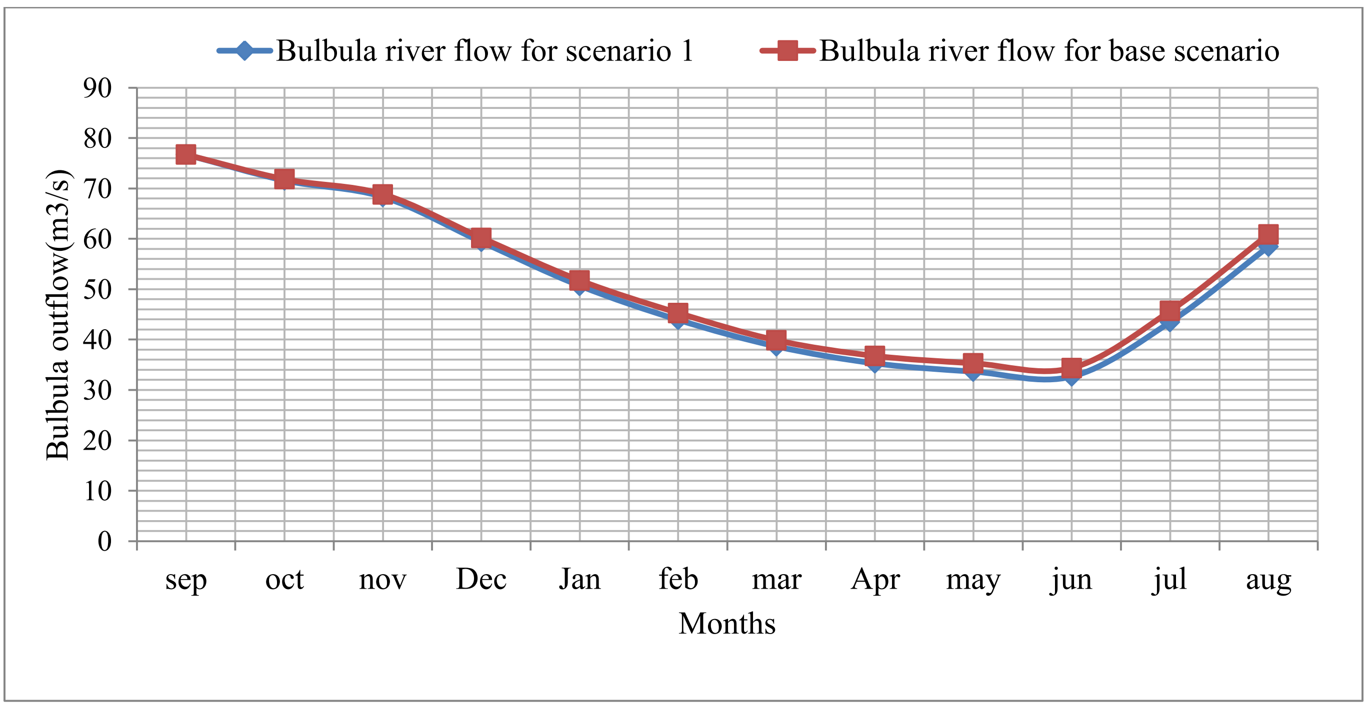


Figure 6.13 Result of Rating curve for Bulbula river in scenario one (Existing abstraction)

6.2.4. Scenario 2 (second scenario) by considering a 3774.7 ha land

Scenario 2, considers Ziway lake inflow, outflow,existing abstraction and abstraction for 3774.7 ha land from the planed scheme for the year from (2006-2014).

The purpose of this application is to calculate the response of lake and Bulbula River to monthly varying irrigation water demand for 3774.7 hectare land.

Table 6.13 Water demand for existing abstraction and for 3774.7 ha land for scenario two (2006-2014)

Months	Sum of existing abstraction(1000m3)	Volume(1000m3) for 3774.7ha
sep	150.00	1740.84
oct	2030.00	5022.79
nov	2140.00	5746.79
Dec	2140.00	5870.32
Jan	2130.00	9245.12
feb	2510.00	4920.65
mar	2750.00	2920.58
Apr	3000.00	3476.45
may	2000.00	2652.41
jun	380.00	2863.01
jul	100.00	2065.02
aug	100.00	917.79
Total(Sum)	19430	47441.77

Results and discussion of scenario- 2-for Ziway lake:

From the result of second scenario (monthly mean):- Lake Ziway Mean lake level remain the same from (2006-2014) years. There is (1.03m rise from the mean 1936.12 m asl).in the other expression the lake drops its level from the full level by 0.84 m from September to Jun then increasing its level in July and august finally in a year the lake drops its level by 0.366m.in this scenario the existing abstraction and the 3774.7 ha land makes the lake to drop in 0.125m (14cm) from this result a 0.088m (8.8cm) drop is for 3774.7 ha land.

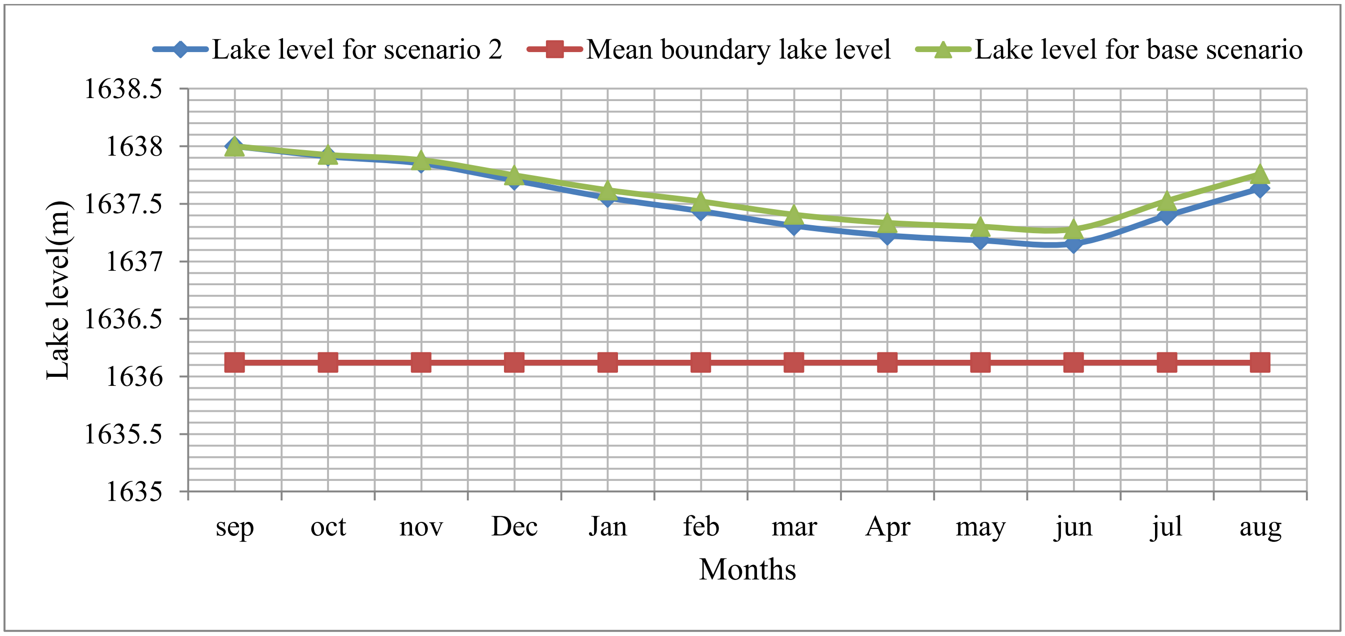


Figure 6.14 Result of Lake level for scenario two (with irrigation scheme of 3774.7 ha)

Table 6.14 Result of the water balance for scenario two (2006-2014)

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656.00	1638	508668.00	76.73
oct	2078344.50	1637.911775	506106.1112	70.94770819
nov	2047010.95	1637.850765	504334.5283	66.94917018
Dec	1971448.64	1637.703639	500062.2744	57.30651153
Jan	1893960.68	1637.552763	495681.1456	47.41811767
feb	1836048.31	1637.436502	493821.3488	41.19147419
mar	1774406.83	1637.309476	493165.8965	35.65315615
Apr	1733548.49	1637.225279	492731.4375	31.98214673
may	1712775.46	1637.182471	492510.5516	30.11574637
jun	1699129.53	1637.154351	492365.4504	28.88969726
jul	1817307.76	1637.397883	493622.075	39.5076876
aug	1935529.28	1637.633701	498031.4126	52.7227702
Total(Sum)	22623166.43		5971100.23	579.41

Results and discussion of scenario- 2- For Bulbula river

From the result of second scenario (monthly mean):- Bulbula river outflow (discharge) doesn't remain the same from (2006-2014) years. the river drops Discharge from the full (76.73 m3/s) by 47.84 m3/s from September to Jun then gaining some amount of discharge in July and august to decrease by 24 m3/s from the full in a year. In monthly mean basis the existing abstraction and the 3774.7 ha land decrease Bulbula outflow by 8.18 m3/s. from this 5.76m3/s is for 3774.4 ha land.

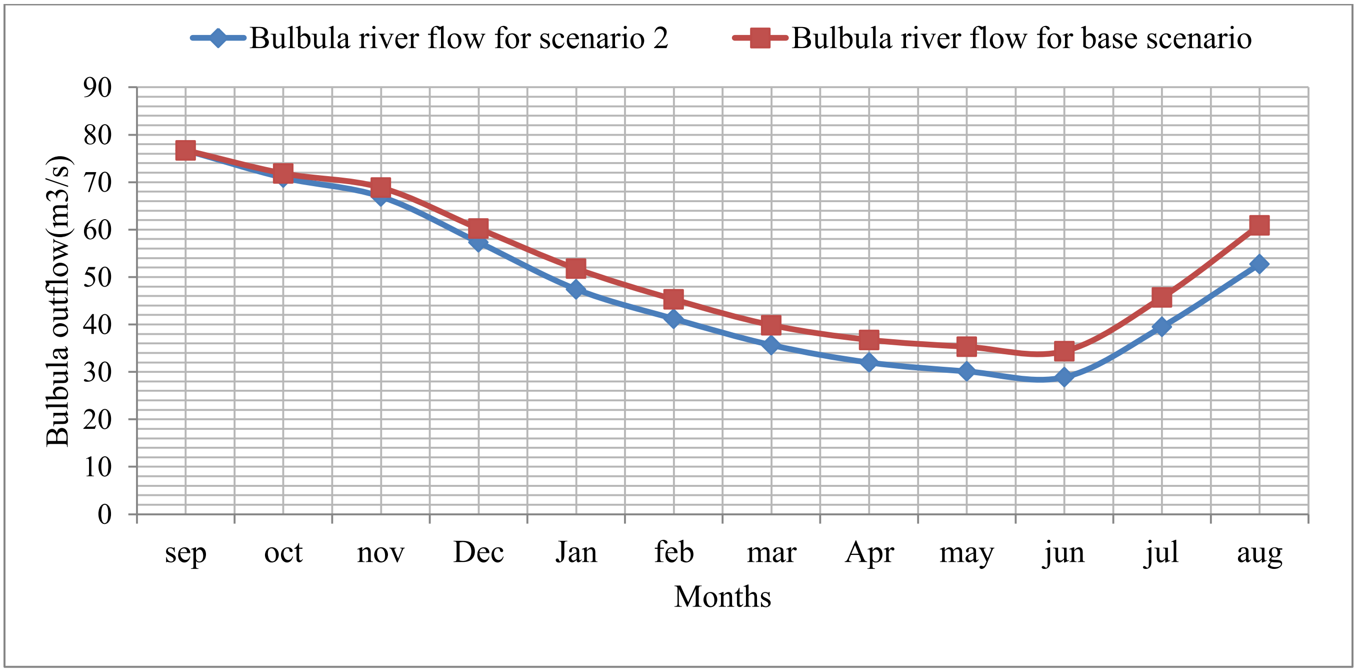


Figure 6.15 Result of Rating curve for Bulbula river for scenario two (with 3774.7 ha land)

6.2.5. Scenario 3- (third scenario) by considering a total of 8443.2 ha land

Scenario 3, considers Ziway lake inflow, outflow, existing abstraction and 8443.2 proposed irrigation scheme (additional scheme of 4668.5 ha land on scenario-2) from the lake for the year from (2006-2014).

