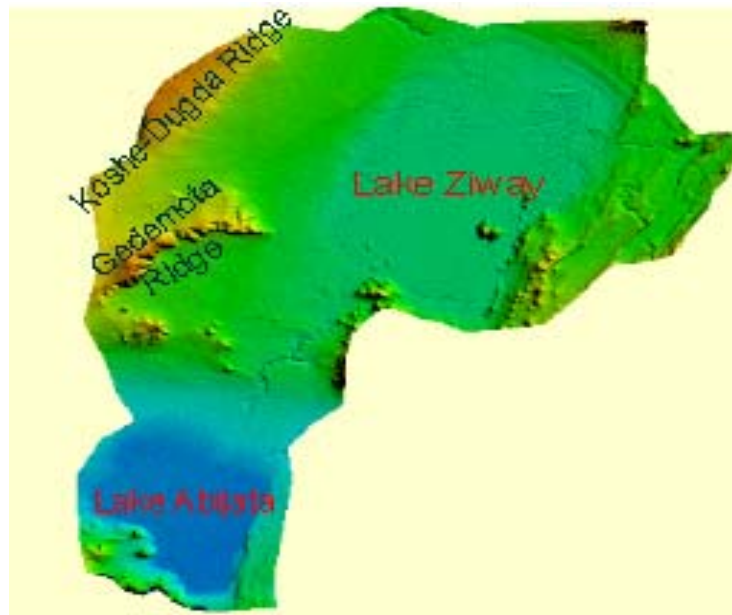




Addis Ababa University
School of Graduate Studies
Faculty of science

Effects of Irrigation Practices and Lacustrine Aquifer Development on Water Availability in Ziway-Abijata Corridor



A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in
Hydrogeology

BY

Tibebu Terefe

February 2007



**ADDIS ABABA UNIVERSITY
DEPARTMENT OF EARTH
SCIENCES
SCHOOL OF GRADUATE STUDIES**

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Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of the material used for the thesis have been duly acknowledged.

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Signature _____

Date and place of submission, March 2007, Addis Ababa

ACKNOWLEDGEMENTS

First of all I would like to thank Almighty God who made possible for me to begin and finish this work successfully.

I am greatly indebted to my research advisor Dr. Tamiru Alemayehu whose unreserved and continued guidance made the compilation of the study possible. He is the person who has always helped me. Hadn't been his assistance in providing his fertile ideas, reference materials and private field equipment, this work would have not been achieved. His constant encouragement made me strong enough to face every ups and down with confidence. So, I express my feeling of profound gratitude to him.

I owe special thanks to the MAWARI Project, which aimed at "The Sustainable Management of Water Resources in East-African Rift System", for the financial and technical support. I received a great amount of experience and exposure from the international annual meeting of the project that had been conducted in Djibouti Republic

My sincere thanks go to management and staff of Oromia Water Resources Bureau, for the assistance they gave me stationery services and facilities for fieldwork. Many thanks to Ato Alemayehu Tegenu, the former Bureau Head, now Minister of the Ministry of Mines and Energy Resources of the Federal Democratic Republic of Ethiopia, who allowed me to follow the postgraduate program besides the continued encouragement he has been offering me during the study.

I am grateful to Ato Jibril Mohammad Roba, East Shoa Zone Administrator (Oromia Regional Government), and his team (the zonal cabinet members); who not only facilitated my postgraduate study, but also for their great concern of the water availability issue in River Bulbula and Lake Abijata. It is Ato Jibril Mohammed Roba and his team who established the first task force at zonal level in the year 2003. The responsibility of the task force was to describe the underlying reasons for the water shortage occurrences in the downstream of River Bulbula. Since then water availability issues got due considerations at the zonal level and many efforts have been made by this middle management body, I witness.

I would like to thank institutions like Ministry of Water Resources, National Meteorological Service Agency, Ministry of Mines and Energy which helped me by furnishing secondary data for the preparation of this work and their kind provision of requested materials and ideas, should be appreciated.

I express my feeling of deep thanks and appreciation to Diimaa, for constant encouragement and caring support I received all time.

The time I had with my friends Aklilu Legesse, Minallah Bushura and Muauz Amare was unforgettable.

Finally, my endless thanks go to my brother Fasika Terefe and sisters Workinesh Milkisa (Shewaye) and Bizunesh Terefe, for their encouragement and dream to see me successful in every aspect.

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ABSTRACT

Water availability is becoming a sensitive issue in the country in general. When it comes to the water stressed regions like the Main Ethiopian Rift the situation is highly aggravated. So it is timely to properly assess the water availability indicators and impact of water utilization for different purposes.

The present study area is located at the floor of the Main Ethiopian Rift, where the interconnected surface water bodies are found in a fine state of balance. The main objective of the study is to evaluate water utilization and its impact on the water resources of the area.

Abstraction from the upstream water resource will have a severe impact on the downstream water bodies. This is evident in the flow regime of River Bulbula. The interconnectivity is not limited to surface water bodies, but there is also strong interaction between surface water bodies and subsurface. So it became evident in this research work that the abstraction from subsurface has got an impact on the overall water resources.

Hydrological data interpretation from stream flow and lake level measurements clearly depicted the trend and status of the water resource in Ziway-Abijata Corridor is at risk. The risk is extreme in the case of downstream closed Lake Abijata.

Since there is no quantitative data on groundwater trend and status, qualitatively speaking still the groundwater resource base is also at risk in the Main Ethiopian Rift in general and the rift floor in particular. The conjunctive nature of the surface and subsurface water resources in the area justifies this condition.

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background

Through out history human progress has depended on access to clean water and on ability of societies to harness the potential of water as a productive resource. Civilizations have flourished with the development or reliable water supplies – and then collapsed as the water supply failed. Any life in our planet earth depends directly or indirectly on water.

From the view point of its global distribution, of all water on earth (about $1.4 \times 10^9 \text{ km}^3$), only 2.7% is fresh water which is available for domestic, industrial and agricultural purposes. The remaining 97.3% is contained in oceans and seas as saline or salt water. This classification shows that the amount of fresh water is very limited as compared to the total volume of water on earth. Still the existing usable fresh water is by far enough to satisfy the current demand. 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 area under study, the Ziway-Abijata Corridor is part of the rift floor in the Lakes Basin of the Main Ethiopian Rift. 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. At present water is used for irrigation, domestic water supply, fishing, recreation; and soda ash production from an alkaline Lake Abijata. These interventions resulted in that water use exceeds sustainable levels and hence the stress is reflected in the ecology of the area.

The recently introduced intensive harvest of water (surface and groundwater) including rain water, for irrigation in general and for other domestic purposes could explain the paradigm shift in rural community regarding water resources utilization.

There are also future water and land resources development plans; these include expansion of irrigation projects, small-, medium- and large-scale, community water supply schemes, artificial

evaporation of lake water for soda ash production, geothermal resource development and expansion of resort areas. All these bear its own substantial influence on the scarce water resources of the area.

1.2. Relevance of the Study

The effects of improper water and land resources utilization on the availability of water resources in Ethiopia in general and on the Central Rift Valley Lakes in particular, drew the attention of many researchers in the water sector and other disciplines of science. Hydrological responses of the catchments to climate and land use changes have got due considerations (Dagnachew Legesse et al., 2003). The disappeared Lake Haromaya in Eastern Ethiopia exemplifies the case.

When we come to the Lakes Basin, we are going to witness the disappearance of both River Bulbula and Lake Abijata, unless and otherwise mitigation measures are taken against the improper utilization of the water resources. The practical problems related to the drying up of River Bulbula and the shrinkage of the terminal Lake Abijata is a burning issue both for the decision makers and the local people. The underlying reason for deterioration of the basin is the water use, does exceed the sustainable use. Recently, the on going water over abstraction from the surface water resources has been synergized with the groundwater development from the lacustrine aquifer of the areas of Lake Ziway.

The newly intensive lacustrine aquifer development in connection with the extensive and intensive water harvesting activities in the floor of the rift valley will put its own impact on the water availability in the system. This study will highlight this development and consequently shows its implications.

1.3. Research Objectives

The general objective of the research is to assess water availability and sustainability issue by analyzing the geologic, structural, climatologic, anthropogenic, and hydrochemical aspects of the corridor.

The specific objectives are the following:

1. To assess the abstraction conditions from the groundwater and surface water bodies for irrigation and other purposes in general,
2. To show the hydraulic link between Lake Ziway and the surrounding lacustrine aquifers,
3. To evaluate the impact of abstraction from shallow aquifers around Lake Ziway area on the level of Lake Ziway itself, and on the overflow Bulbula River and finally on the level and chemical evolution of Abijata Lake,
4. To establish the water quality issue as one dimension of water availability aspect in the study area and also to show the relationship between abstraction and deterioration of groundwater quality,
5. To assess and evaluate indicators of water availability in the rift floor together with contexts and challenges, and
6. Finally to come up with mitigation measures regarding water availability problem in the area.

1.4. Methodology

1. Assessing existing hydrometrologic, hydrochemical, hydrologic and hydrogeologic data to reconstruct the recent lake level and hydrochemical changes in the basin,
2. Gathering Information on abstraction of water for irrigation and different uses from relevant institutions,

3. Gathering and analyzing data on lake levels, river discharges, and abstraction from different water sources,
4. Thorough hydrochemistry analysis and interpretation of the natural water (surface water chemistry, groundwater chemistry) will be conducted to establish surface-groundwater interaction in the corridor. This will be supplemented by taking in-situ measurements of electrical conductivity, total dissolved solids, temperature, salinity, Eh and etc,
5. Whenever possible, groundwater level measurements will be taken to construct the groundwater recharge and discharge areas and to show the groundwater flow direction.

In this study Global Mapper, Surfer 8 and other Geographic Information Systems (GIS) have been utilized for the partitioning of the corridor. Topographic maps of 1:50,000 scales were digitized and analyzed to generate different maps. Besides, computer soft ware, like Aquachem, has been employed.

1.5. Previous Works

Research works in the study area dates back to 1628 when Portuguese missionaries Maonel de Almeida reported the existence of lakes in the northern part of the Main Ethiopian Rift (Eleni Ayalew, 2003). It has been described that ‘Awash receives the water of big river named Meki coming from Lake Ziway (Beckingham and Huntingford 1954 as cited in street, 1982)

The Interrelationship of other three lakes and observation of lake level fluctuation is carried out by Newman 1901 (02), Omer – Cooper in 1926 and Eric Nelson in 1933. The first bathymetric survey was carried out by Vatova 1941, and updated by Ital consultant, 1970.

Hunting Service took aerial photograph of the area in 1952 and 1972. Late Quaternary lakes level fluctuation of the lakes in the basin is reconstructed by Street, 1979. The later work shows the

dramatic change in lakes level during the Quaternary and that the lakes formed one big water body before they shrunk to their present positions.

Di Paola G.M. (1970) provided geologic descriptions of different rock types and geothermal conditions in the area and gave a brief description of hydrothermal areas in the Lakes District.

Di Paola G.M. (1972) presented an overall account of the geology, stratigraphy and structural patterns of the Main Ethiopian Rift within 7°00' to 8°40'N latitudes.

Wenner (1972), in a master plan for water resource and supplies in Chilalo Awraja, Asela, investigated both surface water and groundwater potential of the area. River discharge measurements were taken at different locations in Katar catchments.

Tesfaye Chernet (1982), presented a regional geological and hydrogeological map of the Lakes Region (which include Ziway-Shalla and Awassa Lake Basins) at a scale of 1:250,000 based on geologic, meteorologic, hydrologic, chemical and geothermal investigations. The report includes regional classifications of different types of rocks of the area into different permeability groups and water balance of the region.

Berhanu Gizaw (1985), presented data on the chemical composition of water and gas as well as isotopic data from five geothermal areas in Lakes district and estimated the temperature of geothermal areas.

HALCROW (1992), in the work entitled "Reconnaissance Master plan for the Development of the Natural Resources of Rift Valley Lakes Basin", groundwater and surface water potential of the area was analyzed.

Haile Gashaw (1998) studied Hydrogeology and hydrochemistry of the Lake Ziway area and its surroundings. In this work lake water balance and hydrogeology of part of the current study area was investigated.

Tenalem Ayenew (1998), in his PhD thesis entitled “The Hydrogeological System of the Lakes District Basin, Central Ethiopian Rift”; he analyzed general hydrology and hydrogeology of Ziway-Shalla Basin. The study includes evaluation of groundwater and surface water interaction, water balance and recharge estimation of sub catchments.

JICA and OIDA (2001), in the project study of Meki Irrigation and rural development, the primary emphasis was given to the assessment of water resource potential in Meki-Abijata basin. Accordingly, hydrological analysis and lake water balance were part of the study.

Dagnachew Legesse (2002), presented in his PhD thesis entitled “Analysis of hydrological response of Ziway-Shalla Basin to Changes in Climate and Human Activities”, hydrological analysis, lake water balance, land use land cover map.

Eleni Ayalew (2003) presented in her MSc thesis entitled “Application of Stable Isotopes in the Study of Lakes Dynamics in Ziway-Shalla Basin” the quantification of water budget of the lakes using environmental isotopes.

Alemu Dirribsa (2006), studied in his MSc thesis the groundwater-surface water interaction and analysis of recent changes in hydrologic environment of Lake Ziway catchment. In his work he showed the role of geologic structures and units in affecting the hydrologic dynamics of the catchments.

Shimelis Fikre (2006), presented in his MSc thesis entitled “Hydrogeological System Analysis in Ziway-Shalla Lakes Using Hydrogeochemistry and Isotope Techniques, Central Ethiopia” that the interaction of groundwater-surface water interaction.

Regarding water availability issues, Dagnachew Legesse and Tenalem Ayenew (2006), in their published paper “Effect of improper water and land resource utilization on the central Main Ethiopian Rift Lakes”, revealed that the major changes in the rift valley are related mainly to recent improper utilization of water and land resources in the lakes catchments and direct lake water abstraction aggravated intermittently by climatic changes.

In all the studies conducted so far, as far as water availability and water sustainability issue is concerned, surface water over use and changes in climate got due considerations. The present study will give emphasis to the subsurface water abstraction introduced recently to support irrigation in the area, which can bear a substantial influence on the water availability in the Ziway-Abijata Corridor.

1.6. Limitations of the Study

The monitoring wells for groundwater level in the study area are the lacking information. This very crucial information bears limitations in quantifying the trends and status of the water level in the area, and finally the assessment of groundwater storage.

CHAPTER TWO

GENERAL OVERVIEW OF THE AREA

2.1. Location and Accessibility

Ziway-Abijata Corridor is found in the Ziway-Shalla Basin in the Lakes region of the Main Ethiopian Rift. The corridor extends from Koshe Town (in the west) to Abura (in the east); and from Meki (in the North east) to Bulbula (in the south west).

The basin is accessible by two routes from Addis Ababa. One route is the asphalt road that runs from Addis Ababa-Majo-Ziway with a distance of 163 km; and another route is Addis Ababa-

Alem Gena-Butajira asphalt road with a distance of 133km and Butajira-Ziway all weather road segment having a distance of about 60 km.

The Ziway-Abijata Corridor represents the rift floor portion of the basin. Most of the study area covers the low lying plain land that runs from Meki to Bulbula, and some portion of it touches the lower part of both the eastern and western escarpments.

The area of the corridor is 2692 km², and geographically bounded between latitude 7°30'21" to 8°12'13" and longitude 38°30'30" to 39°04'17"; and UTM location 829619.64 to 906730.43 northing and UTM 445758.71 to 507865.18 easting. In this work, all maps are referenced by Zone 37, UTM and Adindan.

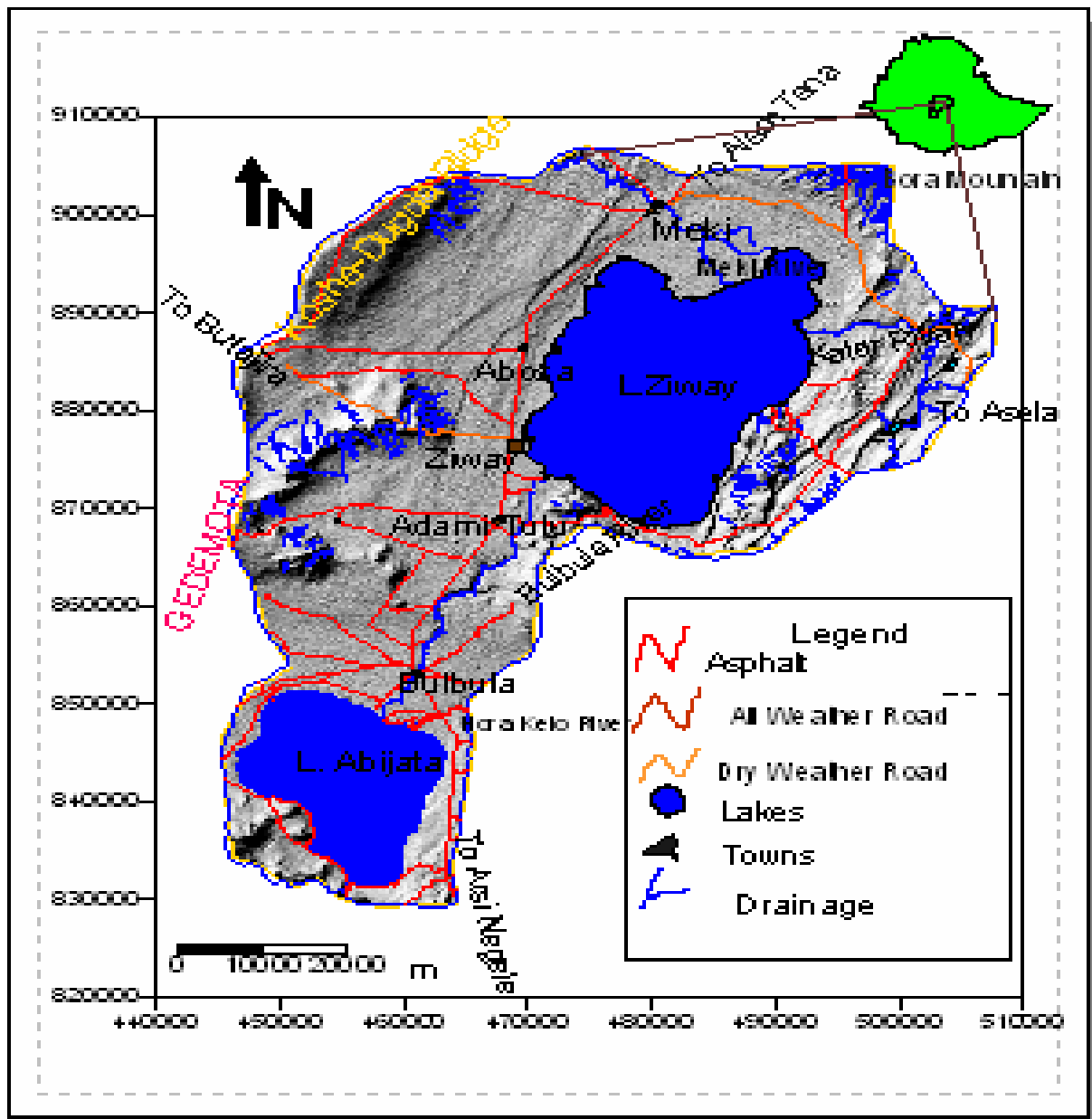


Figure 2.1 Location map of the study area

2.2. Topography and Drainage

The Ziway-Abijata Corridor constitutes part of the rift floor of the Lakes Basin, an internal drainage basin located in the central part of the Main Ethiopian Rift. The latter is a NNE-SSW structure down-faulted through the Ethiopian highlands. The physiography of the area is, therefore the result of volcano-tectonic activities that occurred in the past and also deposition of sediments which are largely of lacustrine origin. As a result the main landscape features in the area include the volcanotectonically formed Ziway and Abijata lakes, fault scarps, fault controlled depressions, volcanic domes, calderas and ridges.

Elevation of the corridor varies from around 1580m a.s.l. at Lake Abijata to more than 2328m a.s.l. on mount Aluto. The western part of the corridor consists of Koshe-Dugda ridge and topographic highs like Chebi Jebule (1980m a.s.l.), Macho (2000m a.s.l.) and Goda (2076m a.s.l.). The eastern section particularly east of Lake Ziway is characterized by distinctive fault system, known as the Wonji Fault Belt. The intense fault system resulted in formation of minor grabens and horsts and volcanic domes. The main topographic features of the area are ridges namely known as: Weshe Danta , Kobota, Gelana, Bosha, and Deneba.

Volcanic mountains Bora, Berecha and Aluto are found in the eastern section of the corridor. Topographic peaks Lencha (1750m a.s.l.), Haroresa (1780m a.s.l.) together with the volcanic rim of the caldera of Lake Shalla form the catchments for Lake Abijata in the southern section.

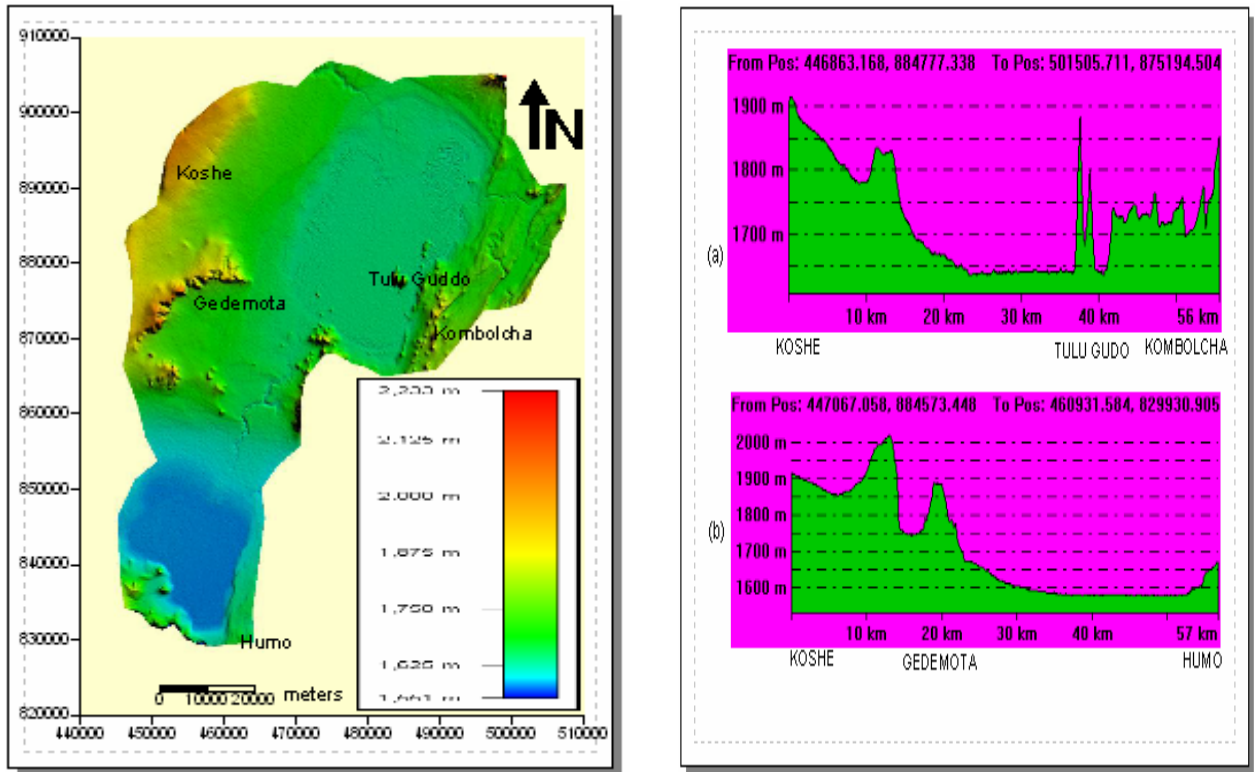


Figure 2.2 Digital Elevation Model (DEM) and associated cross-sections of two traverses

- (a) Koshe-Tulu Gudo-Kombolcha traverse
- (b) Koshe-Gedemota-Humo traverse

There are a number of different scales of perennial and intermittent streams and gullies usually originate from the sides of sloppy scarps, ridges and domes of the area and converge towards the lakes. Meki and Ketar form the perennial Feeder Rivers to Lake Ziway which start from the western and eastern highlands respectively. Bulbula River which is the overflow of Lake Ziway is the only perennial River flowing to Lake Abijata. Hora Kelo intermittently overflows from Lake Langno to Lake Abijata. Both the lakes obtain surface runoff from the surrounding volcanic domes and topographic highs.

Drainage in the eastern highland is well developed and parallel in the pattern. Most streams in this part of the catchments drain towards Lake Ziway via Ketar River. The main tributaries to Ketar River are: Aleltu, Yeloma, Murkicha, Kechema, Chiro, Koto and Chufa.

Drainage within the rift floor is not well developed. Many streams and gullies draining from Koshe-Dugda Ridge, and rims of volcanic domes and topographic highs mostly terminate in the lacustrine sediments before reaching the lakes, but contribute to the groundwater system.