The purpose of this application is to calculate the response of lake and Bulbula river to monthly varying existing abstraction and irrigation water demand for 8443.2 hectare land. This scenario considers the sum of the two irrigation scheme (8443.2 hectare land) from the proposed.

Table 6.15Water demand for existing abstraction and for 8443.2 ha land for scenario three (2006-2014)

Months	Existing abstraction(1000m3)	Volume(1000m3) for 3774.7ha	Volume(1000m3) for 4668.5ha)
sep	150.00	1740.84	1684.83
oct	2030.00	5022.79	4861.22
nov	2140.00	5746.79	5561.93
Dec	2140.00	5870.32	5681.49
Jan	2130.00	9245.12	8947.72
feb	2510.00	4920.65	4861.22
mar	2750.00	2920.58	2826.63
Apr	3000.00	3476.45	3364.63
may	2000.00	2652.41	2567.09
jun	380.00	2863.01	2770.91
jul	100.00	2065.02	1998.59
aug	100.00	917.79	888.26
Annual (sum)	19430	47441.77	46014.52

Results and discussion of scenario 3-For Ziway lake:

From the result of scenario three, (monthly mean):- Lake Ziway Mean lake level remain the same from (2006-2014) years. There is (0.95m rise from the mean boundary of 1936.12 m asl).in the other expression the lake drops its level from the full level by 0.93m from September to Jun then increasing its level in July and august finally in a year the lake drops its level by 0.45m.in this scenario the existing abstraction and the 8443.2 ha land makes the lake to drop in 0.21m (21cm) from this result a 0.173m (17.3cm) drop is due to 8443.2 ha land.

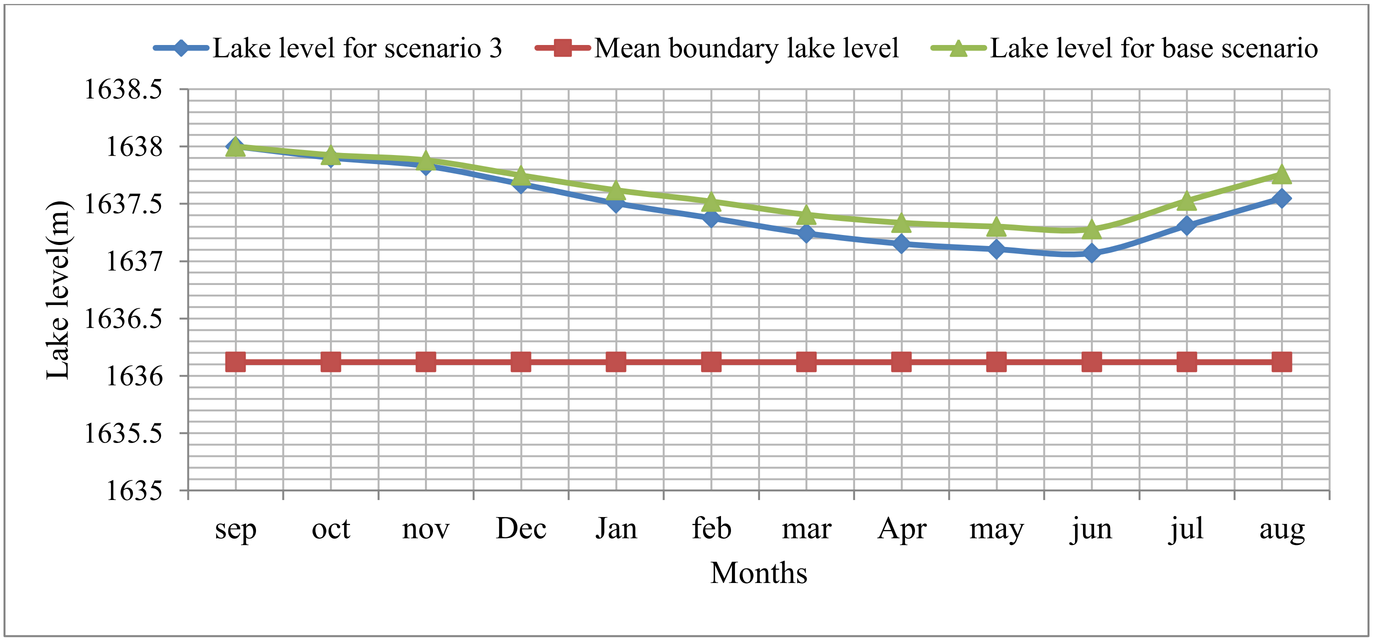


Figure 6.16 Result of Lake level for scenario three (with irrigation scheme of 8443.2 ha)

Table 6.16 Results of the water balance for scenario three (2006-2014)

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656	1638	508668	76.73
oct	2073483.28	1637.902309	505831.2604	70.3273581
nov	2036603.485	1637.830501	503746.0958	65.62105305
Dec	1955442.692	1637.672474	499157.3065	55.26396069
Jan	1869131.554	1637.504677	494173.1328	44.16391316
feb	1806527.415	1637.375667	493507.4443	38.53910287
mar	1742100.342	1637.242902	492822.3719	32.75050694
Apr	1697914.564	1637.151847	492352.5313	28.78053581
may	1674610.883	1637.103825	492104.7363	26.68676396
jun	1658230.803	1637.07007	491930.562	25.21505871
jul	1774389.79	1637.309441	493165.7153	35.65162529
aug	1891733.198	1637.548426	495555.2047	47.13386374
Total(Sum)	22303824.01		5963014.361	546.8637423

Results and discussion of scenario 3- For Bulbula River

From the result of scenario-3 (monthly mean):- Bulbula river outflow (discharge) doesn't remain the same from (2006-2014) years. the river drops Discharge from the full (76.73 m3/s) by 51.51

m3/s from September to Jun then gaining some amount of discharge in July and august to decrease by 29.59 m3/s from the full in a year. In monthly mean basis the existing abstraction and the 8443.2 ha land decrease Bulbula outflow by 13.77 m3/s from this 11.35m3/s is due to 8443.2 ha land.

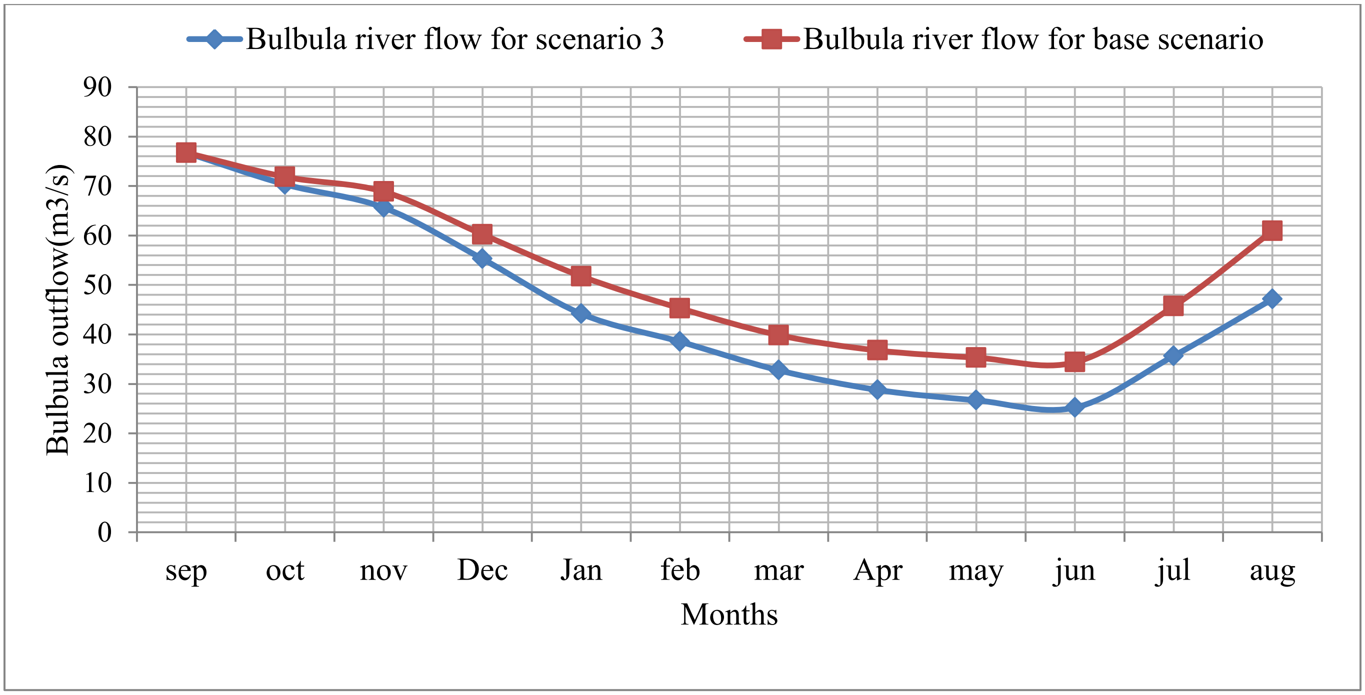


Figure 6.17 Result of rating curve for Bulbula river for scenario three (with 8443.2 ha land)

6.2.6. Scenario 4- (fourth scenario) by considering a total of 14657.2 ha land

Scenario 4, considers Ziway lake inflow, outflow, existing abstraction and 14657.2 proposed irrigation scheme (additional scheme of 6214 ha land on scenario-3) from the lake for the year from (2006-2014).

The purpose of this application is to calculate the response of lake and Bulbula river to monthly varying existing abstraction and proposed irrigation water demand for 14657.2 hectare land. This scenario considers the sum of all proposed scheme.

Table 6.17 Water demand for existing abstraction and for all proposed scheme in scenario four (2006-2014)

Months	Existing abstraction(1000m3)	Volume(1000m3) for 3774.7ha	Volume(1000m3) for 4668.5ha)	Volume(1000m3) for 6214ha
sep	150.00	1740.84	1684.83	2231.54
oct	2030.00	5022.79	4861.22	6438.59
nov	2140.00	5746.79	5561.93	7366.67
Dec	2140.00	5870.32	5681.49	7525.02
Jan	2130.00	9245.12	8947.72	11851.09
feb	2510.00	4920.65	4861.22	6438.59
mar	2750.00	2920.58	2826.63	3743.81
Apr	3000.00	3476.45	3364.63	4456.38
may	2000.00	2652.41	2567.09	3400.06
jun	380.00	2863.01	2770.91	3670.01
jul	100.00	2065.02	1998.59	2647.1
aug	100.00	917.79	888.26	1176.49
Annual (sum)	19430	47441.77	46014.52	60945.35

Results and discussion of scenario 4-For Ziway lake:

From the result of scenario four, (monthly mean):- Lake Ziway Mean boundary lake level remain the same from (2006-2014) years. There is (0.836m rise from the mean 1936.12 m asl).in the other expression the lake drops its level from the full level by 1.04 m from September to Jun then increasing its level in July and august finally in a year the lake drops its level by 0.568m.in this scenario the existing abstraction and the 14657.2 ha land makes the lake to drop in 0.33m (33cm) from this result a 0.29m (29cm) drop is due to 14657.2 ha land.

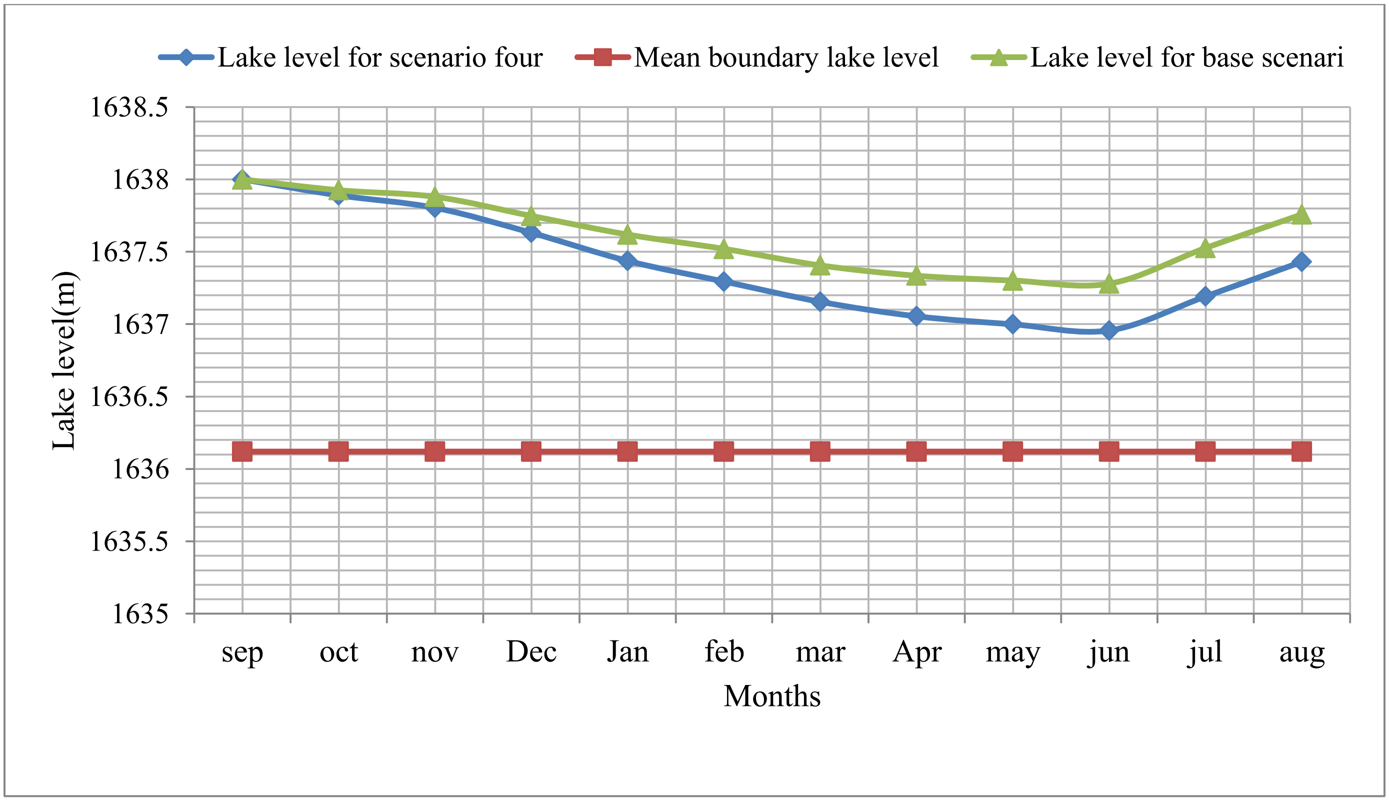


Figure 6.18 Result of Lake level for scenario four (with irrigation scheme of 14657.2 ha)

Table 6.18 Results of the water balance for all irrigation scheme (2006-2014)

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656	1638	508668	76.73
oct	2067044.69	1637.889773	505467.2258	69.50571665
nov	2022819.004	1637.803662	502966.7284	63.86198768
Dec	1934243.132	1637.631197	497958.6944	52.55864213
Jan	1836245.847	1637.436909	493823.4493	41.20922254
feb	1767242.413	1637.294712	493089.7151	35.00945309
mar	1699126.14	1637.154344	492365.4144	28.88939264
Apr	1650533.447	1637.054208	491848.7137	24.52347231
may	1623878.166	1636.999257	491525.1951	22.14059954
jun	1603880.569	1636.956767	491345.9159	20.27502588
jul	1717364.685	1637.191928	492559.3503	30.52807596
aug	1833545.091	1637.431343	493794.7313	40.96656703
Total(Sum)	21879579.18		5955413.134	506.1981555

Results and discussion of scenario 4- For Bulbula river

From the result of scenario- (monthly mean):- Bulbula river outflow (discharge) doesn't remain the same from (2006-2014) years. the river drops Discharge from the full (76.73 m3/s) by 56.45 m3/s from September to Jun then gaining some amount of discharge in July and august to decrease by 35.76 m3/s from the full in a year. In monthly mean basis the existing abstraction and the 14657.2 ha land decrease Bulbula outflow by 19.94 m3/s. from this 17.519m3/s is due to 14657.2 ha land.

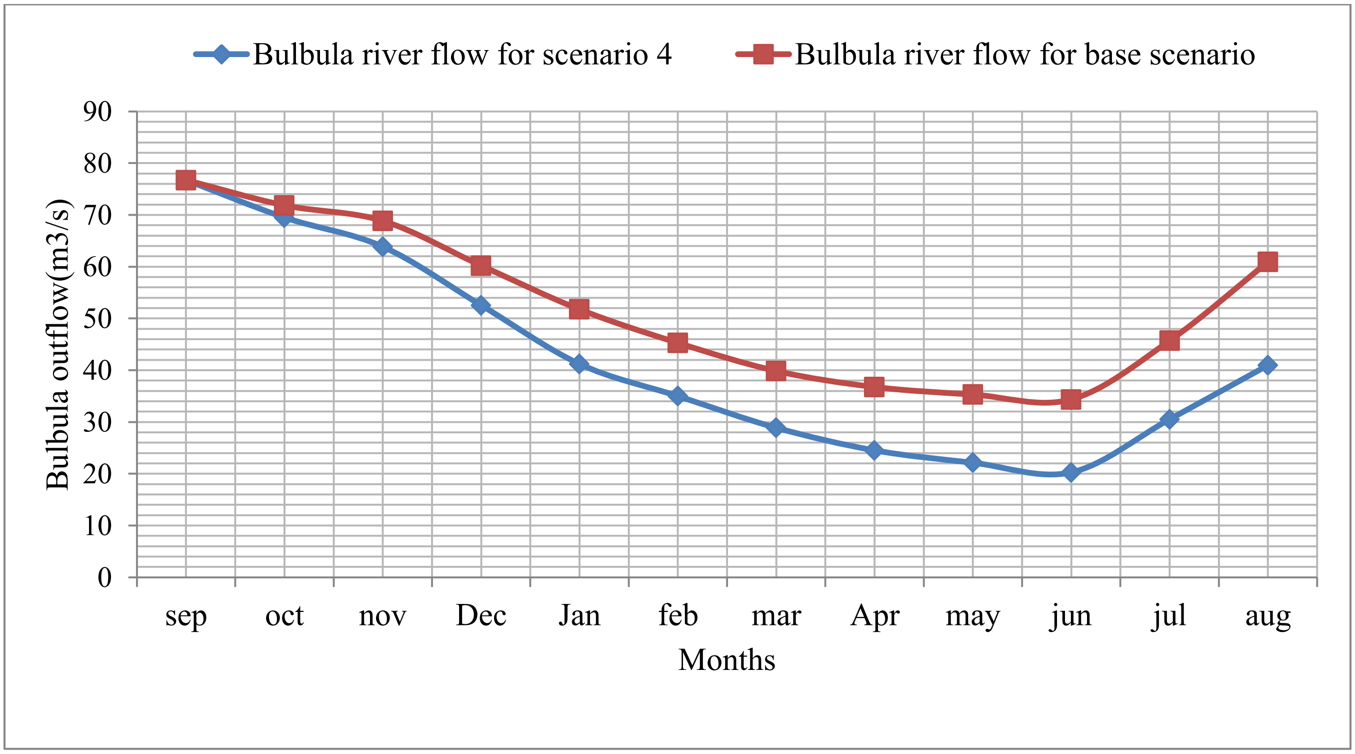


Figure 6.19 Result of rating curve for Bulbula river for scenario four (with 14657.2 ha land)

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

The case study area was Lake Ziway which is located within the central main Ethiopian rift valley. The main and specific objective of the study were to determine water balance of Ziway lake by considering existing and proposed irrigation scheme, to quantify the various water balance components, to assess the effect of water abstracted for irrigation scheme on the lake, to know how the impact on the lake affects the flow through Bulbula river and finally to discuss on the measures taken on the lake and river to protect from drying.

The formulated water balance (excel) model is applied in order to understand the effect of inflow rivers (meki and ketar),flow from un gauged sub catchment, inflow from rainfall, out flow from evaporation, out flow from Bulbula river and out flow from the lake as abstraction for different development project on. These components affect the lake level based on the sequence of hydro climate data (2006-2014) with different assumption.