Within the floor and the neighboring escarpments and highlands the courses of the streams is highly controlled by the geological structures. This is clearly observed in the eastern escarpment of the rift floor, where the ridges which are part and parcel of the Wonji Fault Belt affect the course of the rivers and also responsible for the formation of swampy areas. The Koshe-Dugda Ridge also controls the flow of Woja River, one of the tributaries of Meki River.

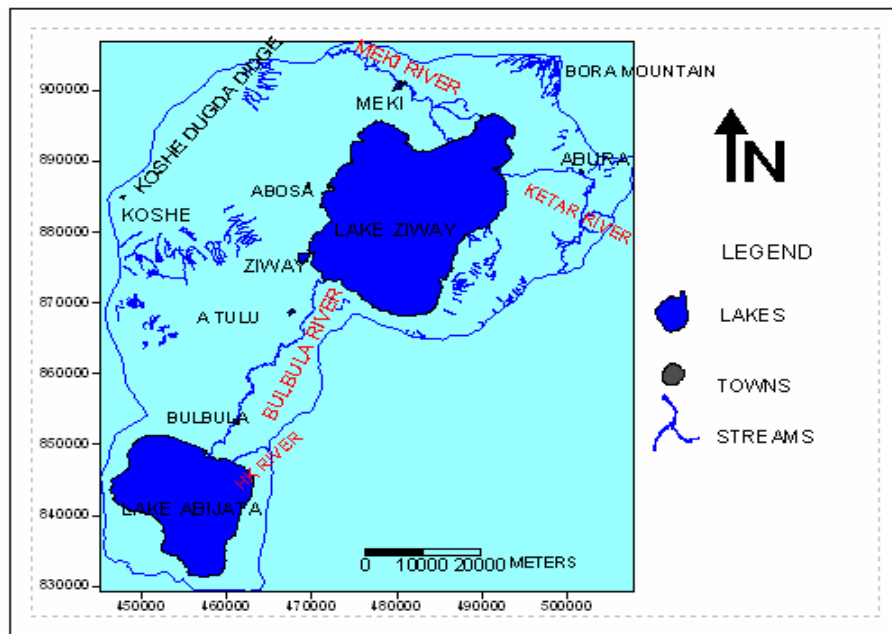


Figure 2.3 Drainage map

2.3. Climate and Vegetation

The rift floor corridor is characterized by a semi-arid climate with mean annual precipitation and mean annual temperature 706 mm and 20 °C, respectively.

The region is characterized by three main seasons. The long rainy season in the summer (June – September; summer monsoon rainfall, locally known as ‘kiremt’) is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) which lies to the north of Ethiopia at that time. Due to the intense heating of the high plateau land, the convergence of the wet monsoonal currents from the southern Indian and Atlantic oceans brings much rain to the region (Griffiths, 1972). The summer rain represents 50-70% of the mean annual total (Degefu, 1987). Highlands flanking the Rift Valley intercept most of the monsoonal rainfall in the region, resulting deficit in a strong moisture deficit in the rift floor in general and near the lakes in particular. The pattern of the precipitation in the rift floor is more of stormy type with relatively high intensity (up to 100 mm/hr) compared to the highlands with only 60-70 mm/hr (Makin et al., 1975).

The dry period extends between October and February (known as ‘bega’) when the ITCZ lies south of Ethiopia, during which time northeasterly trade winds traversing Arabia dominate the region. The ‘small rain’ season ‘belg’ representing 20-30% of the annual amount occurs during March to May when the ITCZ moves from south to north over the country. This coincides with the diminution of the Arabian high as it moves towards the Indian Ocean, causing warm, moist air with a southerly component to flow over most of the country (Griffiths, 1972).

Local climatic conditions are affected by topography, with generally low temperatures and higher precipitations at the higher elevations. The pattern of increasing rainfall associated with increasing altitude is modified in the high altitude area by influence of the high mountains which may cause either rain shadows or areas of heavy orographic rainfall (Makin et al., 1975).

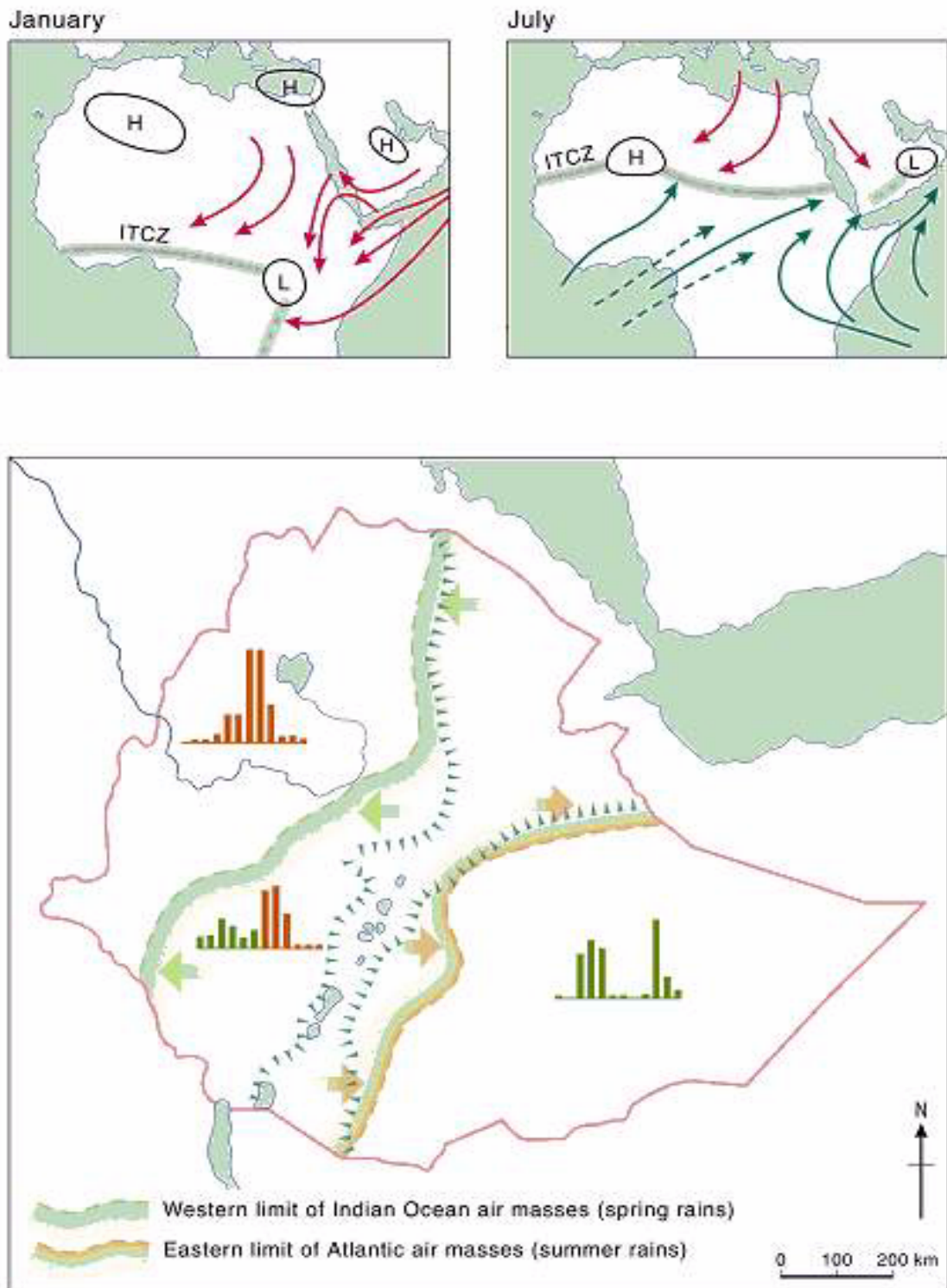


Figure 2.4 Seasonal drifting of the ITCZ and its control on the rainfall regime (from Daniel Gemechu, 1977)

The vegetation in the rift valley is typically of semi-arid land characterized by dry land acacia. Much of the higher escarpments below 3000m are either cultivated or under grass cover. The main crop near the lakes region is maize. With increasing altitude, the basin is mainly characterized by traditionally cultivated/pasture land with wheat and barely being the major crops, together with some oil crops, peas, and 'false banana' *Ensete ventricosum* (a staple food in many parts of the basin and cultivated at altitudes ranging between 1600 and 3000m). There are only some remnants of the montane forest that still existed some decades ago between 2000 and 3000 m on the eastern Ethiopian plateaux bordering the rift and dominated by *Podocarpus gracilior* and *Juniperus procera* (Friis 1986). The Ericaceous belt extends up to 3600m where it grades into Afroalpine type of vegetation (Chaffey, 1978).

2.4. Soil

The soil type in the rift valley is closely related to parent material and the degree of weathering. The main parent materials in the basin are basalts, acidic lavas, volcanic ash and pumice, riverine and lacustrine alluvium. Weathering varies from deeply weathered basalt in humid highland areas to un weathered recent alluvial deposits in the drier central part of the rift valley.

The soils of Ziway area have been classified according to the nature of the soil-forming parent material, topsoil texture, the morphology and arrangement of subsoil layers, the presence or absence of alkalinity or salinity and the effect of water logging brought about by seasonal variations in rainfall and lake level. These criteria have been used as a basis for grouping soil series into four associations (Makin et al., 1975):

Type 1: covers predominantly the rift floor and western escarpment on flat to undulating plains with some hills formed on pyroclastic deposits. Generally the soils are dark grayish free draining friable silty loam to sandy loam with moderate structure and good moisture storing properties.

Type 2: is found on steep faulted undulating and rolling low plateau escarpments of the rift zone. The soil is well drained, moderately deep to deep dark gray or brown, friable silty loam to sandy loam with moderate structure and good moisture storing properties.

Type 3: well drained deep reddish brown to red friable clays to clay loams with strong structure. This soil type is found on flat to undulating plateau of western margin and dominantly in eastern plain.

Type 4: is very thin and shallow soil covering the eastern margin of the study area. The soil is well drained and limited to moisture storing property, stony and has no diagnostic horizon (Regosols/Lithosols according to FAO/UNESCO soil classification).

Out of the above mentioned four categories of soil types only the first two types are very common in the Ziway-Abijata Corridor. The first type accounts for about 70% of the total area coverage and the second type constitutes the remaining 30% of the area excluding the area occupied by constant water bodies (see Figure 2.6).

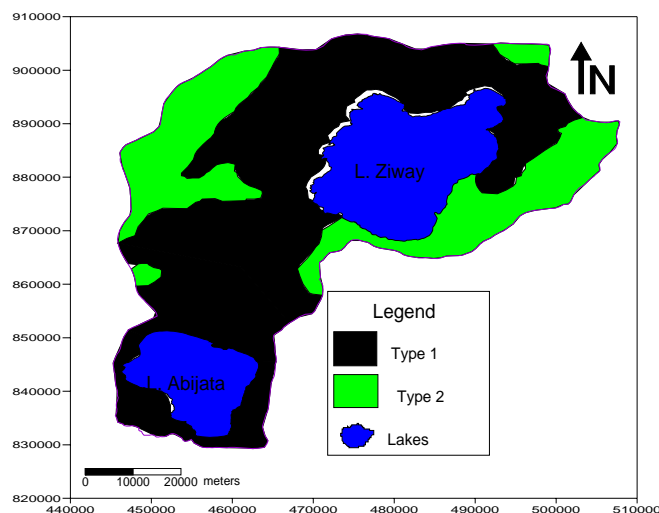


Figure 2.5 Generalized soil map of the study area (from Makin et al., 1976)

2.5. Landuse and Land Cover

The land use/land cover map of the corridor is taken from the work of Dagnachew Legesse, 2002. A dramatic feature of the recent past in the area is that the rapid reduction in the area of wood land and bush land. Another important change in the land use in the area is introduction of irrigated fields, which previously barren land using surface and sub-surface water resources. Consequently, the area of cultivation shown in table 2.1 is under estimated. Another observable

change in the land cover in the corridor is the area occupied by permanent open water body is over estimated, because the presently shrinkage of rift lakes particularly Lake Abijata could account for the case.

Table 2.1 Aerial distribution of land cover units

Class	Cover type	Area (km ²)	Area (%)
1	Permanent open water body	630	23.40
2	Swamps and wet land	99.87	3.71
3	River delta	4.96	0.18
4	Mixed acacia-cultivated land	1250.61	46.46
5	Intensively cultivated land	53.8	2.00
6	Irrigated farm	37.42	1.39
7	Bushes and shrubs	24.34	0.90
8	Mixed cultivated wood land	136.5	5.07
9	Degraded savanna	297.7	11.06
10	Open acacia woodland	156.8	5.82

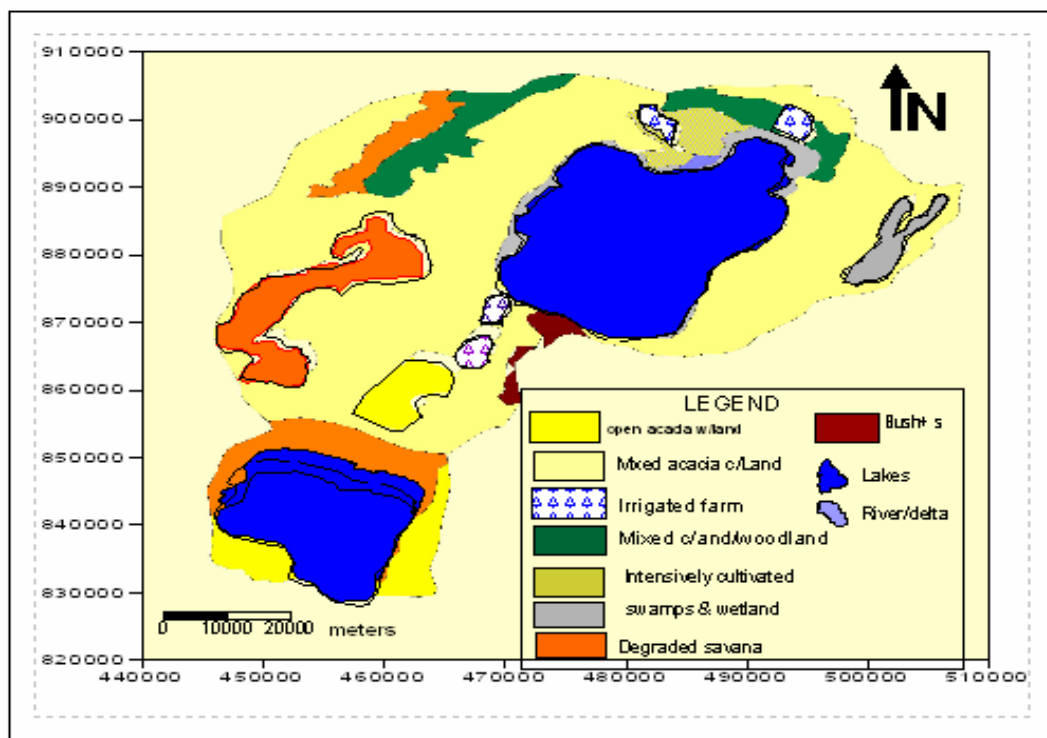


Figure 2.6 Landuse/land cover map (from Dagnachew Legesse, 2002)

CHAPTER THREE

GEOLOGY

3.1. Introduction

The present day geologic and geomorphologic features of the region are the result of Cenozoic volcano-tectonic and sedimentation processes (Tenalem Ayenew, 1998). The Precambrian basement complex upon which all younger formations were deposited contains the oldest rocks, which are mainly located in peripheral regions of the country. The study area is covered by Cenozoic volcanics and sediments.

The Tertiary and Quaternary geologic history of Ethiopia is dominated by a distention tectonic regime and widespread volcanism (Giday Woldegabriel et al., 1990). The Tertiary volcanism started in the Late Oligocene, and was dominated by fissural eruptions of tholeiitic and transitional basaltic lavas with minor ignimbrites. This formed the thick sequence of lava flows and interbedded ignimbritic sheets that is known as the Ethiopian plateau. In the Middle Miocene large central volcanoes were formed. These have variable composition, from transitional to a Na-alkaline. The third phase of activity is Late Miocene to Recent and is more directly associated with the full development of the the Main Ethiopian Rift (MER). Rocks are dominated by rhyolitic pyroclastics, with minor basalts. These are aligned in a NE-SW direction, along the Wonji Fault Belt (WFB). Wonji Fault Belt is the most active part of the MER. It forms a graben within a larger graben or a rift within a rift structure and the faults in this zone are short normal type and are oriented NNE-SSW.

Generally, in the MER volcanism migrated from the plateau areas to the rift. Starting from five million years before present volcanism was mostly concentrated within the rift and since 1 million years ago volcanism was mostly restricted along the axis of extension (i.e., Woji Fault Belt).

Di Paola (1972) identified four main successive events of volcanic activity in the MER between 7°00' and 8°40' latitudes that includes the study area as follow:

1. Fissure eruptions with emplacement of explosives dominantly ignimbritic products followed by volcano-tectonic collapses,
2. Building of silicic central volcanoes on the ignimbrites,
3. Basaltic fissure eruptions and
4. Edification of recent mostly pantelleritic centers with associated “sub-historical” basaltic fissure eruptions.

Di Paola in the same locality, also identified nine volcanic centers from north to south, namely: Ziquala Volcano (thick and viscous alkali trachytic lava flows), Boset-Gudda and Boset-Bericcia Volcanic Complex (very recent pantelleritic obsidian lava flows with pumice and ashes), Gedemsa Caldera Volcano (rhyolitic lavas with pumice and ignimbrite), Bora-Berecha Volcanic Complex (silicic pyroclastics), Chilalo Volcano (thick alkali trachytic lava flows), Badda Volcano (alkali trachytes), Aluto Volcano (silicic pyroclastics: pumice flows, pumice falls and ashes with subordinate rhyolitic lava flows, mostly obsidian), Lake shalla Caldera (ignimbrites and pumice deposits of “sillar” type and some rhyolitic lavas) and Corbetti caldera (pumice flows and pumice falls with subordinate obsidian lava flows).

In the central sector, the Wonji Fault Belt is right laterally offset into four en-echelon rift axis segments: Gedemsa-East Ziway, Ziway-Shalla, Shalla-Awassa and Dugna-Abaya Zones.

3.2. Geological Succession

In the central sector of the MER, the rift shoulders are made up of volcanic and pyroclastic rocks where as large areas of the rift floor are covered by volcano-lacustrine and fluvio-lacustrine deposits. A simplified geologic map for the study area is shown on fig 3.1 and the descriptions of major products in the area have been summarized below.

3.2.1. Nazareth Group and Dino Formation Undifferentiated

Nazareth and Dino Formations form parts of the Trap Series and equivalent to the Ashangi and Magdala group respectively; and unconformably overlying Precambrian and Mesozoic rocks (Mohr, 1970; Halcrow, 1989).

The Nazareth group includes alkaline and alkaline stratoid, silicics, ignimbrites, unwelded tuffs, ash, rhyolites and trachytes. The rocks are intruded by dolerite sills, acidic dykes and gabbro-diabases. The total volcanic sequence is put at 3000m with the thickest sections being recorded in the plateau escarpment of the Awash Basin to the north of the Rift Valley Lakes Basin.

Dino formation is a sequence of contemporaneous and post-Nazareth volcanics. The formation extends from the highland boundaries through much of the valley slopes and escarpments, and into the floor of the valley. It is believed that this formation underlies the valley floor from Lake Abaya northwards. The Dino formation includes water laid pyroclastics with intercalated lacustrine beds and unwelded pumiceous pyroclastic rocks. The thickness varies widely from a few meters to about 30 meters on the plateau and reaches 250 meters in the rift.

3.2.2. Ignimbrites and Tuffs

This group contains ignimbrites, tuffs and subordinate lacustrine sediments. In the western part of the corridor, these rock units are found west of Gedemota Caldera and Gebiba Mountain around Koshe and in the eastern part along the eastern fault escarpment of the Wonji Fault Belt. The ignimbrites are constituted by several layers with variable thickness from 0.5 up to 20 meters. East of Lake Ziway mostly lacustrine deposits are intercalated with ignimbritic sequences, but west of Lake Ziway ignimbritic sequences are separated by paleosoils. Another common pyroclastic product associated with the well welded ignimbrites is unwelded thinly layered pumice, while the poorly welded ignimbrites are mostly rich in big pumice fragments.

3.2.3. Basalts and Associated Flows of the Rift Floor

Alkaline basalts of various Pleistocene and Recent ages are present in the rift floor. The recent basalts outcrop in the floor of the rift; the older ones include basaltic flows, cones and hyaloclastics. A few outcrops of basaltic hyaloclastites which were produced by sub-aqueous basaltic volcanism are located south and east of Lake Ziway and southwest of Shalla. The two main fields of recent basaltic flows are those of the Wonji Fault Belt east and north of Langano and in the western escarpment southeast of Silte.

3.2.4. The Central Rift Volcanic Complexes

This group includes the rift valley hills and small volcanic cones, and is characterized by rhyolitic lava flows and domes associated with the rift floor ignimbrites. Alkaline silicics are the last volcanic products of the group. They are located in the slopes of Bora, Bericho, Aluto, Urgi and Chabbi volcanoes. The pyroclastics are unwelded pumice and tuff, obsidian, pitchstone and rhyolitic lava flows. Among the central volcanic complexes of this group Aluto, Bora-Bericho, Fike, Gedemota rhyolite and Corbetti are the most important geomorphic features of the rift valley; of which we discuss all except the Corbetti. The volcanic activity spans a million years to the present. The current activity is represented by fumaroles, hot springs and the hot ground (Halcrow, 1992).

1. **Aluto Volcanics:** These volcanics are of Late Pleistocene-Holocene age representing multiple flows dominated by pumice, ash, and recent obsidian flows. This silicic volcano is situated between Lake Ziway and Lake Langano, and it is one of the typical examples of a Rift Quaternary pantelleritic center. Before volcanism commenced at Aluto center, the Langano-Ziway Basin was well developed and occupied by ancestral lakes (Street, 1979 in Tenalem Ayenew, 1998). A thick sedimentary sequence was deposited in the basin. The large production of pumice, notably by Aluto, has had a dominant influence on Late Quaternary basin sediments and soils. Both the Late Pleistocene and Holocene lake deposits of the Bulbula plain contain pyroclastic and fluvial-reworked Aluto pumices. Examination of the

disposition and petrography of recent pitchstone flows suggests that Aluto has undergone a similar eruptive history to other silicic volcanoes in the Rift, and is at present in a dormant, post-caldera phase (Dakin, F., Gibson, 1971).

2. **Bora-Bericho:** Bora and Bericho mountains represent one of the most recent volcanic complexes in the area (Di Paola, 1972). The volcanics from these mountains were mapped by Benevenuti et al (1995) as Late Pleistocene-Holocene pumice and obsidian. The eruption from these centers is probably responsible for large pumice and ash deposits in the area, especially in the northern water divide of the Lakes Basin and in the middle Meki Valley.
3. **Fike Mountain:** Mount Fike located on the isthmus between Shalla and Abijata lakes, is a double cone of stratified pumice resulting from eruptions of base surge type. Similar sub-aqueous volcanics outcrop in the denuded cones of the Lencha Mountains on the South shore of Lake Abijata.
4. **Gedemota Rhyolite:** This is an Early Pleistocene alkaline and per-alkaline rhyolitic lava flows and bedded tuff located west of Ziway. The Gedemota ridge is the relict of a large caldera. After the collapse, the center of the caldera has been buried under younger lacustrine and colluvial deposits. Only the western caldera margin exists. The eastern side might have collapsed and been subsequently buried (Tenalem Ayenew, 1998).

3.2.5. Volcano-Sedimentary Rocks and Lacustrine Sediments

These are predominantly volcanoclastic sediments and tuffs associated with lacustrine sediments. Lacustrine deposits exist in the vicinity and beneath the beds of lakes. In many places of the rift floor they are mixed with sediments locally interbedded with volcanoclastics. The sediments have a varied lithology related to their mode of origin; i.e., whether they were quiescent lake deposits, water deposited volcanic ejecta, or coarse sediment introduced into the lakes by flood events. Silts and clays dominate the group are interbedded with tuff, locally with sand gravel.