From the result of formulated model the lake gets maximum amount of water from the two contributing rivers(Meki and Ketar).the total annual average inflow from meki river is 150Mm3 and from ketar river 217.5Mm3 respectively. The lake also gets annual average inflow of 64.6Mm3 water from un gauged sub catchment.

Rainfall is an inflow to the lake however, this component contribute very small amount of water due to high amount of evaporation on Lake Surface and in the area. From the result of the model the net evaporation amount of the lake is very high. Annual average outflow from the lake is 519.6Mm3 as net evaporation.

Bulbula River is an outflow river from the lake. This river has maximum outflow of 76.73 m3/s at the exit point of the lake in the end of august. According to the study of this model without the existing and proposed irrigation scheme this river decrease from $76.73m^3/s$ to $60.91m^3/s$ due to recorded data difference.

Ziway-Meki irrigation project planned to irrigate a gross area of 15500 ha land by using Ziway lake as a water source.in addition this study consider water demand that abstracted from the lake for water supply and for Ziway pumped irrigation. Depend on crop water requirement, Pump operation schedule and irrigation plots (areas), this study consider water demand for a net irrigation area of 14657.2 ha by applying different scenario. Depend on the model the total amount of annual average water demand for 14657.2 ha land is 154.4 Mm3.

The main objective was to determine the lake level by applying irrigation scheme of 14657.2 ha land. From the result of water balance model the lake drops its level from the full level (1638 m) by 0.568 m from September to august of which 0.33m is by the existing abstraction and by the scheme the other 0.23 m drop is due to inflow rivers variation. From this result the existing abstraction and the total irrigation area of 14657.2 ha decreases Bulbula outflow by 20m3/s of which 17.51 m3/s due to the proposed scheme. Such yearly variation would result in a nastic water level and Bulbula river flow decrease in upcoming years.

7.2. Recommendation

The reliability of the lake water balance estimate depend on the accuracy of the water balance components which is recorded for long sequence of period, but this study depend on the latest data (2006-2014) due to the rapid change of lake level in this period from previous period. This study would like to recommend further research should be carried out by increasing the data sequence when the lake show rapid change.

The existing and proposed irrigation scheme makes the lake to drop its level by 0.33m and decrease Bulbula river by 20.m3/s. after the application of the water balance model the minimum amount of Bulbula outflow in month august is 40.96 m3/s so if in the future more amount of irrigation area is proposed based on Ziway lake as a source, Bulbula outflow decreases which has an impact on lake abiyata. Finally this study recommend to the concerned body (stakeholders) additional irrigation scheme makes Bulbula river decrease.

This study was done by using bathymetry map of the lake which is developed in 2006 so the study recommend if the research is supported by latest bathymetry the result may be more attractive, due to this other researcher as much as possible may use and applies latest bathymetry if any.

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9. ANNEXS

Annex 1 Monthly flow of Meki River in (Mm3)

	Meki Flow		**Mm3**		Area 2433 km2								
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	5.39	33.80	42.23	38.24	75.17	11.14	56.42	75.57	42.95	7.24	0.94	1.18	390.27
1964	1.54	0.65	0.78	3.32	4.24	10.05	39.31	70.45	62.11	39.13	4.98	2.95	239.51
1965	1.79	1.32	1.97	1.84	0.94	0.78	11.59	37.70	32.34	26.47	3.75	1.00	121.49
1966	0.76	12.78	12.39	23.23	12.07	4.80	22.13	70.88	74.52	23.53	5.00	1.50	263.59
1967	1.04	0.57	0.86	6.39	46.53	12.01	58.08	72.18	34.07	45.15	48.88	10.34	336.10
1968	2.42	12.18	10.15	84.44	68.44	13.14	28.92	70.51	57.25	16.52	2.57	1.68	368.22
1969	2.02	23.76	31.80	24.64	34.02	20.56	63.21	84.33	52.15	9.82	1.54	0.56	348.41
1970	10.80	3.84	46.09	6.08	6.69	4.53	69.69	111.45	52.57	16.18	4.18	2.34	334.44
1971	1.99	1.11	1.47	5.57	13.64	45.77	82.85	103.28	54.08	7.92	2.58	1.06	321.32
1972	1.09	12.31	113.88	32.80	24.99	10.33	37.81	75.62	36.16	9.06	1.60	0.00	355.65
1973	0.19	0.00	0.00	0.02	1.63	2.69	46.83	65.38	59.52	31.83	2.61	0.25	210.96
1974	0.53	0.00	4.82	2.82	3.27	6.72	58.39	67.74	72.84	19.76	2.31	0.49	239.69
1975	0.30	0.58	0.02	1.57	1.18	11.56	72.77	73.44	116.36	32.33	5.09	1.33	316.52
1976	0.70	0.22	0.22	5.19	15.71	5.39	39.72	50.42	36.10	5.46	14.60	1.99	175.72
1977	6.69	9.52	9.52	9.05	26.68	16.76	83.60	77.02	48.70	47.81	63.43	7.59	406.37
1978	1.22	4.18	4.18	3.12	1.99	9.99	35.39	78.58	41.86	38.20	6.44	2.98	228.13
1979	7.95	14.16	14.16	54.05	35.32	7.72	63.46	80.12	36.05	34.16	10.31	3.10	360.56
1980	2.16	2.41	3.40	5.66	4.04	11.84	44.36	56.43	24.70	11.65	2.12	1.41	170.18
1981	1.07	1.18	36.66	51.92	14.87	7.39	28.51	80.71	58.75	13.68	1.60	3.05	299.39
1982	2.46	4.29	3.46	18.21	19.06	6.55	22.11	80.54	24.97	44.24	6.69	4.35	236.93
1983	1.42	6.67	12.36	30.77	48.11	36.19	26.56	89.43	55.42	20.16	4.48	2.38	333.95
1984	1.65	1.21	1.20	0.82	6.95	11.87	26.81	26.28	34.25	2.89	0.91	0.77	115.61
1985	0.59	0.44	0.45	4.38	17.30	3.27	24.40	72.72	40.24	7.22	0.87	0.45	172.32
1986	0.25	1.25	2.32	12.67	6.83	25.88	63.19	76.78	48.07	5.07	0.51	0.11	242.93
1987	0.02	0.68	20.60	47.30	46.23	37.90	20.12	16.80	18.87	6.73	1.01	0.11	216.37
1988	0.09	1.02	0.40	7.95	5.94	7.87	41.96	62.27	58.23	33.79	7.55	2.45	229.52
1989	0.37	5.88	8.83	25.00	7.91	10.13	40.63	41.13	47.25	26.04	4.26	2.37	219.80
1990	0.88	27.45	54.08	57.02	14.14	15.04	45.72	53.02	39.33	17.20	4.80	2.34	331.02
1991	1.33	6.28	19.20	7.41	2.44	9.80	65.51	93.50	52.18	9.31	2.25	1.79	271.00
1992	2.38	13.48	5.77	12.86	11.27	8.45	18.35	136.74	84.86	33.37	7.74	4.24	339.51
1993	2.48	2.38	2.65	34.86	46.98	31.95	67.48	144.14	51.61	57.06	11.59	2.41	455.57
1994	2.17	1.21	1.64	0.79	1.00	11.16	63.18	153.94	121.27	4.59	2.58	0.63	364.16
1995	1.76	2.00	22.36	12.65	10.02	6.63	28.26	72.11	82.63	6.36	3.37	1.91	250.06
1996	6.54	0.61	19.65	24.63	51.64	86.30	109.10	149.72	63.53	14.86	5.15	3.24	534.98
1997	0.84	0.65	2.65	25.78	7.75	11.31	44.45	44.45	13.99	14.40	16.03	2.47	184.77

1998	4.28	1.79	32.46	8.48	31.52	13.55	73.98	187.79	75.78	61.92	6.62	1.12	499.28
1999	0.24	0.18	7.61	0.30	1.36	7.35	55.29	60.05	26.32	85.06	32.31	4.69	280.76
2000	1.28	0.85	0.43	1.66	8.55	6.80	43.25	84.95	67.33	53.49	21.50	9.29	299.38
2001	0.37	1.04	16.22	9.50	23.55	59.97	112.28	129.68	73.22	8.55	2.98	2.34	439.70
2002	13.24	9.37	5.27	3.64	1.67	13.15	40.97	57.00	31.19	5.78	4.38	1.60	187.25
2003	2.31	1.24	21.03	16.16	5.24	11.96	112.78	125.75	54.14	9.82	0.84	3.80	365.07
2004	2.24	0.65	1.94	1.94	0.65	2.00	18.49	56.20	21.33	8.72	0.39	0.11	114.67
2005	0.33	0.08	1.15	5.98	2.83	5.32	11.40	18.68	12.60	4.28	0.86	0.24	63.74
Mean	***2.23***	***4.56***	***13.24***	***16.49***	***18.27***	***15.43***	***50.19***	***81.35***	***51.88***	***23.16***	***7.94***	***2.38***	***287.34***
Max	***13.24***	***27.45***	***113.88***	***84.44***	***75.17***	***86.30***	***112.78***	***187.79***	***121.27***	***85.06***	***63.43***	***10.34***	***534.98***
Min	***0.02***	***0.00***	***0.00***	***0.02***	***0.65***	***0.78***	***11.59***	***16.80***	***13.99***	***2.89***	***0.39***	***0.00***	***114.67***
stdev	***2.83***	***6.39***	***20.63***	***19.01***	***19.41***	***16.52***	***25.40***	***35.59***	***23.13***	***18.88***	***12.61***	***2.26***	***99.78***
CV	***1.27***	***1.40***	***1.56***	***1.15***	***1.06***	***1.07***	***0.51***	***0.44***	***0.45***	***0.82***	***1.59***	***0.95***	***0.35***
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	5.27	4.308	5.28	6.82	24.26	52.48	84.62	94.82	48.28	22.42	2.7832	2.72	354.06
2007	2.06	4.711	2.2865	4.62	8.6	47.546	109.57	111.6	60.571	14.853	1.776	1.377	369.56
2008	1.141	0.971	0.842	2.42	4.28	8.223	26.15	55.59	39.506	7.4213	0.68	0.21	147.44
2009	0.257	0.051	0.308	1.456	1.399	0.7517	16.28	12.02	12.91	2.22	0.316	0.2	48.168
2010	0.207	0.437	6.94	27.7	20.695	3.595	67.185	84.9	48.081	6.3616	0.409	0.253	266.76
2011	0.139	0.112	0.21	1.01	5.01	6.02	5.05	8.06	10.02	7.65	0.787	0.419	44.487
2012	0.123	0.899	0.89	1.05	5.04	8.02	10.02	8.68	11.21	5.24	7.805	0.051	59.028
2013	0.08	0.777	0.54	0.88	4.07	5.54	6.32	6.76	9.85	3.509	0.331	3.6	42.257
2014	0.05	0.118	0.223	0.24	3.02	6.21	1.32	2.25	5.24	0.012	0	0	18.683
Mean	1.036	1.376	1.9466	5.133	8.486	15.376	36.279	42.74	27.296	7.743	1.6541	0.981	150.05