Alluvium in valleys is also a common feature, varying considerably in thickness and composition. Among the common units of the group the following five lithostratigraphic units have been identified in the Ziway-Abijata Corridor:

- I. Pelite dominated lacustrine deposits: deposits of pelite and peat,
- II. Bulbula deposits: volcano-lacustrine deposits, mainly pyroclastics derived from ash and tuff, subordinate shell beds and sand,
- III. Abijata shore deposits: predominantly sand associated with clay (Holocene),
- IV. Ziway terrace and volcano-lacustrine deposits: Pyroclastics derived from ash and tuff. Also included are pelite, diatomite, silt, and clay with occasional shore sand and shell beds (Holocene),
- V. Meki and Ketar deltaic deposits: sand, silt, and clay (Holocene)

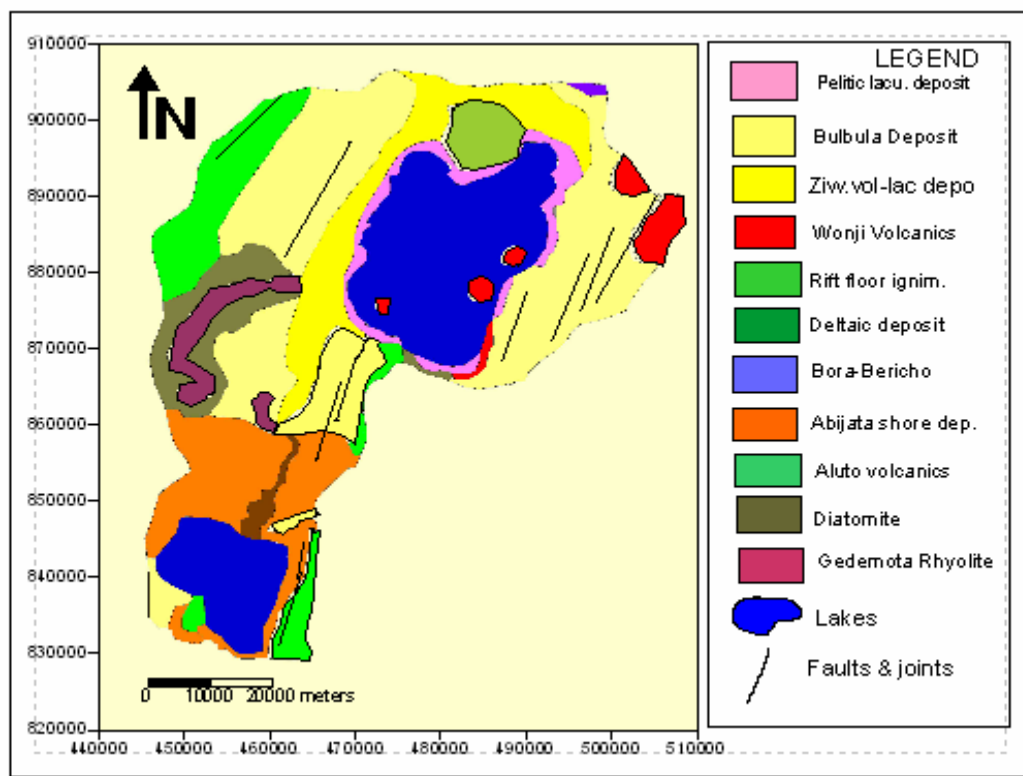


Figure 3.1 Geologic map (taken from Tenalem Ayenew, 1998)

3.3. Geologic Structures

Tertiary volcanism and rift faulting are responsible for basin evolution in the Main Ethiopian Rift (Halcrow et al., 1975). The main geologic structures that have been observed in the corridor include: faults, joints, fractures, calderas and craters.

Large-scale normal block faulting has disrupted the volcanic rocks and formed step-faults and a horst and graben topography. In Ethiopia the rift valley is distinctly separated from adjacent plateaux by a series of normal step-faults usually trending parallel to the NNE-SSW rift axis. In the MER, there are at least four sets of faults; running NNE-SSW, N-S, NNW-SSE and arcuate or semi-circular faults. The first two are dominant and extend for long distances, at times hundreds of kilometers. The latter are located in a few localities and are associated with volcano-tectonic collapse structures (calderas) and central volcanic centers. The majority of faults are associated with large open tensional fissures. The floor of the rift is marked by a persistent belt of intense and fresh faulting, which is a characteristic feature of the active Wonji Fault Belt which extends from south of Lake Chamo to the Lake Abhe area of central Afar. Faults along this active zone form numerous minor horst and graben structures or “rift-in-rift” structures. In some places in the study area, the “rift-in-rift” structures result in swampy and wetland areas as in the case of Arata in the Eastern rift escarpment. The WFB is characterized by young silicic caldera volcanoes as well as by several clusters of hot springs.

Though the rift valley in the MER is asymmetric, the distance between the larger faults and the total displacement are uniform over long distances resulting in symmetry in the corridor. However, the eastern half of the fault is characterized by a large number of intense, normal step-faults due to the effect of WFB. The western escarpment is primarily characterized by one major fault scarp; the displacement sometimes exceeds 1500 meters. The rift consists of two caldera related basins, the Ziway-Langano-Abijata system and Shalla, bordered by Awassa. The two caldera related basins are connected by large fault systems. In the former basin, the rift axis consists of two en-echelon quaternary volcano-tectonic zones, as narrow graben along each margin of the rift floor. The tectonic movements are still active in the Ethiopian rift valley as confirmed by young faults often affecting recent formations and high seismicity of the whole region.

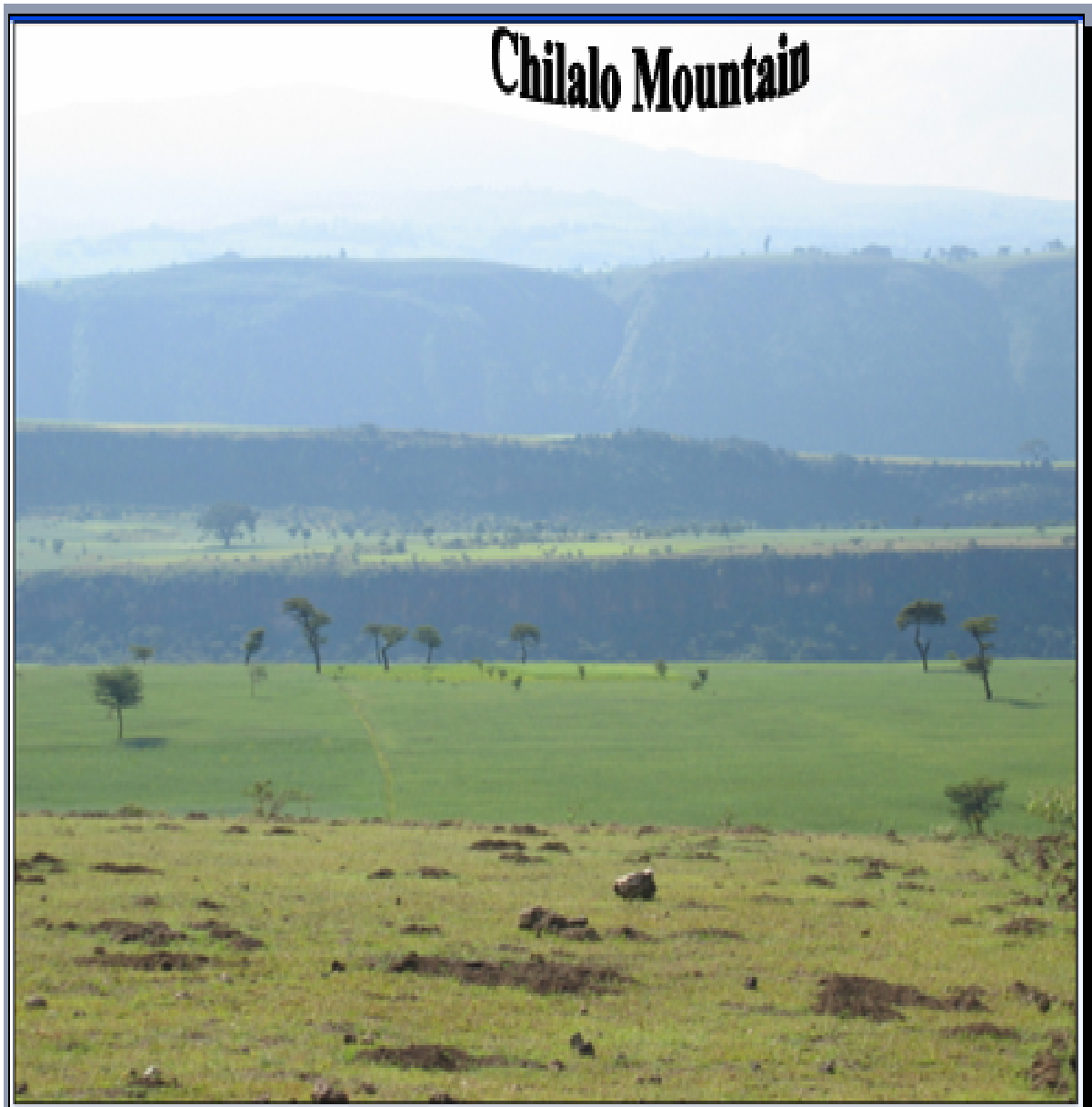


Plate3.1 Step-faults of eastern escarpments

CHAPTER FOUR

HYDROMETEOROLOGY

4.1. Introduction

Hydrometeorology is concerned with the study of the atmospheric and land phases of the hydrologic cycle with emphasis on the interrelations involved (WMO, 1963). Therefore, it is the beginning parameter and very essential in water resources evaluation of a given area. In this study, attempt is made to analyze and review precipitation and evapotranspiration of the corridor based on previous works and available climatic data. At microscopic scale, these two terms describe the initial income of water and the outflow of water in a given area, respectively. These two components provide an indicative examination of the water availability of a given area. Classically, the starting point lies with an overview of the rainfall climate.

4.2. Precipitation

Precipitation is defined as any form of water, which falls on the surface of the earth by the process of condensation and sublimation. From hydrological point of view there are two main forms of precipitation, snow and rain. In the study area rainfall is the most important source of precipitation and thus the main contributor to runoff, stream flow and recharge. The amount of rainfall for the given point is influenced by the location of the area with respect to the sources of moisture, direction of the wind and topography.

Long term mean monthly rainfall records of about 7 stations have been used to characterize the rainfall pattern in the corridor. Figure 4.1 shows, the highest rainfall is recorded at Koshe station and the lowest rainfall record is obtained at Abura station in the rift floor.

Table 4.1 Point Precipitation over meteorological stations in the corridor

No	Station	Location		Altitude (m.a.s.l)	Mean monthly precipitation (mm)														Mean	STDEV	Annual
		Easting	Northing		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
1	Abura	501720	888408	1690	17	34	51	61	54	67	112	95	74	29	12	11	51.4	32.4	617		
2	Abijata	453000	833000	1580	12	60	54	69	76	73	102	78	67	24	2	5	51.8	32.8	622		
3	Adami Tulu	466928	867727	1750	16	40	45	56	58	68	115	114	80	30	6	7	52.9	36.9	635		
4	Bulbula	463242	852989	1610	10	33	50	70	68	71	133	98	62	30	7	3	52.9	39	635		
5	Koshe	448575	886170	1873	22	48	78	91	90	100	171	170	109	51	5	5	78.3	55.8	941		
6	Meki	479804	900885	1663	13	35	56	65	64	77	170	149	87	34	8	4	63.5	52.4	762		
7	Ziway	468772	876938	1646	17	30	56	75	72	83	145	122	86	37	2	4	60.75	45	732		

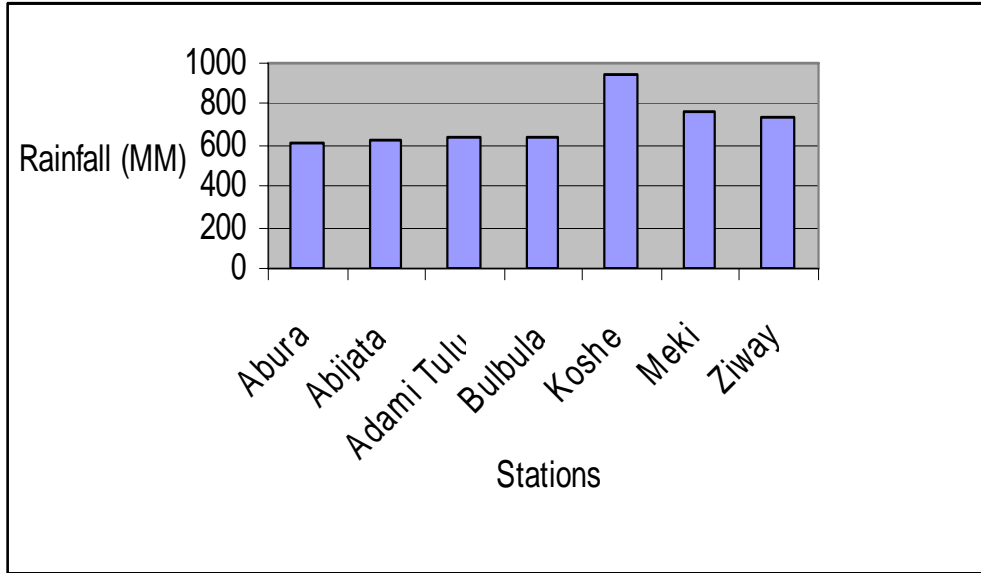


Figure 4.1 Mean annual precipitation of stations in the corridor

4.2.1. Spatial Variations of Precipitation

The spatial variation in precipitation in the corridor is controlled by topography. The long term mean annual precipitation increase with elevation. As it can be seen from table 4.1, the low lying rift floor is marked by the lowest mean annual precipitation 617mm at Abura and the value of the rainfall increases as elevation rises towards either side of the rift; for instance, at Koshe it becomes 941 mm. This may be due to the fact that the rift floor is found in the leeward of both moisture sources. The eastern and western plateaus capture the two moisture sources from the Indian and the Atlantic oceans and the air mass that passes into the rift valley is often hot, making it arid to semi-arid with high moisture deficit. This will show the significance of orographic effect on the spatial distribution of precipitation over the area (Haile Gashaw, 1998 and Eleni Ayalew , 2003). The spatial distribution of rainfall in the corridor is depicted on Figure 4.2.

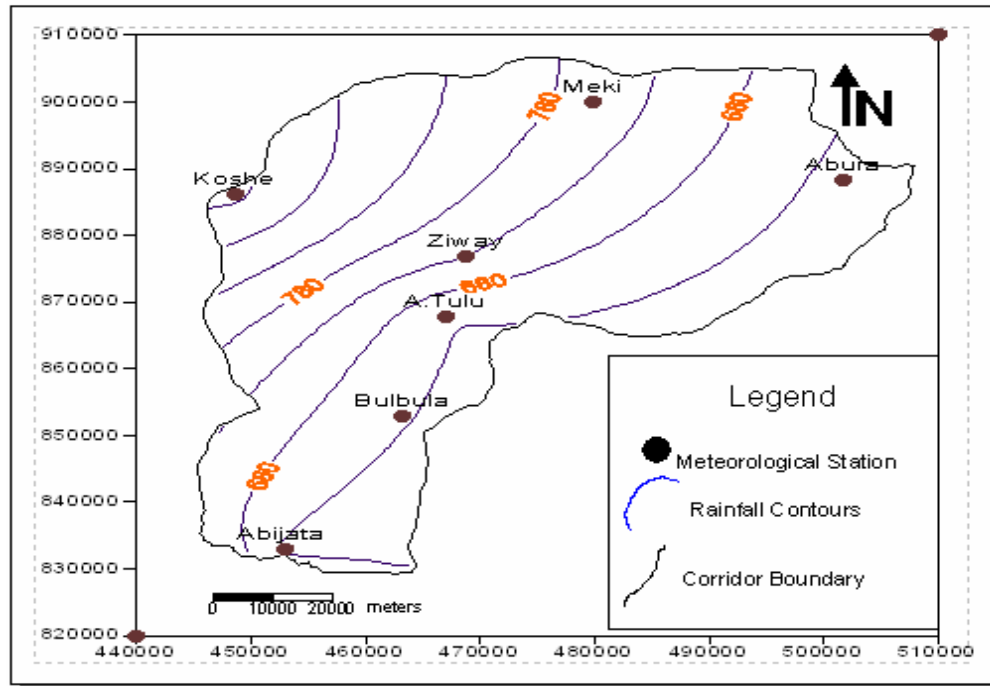


Figure 4.2 Isohyetal map (mean annual precipitation isohyets, mm)

4.2.2 Temporal Variations of Precipitation

The seasonal variability of precipitation is important as it determines the seasonality of other related hydrological variables such as stream flow, groundwater infiltration and the likes. The temporal variation of rainfall, over Ethiopia as it has been mentioned in section 2.3, is governed by the position of the Inter-Tropical Convergence Zone (ITCZ). For most of the station, the highest rainfall is recorded between June and September when the ITCZ is north of Ethiopia. During this time moisture is driven into the country from Atlantic Ocean and the region receives over 70% of its rainfall.

The easterlies and south easterlies moist air current over the highland in the spring produce small to moderate rain in March, April and May, and at this time the ITCZ lies south of Ethiopia.

In most of the cases November, December, January and February are characterized by dry weather. During this time the ITCZ is located in southern Africa leading to derivation of dry air mass from the Arabian Continent (Daniel Gemechu, 1977).

4.2.3. Estimation of Aerial Depth of Precipitation

Since the distribution of the rain gauge stations are almost uniform it is possible to apply the arithmetic average method to determine the aerial depth of precipitation in the corridor.

Based on this method, the aerial depth precipitation has been computed using the arithmetic mean of the amounts measured by the gauges within the area, using the following formula.

$$P_A = \sum_{i=1}^n \frac{P_i}{n} \quad (4.1)$$

P_A : average rainfall for the total area

P_i : measured precipitation at a given station and time

n : number of rain gauges

Then, $P_A = (617+622+635+635+941+762+732) \text{ mm} \div 7 = 706\text{mm}$

This is a good representation of the aerial depth of precipitation in the rift floor where there is no significant slope gradient in topography.

4.3. Evapotranspiration

Evapotranspiration is the total amount of water which returns back to the atmosphere within a given time by evaporation from land or open water bodies and by transpiration from the vegetation cover. Hence it is the combination of evaporation and transpiration. It is considered as a loss from the water budget of a given area due to the fact that it reduces the amount of surface and groundwater in the area. It is customary to divide evapotranspiration into free water (or lake) evaporation and evapotranspiration from plants and soil. Although the driving climatic forces

behind the two processes are the same, evapotranspiration from soil and plants is more complex. This is due to the fact that the nature of evaporating surface of soil and plants is influenced by various physiological and aerodynamic factors as well as the availability of water.

4.3.1 Common Hydrometeorological Factors Affecting Evapotranspiration

4.3.1.1 Temperature

Energy input is necessary for evaporation process. If temperature of the air and the ground is high, evaporation will proceed more rapidly than if they are cool. The capacity of the air to absorb water vapor increases as its temperature rises. Air temperature has a double effect on how much evaporation takes place, while ground and water temperature have a single direct effect.

In the corridor, there are three stations recording maximum and minimum daily temperatures. All the three stations are found in the rift floor. These stations are Abijata Adami Tulu and Ziway. Temperature varies with altitude.

Table 4.2 Mean monthly temperature of the stations in the corridor (°C)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	STDEV	Annual
1	Abijata	21	22	22.3	22	21.3	21	20	19.8	20	17	20	20	20.44	1.46	20.4
2	A.Tulu	19	20	21.5	22	21.6	21	20	19.4	20	19	19	19	20.02	1.1	32.8
3	Ziway	19	20	20.6	21	21	20	19	19.1	18	18	18	18	19.32	1.1	19.3

4.3.1.2. Relative Humidity

The relative humidity of an air mass is the percent ratio of the grams of water per cubic meter of air to the capacity of air to hold maximum amount of air, for the temperature of the air mass (Fetter, 1994).

It expresses the degree of saturation of the air as a ratio of the actual vapor pressure (e_a) to the saturation vapor pressure (e_s) at the same temperature:

$$RH = e_a/e_s \times 100; \quad (4.2)$$

Where, RH: Relative Humidity

e_a : actual vapor pressure,

e_s : saturation vapor pressure

Two stations in the corridor; Adami Tulu and Ziway have monthly records of mean relative humidity. The data show that there is a marked difference in relative humidity both spatially and temporally (see table 4.3).

Table 4.3 Mean monthly relative humidity of the selected meteorological stations (%)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	STD EV
1	A.Tulu	59	66	67	67	74	53	53	54	56	51	44	65	59	8.7
2	Ziway	85	85	84	86	89	90	90	91	91	84	81	82	87	3.5

4.3.1.3. Wind Speed and Turbulence

As water vaporizes into the atmosphere, the boundary layer between earth and air becomes more and more saturated so that the water vapor has to be removed and replaced with drier air continually. This movement of the air and moisture transfer depends on the speed and turbulence. Evaporation has direct relation with the wind speed and turbulence.

Two stations (Ziway and Abijata) located in the corridor have records of wind speed at 2m above the ground surface. The drier months have strong winds; whereas the wet months have lower wind speeds. Comparing the two stations Abijata has stronger wind speed than Ziway, this conditions favors more evaporation in Abijata consequently.

Table 4.4 Monthly average wind speed at 2m above ground surface of meteorological Stations in the corridor (km/hr)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	STDEV
1	Abijata	14	13	10	8	8	8	7	7	6	9	14	11	9	2.8
2	Ziway	10	9	8	8	10	8	7	7	5	10	11	10	8	1.7

4.3.1.4. Sunshine Hours

Since the evaporation requires supply of energy which is mainly derived from solar radiation, the radiation will be a factor of considerable importance. Only two stations Ziway and Abijata which are found at the rift floor have records of sunshine hours. The sunshine hour vary from season to season.

Table 4.5 Average sunshine hours of meteorological stations in the corridor (hours/day)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	STDEV
1	Ziway	10	9	8	8	9	8	6	7	7	9	10	10	8	1.3
2	Abijata	8	8	8	7	7	6	6	6	7	9	9	9	8	1.1

4.4. Estimation of Evapotranspiration

4.4.1. Lakes Water Evaporation

In the corridor lakes evaporation represents open water body, which is significant water loss from corridor. There are two major approaches that may be adopted in calculating evaporation from open water, E_o . The mass transfer method, sometimes called the vapor flux method, calculates the upward flux of water vapor from the evaporating surface. The second or energy budget balance method considers the heat sources and sinks of the water body and air and isolates the energy required for the evaporating process. A third method uses a combination of the two physical methods. Although there may be difficulties in relating the measurements of evaporation from small bodies of water to the real losses from a larger reservoir, tanks and pans evaporation methods are also advantageous.

The pan evaporation method involves the direct measurement of open water evaporation using pan and then by induction generalize for the total area of the reservoir; whereas Penman formula (combined method) is computing the open water body evaporation through calculations using the measured meteorological variables. Since in this study water balance computation is not

intended, only open water evaporation from the two lakes using pan evaporation and actual evapotranspiration has been revised from the previous works.

4.4.1.1. Pan Evaporation

Using a class A pan situated at Ziway and Langano station, evaporation from the two pans is found to be about 2047mm and 2169mm. Since evaporation from pan exceeds that of the nearby lake due to differences in heat storage capacity, air turbulence, heat exchange, advective energy, etc, pan coefficient of 0.83 is used (Tenalem Ayenew, 1998). Accordingly the mean annual evaporation from Lake Ziway and Abijata is 1699mm and 1800mm respectively.

4.4.2 Estimation of Actual Evapotranspiration from the Land Surface

As in the case of rainfall and temperature, there is a zonation of evapotranspiration with altitude. Since the saturation vapor pressure decreases as altitude increases, evaporation rate decreases in the same way. In this case the rift floor will have bigger evapotranspiration than the plateaux. But this has been critically discussed by one of the researchers in the field of study in the area. Dr. Tenalem Ayenew argues this idea strongly that besides temperature; the albedo, emissivity and land cover types are also very important factors (Tenalem Ayenew, 1998). Consequently the author came up with lower evapotranspiration value from the rift floor from bare lacustrine soils than the plateaux mountain areas covered with afro-alpine vegetation.

So, the temperature gradient must go hand in hand with the gradient of water deficit to excess for evapotranspiration to be intensive in arid areas. As a result, annual actual evapotranspiration for the rift (excluding the lakes), the escarpment and the highlands is found to be 656 mm, 892 mm and 917 mm respectively. The lower evapotranspiration value for the rift valley is due to the fact that much of the rift is a rainfall deficit area and most of the land is bare soil and rock with scattered bushes and shrubs (Tenalem Ayenew, 1998).

CHAPTER FIVE

SURFACE HYDROLOGY

5.1. Introduction

The Ziway-Abijata Corridor is characterized by internal drainage basin as all rivers flow into the lakes. No surface water outflow exists out of the corridor currently. The corridor is within the Ziway-Abijata-Langano sub-system in the Ziway-Shalla Basin.

The major rivers rise from the plateau on either side of the corridor and tend to flow generally southern direction into permanent and terminal lakes on the floor of the rift, following the topographic gradient. The major rivers in the basin include Ketar and Meki that flow to Lake Ziway. Bulbula perennially draining Lake Ziway, Horakelo intermittently draining Lake Langano to Lake Abijata respectively. River Gogessa, a branch of Jiddo River, though intermittent, flows to Lake Abijata.

Besides these major rivers, although periodical during the wet season, there are also ephemeral tributaries contribute to the water resources in the corridor.