Annex 2 Monthly flow of Ketar River in (Mm3)

	Katar Flow (Mm^3)			**Area**	**3350**	km2							
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	5.82	32.36	102.36	91.28	125.56	19.23	94.24	126.23	74.14	12.09	1.62	1.97	
1964	4.30	1.20	1.30	5.73	7.08	17.35	65.66	117.68	107.21	65.36	8.60	4.93	406.40
1965	4.99	2.44	3.29	3.18	1.57	1.35	19.36	62.97	55.82	44.22	6.47	1.67	207.33
1966	2.12	23.63	20.70	40.10	20.16	8.29	36.97	118.40	128.63	39.30	8.63	2.51	449.43
1967	2.90	1.05	1.44	11.03	77.72	20.73	97.02	120.57	58.81	75.42	84.37	17.27	568.33
1968	6.75	22.53	16.95	145.75	114.32	22.68	48.31	137.91	53.78	38.25	7.28	5.20	619.71
1969	7.30	15.22	45.16	17.96	23.41	11.56	76.50	164.72	117.00	18.64	7.64	6.01	511.12
1970	10.97	7.01	37.74	33.38	24.38	8.73	67.52	233.70	133.96	44.70	10.91	6.30	619.30
1971	6.54	5.78	5.71	8.12	12.33	31.06	78.38	107.41	77.37	35.46	12.32	8.35	388.84
1972	7.42	9.91	9.72	21.32	20.40	10.43	62.25	102.65	51.65	17.99	9.87	7.07	330.66
1973	5.72	4.70	4.20	4.18	6.59	6.84	35.67	108.80	91.28	43.64	8.61	5.75	325.97
1974	5.81	4.96	11.22	13.89	8.20	11.64	37.44	91.37	75.52	20.24	6.71	5.53	292.53
1975	5.15	4.60	3.53	5.44	5.30	12.29	65.75	241.98	180.27	38.39	8.70	6.75	578.15
1976	5.78	5.23	5.14	6.80	10.76	7.28	36.06	124.33	71.00	12.46	12.15	5.55	302.52
1977	8.79	8.62	6.95	15.23	13.55	13.18	55.06	134.49	115.35	88.11	66.26	10.98	536.57
1978	7.31	7.99	15.29	7.45	9.60	9.74	92.92	155.22	57.56	46.01	12.00	8.54	429.62
1979	12.00	22.98	23.65	93.29	59.00	13.33	106.00	133.83	62.23	57.06	17.80	5.18	606.34
1980	6.89	6.92	6.23	6.35	6.61	10.43	45.42	104.11	49.99	21.20	7.66	6.58	278.40
1981	5.99	5.89	11.01	58.72	21.65	7.57	34.05	172.05	152.98	90.80	9.64	6.58	576.94
1982	7.30	6.95	6.58	14.50	14.66	10.62	33.42	135.33	54.08	41.22	12.17	7.38	344.20
1983	1.29	1.29	1.29	25.90	44.28	63.63	31.91	267.79	111.71	63.25	1.86	11.86	626.06
1984	0.76	0.45	1.20	0.53	8.43	16.82	46.52	68.36	60.69	9.54	6.34	1.02	220.64
1985	5.35	4.75	4.59	8.74	21.30	8.64	44.90	91.10	50.52	10.57	5.20	6.10	261.75
1986	4.96	7.46	9.12	13.66	15.37	26.52	75.46	138.05	92.45	35.17	9.08	4.88	432.18
1987	4.93	4.85	13.05	48.52	26.23	39.58	26.85	51.80	45.69	19.75	6.35	6.72	294.31
1988	4.95	5.67	5.40	6.17	6.74	7.30	61.57	266.32	92.46	54.43	13.83	5.38	530.23
1989	6.43	6.30	6.24	17.11	15.53	10.52	34.39	67.11	78.09	32.41	9.18	7.20	290.52
1990	0.80	29.32	53.62	57.09	14.20	11.54	76.37	88.56	67.89	28.73	8.29	10.73	447.14
1991	5.77	5.99	10.06	14.43	7.42	9.21	37.62	122.62	96.60	16.45	6.85	6.39	339.42
1992	5.41	6.59	4.70	8.15	8.21	8.66	21.92	176.73	144.60	67.18	12.21	6.20	470.55
1993	7.27	17.55	5.88	13.67	30.82	30.98	43.95	141.50	95.63	53.90	19.20	7.58	467.94
1994	5.74	5.14	4.40	4.18	1.46	11.43	61.43	184.46	131.48	18.81	7.52	7.23	443.26
1995	4.18	4.24	21.27	19.35	14.58	6.79	33.75	129.66	158.89	12.30	6.29	5.48	416.79
1996	6.64	4.53	7.65	10.54	18.04	48.05	57.58	171.74	65.29	22.88	6.54	5.65	425.13
1997	7.80	4.47	4.19	16.07	6.97	7.33	36.35	56.20	29.61	14.94	18.65	5.79	208.35
1998	5.85	9.25	13.41	6.37	16.04	9.80	35.88	185.31	132.84	75.30	18.11	7.88	516.06

1999	5.34	1.16	4.58	4.41	4.52	8.54	45.54	90.68	56.81	119.10	19.96	6.33	366.97
2000	4.24	4.22	4.18	3.98	12.51	7.35	26.07	132.07	76.83	67.68	23.32	6.26	368.71
2001	4.71	4.15	5.82	6.88	20.28	37.01	91.92	214.42	101.40	27.98	6.55	6.71	527.83
2002	4.94	5.09	7.41	5.58	2.43	13.47	48.92	71.17	36.01	8.93	3.96	4.79	212.70
2003	6.53	3.72	4.16	10.53	10.17	6.53	44.51	139.12	77.66	20.07	4.93	5.15	333.06
2004	3.94	3.59	3.61	23.34	9.44	8.89	53.66	101.87	71.86	36.34	5.95	4.96	327.44
2005	4.05	3.72	6.14	7.33	*21.38*	*15.55*	*45.69*	*62.80*	*36.24*	*39.67*	*12.85*	*6.88*	262.28
Mean	***5.62***	***7.41***	***10.42***	***20.12***	***21.38***	***15.55***	***52.98***	***134.53***	***86.75***	***39.67***	***12.85***	***6.44***	***412.18***
Max	***12.00***	***29.32***	***53.62***	***145.75***	***125.56***	***63.63***	***106.00***	***267.79***	***180.27***	***119.10***	***84.37***	***17.27***	***626.06***
Min	***0.76***	***0.45***	***1.20***	***0.53***	***1.46***	***1.35***	***19.36***	***51.80***	***29.61***	***8.93***	***1.62***	***1.02***	***207.33***
stdev	***2.24***	***6.57***	***11.36***	***27.01***	***26.69***	***12.55***	***22.26***	***53.71***	***36.06***	***25.66***	***15.09***	***2.74***	***124.53***
CV	***0.40***	***0.89***	***1.09***	***1.34***	***1.25***	***0.81***	***0.42***	***0.40***	***0.42***	***0.65***	***1.17***	***0.43***	***0.30***
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	3.825	3.758	7.2092	38.72	25.1116	15.728	127.97	267.64	138.6	27.93	10.09	6.0066	672.6
2007	3.8927	6.342	3.3902	12.13	12.8875	39.386	96.574	225.02	195.73	40.74	7.571	3.6381	647.3
2008	3.26	2.46	4.28	5.26	12.46	8.64	21.45	68.52	28.15	30.27	7.61	4.56	196.9
2009	0.54	4.244	2.5829	5.96	3.5644	23.32	23.257	12.21	18.25	4.25	2.21	1.25	101.6
2010	0.36	11.71	30.9	48.21	131.119	25.1	8.24	9.59	14.25	5.21	2.13	1.28	288.1
2011	0.54	0.32	2.02	0.45	0.34	0.16	2.14	5.71	2.48	1.03	1.62	4.02	20.83
2012	1.41	0.92	0.64	0.48	0.58	0.62	0.91	0.81	0.75	1.21	1.34	1.21	10.88
2013	0.94	0.85	0.71	0.82	0.65	0.29	0.79	1.93	1.15	0.99	0.73	1.02	10.87
2014	0.22	0.24	0.32	0.41	0.28	0.42	2.2	2.01	1.2	0.24	0.23	0.51	8.28
Mean	1.6653	3.427	5.7836	12.49	20.7769	12.629	31.503	65.938	44.507	12.43	3.726	2.6105	217.5