5.2. The Rivers

5.2.1. Meki River

The Meki River drains an area of 2433 km² of the Guraghe Mountains to the west and north-west of Lake Ziway (Makin et al., 1975). Although the head waters of the Meki River are at an altitude of about 3000 m, the river rapidly descends the Rift Valley escarpment to below 2000 m before being joined by several major tributaries, including the Lebu, the Akomoja, and the Woja. The Woja River, deriving partially from saline swamps to the north of Lake Tufa, contributes some salinity to the main river (see section 7.3 of chapter 7). Down stream of its confluence with the Woja, the Meki is incised in a steep-sided valley until it reaches Meki Town at the head of its

delta. There after, the Meki meanders for about 15 km between slightly rose natural levees through deltaic alluvium before entering Lake Ziway at an average elevation of 1636 m. During the wet season, several shallow overflow channels carry flood waters from the Meki towards Lake Ziway in a variety of directions, so impeding access and causing serious local flooding which raises the water table of the shallow ground water system.

Meki River was draining towards the Awash Basin, the northern nearby basin (Makin et al., 1975). Changes in discharge, Sediment load, and base level during the historic time of the river could have caused the change in the river course. Still these changes are working in the Meki River in resulting in changes in terms of width, meander wavelength, and meander length.

The Meki has been gauged since 1963. One gauging station at Meki Town, another one 5 km upstream of Meki Town and another gauging station further upstream near Dugda Has been installed. In this study river discharge data at Meki Station is used. In average years, the hydrograph of the river gives maximum flows in August with a minor secondary peak in April, and minimum flows between December and March.

5.2.2. Ketar River

The catchments of the Ketar River ascend to over 4000 m on the summits of Mounts Badda and Kaka draining an area of 3350 km². Consequently, the gradient of the river is generally steep through out its course to Lake Ziway, and it is often deeply incised up to 50 m below the surrounding country side (Makin et al., 1975). Ketar was gauged since 1968. Although the overall pattern of flows is similar to Meki, the base flows in dry season are rather higher, and it seems most unlikely that the Ketar would ever dry up (Makin et al., 1975). Ketar River has been gauged at Fite, and Abura, the river discharge at Abura has been utilized in this study.

5.2.3. Bulbula River

The Bulbula River descends about 56 m over a distance of about 30 km between Lakes Ziway and Abijata, draining 7488 km². The level of the river for the first 6 km of its length is the same

as that of Lake Ziway due to the presence of a lava sill which effectively controls the level of the lake. Within this reach the hydraulic gradient is very flat and hence there is no turbulent flow.

Because of this natural impoundment by the lava sill (scoracious basalt), a very huge amount of water is accumulated here. The ground level elevation is about 1643 exactly on the bridge called Melka Guto; the bridge is exactly constructed on the lava sill. This elevation is significantly some meters above the level of Lake Ziway. According to elders in the surrounding area, River Bulbula do not get dry in most of the cases within this reach. This is one of the reasons why many large-scale irrigation schemes on either side of River Bulbula have been concentrated here. Besides these big irrigation schemes, other significant intake positions are also located within this reach. The intake for Ziway Town Water Treatment Plant, intake for Abernosa Ranch and intake for Adami Tulu Research center are some of big water withdrawal positions.

After Melka Guto, i.e., beyond the lava sill (impoundment), even though the hydraulic gradient tends to increase to result in turbulent flow locally in the river, the flatness of the gradient still continues up to the down stream reach called Melka Robi. Because of the relative flatness of the hydraulic gradient, up to Melka Robi, most of the time, River Bulbula will not get dry. River Bulbula is very susceptible after the Melka Robi reach.

After Melka Robi the gradient is big enough to result in strong turbulent flow. Because River Bulbula becomes incised in a steep-sided gorge to over 50 m within the surrounding poorly consolidated ash deposits. The gorge continues almost to Lake Abijata into which the Bulbula flows over a shallow beach (Makin et al., 1975).

Except periodically during the wet season, the flow in the Bulbula usually derives entirely from Lake Ziway. However, the Bulbula has significant catchments of its own, and partially during the wet season, ephemeral tributaries from the east also contribute to the flow. Whenever the level of Lake Ziway falls below that of the controlling sill, as happened between April and July in 1973 and again in 1974, the Bulbula dries up. The lava sill is a natural control for the level of Lake Ziway. This river is totally dependent on water from Lake Ziway. No base flow contribution to the river at least from Melka Guto reach, along its way to Lake Abijata. Bulbula has been gauged

at two stations (upstream at Kerkersitu and down stream at Bulbula Town), the latter being abandoned in 1998.

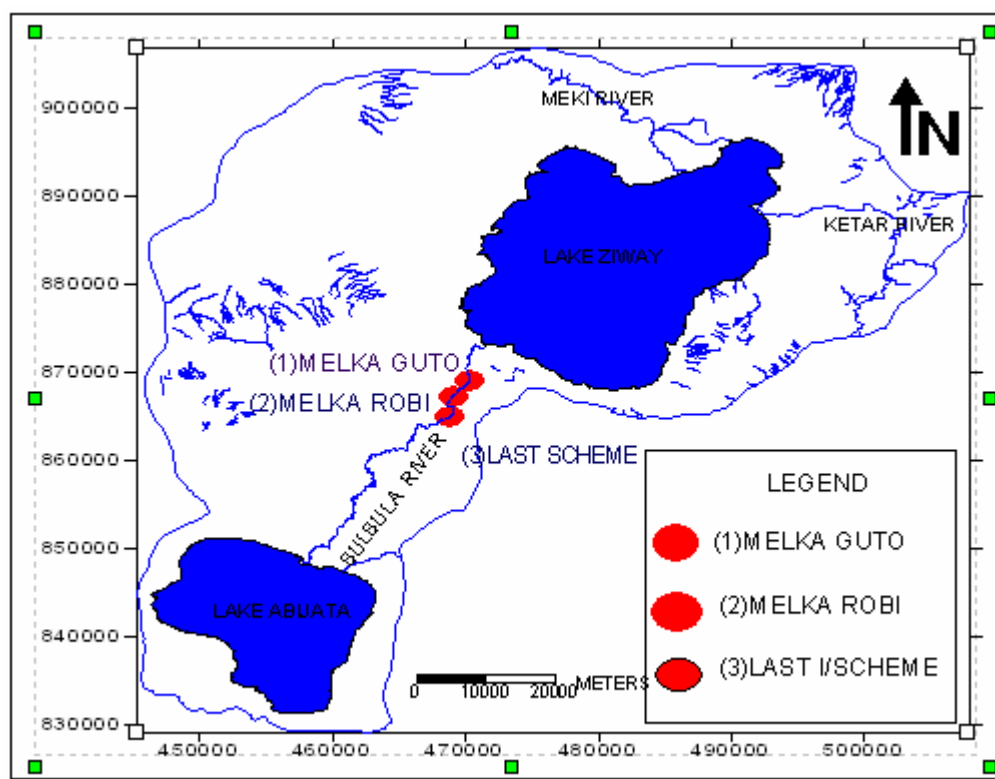


Figure 5.1 Melka Guto, Melka Robi reaches and the last irrigation scheme on River Bulbula

5.2.4. Hora-Kelo

Hora Kelo is an intermittent river flowing from Lake Langano to lake Abijata. It descends some 5 m between the two lakes. It drains a catchments area of 2006 km². It has been gauged near the bridge on the road Bulbula to Arsi Negelle. When compared with Bulabula its contribution is about 20% to Lake Abijata. When water recedes in Lake Langano during dry seasons it stops flowing to Lake Abijata.

5.2.5. Gogessa River

Gogessa River, a branch of Jiddo River-which flows to Lake Shallaa, is draining the land to the west of Lake Abijata intermittently.

5.3. The Lakes

In the Lakes Basin there are four lakes, namely: Ziway, Abijata, Langano and Shalla. The first two are found in the study area. These lakes are found geographically near to each other; however, depict considerable variation in terms of hydrologic, chemical, and isotopic properties. These differences may be related to differences in water balance between inflows and outflows and to differences to their morphometry (Eleni Ayalew , 2003).

Table 5.1 Basic Morphometric data of the lakes (after Tenalem Ayenew, 1998)

Lakes	Altitude (m.a.s.l)	Lake area (km ²)	Catchments area (km ²)	Maximum depth (m)	Mean depth (m)	Volume (mcm)
Ziway	1636	440	7736	8.9	2.5	1466
Langano	1585	230	2000	47.9	17	3800
Abijata	1578	180	10744	14.2	7.6	954
Shalla	1550	370	2300	266	87	37000

5.3.1. Lake Ziway

Lake Ziway is the shallowest and largest lake in the basin, which can be compared with a very shallow saucer. It is located at the highest altitude compared to the other lakes. It lies in shallow faulted basin. Apart from the Ketar and Meki, Lake ziway has its own catchments covering 7736 km². It is a fresh water lake with short residence time (about 1.5 – 2 years) (Eleni Ayalew, 2003). The lake is used for commercial fishing and has a potential of 3000 tones of fish per year (Atkins & partners, as cited in Tenalem Ayenew, 1998).

The lake has eleven islands of various size formed of scoria or hyaloclastites (Eleni Ayalew, 2003). There are several mineralized springs around the lake shore and there might be a significant groundwater flow towards the lake. But, the hot springs on Tulu Gudo Island represents the volcanic origin making the catchments very complex and complicated.

Despite high evaporation from the lake surface, the inflow plus rainfall on the lake surface exceeds evaporation, thus giving rise to the Bulbula River outflow. Records of lake level at Ziway Town since 1967 show considerable variations; these variations have had a striking effect on the flow of Bulbula and eventually on the terminal Lake Abijata. Therefore, there is a close correlation between the hydrograph of Lake Ziway, River Bulbula and Lake Abijata (Makin et al., 1975).

5.3.2. Lake Abijata

Lake Abijata is the smallest, saline, alkaline closed-basin lake situated in a shallow depression about 18 km long in the central part of the MER. The main inflows to this lake are the Bulbula and Hora Kelo rivers draining from lakes Ziway and Langano respectively. The upstream lakes Ziway and Langano are mainly fed by rivers emanating from the highlands on either side of the rift. Including the Ziway and Langano sub-basins, the catchments area of lake Abijata is about 10,744 km². During the past three decades, the discharge of the Bulbula and Hora kelo rivers (mean: 812 mm/yr and 281 mm/yr, respectively) represented twice the direct precipitation inputs (mean: 620 mm/yr) to the lake. Groundwater flows from the north and northwest represent another significant source (180 mm/yr); (Tenalem Ayenew, 1998). Intermittent run-off from local drainage channels during the rainy seasons are of minor contributions.

As a closed lake, the only significant loss from Lake Abijata is evaporation, although recently, the loss has been enhanced by development schemes in the catchments such as pumping of water from the lake for soda ash production, diversion of Feeder Rivers and direct use of the Lake Ziway water for irrigation and domestic water supply. The variability of annual evaporation rate is by far less than that of water inputs originating from the highlands. Therefore, due to its terminal position in the corridor and its shallow depth, Lake Abijata is especially susceptible to changes in rainfall in the surrounding plateau as well as to human water use in its catchments. Currently it has shrunk dramatically in its size.

Prior to the introduction of water abstraction for soda ash production, evaporation is the only way of water loss from the lake, resulting in relatively high residence time (10 to 12 years), resulting

in turn high salinity (Eleni Ayalew, 2003). The ionic concentration of the Lake Abijata water is typical of East African soda lakes (Talling and lemoalle, 1998; Talling and Talling, 1965).

5.4. Hydrological Data

In the discussions made in chapter 4, the importance of the quantification of precipitation and evapotranspiration has been underlined in that the two components provide an indication to the water resource availability of an area. In a similar fashion, in surface hydrology, there are data of great significance that tell about the water resources of an area in an observable way. These important hydrological data are the amount of water flowing in the stream and amount of stored in reservoirs. The measurements of stream flow and the lake level form the basis for the evaluation of the surface water resource. The stream flow data and the lake level data are obtained from The Federal Ministry of Water Resources (see table 5.2 and 5.3). The information obtained from these data is very crucial in assessing the water availability (this will be discussed in detail in chapter 8) of the area.

5.4.1. Stream Flow Measurement

All rivers, but Gogessa are gauged. River discharge data for the four streams has been analyzed.

Meki River, based on its discharge data of the past 37 years (1969-2005) recorded at Meki Town, the mean annual discharge is about 230mcm. High discharge occurs during the months of July and August. The Analysis of natural flows in the Meki River has shown that, during a substantial portion of the year, reliable discharges are extremely low. This is because the river faces severe losses in the lower reaches due to the passage of the river through a swamp complex (Halcrow, 1992; Alemu Diribsa, 2006).

Ketar River, originates from the highlands of Arsi, draining an area of about 3350 km². The average seasonal discharge varies from 5mcm during the months of December to February; and to 127mcm in August based on hydrologic data of years 1970-2005. According to this data the average annual discharge of the river is about 363mcm.

The annual peak flow of Meki and Ketar rivers are highly interrelated with the peak precipitation during the wet seasons, in the months of July and August (see figure 5.2).

River Bulbula, being obtained in the similar geographic location with the above mentioned rivers, it depicts different peak period in its discharge. The fact that Lake Ziway is the sole water source of the river, its peak period is inherently dependent on the amount of water available in Lake Ziway and lake level. Bulbula's peak period shifts to months of October and November till Lake Ziway gets sufficient water from the Feeder Rivers Meki and Ketar. The amount water in River Bulbula is the function of the storage capacity and lake level of Lake Ziway. The same thing happened to Hora Kelo River which is the over flow of Lake Langano. Hora Kelo has to wait till Lake Langano stores enough water from the Feeder Rivers (see figure 5.2). Hora Kelo emanates from Lake Langano and drains to Lake Abijata. These two rivers in turn determine the amount of water in the terminal lake Abijata, though their contribution is different in amount.

Based on the river discharge data of the years 1980-2005, the average seasonal discharge of Bulbula varies from about 2mcm in the months of June and May to 37mcm in October. The average annual discharge of Bulbula is 169mcm. Unbalanced abstraction of water for irrigation and other purposes from Lake Ziway and Bulbula itself made the river intermittent these days. River Hora-Kelo, which is intermittent, has seasonal discharge of 0.2mcm in dry months April and May; and during its peak period in the month of October it will have about 8mcm. According to its river discharge data for the years 1996-1999, the average annual discharge of Hora-Kelo to the terminal Lake Abijata is about 36mcm (see table 5.2. and figure 5.2).

Table 5.2 Mean monthly Discharges of main rivers (mcm)

No	River	Recording period	Discharge (mcm)														
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	STD EV	Annual
1	Ketar	1970-2005	6	6	9	14	14	14	43	127	77	36	11	6	30	37	363
2	Meki	1969-2005	2	4	11	16	14	12	40	65	40	18	6	2	19	19	230
3	Bulbula	1980-2005	12	6	5	3	3	3	6	18	35	37	25	16	14	12	169
4	Hora Kelo	1996-1999	2	1	1	0.2	0.3	1	2	5	7.5	8	5	3	3	2.7	36

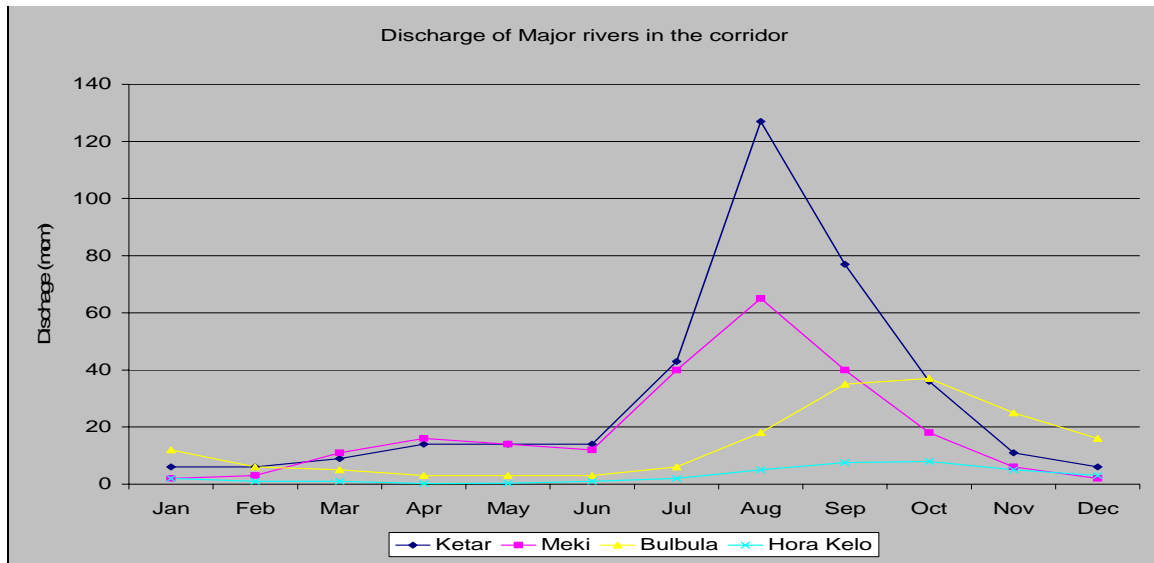


Figure 5.2 Long-term mean monthly discharges of major rivers in the corridor

5.4.2 Lake Level Measurements (surface water storage)

Lake level data relative to the reference datum are available for lakes Ziway and Abijata.

Table 5.3 Mean monthly lakes level (m) for Abijata and Ziway

No	Lake	Recording period	Lake level (m)														Mean	STDEV
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec				
1	Abijata	1978-2005	3.9	3.7	3.58	3.2	2.94	2.8	3.2	3.12	3.4	3.5	3.75	3.7	3.4	0.3		
2	Ziway	1975-2005	1.1	1	0.85	0.8	0.76	0.7	0.8	1.16	1.5	1.5	1.39	1.2	1.1	0.3		

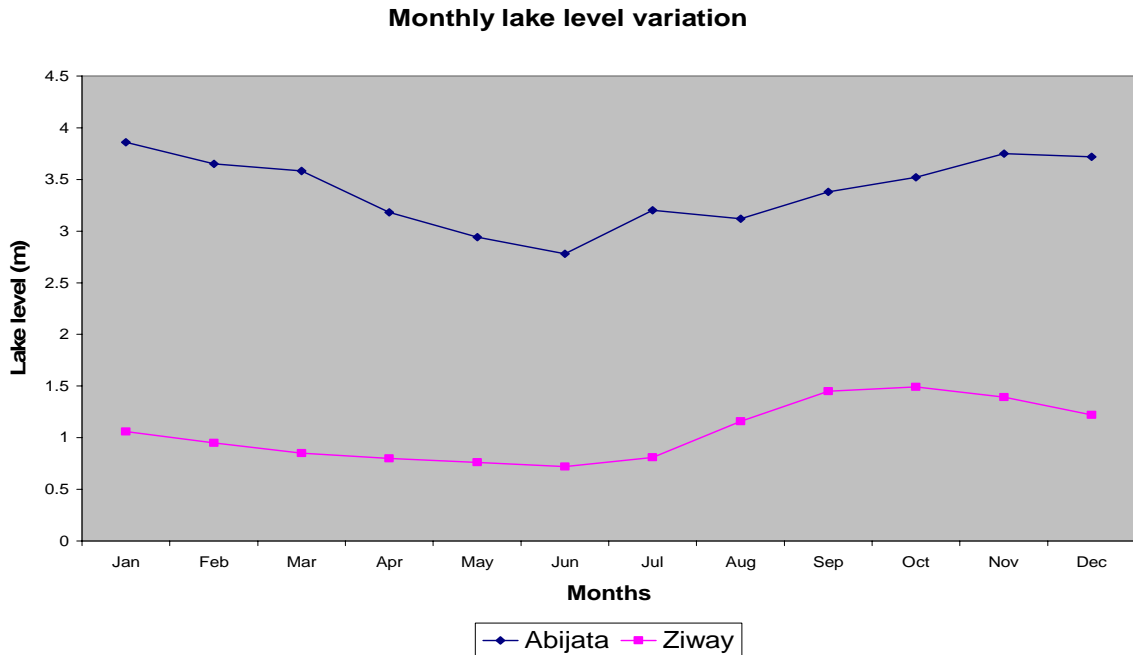


Figure 5.3 Mean monthly fluctuation of lakes level

Mean monthly lakes level of the two lakes depicts that they show minima for wet months June to July. The level starts to increase in August when the Feeder Rivers with the water they collect from highlands reach the rift floor.

Lake Ziway attains maximum level in October, lagging for about 45 days after the Feeder Rivers Meki and Ketar reach their peak in August. Lake Abijata needs lag time of three to four months (September to December), after the main rainy season, before it reaches its maximum height in January. From the lakes level curves it is apparent that the discharge from rivers is crucial to the hydrology of the lakes other than sources like rainfall on the rift floor and associated run-off.

In general the stream flow measurement and surface water storage; is the most important hydrological data to assess the status and trends of surface water resource. These two measurements are input data for analyzing water availability and sustainability issues in chapter eight.

CHAPTER SIX

HYDROGEOLOGY

6.1. Introduction

The occurrence and distribution of groundwater is controlled by three major factors. These factors are *lithology*, *stratigraphy* and *structures* of the geologic deposits and formations.

The lithology is the physical makeup, including the mineral composition, grain size, and grain packing, of the sediments or rocks that make up the geologic system. In unconsolidated medium, permeability is dependent on grain size, shape of grain, sorting. Coarse grained, rounded and well sorted materials are very good aquifers; while fine grained and poorly sorted materials are poor in terms of aquifer productivity (aquicludes).

The stratigraphy describes the geometrical and age relations between the various lenses, beds, and formations in geologic systems of sedimentary origin. The stratigraphy of alternating pervious and impervious formations characterizes the aquifer types. Besides aquifer characterization, the stratigraphic arrangement of aquifers in relation to the confining layers is one of the factors that determine depth to the aquifer.

Structural features, such as cleavages, fractures, folds, and faults are the geometrical properties of the geologic systems produced by deformation after deposition or crystallization. In consolidated sedimentary rocks, since primary permeability is reduced by cementing materials the occurrence of aquifers depends on fracturing. In the case of volcanic rocks the occurrence of aquifers mainly depends on structure and the process resulting in those rocks. Volcanic rocks resulting from explosive magmatic activity, like pumice falls and scoria have very high inter-granular permeability while in lava flows primary permeability is mainly due to jointing at the time of flowing.

Besides the above three factors weathering of formations has the impact on aquifer characteristics. In lava flows, cinder cones and spatter cones; weathering mostly has a negative effect on permeability of rocks by filling the openings in the lava flows and inter-granular spaces in cinder and spatter cones, while in tuffs and ignimbrites it may have a positive effect by separating different layers forming these rocks. In view of these factors the nature of geological setting of the Main Ethiopian Rift system in general and the rift floor in particular is very complex.

As far as lithologic formations are concerned the Ziway – Abijata corridor that comprises the rift floor in MER is dominated by extensive volcano - lacustrine deposits. This is attributed to the formation of the lakes and which have been coupled with erosion processes and volcanic activity. As it has been discussed in chapter three, these fluvio-lacustrine deposits are originated from pyroclastics which in turn derived from ash and tuff. Also included are pelite, diatomite, silt, and clay. Rivers Meki and Ketar also contributed to the alluvium along their water courses.

Regarding the succession of the formations (Stratigraphy) in the area, it is highly complicated by extensive alkaline basalt extrusion associated with faulting and consequently rift development. The basalt extrusions were inter spread with large accumulations of pantelleritic rhyolite and trachyte, comprising flows, breccias, ignimbrites and related shallow intrusions. Besides, there are Quaternary sediments which are transported alluvial and colluvial as well as lacustrine (Reiman, C. et al., 2003). The assessment of succession of formation (stratigraphy), lithology and structure in the area brings two types of aquifers. The one in which the role of faulting is very prominent, the aquifer is called clefted aquifer (common in lava flow volcanic rocks) where groundwater transmission is governed by fracture and fissure flow. The other one is in which primary porosity is prominent the aquifer is called pore aquifer (common in unconsolidated volcano-lacustrine deposits).

6.2. Hydrostratigraphic Units and Aquifer Characteristics

Hydrostratigraphic units comprise rocks of similar hydrogeologic properties. Several geologic formations may be combined into a single hydrostratigraphic unit depending on the scale of the

problem domain and the hydrogeologic character of the rocks. The Ziway-Shalla Basin has been categorized into six hydraulic conductivity zones in general (Tenalem Ayenew, 1998). Among these only three of them are found in the present study area.

6.2.1. High to Very High Permeability Zone (K: 10-20 m/day)

This zone consists of recent basalts and highly fractured ignimbrites in the eastern fault escarpment. Permeability in these areas is largely related to joints, faults, vesicles and fragment size of scoria (Wonji volcanics and hyaloclastics). Coming to the fractured aquifers their permeability and productivity depends on their fracture porosity. Groundwater in the volcanics in the highlands bordering the rift and in the valley sides is controlled by fracture and fissure flow in a layered permeability sequence which is severely faulted, and rapid infiltration occurs in areas covered by fractured volcanics. As a result a large proportion of the recharge, both direct and indirect, is rejected as spring flow along the fault planes. This produces fast circulation of the groundwater resources in the eastern part of the rift floor. In general, the rift floor acts as a discharging zone, which contains numerous perennial rivers, fresh and saline lakes, cold and thermal springs. The cold springs are under the force of gravity from the highlands and escarpments; whereas the geothermal springs are non-gravitational and are volcanic origin.

6.2.2. Medium Permeability Zone (K: 2.5-5 m/day)

This group includes the lacustrine deposits and is the dominant zone in the study area. These deposits include clay, diatomite, shale beds and reworked pumice. This group also includes rhyolite, pumice, tuff and ignimbrite with low secondary permeability. The lacustrine sediments show a lot of differences in their permeability; those showing the highest permeability are the ones consisting of volcanic sands, water lain volcanic sands providing more than 10 liters/sec for no drawdown. On the other hand, fine-grained sediments with inter bedding of massive tuffs and fine ash are also known. As a whole, the lacustrine sediments may be taken to have a moderate or high permeability and productivity and the permeability is of inter-granular type (pore aquifer). Regarding alluvial deposits two types of them are recognized: (1) those spread out in alluvial plains and (2) those, which occur as thin strips along streams. The Meki Delta is characteristics of

the alluvial plains; where as thin strips along rivers Meki, Ketar, Bulbula and Hora Kelo represent the second type of alluvial in the study area. These are troughs in the lowlands where during the pluvials streams deposited large amounts of sediments carried down from the highlands. In the alluvial plains, alternating layers of fine and coarse sediments are characteristic and in many cases lacustrine sediments could also be found underneath. Alluvial along streams are some of the most common shallow groundwater aquifers, which can be tapped by large diameter hand dug wells; as it is done in the course of River Bulbula during the times when the river gets dry. Volcanoclastics and lacustrine sediments are mostly recharged by river runoff in this valley floor.

6.2.3. Low Permeability Zone (K: 0.1-0.01 m/day)

These are acidic volcanic plugs and caldera rims with very low permeability and with little or no soil cover. These plugs and caldera rims are dominated by silicic pyroclastic like pumice flow and ash with subordinate obsidian lava flows.

6.3. Hydraulic Properties of Aquifers

Groundwater exists in the small openings between the particles of clay, silt, sand and gravel that make up the alluvial deposits of the aquifer. The percent of the total volume of the aquifer occupied by these openings or pores is called the porosity. Typical porosity values for alluvial deposits 40 to 70 percent for clays, 35 to 50 percent for silts, 25 to 50 percent for sands and 25 to 40 percent for gravels (Freeze and Cherry, 1979).

The total maximum volume of groundwater in the fully saturated fluvio-lacustrine sediment in the study area can be estimated by multiplying the saturated volume of the aquifer by the porosity. The porosity determines the total volume of water the aquifer can hold but does not determine how much water may be obtained from the aquifer for use. Representative values of specific field for several loose and consolidated materials are established by experimentation.

Movement of water through rocks is through interconnected pores, fissures, and conduits. Permeability is a measure of the ease of flow through rocks. The permeability relates to pores and voids that are interconnected, and differs from porosity, which is the total pore volume. Clay has a high content of water, stored in the molecular lattice, but these water sites have practically no interconnections. Thus, in spite of its high capacity for containing water, clay has a low permeability, making it a most efficient aquiclude.

The storage coefficient for unconfined aquifer corresponds to its specific yield (S_y) or effective porosity, is a measure of the ratio of the volume of water that will drain because of gravity to the total volume of saturated aquifer. The maximum volume of water that can be obtained from an unconfined aquifer is estimated by the product of the saturated volume of the aquifer and the specific yield of the aquifer forming porous materials.

Where the aquifer is confined, the volume of available water is determined by the storage coefficient S (Storativity). The storage coefficient (or storativity) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface. The storativity, S is a dimensionless quantity involving a volume of water per volume of aquifer. This coefficient can best be determined from pumping tests of wells or from groundwater fluctuations in response to atmospheric pressure or ocean tide variations.

The hydraulic conductivity is the capacity of the aquifer to transmit water and is measured as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area at a right angle to the direction of flow. Reported horizontal hydraulic conductivity values for the aquifer as measured by aquifer tests in the area are between 8.4 m/day (at Adami Tulu) and 3.12 m/day (at Bulbula) (Tenalem Ayenew, 1998). The SI unit for the hydraulic conductivity is $[L/T]$.

Transmissivity sometimes called the coefficient of transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient, and equals the hydraulic conductivity (K) multiplied by the thickness of the

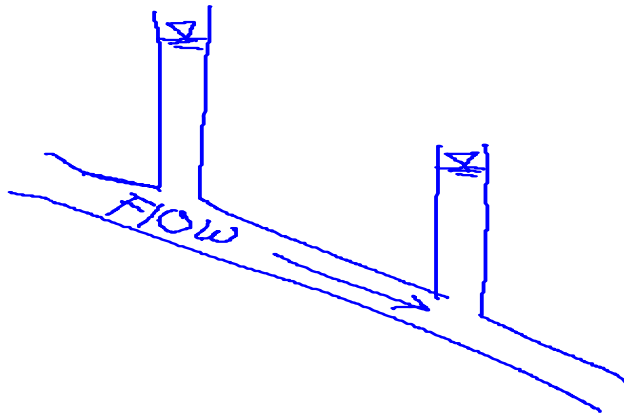
aquifer. The unit for the transmissivity is $[L^2/T]$. Reported transmissivity values for the above mentioned wells are between $221m^2/day$ and $156m^2/day$ respectively.

6.4. Groundwater Flow and Dynamics

The three-dimensional body of earth material saturated with moving groundwater that extends from areas of recharge to areas of discharge is referred to as a ground-water-flow-system. Aquifer material can be composed of unconsolidated (e.g., sands and gravels) and (or) consolidated geologic material commonly called bedrock aquifers. In either case, groundwater flows through the void spaces or pores in the aquifer material.

Groundwater is an important source of water; it may provide the base flows for rivers, or act as an under ground reservoir from which water can be pumped, and as a location into which water can be drained. Consequently it is the flow of groundwater which must be examined.

Unlike a surface water reservoir, the upper surface of the groundwater (the water table or the phreatic surface) is not horizontal; a sloping water table results from the resistance to flow caused by hydraulic conductivity. Although the flow of groundwater is an important process, the actual groundwater flows can not be measured directly. Consequently, an alternative method of identifying groundwater conditions is required and this is provided by the groundwater head (or groundwater potential). The groundwater head at a location in an aquifer is the height to which water will rise in wells. Groundwater flows from a higher to lower groundwater head. A typical example of the use of the groundwater head to identify the direction of the groundwater flow is shown in figure 6.1.



In the figure, the flow is from left to right because the lower groundwater head is in the piezometer to the right, which is in the direction of the dip of the strata. This flow could be caused by the presence of a pumped well or spring to the right of the section

Figure 6.1 Identification of flow directions in one dimension

A volcanic formation can be considered as a combination of porous layers and blocks criss-crossed by fissure. Groundwater flow tends to follow preferential paths such as through interconnected void spaces, along micro cracks, between grain boundaries and in large-scale fractures in response to differences in fluid pressure and elevation. But most groundwater is stored in the bulk of the volcanic formations as slowly flowing water. The model of storage in blocks and flow in fissures is a better description than that of a granular-like aquifer, but the actual behavior is somewhere between the two. The behavior changes from place to place according to the dominant type of volcanic formations; such as, lava flows, pyroclasts, ignimbrites or altered volcanics with intruded dykes. The actual groundwater flow system in lavas and ignimbrites far from eruptive centers is best described by the fissure and block model.

In developing a conceptual model of a flow system, it is important to consider the topographic setting. Topographically higher areas are typically zones of intake or recharge, while topographically lower areas are areas of discharge. Flow directions are from recharge to discharge areas.

The natural flow of groundwater incorporates; recharge areas, discharge areas and groundwater divides. A groundwater divide is an imaginary impermeable boundary that separates one flow system from the other. In the most symmetric systems they coincide with the surface water

divides and their orientation is precisely vertical. In general, topography, geology and structure govern groundwater flow system.

To determine groundwater movement and flow direction in the study area, groundwater elevations in 120 hand dug wells have been measured, and then groundwater contour map and groundwater flow direction have been established (see figure 6.2). The groundwater flow direction is in a similar direction to the surface water flow direction; following the topographic gradient. The topographic gradient is from Lake Ziway area to Lake Abijata area. By comparing the similarity in the direction of flow of the stream (River Bulbula) and the groundwater it is possible to see the surface-groundwater interaction; in that the river is feeding the groundwater. This situation agrees with the observed phenomena that River Bulbula does not have any base flow from the groundwater source, which sustains its flow year round. So, Lake Ziway remains the only water source for River Bulbula.

Groundwater flow may be divided into smaller flow sub-systems as it is observable around Meki area, because of the degree of interaction between groundwater, the well fields and the larger surface water body, Lake Ziway.

Groundwater velocity is affected by the groundwater gradient, hydraulic conductivity of the aquifer, and porosity. Groundwater velocity is greater with increased groundwater gradient, and larger hydraulic conductivity. The greatest groundwater gradients within the lacustrine sediments in the corridor are located near pumping wells, rivers, and the lake. Pumping wells create a cone of depression on the potentiometric surface such that the groundwater gradient and the groundwater velocity are greatest near the pumping wells. Rivers can produce large changes in groundwater gradient and direction as stage rises and falls. Assuming a constant groundwater gradient, groundwater velocity increases with depth.

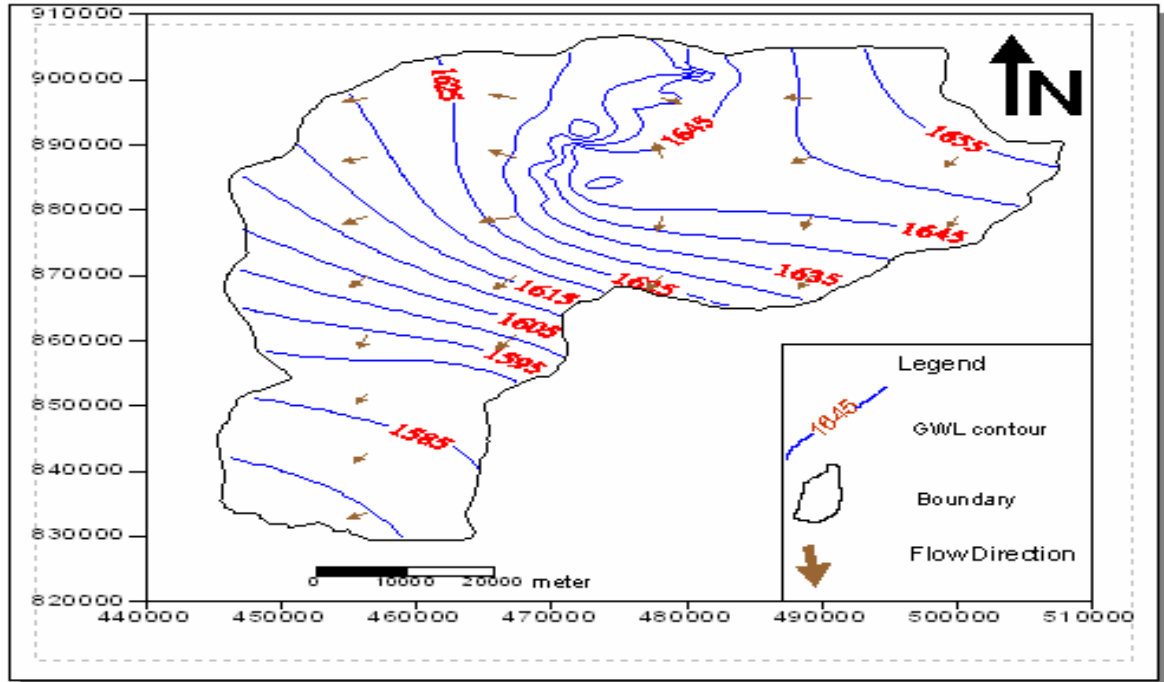


Figure 6.2 Groundwater contour and groundwater flow direction

Contour maps of groundwater levels and flow lines provide very useful data for locating new productive wells in a given area. Even though, it is difficult to show in the above figure, convex contour lines indicate regions of groundwater recharge, while concave contour lines are associated with groundwater discharge areas.

Furthermore areas of favorable hydraulic conductivity can be ascertained from the spacing of the contour lines. In fact for areas with uniform groundwater flow, the portions having wide water table contour spacing and consequently flat gradients characterized by higher hydraulic conductivity or permeability.

This could be verified from the field observation in bore holes surrounding around Lake Abijata. Hydraulic conductivity data for a Borehole between Abijata and Langanu (18.57 m/day), Adami Tulu (8.4 m/day), Jido Kombolcha (6.69 m/day), Bulbula (3.12m/day) and well at Children's center at Alage (6.14 m/day) all wells are installed in the lacustrine sediment (Tenalem Ayalew, 1998).

6.5. Groundwater Recharge and Discharge Conditions

6.5.1. Recharge Conditions

Groundwater recharge may be defined in a general sense as the downward flow of water reaching the water table, forming an addition to the ground water reservoir. A clear distinction should be made, both conceptually and for any modeling purposes, between the potential amount of water available for recharge from the soil zone and the actual recharge. Recharge of groundwater may occur naturally from precipitation, rivers, canals and lakes and as man-induced phenomenon via such activities as irrigation and urbanization. Losses from irrigation programs frequently provide a contribution which exceeds that from rainfall.

Two principal types of recharge are recognized as direct and indirect recharge (FAO, 1981; Llyoyd, 1986).

- i) Direct recharge is defined as water added to the groundwater reservoir in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone.
- ii) Indirect recharge results from percolation to the water following runoff and localization in joints, as ponds in low-lying areas and lakes, or through the beds of surface water courses. Two distinct categories of indirect recharge are thus evident; viz, that associated with surface water courses, and a second localized form resulting from horizontal surface concentration of water in the absence of well defined channels.

There are many factors that affect recharge in an area. These are: topography, nature of irrigation scheduling, rivers, soil zone, unsaturated zone between soil and aquifer and the ability of aquifer to accept water. Precipitation forms the principal source of direct recharge, which occurs in areas with a surplus rainfall over evapotranspiration. These areas are mainly located in the highlands; in the rift valley floor the opposite is true. In Ziway-Abijata Corridor, the most part of which constitutes the rift floor, some direct recharge from precipitation may occur at the top of rift volcanoes (Aluto and Bora Berecha). Although from a water balance point of view direct

recharge is probably not important in the corridor, depressions and occasional surface runoffs entering into volcanic vents and flow in ephemeral streams may contribute locally to ground water flow.

In the Corridor, the two most important aquifers have been identified; these are the pore aquifers and the bedrock aquifers. The former could be sub-divided into alluvial aquifer and the lacustrine aquifers. The presence of pore aquifers, depressions, and major surface water bodies - Rivers and lakes favors indirect recharge in the rift floor. Field base flow measurements revealed that channel loss from the large rivers (for instance River Meki) in the permeable lacustrine sediments where they drain flat plains of the escarpment and the rift valley (Tenalem Ayenew, 1998; Alemu Diribsa, 2006). From the dilution effect of surface water on the subsurface water in the rift floor (chapter 7), Lake Ziway and the rift Floor Rivers; Bulbula, Hora Kelo and Gogessa also contribute for the indirect recharge. In streams those are flowing along the escarpments, particularly in the eastern part, along their upper reaches some rivers also loose water in large marginal faults making the streams the loosing (or influent) streams (Alemu Diribsa, 2006). This is true for river Ketar. River Ketar at its lower reach is a gaining (or effluent) river, and this could be justified by the presence of several springs and the increase in the river discharge.

In quantification of recharge in the central rift valley, research work conducted by many researchers and by many methods depicts different values for different physiographic terrains. Among the methods, the soil-water balance approach eliminates recharge in the rift floor (Tenalem Ayenew, 1998). The water balance method represents only direct recharge. But the practical observation from indirect recharge sources from channel losses of rivers violates this zero quantification. When other sources of recharge, for instance, irrigation return flow water, which is applicable in the Ziway-Abijata Corridor is added, the quantification of recharge further be complicated.

Considering the direct recharge, taken at the face value, groundwater recharge increases as the mean annual rainfall increases and it has been found that the direct recharge from rainfall in each area is about 10 to 20 % of the mean annual rainfall (Tesfaye Cherinet, 2003). With this generalization, the rift floor at the MER, groundwater recharge was estimated to be 150-250

mm/yr; and taking the value of 706mm arial depth of precipitation from section 4.2.3. Recharge in the corridor will be in the range Of (70.6mm– 141.2mm). In general, recharge in the highlands is mainly from direct precipitation as annual rainfall is higher than that of annual evapotranspiration. As a result waters in these areas are characterized by lower TDs and EC. On the escarpment recharge is facilitated by the presence of fractures and fault systems, mainly in eastern escarpment. Although recharge from intense storm in short duration is possible in the rift floor, recharge from channel loss of major rivers through lacustrine and alluvial sediments is important.

6.5.2. Discharge Conditions

The term discharge relates to the emergence of groundwater to the surface as springs, water feeding swamps and lakes, and water pumped from wells. The presence of significant topographic differences and suitable geologic structures facilitate the existence of groundwater head differences in Ziway-Abijata Corridor between Lake Ziway and Lake Abijata. The groundwater head distribution follows the shape of the topographic contours within the corridor. The form of the water table is a subdued replica of the land surface. Figure 6.2 shows that, Lake Abijata area is a discharge zone for the corridor.

The groundwater obtained from the lacustrine and alluvial deposits in the corridor with ambient temperatures represent the shallow groundwater system. This shallow groundwater flow system is confined to the upper permeable soil zone, weathered and fractured rocks and is considered to be phreatic near-surface aquifer. Productive hand dug wells presently concentrated all over the corridor tap water from this upper permeable soil zone and the underlying deeply weathered rock. The groundwaters derived from deep circulation with anomalous high temperatures represent the deep groundwater system. Limited groundwater movement with high residence time may exist in this zone. This water is characterized by high EC and TDS.

At present, though no effect could be sensed there is big utilization of groundwater resources particularly for irrigation on top of the formerly groundwater abstraction for domestic purposes. This aspect will be discussed in chapter 8.

CHAPTER SEVEN

HYDROCHEMISTRY

7.1. Introduction

The chemical composition of natural waters and the amount of its ionic species depend on several factors. These are type of soil and rock through which the water passes, the degree of weathering and solubility of the mineral components of the rocks and soils, the extent and duration of the contact with rocks and soils, the temperature conditions, the type of dissolved and suspended solutes that falls with precipitation. A major impact of the environmental factors influencing the composition of water may also come from human activities. Climatic patterns tend to produce characteristics plant communities and soil types, and the composition of waters of streams draining such areas could be influenced by the ecological balance. Bicarbonate (HCO_3^-), for example, tends to predominate in water in areas where vegetation grows profusely.

Elevated concentrations of solutes can occur in certain hydrogeologic environments, such as increases in salinity due to evaporative concentration, high fluoride concentration with association of volcanism and geothermal activities, high sulfate concentrations associated with weathering of basement rocks, dissolution of evaporites in sedimentary sequences, and hardness associated with carbonate rocks.

More than ninety percent of the dissolved solids in groundwater can be attributed to eight ions: sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) (Freeze and Cherry, 1979). These ions are usually present at concentrations greater than 1 milligram per liter (mg/l). Silica (SiO_2), a non-ionic species and nitrate (NO_3^-) are also typically present at concentrations greater than 1 mg/l.

The study of water chemistry gives important indications of the geologic history of the enclosing rocks, the velocity and direction of movement, and the presence of hidden ore deposit. The main objective of using the hydrochemistry in this study is to serve two purposes. These are, to show

the effect of the geologic formation on the composition of the water and to describe surface and groundwater interaction in the area.

7.2. Data Collection and Analysis

Hydrochemical data representing the study area is collected from different institutions and previous studies conducted in the area. After assessing and organizing the existing secondary data, extra samples also collected from the field for data on major and trace elements. Samples were collected in leak proof plastic bottles. The analytical procedures adopted are, atomic adsorption for cations and ion chromatography for anions.

Finally five different water sources have been identified for analysis and interpretation. These sources comprises both surface and groundwater and including samples from lakes, rivers, hot springs, bore holes and hand dug wells (see table 7.1, 7.3 and 7.5). These items have been analyzed and interpreted to characterize the composition of the natural water in the area. The sampling points are depicted on figure 7.1.

The chemical data has been supplemented by the in-situ measured parameters (20 samples) taken mostly from the recently dug wells in Ziway and Bulbula area (see annex I). The in-situ measured properties are those closely related to the environment at the sampling site at that instant of time. These are: Temperature, pH, total dissolved solids, and electrical conductivity. Using these two batches of samples electrical conductivity map for the area has been produced (see figure 7.3).

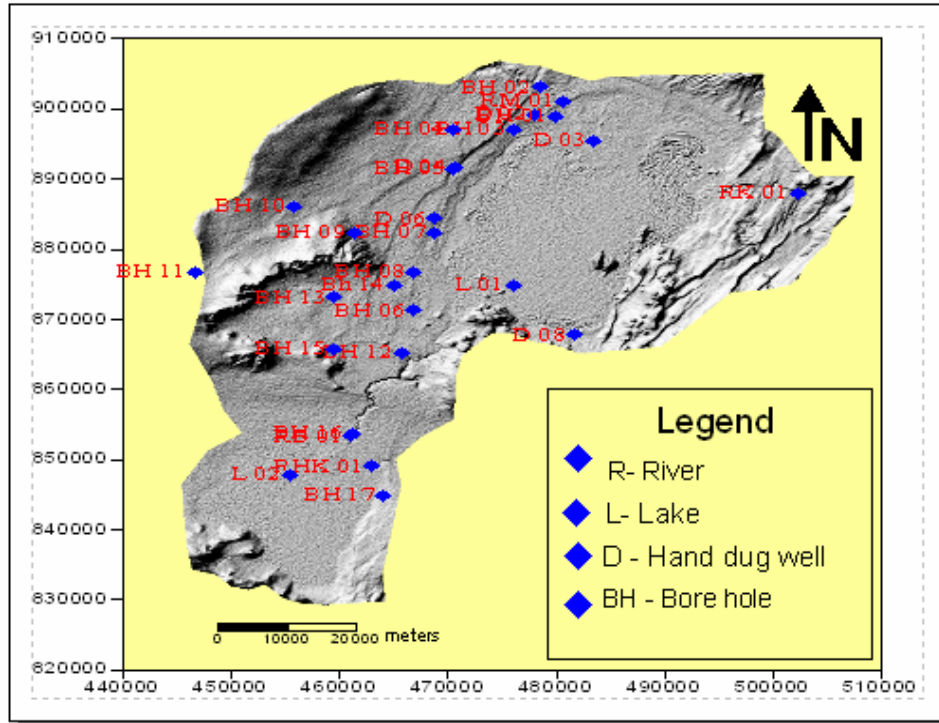


Figure 7.1 Water sampling sites

7.3. Surface Water Chemistry

7.3.1. The Rivers

In this study samples of the four major rivers are analyzed and interpreted. These rivers are Ketar, Meki, Bulbula and Hora-kelo. The first two are draining the eastern and western highlands respectively and both flows to Lake Ziway; the latter two are the overflows of open lakes Ziway and Langano respectively and both flows to the closed terminal Lake Abijata.

The water carried in streams is often considered to consist of a base-flow fraction made up of groundwater that infiltrates into the channel and a direct runoff fraction that enters the drainage system during and soon after precipitation. The direct runoff presumably has had no residence time in the groundwater reservoir and only short contact with soil or vegetation. Reactions in the soil zone, however, are commonly extensive enough that the direct runoff has a considerably

higher dissolved solids concentration than the original rain or snow. The base flow has a still greater dissolved-solids concentration.

Rivers and streams draining the highlands (Meki and Ketar) are of low salinity including low F concentration; whereas, rivers which drain evaporating lakes have significant hydrochemical enrichment including fluoride. Hora-Kelo is the most saline river because it overflows from Lake Langano which has the TDS value 1733 (Birhanu Gizaw , 1996). See table 7.1.

Besides mixing of groundwater and runoff, the natural factors that influence stream composition include reactions of water with mineral solids in the streambed and in suspension, reactions among solutes, and losses of water by evaporation and transpiration. Evaporation plays a great role when the river is an outlet of a reservoir or a lake, as in the case of Bulbula and Hora-Kelo Rivers.