Annex3 Monthly flow for un gauged sub catchment (Rainy season) in Mm3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1966	0.00	8.57	0.00	0.00	0.00	0.00	15.83	23.72	16.08	0.00	0.00	0.00	64.20
1967	0.00	0.00	0.00	0.00	0.00	4.10	24.71	0.00	0.00	0.00	0.22	0.00	29.03
1968	0.00	0.00	0.00	2.76	0.00	1.54	7.75	19.43	15.73	0.00	0.00	0.00	47.20
1969	0.00	0.05	0.00	0.00	0.00	0.00	17.17	32.71	0.00	0.00	0.00	0.00	49.93
1970	0.00	0.00	2.23	0.00	0.00	0.00	19.10	30.76	9.34	0.00	0.00	0.00	61.43
1971	0.00	0.00	0.00	0.00	0.00	7.44	26.71	25.57	0.00	0.00	0.00	0.00	59.72
1972	0.00	0.00	0.00	0.07	0.00	8.21	26.91	39.73	0.00	0.00	0.00	0.00	74.92
1973	0.00	0.00	0.00	0.00	8.79	16.13	49.47	11.65	24.23	0.00	0.00	0.00	110.26
1974	0.00	0.00	7.98	0.00	9.63	6.36	28.18	22.44	8.14	0.00	0.00	0.00	82.72
1975	0.00	0.00	0.00	0.00	0.00	15.87	34.34	0.00	11.05	0.00	0.00	0.00	61.26
1976	0.00	0.00	0.00	0.00	0.00	21.69	11.48	49.12	0.00	0.00	0.00	0.00	82.29
1977	0.00	0.00	0.00	5.24	0.00	12.70	24.14	17.06	0.00	7.52	0.00	0.00	66.66
1978	0.00	1.17	0.00	0.00	0.00	8.02	22.36	23.40	0.00	0.00	0.00	0.00	54.95
1979	0.00	0.00	16.80	0.00	3.89	0.79	34.92	41.52	0.00	0.00	0.00	0.00	97.92
1980	0.00	0.00	0.00	0.00	0.00	3.35	17.79	43.93	0.00	0.00	0.00	0.00	65.07
1981	0.00	0.00	6.91	12.52	0.00	0.00	27.12	30.45	11.84	0.00	0.00	0.00	88.84
1982	0.00	0.00	0.00	0.00	0.00	0.00	32.12	36.85	0.00	0.00	0.00	0.00	68.98
1983	0.00	0.00	0.00	10.22	9.87	0.00	26.22	33.44	0.00	0.00	0.00	0.00	79.75
1984	0.00	0.00	0.00	0.00	11.16	12.99	22.29	12.78	0.00	0.00	0.00	0.00	59.21
1985	0.00	0.00	0.00	0.00	0.00	0.00	9.46	15.59	0.00	0.00	0.00	0.00	25.06
1986	0.00	3.79	0.00	0.00	1.48	9.79	20.04	0.00	0.00	0.00	0.00	0.00	35.10
1987	0.00	0.00	0.00	0.00	0.66	0.00	19.28	0.00	0.00	0.00	0.00	0.00	19.94
1988	0.00	0.00	0.00	0.00	0.00	3.89	27.18	34.46	12.61	0.00	0.00	0.00	78.15
1989	0.00	0.00	14.80	0.53	0.00	5.51	21.17	31.99	6.16	0.00	0.00	0.00	80.16
1990	0.00	4.48	0.00	0.00	0.00	0.00	39.51	38.32	0.00	0.00	0.00	0.00	82.31
1991	0.00	0.00	0.06	0.00	0.00	7.38	29.55	28.29	0.00	0.00	0.00	0.00	65.28
1992	0.00	0.00	0.00	0.00	0.00	15.60	25.55	23.79	0.00	0.00	0.00	0.00	64.95
1993	0.00	0.00	0.00	12.19	0.00	4.67	12.38	20.74	0.00	0.00	0.00	0.00	49.97
1994	0.00	0.00	0.00	0.00	0.00	11.57	19.23	31.69	0.00	0.00	0.00	0.00	62.49
1995	0.00	0.00	0.00	19.25	0.00	0.00	25.47	12.47	0.00	0.00	0.00	0.00	57.19
1996	0.00	0.00	0.00	0.00	3.63	7.98	26.19	43.79	0.00	0.00	0.00	0.00	81.59
1997	0.00	0.00	0.00	1.18	0.00	8.64	19.88	0.00	0.00	0.00	0.00	0.00	29.70
1998	0.00	0.00	0.00	0.00	0.00	4.35	22.28	26.94	0.00	0.00	0.00	0.00	53.56
1999	0.00	0.00	0.00	0.00	0.00	6.59	22.97	31.60	0.00	0.00	0.00	0.00	61.17
2000	0.00	0.00	0.00	0.00	0.00	0.00	15.98	20.67	7.66	0.00	0.00	0.00	44.31
2001	0.00	0.00	7.79	0.00	2.56	7.88	35.72	29.10	0.00	0.00	0.00	0.00	83.05
2002	0.00	0.00	0.00	0.00	0.00	6.74	18.37	24.15	0.00	0.00	0.00	0.00	49.26
2003	0.00	0.00	0.00	8.20	0.00	5.76	19.66	22.13	0.00	0.00	0.00	0.00	55.75

2004	0.00	0.00	0.00	7.67	0.00	8.08	23.88	27.99	13.05	0.00	0.00	0.00	80.66
2005	0.00	0.00	0.00	0.00	23.78	21.69	49.47	51.30	30.78	0.00	0.00	0.00	177.02
Mean	***0.00***	***0.45***	***1.41***	***2.00***	***1.89***	***6.38***	***24.30***	***25.24***	***4.17***	***0.19***	***0.01***	***0.00***	***66.03***
Max	***0.00***	***8.57***	***16.80***	***19.25***	***23.78***	***21.69***	***49.47***	***51.30***	***30.78***	***7.52***	***0.22***	***0.00***	***177.02***
Min	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***7.75***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***19.94***
stdev	***0.00***	***1.61***	***3.92***	***4.48***	***4.68***	***6.02***	***9.08***	***13.49***	***7.49***	***1.19***	***0.04***	***0.00***	***26.65***

Annex 4 Monthly Rainfall at ziway station (mm)

Station **Ziway** Element **Monthly Rainfall** **(mm)**

year	month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970	66.5	0.0	70.2	43.6	21.2	50.8	8.7	54.2	93.7		0.0	0.0	
1971	6.8	1.0	30.4	100.8	67.0	143.6	116.2	114.4	27.8	0.0	3.4	1.6	613.0
1972	0.0	0.0	0.0	178.9	78.2	46.9	124.8	132.3	67.1	31.4	0.0	0.0	659.6
1973	0.0	0.0	0.0	9.0	164.4	70.5	168.8	121.2	111.4	33.8	0.0	2.6	681.7
1974	3.6	5.5	152.4	1.2	67.6	75.2	118.1	218.7	213.4	0.0	0.0	0.0	855.7
1975	0.0	29.4	3.3	23.6	105.6	187.8	304.1	48.6	246.5	7.1	0.0	0.0	956.0
1976	0.0	1.8	47.3	31.8	96.2	64.2	175.3	76.2	37.1	6.9	21.9	0.0	558.7
1977	63.1	9.0	6.0	154.3	96.4	168.7	180.4	143.9	55.5	218.8	0.0	0.0	1096.1
1978	10.9	178.3	45.6	65.6	13.2	181.9	61.9	221.8	93.4	45.5	1.6	5.5	925.2
1979	91.9	102.4	70.0	61.6	148.6	105.2	150.0	98.0	87.9	71.0	0.0	6.2	992.8
1980	25.8	14.9	14.4	48.3	3.6	53.8	129.3	116.8	63.4	43.6	0.0	0.0	513.9
1981	0.0	28.2	248.9	68.7	21.7	2.2	237.1	145.4	234.2	5.2	0.0	0.6	992.2
1982	51.0	14.7	136.2	76.8	68.0	16.6	117.0	218.7	39.3	142.3	9.5	0.0	890.1
1983	34.4	56.3	85.9	100.6	152.1	43.3	153.2	146.5	64.6	27.2	0.0	0.0	864.1
1984	0.0	0.0	10.6	102.6	90.6	57.5	213.0	116.2	63.5	0.0	0.0	0.0	654.0
1985	0.4	0.0	30.6	105.4	118.6	40.0	155.7	138.2	69.0	1.3	0.0	0.0	659.2
1986	0.0	53.0	19.7	53.7	110.3	88.4	70.5	54.0	65.8	22.2	0.0	0.0	537.6
1987	0.0	29.8	56.3	47.6	219.6	16.2	67.5	54.1	44.7	17.1	0.0	0.0	552.9
1988	3.2	20.9	1.8	49.8	13.0	118.9	138.2	92.9	169.3	99.1	0.0	0.2	707.3
1989	4.7	50.3	195.7	129.9	2.9	101.9	120.0	150.5	133.1	12.5	0.0	49.6	951.1
1990	0.0	140.8	16.6	52.1	37.8	44.0	162.2	141.6	88.8	0.5	0.0	0.0	684.4
1991	1.7	98.2	141.0	12.8	26.2	114.0	171.9	144.3	47.0	10.7	0.0	9.2	777.0
1992	20.3	21.8	6.2	58.6	75.2	99.4	208.5	153.6	27.5	116.5	1.5	0.9	790.0
1993	42.1	122.4	0.4	100.2	128.5	68.5	223.7	147.5	49.4	71.0	0.0	0.0	953.7
1994	0.0	0.0	24.1	9.0	49.1	145.0	126.4	92.9	34.7	22.4	4.6	0.0	508.8
1995	0.0	28.8	68.0	141.3	21.6	49.5	79.9	131.7	28.5	3.1	0.0	11.6	564.0
1996	13.8	8.2	53.9	110.4	127.1	128.4	125.4	161.5	106.4	0.0	32.8	0.0	867.9
1997	20.0	0.0	70.4	229.5	4.7	150.4	161.0	57.4	45.8	108.4	0.3	0.0	847.9
1998	6.1	22.3	43.4	48.7	57.7	44.9	166.5	177.8	97.4	90.8	0.0	0.0	755.6
1999	5.5	0.0	28.5	2.4	44.2	110.3	85.0	63.8	72.0	133.8	0.0	0.0	545.5
2000	0.0	0.0	3.0	65.2	97.3	34.0	215.5	95.7	106.9	31.1	1.2	24.2	674.1
2001	0.0	0.0	107.8	28.2	131.7	78.3	137.4	130.6	54.6	0.1	0.0	1.8	670.5
2002	12.0	21.8	37.9	55.6	51.1	48.0	94.6	73.6	61.7	0.0	0.0	1.3	457.6
2003	21.2	0.3	98.0	127.1	21.3	82.9	221.7	156.7	101.0	0.0	3.2	17.4	850.8
2004	91.8	0.8	24.7	150.3	0.0	94.1	176.7	129.6	92.7	10.9	2.7	0.0	774.3
2005	48.5	14.3	85.4	100.8	197.0	55.4	103.0	90.3	140.0	4.6	1.4	0.0	840.7
Mean	**17.9**	**29.9**	**55.0**	**75.5**	**75.8**	**83.7**	**150.3**	**124.5**	**88.6**	**40.2**	**2.3**	**3.8**	**747.5**

Max	**91.9**	**178.3**	**248.9**	**229.5**	**219.6**	**187.8**	**304.1**	**221.8**	**246.5**	**218.8**	**32.8**	**49.6**	**1096.1**
Min	**0.0**	**0.0**	**0.0**	**1.2**	**0.0**	**2.2**	**61.9**	**48.6**	**27.5**	**0.0**	**0.0**	**0.0**	**457.6**
STDEV	**26.3**	**44.5**	**58.7**	**53.5**	**57.6**	**47.7**	**54.0**	**45.6**	**55.3**	**53.3**	**6.6**	**9.6**	**170.0**
75%	**0.2**	**0.0**	**15.5**	**39.4**	**37.0**	**51.5**	**113.9**	**93.8**	**51.3**	**4.2**	**0.0**	**0.0**	**632.9**
85%	**0.0**	**0.0**	**0.0**	**20.1**	**16.1**	**34.3**	**94.3**	**77.3**	**31.3**	**0.0**	**0.0**	**0.0**	**571.4**
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	1	15.8	39.1	197.5	45	137.9	185.6	65	72.8	9.5	0	7.3	776.5
2007	10.5	46.1	22.7	59.6	166.1	136.6	195.1	83.3	59.3	22.7	1.6	0	803.6
2008	0	0.4	8.7	2.2	80.3	112.2	292.3	194.2	62.6	65	224.2	0	1042
2009	64.8	0	51	11.9	55.3	50.5	187.4	82	60.6	136.1	0	29.1	728.7
2010	2.2	142.2	56	91	124.3	59.7	182.2	109	90.4	0	0	6.3	863.3
2011	0	4.2	67.3	19.6	51.1	129.8	184.3	126	83	0	7.6	0	672.9
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	64.7	106.1	64	249	76	84.2	51.3	1	0	696.3
2014	0	38.6	55	22.4	98.9	41.3	148.4	220.6	15.7	101.7	0.3	0	742.9
Mean	8.7222	27.48	33.311	52.1	80.7889	81.333	180.48	106.23	58.733	42.92	26.08	4.7444	702.9