Table 7.1 Major ionic composition of surface water (rivers and lakes) (in mg/l)

No	Features	Major Ionic compositions											TDS (mg/l)	EC (μ S/cm)	pH
		Cations				Anions									
		Na ⁺	Ca ²⁺	Mg ²⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	CO ₃ ²⁻	SO ₄ ²⁻	F ⁻	NO ₃ ⁻	SiO ₂			
1	Meki River at Meki Town	75	11	2	1	214	11		0.7	0.7		37	365	438	8.5
2	Ketar River at Abura	9.7	25.2	4.1	3.1	134	1.3		1	0.3	0.4		40	210	
3	Bulbula River at the bridge	50	15	5	13	13		189	37	3	37	1	325	498	8.3
4	Hora Kelo River	425	3	2	30	202	35	675	6	6		1	1394	1752	9
5	Lake Ziway	28.14	16.8	5.94	11.14	244	14.83	30	1	1.22			364	560	8
6	Lake Abijata	4700	1	0.5	250	2367	2095	311	1	130			13480	20738	9.6

Table 7.2 General information and water quality aspects of surface water (rivers and lakes)

No	Features	Water Type	SAR	ESR	Hardness(in mg/l CaCO ₃)		Conductivity (μ S/cm)	Group	Alkalinity (mg/l)
					Tem	Perm			
1	Meki River at Meki Town	Na-HCO ₃	5.46	4.57	35.7	0	438	C2: medium salinity water	175.4
2	Ketar River at Abura	Ca-HCO ₃	0.47	0.26	79.7	0	210	C1:Low salinity water	109.8
3	Bulbula River at the Bridge	Na-CO ₃ -Cl-F	2.86	1.88	58	0	498	C2: medium salinity water	325.6
4	Hora Kelo	Na-CO ₃	46.64	58.83	88	0	1752	C3: high salinity water	72.26
5	Ziway	Na-Ca-CO ₃	1.5	0.92	66.4	0	475	C1: Low salinity water	200
6	Abijata	Na-Cl-HCO ₃	958.23	2245.68	4.6	0	20738	Brine	2458.2

7.3.2. The Lakes

A lake that has a surface outlet represents a holding and a mixing basin for the stream flow that emerges as in the case of Lake Ziway and lake Langano. The detention time of water in a lake provides an opportunity for slow reactions to come closer to completion than they can in the rapidly moving water of a river. Mixing, however, may not be complete, so at any given time the water in one part of the lake may be greatly different in composition and properties from that in the other parts of the lake. Closed-basin lakes become saline owing to evaporation of water and continued influx of solutes.

An important influence on lake composition is thermal stratification (USGS, 1989). During warm weather, an upper, heated layer of water of relatively low density may form at the surface, floating on the deeper, cooler water below and insulating the deeper layer from direct contact with atmospheric oxygen. In deep lakes, during the summer season, this stratification may persist for long periods, and in time the deeper water becomes depleted in oxygen, owing to the biochemical process. In cooler seasons, the stratification disappears, surface and deeper water physically overturn, and oxygen again becomes dispersed throughout the lake.

Like the thermal waters in the rift floor, the water in the closed-basin Lake Abijata is characterized by high Na, HCO_3 and F, though the mechanism of enrichment is different. The TDS value of the fresh Lake Ziway is 364 mg/l, whereas the saline Lake Abijata has TDS value 13,480 mg/l (see table 7.1). As a result, Abijata has the potential to produce soda ash (Na_2CO_3); this is also true for other saline and alkaline lakes Chitu and Shalla. Evaporation of lake water from Abijata initially gives trona ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) and then by further drying at a high temperature soda ash will be produced (Birhanu Gizaw, 1996).

The notable difference between the TDS values of the lakes (Table 7.1) is a matter of balance in mass flux. For instance, the salt content of Ziway and Langano differs considerably despite their close proximity. Both Langano and Ziway drain into Abijata through Hora-Kelo and Bulbula rivers respectively. Hence the circulation of water through Ziway is greater, resulting in a lower

TDS than for Langano (Birhanu Gizaw, 1996). Lake Abijata also receives an inflow from the Goggesa River during the wet season.

Lake Ziway has outflow through Bulbula River, which keeps a lower water residence time. Therefore the lake is characterized by low salinity when compared with other nearby lakes. The lake is dominated by sodium and calcium. Bicarbonate is the dominant anion. The pH of the lake is around 7.8.

Lake Abijata is the final evaporating basin for lakes Ziway and Langano and has no surface and groundwater outflows. The lake is very saline. Its salinity is estimated to be more fifteen and sixty times than lakes Langano and Ziway respectively. Precipitation of trona is well marked around the margin of Lake Abijata (Eleni Ayalew, 2003). Sodium is dominant cation. Bicarbonate is the dominant anion followed by chloride. The lake is characterized by pH 9.6 and TDS of 13,480 mg/l.

Table 7.1 depicts that as alkalinity and salinity increases, the cations Ca and Mg assume lowest values, which are important cations in an open Lake Ziway. The high F values in saline lakes (in our case Lake Abijata) of the East African Rift reflect the nearly complete removal of Ca by carbonate precipitation. Therefore, in these lakes F can increase until saturation, with respect to villiumite (NaF), is reached (Kilham and Hecky, 1973), though currently none of the waters reaches this state (von Damm and Edmond, 1984). The systems are under saturated with respect to anhydrite/gypsum and fluorite (CaF₂), but saturated with respect to calcite. Therefore, the lakes can not achieve saturation with gypsum because of high alkalinity and relatively low Ca (Birhanu Gizaw, 1996).

The progressive decrease and low content of magnesium in saline Lake Abijata and absence of simple salt that contain magnesium in lake sediments is an interesting characteristic of the basin. Among the suggestions forwarded for the sink of magnesium is the one given by von Damm and Edmond 1984 that reverse weathering i.e., the neo formation of smectite and net removal of one or more base cation and silicates is possible in the Lakes Basin. Uptake of Mg by algae may also be a possible sink for magnesium (Eleni Ayalew, 2003).

Sodium, which is mainly contributed from the drainage area through the inflows to the lakes progressively, increases in the lakes proportionately with chloride enrichment because saturation for sodium is not yet reached. The flushed Lake Ziway has low sodium content which could be attributed to the lower residence time of the water; whereas the terminal and closed Lake Abijata is characterized by enrichment of sodium and chloride ions as it lacks out flow and consequently by high water residence time and eventually by strong and rapid evaporation. Another possible source of chloride content of the terminal lake could be contributed from hydrolysis of volcanic rocks (for instance, from the dissolution of biotite and hornblende of volcanic rocks such as obsidian).

7.4. Groundwater Chemistry

The Ziway-Abijata Corridor represents the rift floor of the MER, which is known as the evaporating pan for the Lakes Basin. In the corridor the groundwater transmission is in the pore aquifers of the lacustrine deposits with some exceptions of fracture and fissure flow component along the foot of both eastern and western parts of the escarpment. As it has been mentioned in chapter Six, the study area is dominated by volcano-lacustrine sediments, which originated from the existing volcanic rocks and lacustrine sediments.

The data available regarding the groundwater system in the MER separates the system into a shallow and a deep groundwater system. The chemical analysis from 17 bore holes and 5 hand dug wells (both representing shallow aquifers) has been interpreted. Chemical analysis from two hot springs from Tulu Guddo Island has been interpreted to represent the deep groundwater system in the corridor for these springs represent non-gravitational springs of volcanic origin. The temperature gradient and the evolution of the natural waters support this classification.

7.4.1. Boreholes and Hand Dug Wells

The ionic composition of both hand dug wells and boreholes is highly variable spatially in the study area. From the chemical analysis of the samples of the shallow aquifers Na^+ is the dominant cation with the exception of a hand dug well from the lacustrine aquifer in Meki Town in which

case Ca^{2+} is the dominant cation. The reason for this could be the source for Ca^{2+} could be from the surface water River Meki. The low fluoride concentration (0.7 mg/l) in this well also shows the dilution effect of the surface water on the groundwater. This situation further magnifies the presence of surface-groundwater interaction. The dominance of sodium is attributed to the extensive distribution of acidic rocks in the area.

Though it is not dominant, Ca^{2+} is found in a big amount in a well drilled south-west shore of Lake Ziway in an irrigated Gerbi Farm. This value is 91 mg/l represents the maximum value for Ca^{2+} in the study area. The Ca^{2+} content for Lake Ziway is 16.8 mg/l; showing that there is another source for Calcium in this area other than Lake Ziway. The probable reason for that could be the agricultural inputs application in the irrigated field. In all samples of water in the study area K^+ follows Ca^{2+} , whereas Mg^{2+} is the least occurring cation.

Considering Bicarbonate (HCO_3^-) is the dominant anion followed by Chloride (Cl^-). The groundwater in boreholes located on the rift floor around the lakes and between the lakes is characterized by higher salinity and dominated by sodium bicarbonate. The fluoride distribution in the area is mainly favored by the parent formation (acidic volcanic rocks) and alkalinity of the media.

In general, in the study area, the chemical composition of the subsurface water is governed by geologic formations and the effect of dilution and/or concentration of surface water.

Table 7.3 Major ionic composition of groundwater (bore holes and hand dug wells) (in mg/l)

No	Feature	Major Ionic compositions										TDS (mg/l)	EC (μ S/cm)	pH
		Cations				Anions								
		Na ⁺	Ca ²⁺	Mg ²⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	F ⁻	NO ₃ ⁻	SiO ₂			
	I. HDW													
1	Meki town	28	69	3	5	300	8	2	0.7		77	493	758	7.4
2	Chefe Jila (a)	165	43	8	20	519	16	23	1.9		68	867	1334	8
3	Abono (2)	184	1.4	1.11	15.75	658.8	20.13	87.7	8.37		110	1087	1672	8.3
4	Abosa	456	21	8	20	996	129	74	2.1		98	1806	2778	8
5	Chefe Jila (b)	345	36	14	33	1007	48	33	10		43	1571	2417	8
	II. Bore holes													
1	Meki 01	73	46	6	4	355	14	3	1.3		75	579	891	7.8
2	Oda Bokota		28	10.8		244			0.22			372	744	6.78
3	Korke Adi	191	1.4	0.83	11.7			13.6		8.86		1107	1703	8.3
4	Choro ke	175		0.56	13	672	50.3	55.3	6.49		89	1062	1459	8
5	Wayo School	442	6.4	2.92	26.4	963.8	34		9		96.8	1102	1696	8.4
6	Gerbi farm	190	91	6	10	561	119	88	1.5		64	1132	1741	7.4
7	Edo Kontola	394.4	12.8	10.7	18.15	951.6	85.93		3.9		83.3	1074	1653.6	8.56
8	Ziway Prison	118	12.3	4.48	12.75			19.27	5			1161	1786	7.6
9	Galo Fehcasa	414.8	3.2	2	11.2	805.2	53.9	77	14		45	1550	1430	8.9
10	Gebiba	149			12.72	370.9	40.47	84.7	10.9		109	778	1210	8.8
11	Koshe	140	19	5	16	418	16	6	2.6		113	736	1132	7.9
12	Aneno	258.4	1.6	0.97	8.58	556.32	20	9.06	8		95.2	1010.6	657	8.5
13	Boremo	184	4		11.63	707.6	71.36	16.5	23.3		100	1118	1526	8.6
14	worga Gerbi	482.8	11.2	5.84	24.75	1122.4	98	41.97	14.4		98	1246	1917	8.15
15	wayso Macho	595	3.2	0.97	26.4	951.6	188	114.4	19.2		93.9	1526	2347.5	8.9
16	Bulbula	334	3.6	3.2	9.3	679	25.2	48.1	21	19		918	1413	8.75
17	Daka Hora Kelo	2900	6.2	2.7	50	3891	966.1	133	158	31		6650	9710	8.9

Table 7.4 General information and water quality aspects of groundwater (hand dug wells and bore holes)

No	Feature	Water Type	Sodium adsorption Ratio (SAR)	Exchangeable Sodium Ratio ESR	Hardness(in mg/l CaCO ₃)		Conductivity (µS)	Alkalinity (mg/l)
					Temp	Perma.		
	I. HDW							
1	Meki town	Ca-Na-HCO ₃	0.9	0.33	184.5	0	758	245.9
2	Weldiya	Na-Ca-HCO ₃	6.06	2.56	140.2	0	1334	425.4
3	Abono (2)	Na-HCO ₃	28.19	49.66	8.1	0	1672	539.9
4	Abosa	Na-HCO ₃	21.48	11.63	85.3	0	2778	816.3
5	Chefe Jila (b)	Na-HCO ₃	12.36	5.09	8.25	0	2417	825.3
	II. Bore holes							
1	Meki 01	Na-Ca-HCO ₃	2.69	1.14	139.5	0	891	290
2	Oda Bokota	Ca-Mg-HCO ₃	0	0	114.3	0	744	200
3	Korke Adi	Na-HCO ₃	31.61	60.14	0	6.9	1703	0
4	Choro ke	Na-HCO ₃	0	0	2.3	0	1459	550.7
5	Wayo School	Na-HCO ₃	36.35	34.36	28	0	1696	789.9
6	Gerbi farm	Na-Ca-HCO ₃	5.21	1.64	251.7	0	1741	459.8
7	Edo Kontola	Na-HCO ₃	19.68	11.29	76		1653.6	779.9
8	Ziway Prison	Na	7.32	5.22	0	49.1	1786	0
9	Galo Fehcasa	Na-HCO ₃	44.81	55.65	16.2	0	1430	659.9
10	Gebiba	Na-HCO ₃ -SO ₄	0	0	0	0	1210	303.2
11	Koshe	Na-HCO ₃	7.39	4.48	68	0	1132	342.6
12	Aneno	Na-HCO ₃	39.78	70.41	8	0	657	455.9
13	Boremo	Na-HCO ₃	25.3	40.1	10	0	1526	579.9
14	worga Gerbi	Na-HCO ₃	29.12	20.19	52	0	1917	919.9
15	wayso Macho	Na-HCO ₃ -Cl	74.79	108.07	12	0	2347.5	779.9
16	Bulbula	Na-HCO ₃	30.87	32	22.1	0	1413	556.5
17	Daka Hora Kelo	Na-HCO ₃ -Cl	244.69	237.33	26.6	0	9710	3188.9

7.4.2. Hot Springs

Samples from two hot springs, the origin of emergence of which is volcanic (non-gravity spring) on Tulu Gudo Island on Lake Ziway shows ionic variations. They also vary in temperature and discharge (see table 7.5).

Table 7.5 Major ionic composition of hot springs (in mg/l)

Feature	Major Ionic compositions										TDS (mg/l)	EC (μ S/cm)	pH	Temp(°C)
	Cations				Anions									
	Na ⁺	Ca ²⁺	Mg ²⁺	K ⁺	HCO ₃ ⁻	CO ₂	Cl ⁻	SO ₄ ²⁻	F ⁻	SiO ₂				
Hot spring 01	240	15	8	25	704	208	31	<10	7	159	1404	2160	7.6	60
Hot spring 02	400	8	5	38	988	58	95	31	5	176	1804	2775	8.2	78

Table 7.6 General information and water quality aspects of hot springs

No	Hot springs	Water Type	Sodium adsorption Ratio (SAR)	Exchangeable Sodium Ratio (ESR)	Hardness (in mg/l CaCO ₃)		Conductivity (μ S)	Alkalinity (mg/l)
					Temp.	Perma.		
1	T Gudo 01	Na-HCO ₃	12.45	7.42	70.3	0	2160	577
2	T Gudo 02	Na-HCO ₃	27.73	21.47	40.3	0	2775	809.7

7.5. Water Types

From the above result analysis and interpretation, differentiation of the origin of the various water types could be made. From the tables given above evolution of water from the recharge area to discharge area both in the case of surface and groundwater is visible. The evolution of the water is highly related to the lithologic formation and evaporating body it come across. The water type in every case is given in tables 7.2, 7.4 and 7.6. In the recharge area Ca – Bicarbonate dominated waters are present, whereas in discharge areas Na- Bicarbonate waters dominate (see also fig 7.2)

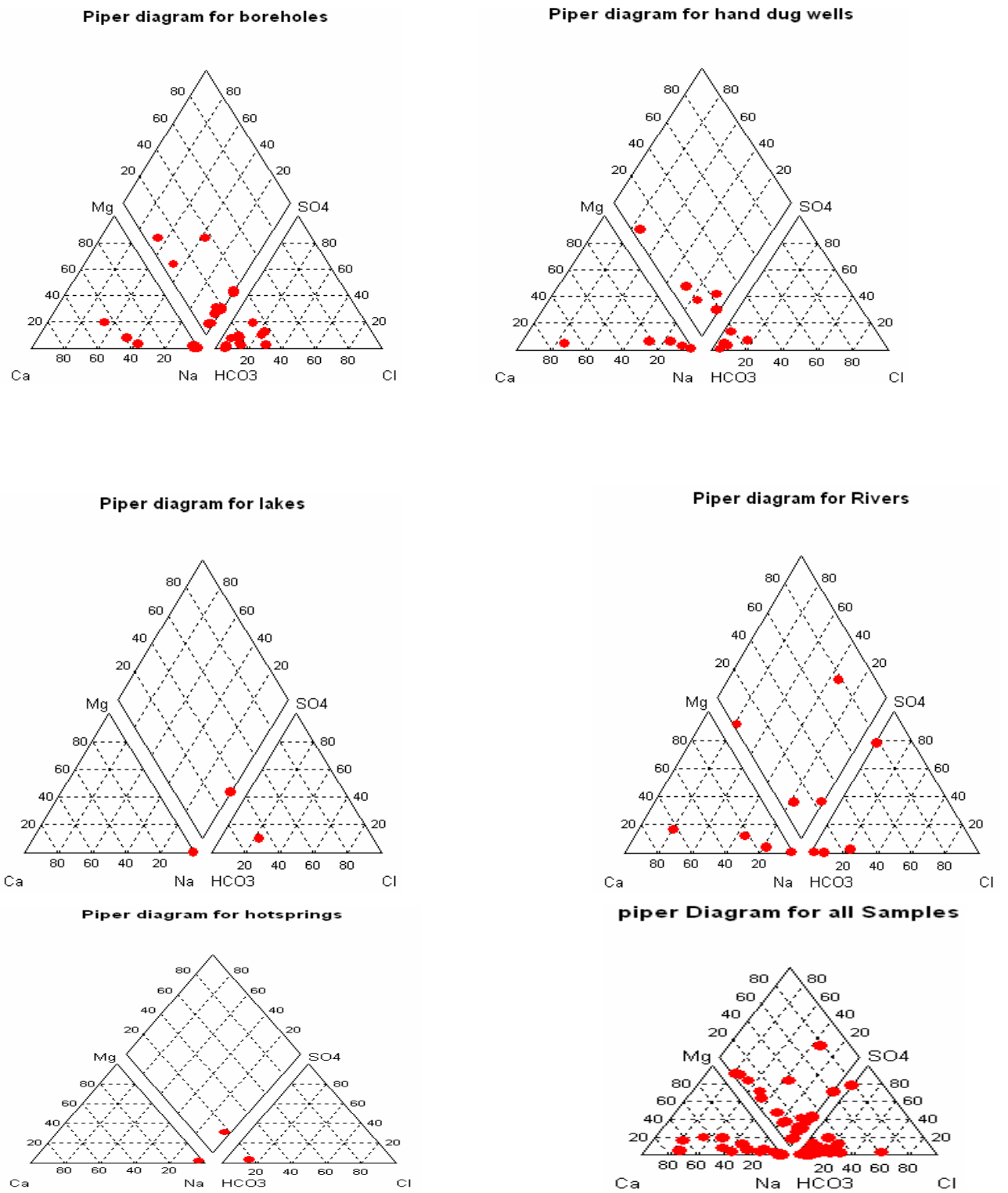


Figure 7.2 Piper plots for different water samples

7.6. Physico-Chemical Parameters as Signatures of Surface-Groundwater Interaction

7.6.1. Electrical Conductivity

Electrical conductivity is the ability of a substance to conduct an electric current and it is usually measured in micro siemens per centimeter or micro mhos per centimeter, both are numerically equal values. This parameter has been measured for all water types focusing more at samples from hand dug wells, and the primary data generated has been supplied with the previously measured electrical conductivity in the study area. Electrical conductivity analysis for surface water (lakes and rivers), hand dug wells and bore holes have been analyzed and individually to see the relationship between the three categories. The three categories depict a pattern similar to each other. In general, electrical conductivity is increasing from Meki-Ziway area towards Lake Abijata area in all cases. However, there are also local anomalies that violate such trends. This is due to local mineralization.

The EC value shows strong anomaly for surface water bodies both in the case of lakes and rivers. Ketar River has the lowest EC value (210 $\mu\text{S}/\text{cm}$); whereas, Hora-Klo River has the largest value (1752 $\mu\text{S}/\text{cm}$). Lake Ziway because it is flushed and open water body has EC 475 $\mu\text{S}/\text{cm}$ and Lake Abijata is with the highest value 13,480 $\mu\text{S}/\text{cm}$. This is because of the terminal position of the closed lake (see figure 7.3).

In the case of hand dug wells and bore holes, the proximity either to open and flushed lake or saline/alkaline and closed terminal lake matters. The proximity either to the river draining the highlands or flowing in the rift floor also matters. The dependency of EC value for hand dug wells and bore holes on the nearby surface water body strengthens the surface-groundwater interaction in the rift floor. But, as it has been mentioned above there are anomalous EC values, even though the flushed fresh surface water body is nearby (see table 7.1 and 7.3).

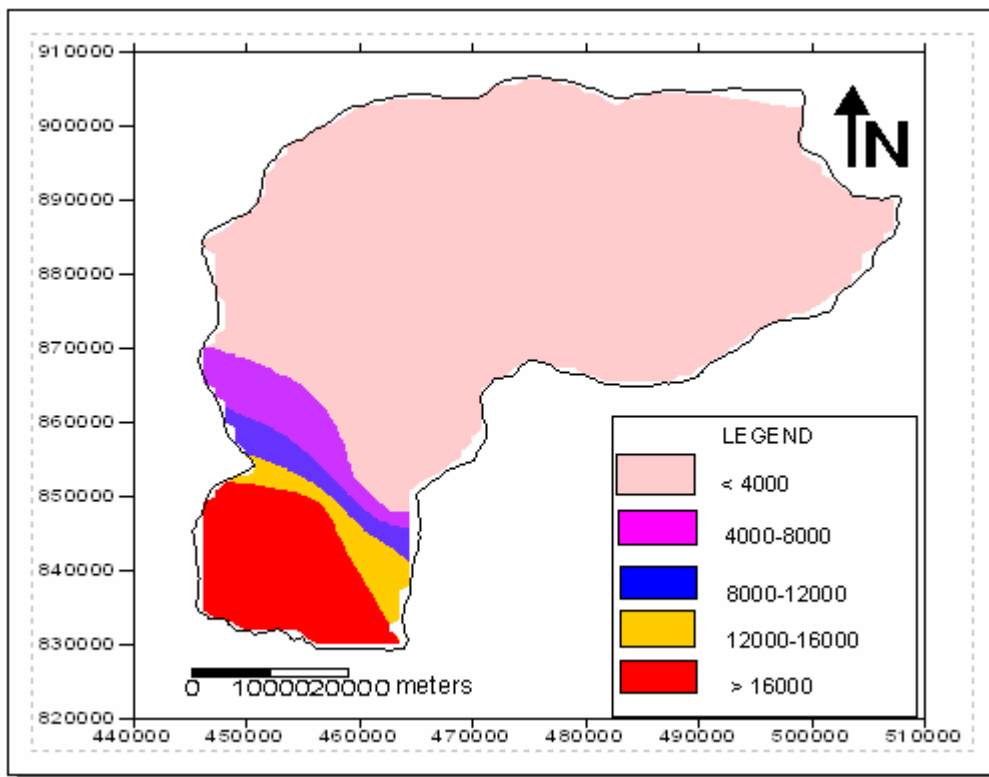


Figure 7.3 Electrical conductivity of surface and shallow groundwater bodies ($\mu\text{S}/\text{cm}$)

7.6.2. Fluoride Occurrence and Distribution

The central rift valley sector of the MER is known for the abundance of fluoride occurrence in the natural waters. Fluoride concentrations above 1.5 mg/l have been reported from all parts of Ethiopia, but the highest levels were found in the rift valley, the lowland area with the most recent volcanic activity in the country. The natural concentration of fluoride in groundwater depends on many factors, like the geologic, chemical and physical characteristics of the aquifer, the porosity and acidity of the rocks, the temperature, the action of other chemical elements and the depth of the wells (Tamiru Alemayehu, 2006).

There are about 150 fluoride bearing minerals however villiaumite, fluospars, flourapatite and cryolite are the most abundant ones. Many rocks of the rift are enriched in those minerals. Especially amorphous rocks, like pumice, tuffs, pyroclastics and porphyry or other easily weatherable materials, like volcanic ash or sediments of salt lakes are concentrated by washing out the fluoride component into the surface and groundwater. Leaching out the fluoride from easily weatherable volcanic rocks is thought to be the main source of high fluoride levels in water resources of the area. This process is promoted by hydrothermal waters. High fluoride water sources

are characterized by high sodium and bicarbonate as well as high alkaline media (see tables 7.1 and 7.3). High fluoride groundwaters (not always true) have sodium and bicarbonates as the dominant dissolved constituents, with relatively low calcium and magnesium concentration. Such water types also generally have high pH values and these can be useful proxy indicators of the potential problems. Fluoride abundance is related to changes in calcium concentration that results from dissolution of calcium minerals. High concentration of fluoride suggests calcium depletion in the water (see tables 7.1 and 7.3).

Besides the above factors, the fluoride content of water sources depends on the hydrology of the area. Wells drilled near to fresh surface water bodies (in table 7.3 Meki 01 and Gerbi farm wells which are drilled close to Meki River and lake Ziway respectively) show low fluoride content; whereas wells in the same lacustrine aquifer, but a bit far away from the surface water bodies (in the same table Ziway prison well and Galo Fechasa) have relatively bigger fluoride content. This shows that the dilution effect of the fresh surface water bodies on the fluoride content. This in turn magnifies the surface-groundwater interaction in the study area. The fluoride distribution has been depicted on figure 7.4.

Comparing water sampling sites map (fig 7.1), EC distribution map (fig 7.3), and fluoride distribution map (fig 7.4), lithologic logs of wells (appendices 2, 3, and 4) and the chemical composition of water samples (tables 7.1 and 7.3), the following conclusions could be derived:

- ◆ High EC, pH and fluoride values correlate,
- ◆ Existence of surface-groundwater interaction (from the dilution effect) and
- ◆ Fluoride dependency on lithologic formations (see lithologic logs on appendix 2,3, and 4)

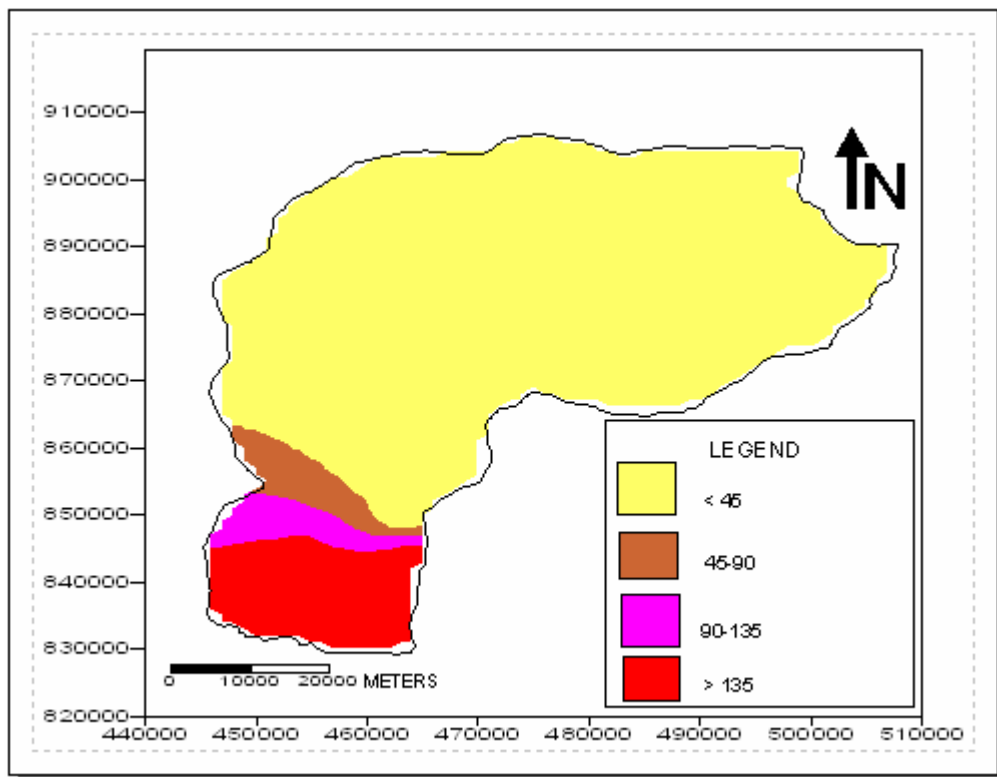


Figure 7.4 Fluoride distributions in Ziway-Abijata Corridor (in mg/l)

CHAPTER EIGHT

EFFECTS OF IRRIGATION PRACTICES AND LACUSTRINE AQUIFER DEVELOPMENT ON WATER AVAILABILITY IN ZIWAY-ABIJATA CORRIDOR

8.1. Introduction

Measured on conventional indicators, water stress is increasing. For almost a century water use has been growing almost twice as fast as population. This trend will continue. Irrigated agriculture will remain the largest use of water, it currently accounts for more than 80% of use in developing countries (Human Development Report, 2006).

In the central rift valley sector of the MER, environmental implications of water and land resources development became evident. Improper utilization of water resources in the area resulted in substantial changes in the hydrologic and hydrogeologic setting of the rift lakes (Dagnachew Legesse et al., 2006). Water abstraction for commercial and farm plots irrigation, for water supply purposes and for soda ash production are the major ones besides the intensive evapotranspiration water loss in area.

In the already water stressed region new developments are underway that compete for the water resources; both surface and groundwater. These new developments include expansion of horticulture and floriculture farms, introduction of large-scale irrigation schemes, and intensive and extensive irrigation practices on the farmers plot all over the area and water supply developments. Aquifer development for irrigation is also an intensive and extensive development in the area.

The lakes in the rift floor of the basin are strongly dependent for water sources on the Feeder Rivers from the highlands; and the terminal lake which is Abijata is in turn dependent on the water sources from the two nearby lakes Ziway and Langano, through out flow rivers Bulbula and Hora Kelo respectively. Any substantial resource development principally in terms of storage will bear significant impacts upon lake level. The critical issue is the spill regime from Lake Ziway to Abijata.

In such a fragile eco-system, the balance between supply and demand for water is a delicate one, marked over time by upstream and downstream conflicts, natural disasters, and the day-to-day

demands for a multiplicity of uses for this most vital resource. Although a renewable resource, water is not always available to a thirsty nation when and where it is needed, nor is it always of suitable quality for the intended use. Water must be considered as a finite resource that has limits and boundaries to its availability and suitability for use. This chapter is devoted to the outlining of water availability indicators and the effects of irrigation practices and lacustrine aquifer development on water availability in the area.

8.2. Indicators of Water Availability

Competition for water to meet the needs of homes, cities, farms, and industries is increasing. At the same time, requirements to leave water in the streams and rivers for environmental and recreational uses are expanding. Water availability and use are a function of the total flow of water through a basin, its quality, and the structures, laws, regulations, and economic factors that control its use.

Most of the time availability of water is viewed simply as an issue of quantity, and water management could focus largely on controlling or alleviating impacts of droughts and floods. With the specific hydrogeologic and hydrochemical setting in the MER water quality is also the fundamental issue in the study area.

Data that are crucial to issues of water availability include water quality, population statistics, land uses, water costs and pricing, climate data, and in stream-flow requirements for aquatic habitats. There are indicators that would reflect the status and trends in water availability. These indicators are for surface water flows and storage, groundwater levels and storage, and water use.

8.2.1. Surface Water Indicators

Indicators of surface-water availability would include measurements of both stream flow and Surface-water storage (lakes level in this case), each of which change continuously in response to natural and human induced processes.

8.2.1.1. Stream flow

As far as stream flow is concerned, there is a good start to gauge the main rivers in the basin (chapter five). Stream flow indicators that support longer term water-availability decisions require more interpretive, value-added information at annual and longer time scales than is currently obtainable. To fulfill these longer term requirements, the following three specific types of stream flow indicators would need to be produced:

- ◆ Annual summaries of surface water discharge which would provide simple and concise representations of the net effects of climatic events, water management, and water withdrawals on surface-water supply during a year, as well as from one year to the next for each of the hydrologic accounting unit of the basin,
- ◆ Periodic summaries of changes in surface water discharge for each hydrologic accounting unit over periods of 5 to 10 years, and
- ◆ Periodic assessments of long-term trends in surface-water discharge in each hydrologic accounting unit: The ability to determine systematic long-term changes in surface water supplies is an important capability of the national stream-gauging network.

8.2.1.2. Surface Water Storage (Lake Level)

One of the methods applied in the MER to account for surface water storage is having a data on lake level fluctuations. Both Lakes Abijata and Ziway have lake level recording stations. The primary changes in surface-water storage in most basins arise from changes in the total capacity of, and conditions within, surface reservoirs. Total reservoir storage conditions change in response to hydrologic and water-use variability, reservoir sedimentation, and reservoir construction and removal.

Table 8.1 Mechanisms that cause changes in stream flow and surface storage

Natural Mechanisms	Human-induced Mechanisms
Runoff from rainfall,	Surface water withdrawals & trans basin diversions,
Evaporation from soil & surface water bodies	Land use changes such as urbanization that alters rates of erosion, infiltration, overland

	flow or evapotranspiration
Sedimentation of lakes & wetlands,	Irrigation return flow,
Groundwater discharge from aquifers,	Stream channelization and levee construction
Groundwater recharge from surface water bodies,	Construction, removal and sedimentation of reservoirs and storm water detention ponds
Transpiration by vegetation,	

8.2.2. Groundwater Indicators

Long-term, systematic measurements of ground-water levels provide essential data needed to evaluate changes in ground-water storage over time. The measurement of groundwater levels in the study area is lacking. Groundwater indicators include measurements of groundwater levels and storage.

8.2.2.1. Groundwater Levels

The groundwater level indicator plays a very great role reflecting specific geographic regions or specific types of aquifers, terrains, environments, or land-use settings. These various indices would provide water managers, major water users and the public with quick summaries of magnitudes and significance of trends in water-level changes. Ground-water systems are dynamic and adjust continually to short term and long-term changes in climate, groundwater withdrawals, and land uses. Because subsurface hydraulic properties are highly variable, water level responses to stresses vary considerably with location and depth. Stresses take time to propagate through ground-water systems, so water-level changes are transient phenomena that are strongly affected by distances from the monitoring wells to imposed stresses. .

Table 8.2 Mechanisms that cause changes in groundwater-levels and storage (modified from Freeze and Cherry, 1979)

Natural Mechanisms	Human-induced Mechanisms
Recharge	Groundwater withdrawals
Evaporation from the water table	Agricultural irrigation

Transpiration by vegetation	Drainage of agricultural lands, swamps, and wetlands
Discharge to streams, springs and seeps	Artificial recharge of water
Surface water level fluctuations in hydraulically connected streams, lakes and ponds.	Leakage from surface water reservoirs
	Urbanization impacts such as leaky water and sewer lines, lawn irrigation, and impervious surface (paved roads, parking lots, etc)

8.2.2.2. Groundwater Storage

Qualitatively speaking there are signs of the depletion of groundwater storage in the nation in general and in the Main Ethiopian Rift in particular. The drying up of Burka Dalacha Spring at the northern peak of the study area could be an example in the case at hand. Drying of springs represent the depletion of groundwater could cause large-scale, regional decline of the water table and accompanying reductions in groundwater storage. The assessment of changes in aquifer storage would be based on basin wide summaries of observed water-level changes and ancillary data describing the aquifers and their changing storage conditions. These assessments would require a greater level of effort than that required for development of the ground-water-level indices because estimates of changes in ground-water storage require knowledge of aquifer storage properties and spatial interpolation of ground-water-level measurements. Changes in ground-water use and the effects of ground-water development are not usually as variable year to year as are those for surface water and, therefore, the periodic assessments of ground-water storage could be made at 5- to 10-year intervals.

8.2.3 Water Use Indicators

Besides the above indicators, water use information is also a very crucial input for water resources management. Water use can be divided into off stream use, in stream use and wastewater release.

A. Of stream use: is a water use that refers to water being diverted or withdrawn from a surface- or groundwater source and conveyed to the place of use. To determine the total quantity of off stream water use (self-supplied withdrawals and public-supply deliveries), five subtypes of use are evaluated, as explained below.

1. Withdrawal—the quantity of water diverted or withdrawn from a surface- or groundwater source.
2. Delivery/release—the quantity of water delivered at the point of use and the quantity released after use.
3. Conveyance loss—the quantity of water that is lost in transit, for example, from point of withdrawal to point of delivery, or from point of release to point of return.
4. Consumptive use—that part of water withdrawn that is evaporated, transpired, or incorporated into products or crops. In some instances, consumptive use will be the difference between the volume of water delivered and the volume released.
5. Return flow—the quantity of water that is discharged to a surface- or ground-water source after release from the point of use and thus becomes available for further use.

B. In stream use: is a water use that takes place without the water being diverted or withdrawn from surface- or ground-water sources. Examples of in stream uses are hydroelectric power generation, navigation, freshwater dilution of saline estuaries, and maintenance of minimum stream flows to support fish and wildlife habitat, and wastewater assimilation. Such uses compete with off stream uses and affect the quality and quantity of water resources for all uses, effective water-resources management requires that methods and procedures be devised to enable in stream uses to be assessed quantitatively

C. Waste water release: refers to water released from private and public wastewater-treatment facilities.

8.2.4. Undervaluation and Zero-Pricing, another Dimension of Water Availability Indicator

Water in any aspect is a priceless resource, yet its value is under estimated in our country. Water pricing other than domestic supply is not a practice in our country. The perception of water as an infinite resource clearly contributes to undervaluation.

Water in Ethiopia is the most abused resource. No body cares how and when to utilize water for the intended purpose. The negligence and ignorance in utilization of this scarce resource led to the disappearance of lakes, springs and streams which were perennial before. Lake Haromaya is the Ethiopia's most human caused ecological disaster.

In water stressed regions like the floor of the rift valley, which is known for its water scarcity, water utilization is under zero-pricing. Zero pricing has sustained overuse. With unbalanced and improper utilization of the water resources and with the prevailing changes in climatic conditions; lakes, rivers and springs will disappear under the eyes of this generation.

In general, the development and reporting of indicators of water availability and use could be analogous to the task of other sectoral statistical variables that produce and regularly update indicator variables that describe economic, demographic, and health conditions of the Nation. The assessment also would provide regional information on recharge, evapotranspiration, inter basin transfers, and other components of the water cycle within a basin. This regional information would support analyses of water availability that are undertaken by many agencies nationwide and would benefit research quantifying variability and changes in the national and global water cycle.

8.3. Effects of Irrigation Practices on Water Availability

As a productive resource, water is unique in that it can never be managed for a single use. It flows between sectors and users. Upstream abstraction will put a shortage to the downstream users. Trans-boundary aquifers and lakes are issues for countries who share that aquifer or reservoir. In line with government's poverty alleviation program, there are numerous irrigation development activities using abstraction of water from rivers and lakes in the study area.

8.3.1. Rivers Water Abstraction and its Effect

8.3.1.1. Abstraction from Ketar River

Large-scale irrigation was started in Ketar catchments in mid 1980's by Ketar Irrigation Project. Since then, irrigation demand has been increasing by using the river and its tributaries. In the highland area potato is the most dominant vegetable while tomato, cabbage, onion and papaya are produced in lowland areas. Assuming 600mm average water requirement (FAO Irrigation, Drainage and Salinity Paper, 1973) and 60% of the irrigable areas to be developed twice a year, the total water abstracted currently to satisfy the demand of 2115ha crop will be 20.3mcm (Alemu Dribsa, 2006).

8.3.1.2. Abstraction from Meki River

About 462ha of land is under cultivation to produce potato, tomato, onion and pepper using Meki River (Alemu Dribsa, 2006). Using similar computational methods as mentioned above, the total annual abstraction from the river is about 6mcm.

8.3.1.3. Abstraction from Bulbula River

About 1307.09ha of land is under cultivation to produce different horticultures and floricultures using Bulbula River. Total annual abstraction from the river for the mentioned purpose is about 58.5mcm (Ormia Irrigation Development Authority, 2007). In addition, a total of 4.5mcm is annually taken from the river for Ziway town domestic water supply since April 2003 (Oromia Water Resources Bureau, 2004).

Table 8.3 Estimated abstraction of water from Rivers Ketar, Meki and Bulbula (mcm)

Year	Rivers		
	Ketar	Meki	Bulbula
1980	0.24	0.85	
1990	7.14	1.21	
2000	11.27	3.43	
2006	25.38	5.54	63

The above table depicts that abstraction in the rivers Meki, Ketar and Bulbula, is increasing in an alarming rate. The effect of this abstraction on the amount of water in the streams and finally on

Lakes Ziway and its associated overflow Bulbula River is very tremendous. This high level abstraction has resulted in an alarming reduction of lake level in Abijata. This drastic impact has been aggravated by abstraction of water for soda ash production (see figure 8.1 and 8.2).

From figure 8.1 the impact of water abstraction on the stream flow is very evident that the amount of stream flow is getting decreased from year to year. Even though all the rivers are affected by the abstraction, the effect in the case of Bulbula is drastic. Unless and otherwise mitigation measures are taken, these rivers are at risk.

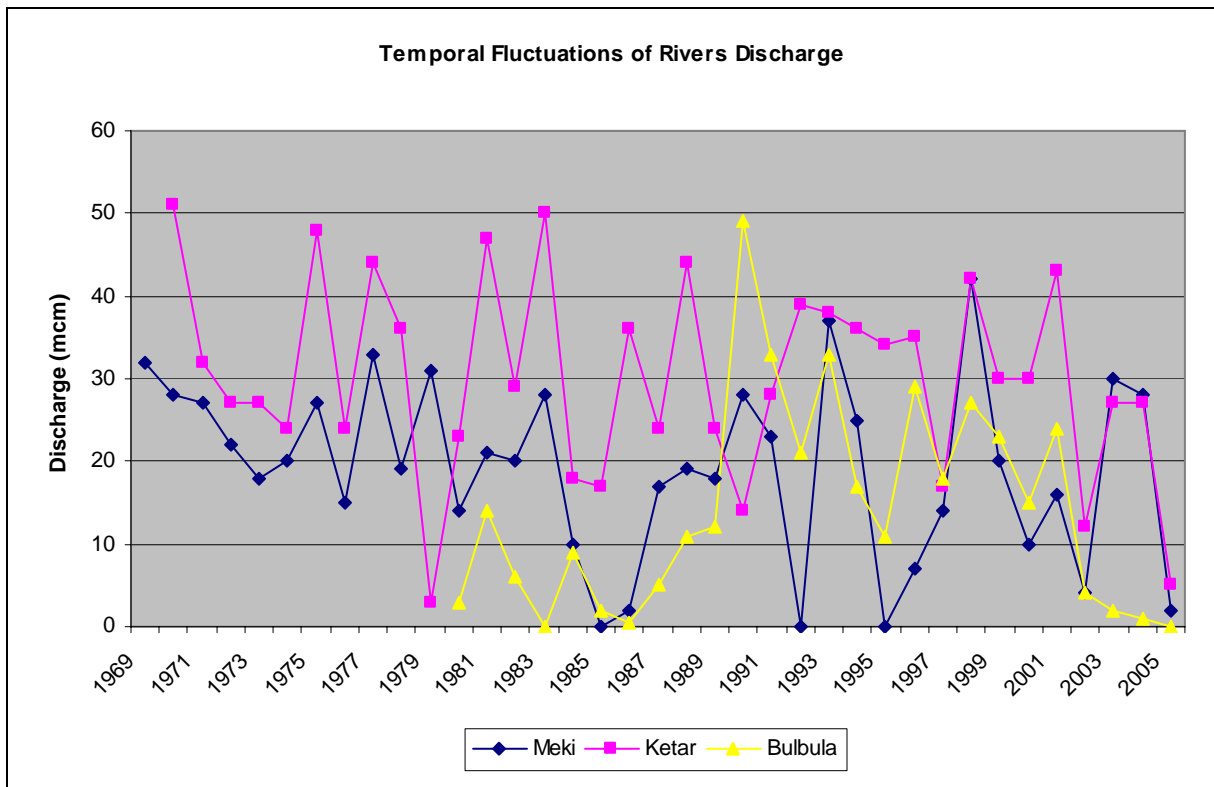


Figure 8.1 Temporal fluctuation of Rivers Discharge

8.3.2. Lakes Water Abstraction and its Effect

8.3.2.1. Abstraction from Lake Ziway

Due to its accessibility, favorable location in relation to Addis Ababa and fresh water quality, Lake Ziway has been considered the most important water exploitation area in the rift valley (HALCROW, 1992). A land total of about 1197.25ha is irrigated using the lake water (Oromia Irrigation Development Authority, 2007). Onion, tomato, floriculture and different crops are grown

in the area. Assuming 600mm average water requirement for single season; and if two phases of irrigation are considered annually, the total abstraction of lake water will be about 44.5mcm (Alemu Dribsa, 2006).

8.3.2.2. Abstraction from Lake Abijata

Due to its salinity and alkalinity, Lake Abijata is not suitable for irrigation. Water is abstracted from the lake for soda ash production. One tone of soda requires the abstraction of 150 tones of water representing an estimated volume of 2.25mcm each year. Even though there is an expansion proposal, it could not be realized due to critical water scarcity in the lake. This manifests that the absence of impact assessment during the feasibility study of projects in this country.

Table 8.4 Estimated abstraction of water from Lakes Ziway and Abijata (mcm)

Year	Sources of abstraction	
	Lake Ziway	Lake Abijata
1980	8.79	
1990	16.23	2.25
2000	27.68	15
2006	44.5	< 2.25

In the last two-three years new developments in horticulture and floriculture production at the floor of the rift valley has increased the rate of abstraction at an exponential rate. Besides the observed unbalanced water abstraction at any possible reaches; the strong evapotranspiration, population growth, environmental degradation and climatic changes resulted in water stress in the floor of the rift valley in turn resulted in ecological stress.

The perennial River Bulbula became intermittent and the shrinkage of Lake Abijata prohibited the production of soda ash. These are highly visible products of overuse. These are grave implications and the cost to be transferred to the down stream people, environment and future generations. Shrinking of Lake Ziway leads to no overflow through River Bulbula. Hence Lake Abijata is

showing drastic reduction in level and reached the stage where it became impossible to produce soda ash from the lake. The effect of water exploitation in the study area can be manifested by looking at the temporal lakes level fluctuation (see figure 8.2).