Annex 5 Mean monthly rainfall of stations in and around Ziway-Langano-Abiyata lake sub-basins

		UTM (m)														
		East	North	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Alem Tena	493139	916896	16	35	58	80	39	73	196	163	98	26	5	3	793
2	Assela	514334	878551	18	44	95	117	103	138	191	202	161	65	19	14	1167
3	Adamitulu	466929	868196	18	34	47	85	58	61	122	126	84	40	20	7	701
4	Butajira	436188	903305	35	65	129	129	116	125	175	160	122	53	13	14	1137
5	Buie	450103	919485	31	49	92	82	73	119	207	196	99	35	9	12	1004
6	Dera	534882	920294	13	24	41	44	62	57	149	162	82	42	15	9	698
7	Eteyw	525498	898451	25	29	67	86	87	91	213	206	159	55	10	5	1033
8	Koka dam	502523	932913	12	18	32	47	54	53	168	172	71	25	8	8	668
9	Kulumsa	520179	887267	24	52	75	93	90	93	167	166	109	45	5	5	925
10	Langano	467581	845541	20	20	38	67	69	91	128	112	77	40	9	10	680
11	Lemu Bekoji	526954	831146	42	67	76	94	136	138	302	241	140	48	36	9	1328
12	Meki	481329	901526	13	40	56	62	61	71	168	150	90	33	8	4	755
13	Nazeret	529543	943430	14	29	54	54	58	70	222	223	100	35	9	7	876
14	Wonji	523718	934046	11	28	50	52	60	76	205	200	95	36	9	6	828
15	Ziway	468385	875639	18	30	57	76	76	84	146	121	89	40	2	4	742
16	Bulbula	461590	853311	17	30	50	69	65	72	130	103	69	37	8	4	656
17	Hombole	475666	925309	16	43	63	60	55	103	240	229	104	32	7	3	957
18	Koshe	497023	831631	24	52	75	93	90	93	167	166	109	45	5	5	925
19	Ticho	556077	862857	42	99	103	149	103	91	155	174	131	89	41	35	1212
20	Gobesa	554297	841824	53	45	111	178	137	86	150	188	139	129	52	46	1314
21	Degaga	479407	822267	23	30	87	91	104	131	189	173	155	61	18	14	1075
22	Kersa	497023	831631	26	49	123	108	93	76	148	120	104	48	21	12	927
23	Ogolcho	500582	889876	12	34	72	64	66	84	165	109	98	33	9	4	751
24	Sagure	517403	856067	14	27	60	76	81	96	157	148	75	33	8	6	781
25	Hosaena	372801	834073	28	46	96	139	129	120	158	178	152	72	19	25	1164
26	Tora	435703	868681	25	44	77	122	100	85	134	123	115	50	8	6	889
27	Durame	372801	811321	24	28	84	161	112	99	136	140	120	105	34	21	1062

Annex 6 Mean values of maximum and minimum temperatures for 18 stations located in and around the project area.

	Mean Monthly Max Temp						Degree Celsius							
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Abomisa	28	29	30	31	28	28	28	28	27	26	28	0	26
2	Adamitulu	27	28	29	29	29	27	25	25	26	28	28	27	27
3	Alem Tena	27	48	30	30	31	29	26	26	44	28	27	27	31
4	Assasa	25	25	25	24	25	24	21	21	22	23	24	24	24
5	Assela School	22	23	23	23	23	21	20	19	19	21	21	21	21
6	Awassa	29	30	29	28	27	25	24	25	26	27	28	28	27
7	Bokoji	21	29	21	20	20	18	16	17	18	18	20	20	20
8	Buie	25	26	27	27	27	26	23	23	25	25	25	25	25
9	Butajira	26	26	26	26	26	25	24	24	25	26	26	26	25
10	Degaga	25	26	26	25	25	23	21	21	22	24	24	24	24
11	Langano	28	29	29	29	29	28	26	26	27	28	28	28	28
12	Melkasa Farm	28	29	30	41	31	30	27	26	27	29	28	28	29
13	Melkasa Research	26	27	28	28	29	29	25	25	26	27	26	26	27
14	Meraro	19	20	20	19	20	19	17	18	18	18	19	19	19
15	Sagure	23	24	24	23	23	21	20	19	21	22	23	23	22
16	Ticho	22	22	22	21	21	22	20	20	20	20	20	21	21
17	Wonji	26	27	29	29	30	29	26	26	27	27	26	26	27
18	Ziway	26	27	28	28	29	29	25	25	26	27	26	26	27
	Mean Monthly Min Temp						Degree Celsius							
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Abomisa	14	14	16	17	17	17	16	16	16	15	14	13	15
2	Alem Tena	12	13	15	15	15	15	14	14	14	13	10	10	13
3	Assasa	2	5	6	8	8	9	10	9	7	5	2	2	6
4	Assela School	7	8	9	10	10	10	10	10	10	9	7	6	9
5	Awassa	11	12	13	14	14	14	14	14	13	12	10	10	13
6	Bokoji	7	8	9	9	9	8	8	8	7	7	7	7	8
7	Buie	8	9	10	11	11	10	9	10	9	8	7	7	9
8	Butajira	11	11	12	12	12	12	12	12	12	11	11	10	11
9	Degaga	7	7	9	11	10	11	11	10	10	9	7	6	9
10	Langano	13	12	14	15	15	14	14	14	14	13	12	11	13
11	Melkasa Farm	11	13	15	15	16	16	20	15	14	12	11	11	14
12	Melkasa Research	13	13	15	15	15	15	15	15	14	13	12	11	14
13	Meraro	5	5	6	8	7	6	7	7	6	6	4	5	6
14	Sagure	8	7	8	9	9	8	9	14	8	6	5	4	8
15	Ticho	7	8	9	9	9	9	9	9	9	8	7	6	8
16	Wonji	11	12	14	14	14	16	16	15	14	15	10	10	13
17	Ziway	12	13	15	15	15	15	15	15	14	13	12	11	14

Annex 7 means monthly climatic elements in and around the project area.

	Mean Monthly Wind speed (m/s)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	1.81	2.10	2.09	2.02	2.23	2.28	2.18	1.61	1.20	1.41	1.71	1.82	1.87
Assasa	2.20	2.20	2.30	2.74	3.20	2.74	2.50	1.86	1.36	1.84	2.10	2.23	2.27
Awassa	0.84	0.87	0.81	0.75	0.85	1.10	1.04	0.95	0.72	0.57	0.68	0.76	0.83
Bokoji	2.47	2.38	3.44	2.94	2.66	1.72	1.38	1.28	1.58	2.12	2.68	2.50	2.26
Buie	2.05	2.13	2.10	1.84	1.98	1.58	1.47	1.39	1.35	1.88	2.02	2.03	1.82
Melkasa Research	2.70	3.14	2.15	2.29	2.08	1.41	2.13	1.36	1.09	1.56	1.08	1.40	1.87
Meraro	2.46	2.61	2.93	3.04	2.81	1.86	1.53	1.48	1.97	2.76	2.77	2.56	2.40
Wonji	1.32	1.26	1.25	1.12	1.11	1.52	1.64	1.28	0.84	0.97	1.26	1.36	1.24
Ziway	1.81	1.85	1.74	1.68	1.96	2.61	2.42	2.07	1.46	1.64	1.81	1.85	1.91
	Mean Monthly Sunshine Hours												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	8.5	8.3	7.9	7.1	8.7	8.4	6.9	7.1	6.8	7.5	9.1	9.1	7.9
Assasa	8.0	7.4	7.1	6.2	7.1	5.6	4.6	5.4	5.8	6.8	8.2	8.7	6.8
Awassa	8.8	8.5	7.8	6.6	7.5	6.6	4.9	5.3	5.8	6.8	8.9	9.1	7.2
Bokoji	8.2	7.6	7.1	5.8	6.6	5.2	3.1	3.4	4.6	6.1	7.8	8.5	6.2
Buie	8.8	8.6	8.3	8.1	8.1	6.7	5.0	5.3	6.8	8.7	9.8	9.2	7.8
Melkasa Farm	9.3	9.1	8.4	8.2	9.2	8.5	7.3	7.3	7.9	8.8	10.0	9.8	8.6
Meraro	8.4	7.7	7.9	6.7	7.6	6.4	4.6	5.3	6.1	6.7	8.7	8.9	7.1
Wonji	8.8	8.5	8.4	8.4	8.9	8.6	7.0	7.1	7.5	8.8	9.6	9.3	8.4
Ziway	9.5	9.4	8.4	8.4	9.1	8.4	6.4	6.7	7.1	9.1	10.2	10.1	8.6
	Mean Monthly Pitche Evaporation (mm)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	190	474	219	219	292	289	221	162	143	186	206	193	2796
Assasa	207	169	172	152	156	161	102	85	96	161	189	204	1855
Awassa	203	200	199	142	117	112	98	96	86	117	163	186	1719
Bokoji	218	172	196	155	158	114	72	73	109	148	180	216	1810
Buie	172	182	186	187	176	104	142	75	102	161	186	186	1859
Meraro	168	223	158	115	160	88	58	56	92	119	155	145	1537
Ziway	182	211	185	182	179	163	126	116	122	188	206	198	2059

Annex 8 Mean monthly relative humidity (%)

	Mean Monthly Relative Humidity at 0600 HR LST (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	77	69	71	71	65	67	78	81	79	75	69	72	73
Assasa	72	72	73	75	78	79	85	88	88	76	72	73	78
Awassa	84	82	87	92	94	92	92	92	95	93	88	87	90
Bokoji	77	77	81	85	83	88	92	93	90	83	76	75	83
Buie	81	80	79	79	81	85	88	89	86	78	79	79	82
Melkasa Research	74	74	74	77	80	81	86	89	89	78	74	75	79
Meraro	82	78	79	84	82	87	91	93	92	86	82	83	85
Wonji	82	80	79	83	83	79	86	89	92	91	85	85	85
Ziway	82	80	81	84	87	88	90	91	91	82	78	79	84
	Mean Monthly Relative Humidity at 1200 HR LST												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	55	49	48	47	41	42	55	61	56	50	43	48	50
Assasa	44	47	46	52	48	53	67	69	61	50	45	44	52
Awassa	44	44	46	54	59	62	67	65	61	53	43	44	53
Bokoji	51	54	55	62	61	71	82	83	76	68	55	50	64
Buie	59	54	57	58	57	67	75	76	67	56	59	56	62
Melkasa Research	43	44	42	43	43	47	60	62	56	38	36	40	46
Meraro	46	41	44	55	53	59	72	70	63	60	49	47	55
Wonji	38	40	38	41	37	39	52	57	58	40	36	38	43
Ziway	62	61	60	59	60	62	71	72	66	57	56	58	62
	Mean Monthly Relative Humidity at 1800 HR LST												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	50	44	45	49	45	43	56	63	65	56	44	46	50
Assasa	46	51	51	59	55	61	74	77	73	63	55	51	60
Awassa	59	56	57	59	58	59	67	69	67	60	59	60	61
Bokoji	62	63	63	70	70	76	87	89	84	77	69	62	73
Buie	54	49	51	54	51	63	74	75	68	57	53	56	59
Melkasa Research	38	39	39	42	41	40	53	61	60	41	36	37	44
Meraro	59	51	52	66	64	72	82	84	79	72	61	55	67
Wonji	38	40	38	41	37	39	52	57	58	40	36	38	43
Ziway	59	56	57	59	58	59	67	69	67	60	59	60	61
	Mean Monthly Relative Humidity (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abomisa	61	54	55	55	50	51	63	68	67	60	52	55	58
Assasa	54	57	57	62	60	64	75	78	74	63	57	56	63
Awassa	62	60	63	68	71	71	76	75	74	69	63	63	68
Bokoji	63	65	66	73	71	78	87	88	83	76	67	62	73
Buie	65	61	63	64	63	72	79	80	74	64	63	64	68
Melkasa Research	52	52	52	54	55	56	67	71	69	53	49	51	57
Meraro	62	57	58	69	67	73	82	82	78	73	64	62	69
Wonji	53	53	52	55	53	53	63	68	69	57	53	54	57
Ziway	67	66	66	67	68	70	76	77	75	67	64	66	69

Annex 9 Data to calculate water balance of the lake for the year from 1963-2005(Previous year) without Any abstraction.

Months	INFLOW DATA TO THE LAKE					
	Rainfall(mm)	meki(MMC)	ketar(MMC)	ungaged flow(MMC)	Sum of inflow(MMC)	inflow in (1000m3)
Jan	15.8	*2.23*	*5.62*	*0.00*	*7.85*	*7848.84*
feb	35.9	*4.56*	*7.41*	*0.45*	*12.42*	*12417.45*
mar	52.8	*13.24*	*10.42*	*1.41*	*25.08*	*25077.30*
Apr	72.7	*16.49*	*20.12*	*2.00*	*38.60*	*38600.02*
may	68.8	*18.27*	*21.38*	*1.89*	*41.54*	*41536.95*
jun	76.6	*15.43*	*15.55*	*6.38*	*37.36*	*37362.23*
jul	150.9	*50.19*	*52.98*	*24.30*	*127.46*	*127462.14*
aug	132.6	*81.35*	*134.53*	*25.24*	*241.13*	*241125.01*
sep	88.8	*51.88*	*86.75*	*4.17*	*142.80*	*142802.90*
oct	35.8	*23.16*	*39.67*	*0.19*	*63.02*	*63016.74*
nov	8.1	*7.94*	*12.85*	*0.01*	*20.79*	*20789.16*
Dec	3.6	*2.38*	*6.44*	*0.00*	*8.81*	*8812.97*
Annual	742.4	287.12	413.71	66.03	766.85	766851.70

Months		OUTFLOW FROM THE LAKE
	Evaporation(mm)	net Evaporation(mm)
Jan	*145.30*	120.22
feb	*145.40*	106.80
mar	*162.70*	121.16
Apr	*158.40*	121.04
may	*169.50*	42.04
jun	*165.00*	-76.13
jul	*133.70*	-9.10
aug	*135.40*	72.38
sep	*133.70*	112.91
oct	*153.50*	144.69
nov	*147.50*	-619.35
Dec	*145.60*	145.60
Annual	1795.70	282.26

Annex 10 Data to calculate water balance of the lake for the year from 2006-2014 (Latest year) without any abstraction

Months	All INFLOW DATA TO THE LAKE					
	Rainfall(mm)	Meki (MMC)	ketar(MMC)	ungaged flow(MMC)	Sum of inflow(MMC)	inflow in (1000m3)
Jan	7.7	*1.04*	*1.67*	*0.00*	*2.70*	*2701.63*
feb	33.0	*1.38*	*3.43*	*0.42*	*5.22*	*5218.69*
mar	32.0	*1.95*	*5.78*	*0.86*	*8.59*	*8586.74*
Apr	50.2	*5.13*	*12.49*	*1.38*	*19.00*	*19002.96*
may	73.3	*8.49*	*20.78*	*2.01*	*31.27*	*31272.88*
jun	74.4	*15.38*	*12.63*	*6.20*	*34.21*	*34206.75*
jul	181.2	*36.28*	*31.50*	*29.17*	*96.96*	*96956.76*
aug	113.2	*42.74*	*65.94*	*21.54*	*130.22*	*130218.51*
sep	58.9	*27.30*	*44.51*	*2.76*	*74.57*	*74565.81*
oct	38.2	*7.74*	*12.43*	*0.20*	*20.37*	*20374.10*
nov	90.4	*1.65*	*3.73*	*0.06*	*5.44*	*5442.03*
Dec	4.5	*0.98*	*2.61*	*0.00*	*3.59*	*3591.63*
Annual	757.0	150.0	217.5	64.60	432.14	*432138.48*

Outflow from the lake

Months	Evaporation(mm)	net Evaporation(mm)
Jan	*145.30*	137.61
feb	*145.40*	112.37
mar	*162.70*	130.73
Apr	*158.40*	108.25
may	*169.50*	96.19
jun	*165.00*	90.58
jul	*133.70*	-47.50
aug	*135.40*	22.24
sep	*133.70*	74.82
oct	*153.50*	115.27
nov	*147.50*	57.08
Dec	*145.60*	141.06
Annual	1795.70	1038.70

Annex 11 existing and proposed abstraction from the lake

Months	**Sum of abstraction(1000m3)**	Volume(1000m3) for 3774.7ha	Volume(1000m3) for 4668.5ha)	Volume(1000m3) for 6214ha
sep	150.00	1740.84	1684.83	2231.54
oct	2030.00	5022.79	4861.22	6438.59
nov	2140.00	5746.79	5561.93	7366.67
Dec	2140.00	5870.32	5681.49	7525.02
Jan	2130.00	9245.12	8947.72	11851.09
feb	2510.00	4920.65	4861.22	6438.59
mar	2750.00	2920.58	2826.63	3743.81
Apr	3000.00	3476.45	3364.63	4456.38
may	2000.00	2652.41	2567.09	3400.06
jun	380.00	2863.01	2770.91	3670.01
jul	100.00	2065.02	1998.59	2647.1
aug	100.00	917.79	888.26	1176.49
Annual(Sum)	19430	47441.77	46014.52	60945.35

Annex 12 the whole(final) result of the water balance

STAGE-AREA-CAPACITY-OUTLATE CAPACITY CURVE

Column A	Column B	Column C	Column D
Lake Level(M)	**Area(1000M2)**	**Volume(1000M3)**	**Out late capacity(M3/s)**
1627	0	0	0
1628	490	95	0
1629	3827	2082	0
1630	7814	7849	0
1631	15909	19356	0
1632	33457	42293	0
1633	171031	138942	0
1634	325416	394283	0
1635	386184	755341	0
1635.5	419266	952684	0.27
1636	427812	1159385	2.56
1636.5	462103	1388907	9.11
1637	491569	1624228	22.16
1637.5	494149	1866862	43.96
1638	508668	2123656	76.73

Row 1	Volume in august (1000m3)=	2123656.00
Row 2	lake level in august(m)=	1638
Row 3	Area of lake in august(1000m2)=	508668.00
Row 4	out late capacity(m3/s)=	76.73

Months	Total inflow from river and ungauged(1000m3)	Sum of existing abstraction(1000m3)
sep	74565.81	150.00
oct	20374.10	2030.00
nov	5442.03	2140.00
Dec	3591.63	2140.00
Jan	2701.63	2130.00
feb	5218.69	2510.00
mar	8586.74	2750.00
Apr	19002.96	3000.00
may	31272.88	2000.00
jun	34206.75	380.00
jul	96956.76	100.00
aug	130218.51	100.00
Total(Sum)	432138.4802	19430

Volume(1000m3) for 3774.7ha	Volume(1000m3) for 4668.5ha)	Volume(1000m3) for 6214ha
1740.84	1684.83	2231.54
5022.79	4861.22	6438.59
5746.79	5561.93	7366.67
5870.32	5681.49	7525.02
9245.12	8947.72	11851.09
4920.65	4861.22	6438.59
2920.58	2826.63	3743.81
3476.45	3364.63	4456.38
2652.41	2567.09	3400.06
2863.01	2770.91	3670.01
2065.02	1998.59	2647.1
917.79	888.26	1176.49
Total sum 47441.77	46014.52	60945.35

Net evaporation(mm)	Net evaporation(1000m3)	volume of lake (1000m3)
74.82269385	38059.91003	2154354.69
115.2673407	58632.80768	2067044.69
57.08049941	28852.32168	2022819.00
141.0643399	70950.66954	1934243.13
137.611793	68524.98876	1836245.85
112.3714658	55491.66483	1767242.41
130.7307592	64461.99278	1699126.14
108.2492661	53298.19476	1650533.45
96.18525996	47308.59639	1623878.17
90.57607199	44520.42146	1603880.57
-47.49824795	-23338.07014	1717364.69
22.24211613	10955.56227	1833545.09
Total sum	517719.06	21910277.87

level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
1638.059773	510403.688	80.6475216
1637.889773	505467.2258	69.50571665
1637.803662	502966.7284	63.86198768
1637.631197	497958.6944	52.55864213
1637.436909	493823.4493	41.20922254
1637.294712	493089.7151	35.00945309

1637.154344	492365.4144	28.88939264
1637.054208	491848.7137	24.52347231
1636.999257	491525.1951	22.14059954
1636.956767	491345.9159	20.27502588
1637.191928	492559.3503	30.52807596
1637.431343	493794.7313	40.96656703
		510.1156771

Since the lake is full beyond its capacity in September so the arranged final result is as follow below

Months	volume of lake (1000m3)	level of lake(m)	Area of lake (1000m2)	Bulbula out flow(m3/s)
sep	2123656	1638	508668	76.73
oct	2067044.69	1637.889773	505467.2258	69.50571665
nov	2022819.004	1637.803662	502966.7284	63.86198768
Dec	1934243.132	1637.631197	497958.6944	52.55864213
Jan	1836245.847	1637.436909	493823.4493	41.20922254
feb	1767242.413	1637.294712	493089.7151	35.00945309
mar	1699126.14	1637.154344	492365.4144	28.88939264
Apr	1650533.447	1637.054208	491848.7137	24.52347231
may	1623878.166	1636.999257	491525.1951	22.14059954
jun	1603880.569	1636.956767	491345.9159	20.27502588
jul	1717364.685	1637.191928	492559.3503	30.52807596
aug	1833545.091	1637.431343	493794.7313	40.96656703
Total(Sum)	21879579.18		5955413.134	506.1981555