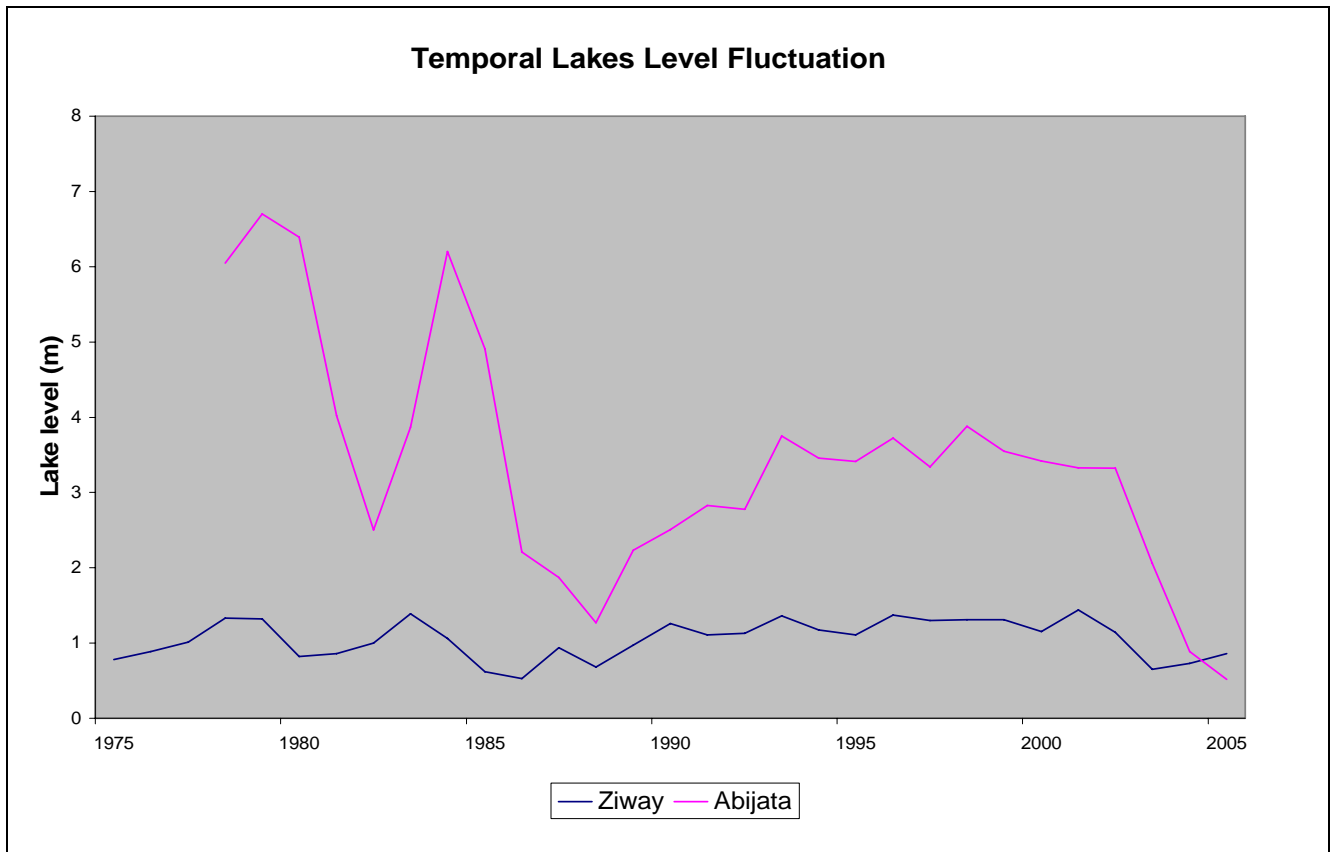


Figure 8.2 Temporal lake level fluctuations

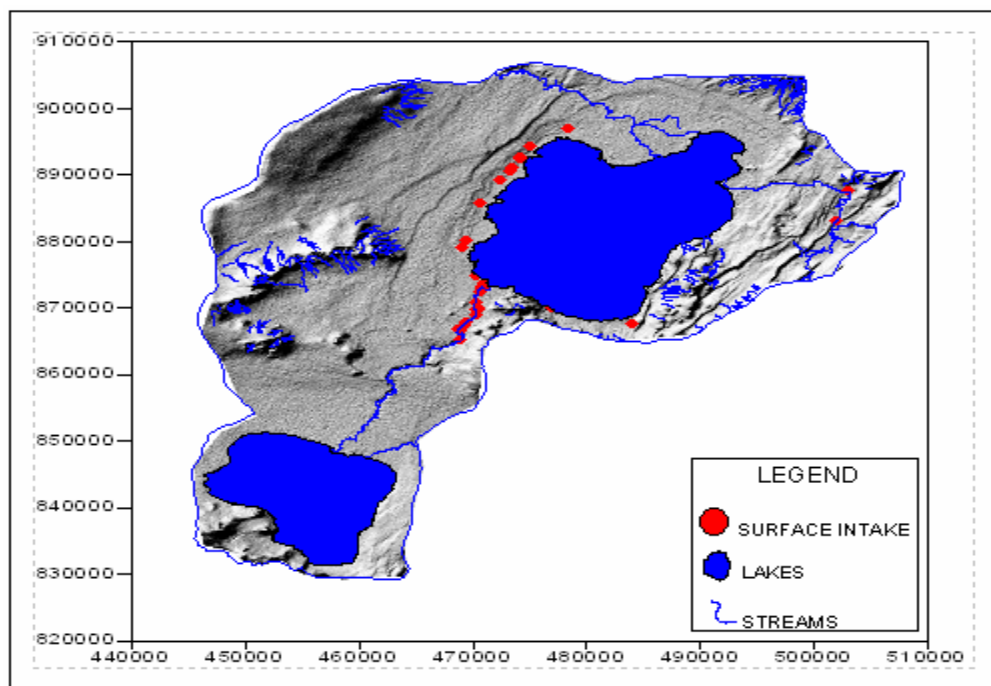


Figure 8.3 Surface water abstraction points for irrigation purpose

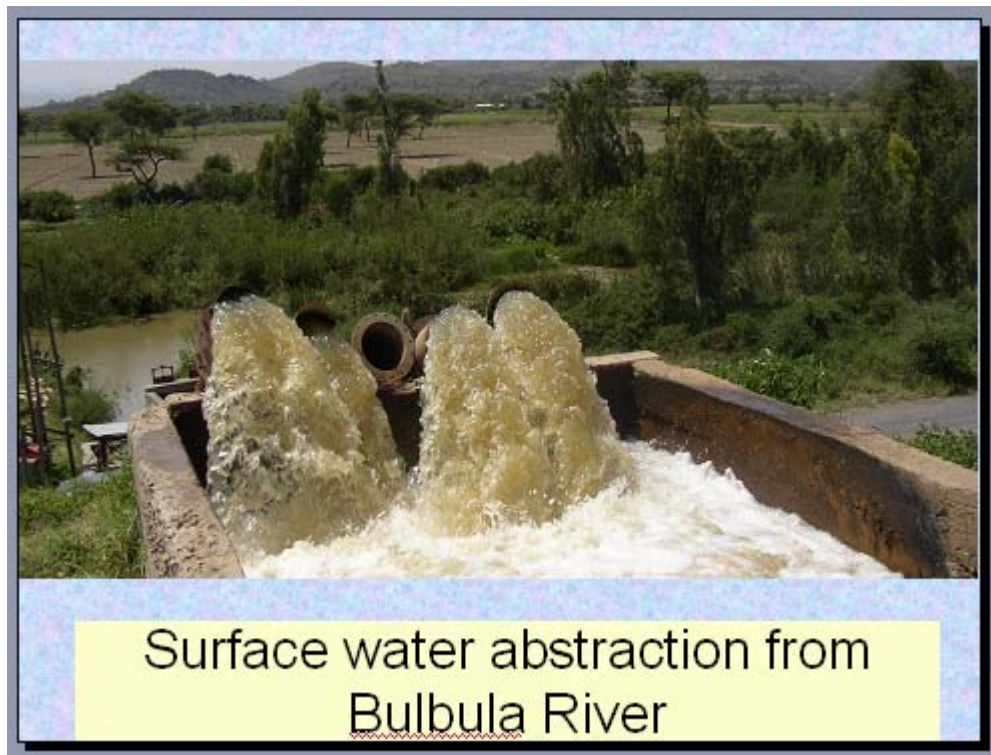


Plate 8.1 Water abstraction for irrigation (Ziway state farm)

8.4. Effects of Lacustrine Aquifer Development on Water Availability

In line with the government's poverty alleviation program tremendous effort is underway to utilize water resources in the country to improve production and productivity. Besides the rain fed agriculture irrigation development at farm plots is extensively being implemented almost all over the country. Where the existence of water resources is possible from rivers, lakes and springs the water will be taken out from its natural course; either by gravitational force or pumpage. Where such kind of potential is not found water harvesting mechanism has been introduced. Water harvesting ranges, from catching water from roofs, sloppy areas, and flood diversion during the wet season up to digging wells at the farm plots and house yards. In many places in Ethiopia, farm activity is becoming the year round engagement as opposed to the previously rain dependent and seasonal farming practices. In a country where household food self sufficiency is a chronic problem, utilization of natural resources to the betterment of the livelihood of the society is not to be questioned. One thing to be questioned is the optimum utilization of natural resources.

In this study attempt has been made to take inventories of wells that are dug for irrigation purposes. These wells are concentrated around Lake Ziway on the lacustrine aquifer. In chapter six it has been established that the lake feeds the wells (section 6.4). Among tremendous wells about 81 productive wells have been identified from Dugda Bora and Adami Tulu Jiddo Districts around the lake.

Water is discharged from all the wells by the 5 Horse power Robin pump Japan Origin. Model PTD 306 with 3” suction and with discharge capacity of 15 l/sec is the commonest Robin pump in the area. Model PTD 406 with 4” suction and with discharge capacity of 22 l/sec is very rare; hence estimation of abstraction is made using the pump with 15 l/sec. The head of the pump ranges from 6m (suction head) to 21m (Suction head + delivery head + friction loss). Discharge is inversely proportional to head, so the farmers in the area always try to maintain the suction head by digging another well near the production well to put the pumps.

Onion, tomato, potato, cabbage, pepper and other fruits and vegetables are the common ones growing in the area. Since onion and tomato are dominant taking coverage of 70% and 30% respectively, estimation of abstraction is made using these two crops. One cropping season for onion and tomato is 120 days and 90 days respectively; and the irrigation interval for both vegetables is every five days for 10 hours (Oromia Irrigation Development Authority, 2007). Therefore onion is irrigated 24 times and tomato is irrigated 18 times per season.

Using robin pump with 15 l/sec discharge it is possible to irrigate 0.75 ha of land within 10 hours; and from this assumption it is possible to obtain the total land irrigated by multiplying the number of pumps by 0.75 ha. Assuming two cropping seasons for these two crops water abstraction is estimated to be about 1.9mcm annually from the 81 dug wells (see table 8.5).

Table 8.5. Abstraction estimation from the lacustrine aquifer in Lake Ziway area.

Crop type	No of pumps	Water required for two seasons (m ³)	Irrigated land (ha)	
			In one season	In two seasons
Onion	57	1,477,440	42.75	85.50
Tomato	24	466,560	18	36.00
Total	81	1,944,000	60.75	121.50

From hydrochemical interpretation point of view it has been established that there is strong surface-groundwater interaction in the study area. The groundwater in the dominant lacustrine aquifer in the floor of the rift is fed from surface water notably Lake Ziway and Streams flowing across the area. This interaction will lead to the fundamental approach of the conjunctive use water resources in the area.

Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, groundwater withdrawal, and land use. Groundwater levels are controlled by the balance among recharge to, storage in, and discharge from an aquifer. Physical properties such as the porosity, permeability, and thickness of the rocks or sediments that compose the aquifer affect this balance. So, too, do climatic and hydrologic factors, such as the timing and amount of recharge provided by precipitation, discharge from the subsurface to surface-water bodies, and evapotranspiration. The effects of such human-induced changes on ground-water recharge and storage are often incremental, and the cumulative effects may not become evident for many years. But, the withdrawal of ground water by pumping is the most significant human activity that alters the amount of ground water in storage and the rate of discharge from an aquifer, and hence its impact is visible soon in relative terms.

The removal of water stored in geologic materials near the well sets up hydraulic gradients that induce flow from more distant parts of the aquifer. As ground-water storage is depleted within the radius of influence of pumping, water levels in the aquifer decline. The area of water-level decline is called the cone of depression, and its size is controlled by the rate and duration of pumping, the storage characteristics of the aquifer, and the ease with which water is transmitted through the geologic materials to the well.

The development of a cone of depression can result in an overall decline in water levels over a large geographic area, change the direction of ground-water flow within an aquifer, reduce the amount of base flow to streams, and capture water from a stream or from adjacent aquifers. Within areas having a high density of pumped wells, multiple cones of depression can develop within an aquifer (see figure 8.4).

Presently there are many wells dug for irrigation purpose. Due to the large number of the wells within small area and absence of technical input during well construction, the problem of well

interference is observed at places. There is also in indication of relationship between the shrinkage of Lake Ziway and the lowering of water level in hand dug wells.

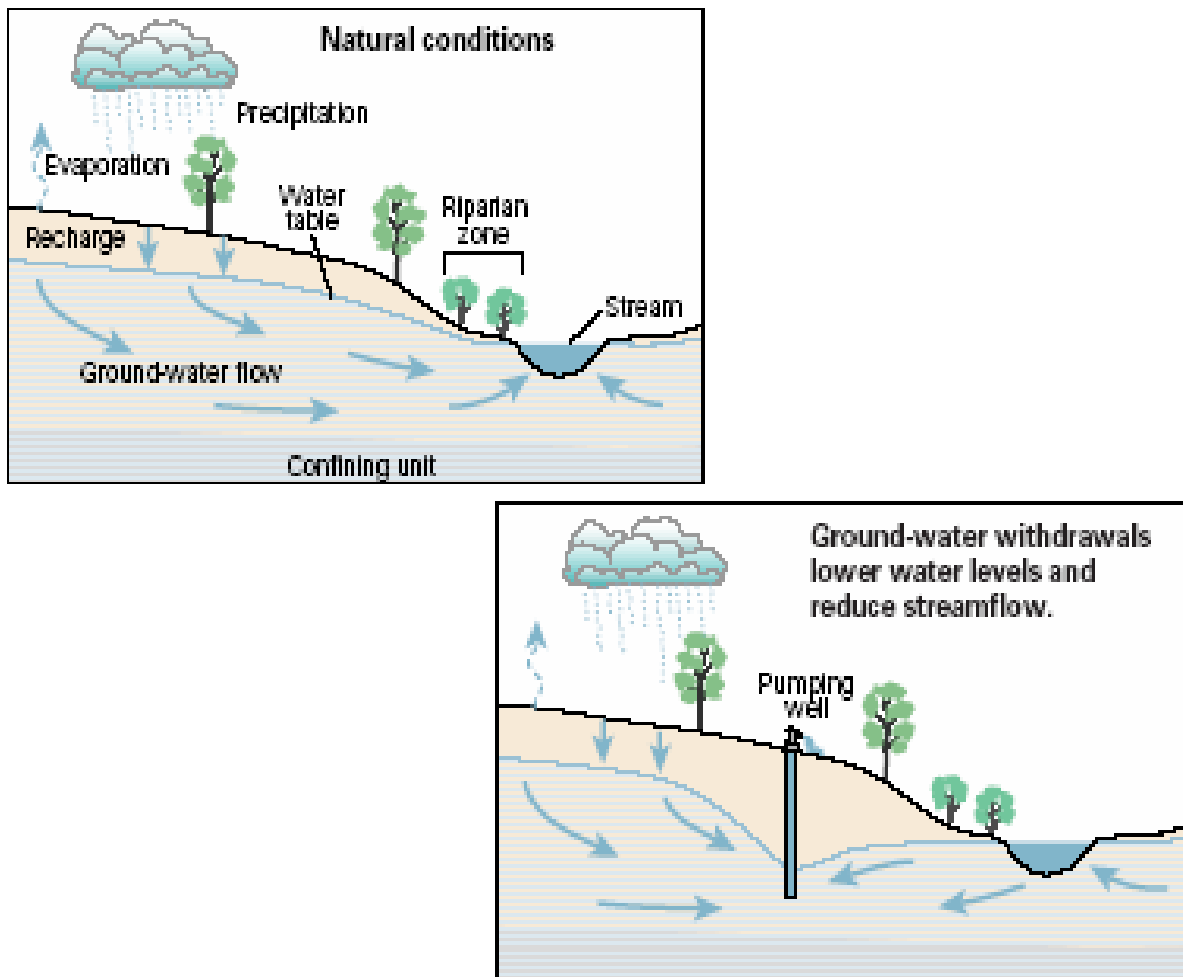


Figure 8.4 Impact of development of cone of depression on the groundwater flow direction; and on streams getting base flow from the subsurface.

So, if things continue like this the introduction of so many cones of depression in Ziway area, there is a strong possibility of diverting the groundwater flow direction from its natural course. Unless and otherwise checked at some point water resources exploitation in the area will bring about irreversible hydrological change in the environment.



Plate 8. 2 One of the hand dug wells in Ziway area

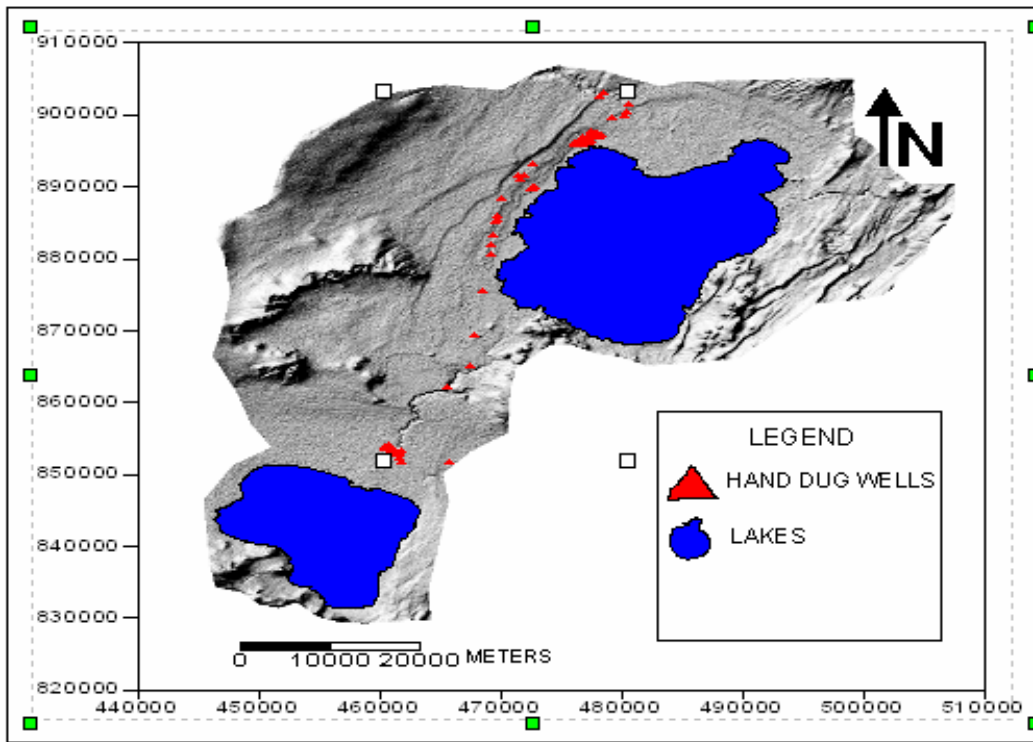


Figure 8.5 Distribution of hand dug wells

CHAPTER NINE

SYNTHESIS

The study attempts to improve the knowledge of the hydrogeology of the complex rift floor by considering all relevant data and information. As far as the hydrochemistry of the area is concerned there are complex and complicated situations in that it is really very difficult to generalize about the hydrochemistry of the area, unless and otherwise thorough investigation of the hydrochemistry. In places there are wells in a very near distance with significant variation of hydrochemistry. This is very evident from the primary data generated from the newly hand dug wells in Ziway area and Meki Town.

In this research work it became clear that hydrochemistry is governed by the local lithologic formations besides other factors. In the Ziway-Abijata Corridor, there is strong similarity in the increment of ionic concentration and trend as one goes from the recharge area to the discharge area between surface and subsurface water resources. It became very evident that hydrochemically the surface and groundwater body influences each other interchangeably in terms of ionic content, and different media (for example alkalinity). This will justify the surface-groundwater interaction in the area.

When the water availability issue is assessed, interpretations from measurements of streams discharge and lakes levels depicted that the problem is very chronic. The decrease in level in Lake Abijata is tremendous and it is understood that there is no effort to improve the devastating condition. There is neither concern in the upstream water users nor mitigation measures from relevant and concerned institutions to alleviate the problem. Things continued as usual. Expansion of irrigated farm of different scales is under way creating competition for the water exponentially.

From surface-groundwater interaction point of view it has been established that the system is one (conjunctive). Introduction of intensive and extensive aquifer development will put drastic impact on the water resources. Bringing water from the aquifer that has connection with the Lake Ziway is not relieving the lake; rather it is penetrating the bed of the lake and aggravates the depletion of the water from the lake. The consequences will not only be limited to the lake but also to the down stream both in terms of surface hydrology and groundwater environment. These exploitations will be synergized with upstream environmental degradation, sediment accumulation in the lakes, population pressures and climatic changes.

Water utilization is not based on proper assessment of the resource base and this resulted in water undervaluation. Undervaluation and zero pricing for water aggravated the water availability severely. Nobody cares about the 'what amount' of the resource during utilization.

The importance of water availability indicators has been outlined in this work. From surface water resources management point of view, stream gauging and storage measurement is a good start but it should be complemented with the groundwater level monitoring. In the absence of proper water availability indicators it is difficult to properly evaluate the water resources in the area; and without proper evaluation water valuation is impossible.

The problems in the water stressed rift floor areas are intertwined and complicated and the absence of proper water resources management intensified water exploitation and the result will be losing the whole environment as it has been witnessed in Lake Haromaya, River Bulbula, River Hora Kelo, and Lake Abijata, unless and otherwise situations are managed.

CHAPTER TEN

CONCLUSION AND RECOMMENDATION

10.1 Conclusion

Water availability is a big issue in the study area. This has been manifested by the decreasing of streams discharge and depletion of surface water storage. Water availability indicators particularly surface water indicators clearly showed that the water shortage in the area.

The cause for water shortage is over abstraction. Rivers Ketar, Meki, and Bulbula are highly abstracted for irrigation, domestic water supply; Lake Ziway is also abstracted for intensive irrigation purpose and domestic water supply. Intense abstraction has got its own impact on the down stream closed terminal Lake Abijata. Because of this over abstraction of water in the up stream reaches of rivers and lakes produced critical shortages in the downstream reaches.

Recently lacustrine aquifer development is newly undertaking. Hydrochemistry analysis showed that there is strong surface-groundwater interaction. Since there is strong surface-groundwater interaction, both surface water abstraction and lacustrine aquifer development will aggravate the water availability issue in the area.

Undervaluation and zero-pricing played a very great role in the overuse of the water resources in the Ziway-Abijata Corridor.

Water resources in general; and downstream water resources in particular, specifically the overflow of Lake Ziway River Bulbula and the closed terminal Lake Abijata are at risk.

10.2 Recommendation

Based on the result of the present study and the problems faced during the present investigations, the following systematic recommendations are made;

- ◆ Groundwater level monitoring is lacking, in the absence of which proper groundwater evaluation is difficult. Groundwater level monitoring is also resolves the quantification of recharge quantification. The conventional methods for recharge quantification have their own limitations; but if these methods are supported with the data showing the exact level fluctuation will leads to the real conditions. Site-scale studies and basin-scale strategies benefit from this level monitoring,
- ◆ To create dynamism and then improvement in the water utilization in the country in general, and in the study area in particular, water pricing must be introduced urgently in the water sector. Mechanisms like, licensing of new production bore holes, and resources regulation must be exercised. Without creating dynamism in water resources utilization, nobody is concerned to think thoroughly about the irrigation

designs which are very inefficient. But if water pricing is introduced the furrow and flooding irrigation types which are common in improperly managed and administered water resources system will shift to the redefinition of irrigation designs.

- ◆ To implement water pricing the utilized water must be measured, so introduction of general water meters for all types of schemes must also be exercised (all rural water supply schemes, irrigation schemes, industrial schemes, ... any scheme that utilizes water should register the amount of water it utilized!!). These measurements are very important not only for water resources management but also for water resources evaluation and modeling.
- ◆ Water shed management is also very crucial.
- ◆ Surface water harvesting (artificial recharge) which is found in its infancy in this country must be strengthened.

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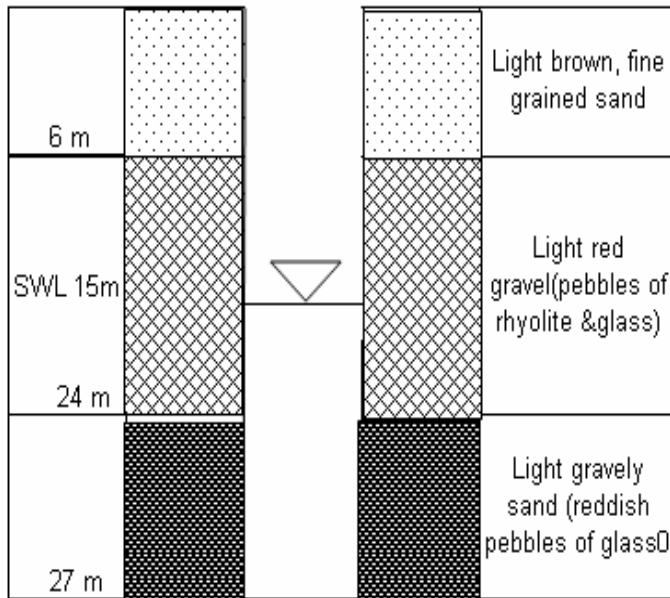
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Annex I. In-situ measured parameters for hand dug wells

No	Name	Code	Location		altitu de	In-situ measured parameters						Remark
			Easting	Northing		pH	Conductivity ($\mu\text{S/cm}$)	TDS (mg/L)	Temp ($^{\circ}\text{C}$)	Eh (mv)	Salinity(%)	
1	Beshune	HDW 02	469992	888330	1664	6.88	2310	1380	29.6	-2.91	1.1	Wayo village
2	Tesfaye	HDW 05	461077	853174	1598	6.44	795	480	22.8	-0.7	0.6	Bulula
3	Ziway T,H	HDW 07	468438	875637	1648	6.87	1332	800	26	-27.7	0.8	Domestic
4	Jaleto	HDW 08	469164	881965	1641	6.96	1540	930	22.6	-36	0.8	"
5	Abiti	HDW 09	469565	885259	1656	6.8	241	1437	23.9	-25.1	1.2	"
6	Kemal	HDW 10	469731	885922	1654	6.78	1108	667	24.9	-15.3	0.7	"
7	Yemaneh	HDW 11	471629	891219	1664	7.03	2380	1450	27.9	-37	1.1	"
8	Iyasu	HDW 16	478058	897127	1645	6.83	6.11	3.67	23.4	-10.6	2.6	Near the lake
9	Abay	HDW 17	477937	897636	1654	6.56	1003	589	25	-27	0.7	
10	Korbu	HDW 18	477385	897037	1646	6.9	1485	900	22.7	-8	0.8	
11	Teshome	HDW 19	477326	896469	1644	6.7	2780	1417	24.2	-22.4	1.2	Near the lake
12	Godana	HDW 20	476745	896765	1652	6.87	818	490	24.2	-10.6	0.6	Away from lake
13	Tepho Chorok	BH 21	472647	893143	1666	7.32	860	1425	-	-15	0.8	Away from lake (bore hole)
13	Firdu	HDW 22	471916	891555	1650	7.2	1685	1012	28.7	-12	0.8	Wayo road
14	zergaw	HDW 23	471490	891736	1668	7.3	1880	1318	28.7	-18	1	" "
15	Gaddise	HDW 28	480297	900063	1662	7	1171	706	30	-1.8	0.7	Meki Town
16	Abebe	HDW 29	468443	875684	1650	7.05	1143	689	27.8	-2	0.7	Ziway Town
17	Awash Hotel	HDW 30	479210	899745	1665	6.97	4070	2.44	21.4	-3.6	1.8	Meki Town
18	Gerbi Diversi	Lake 01	478550	896770		6.47	650	422.5	27.1	-13.4	-	Lake Water
19	Share complex	WasteD C 03	470553	874349	1639	6.92	1672	101.3	19.3	-34.5	0.4	Waste Disposal
20	Share complex	WasteD C 04	470553	874349	1639	6.87	585	35	19.6	-20.8	0.3	Waste Disposal

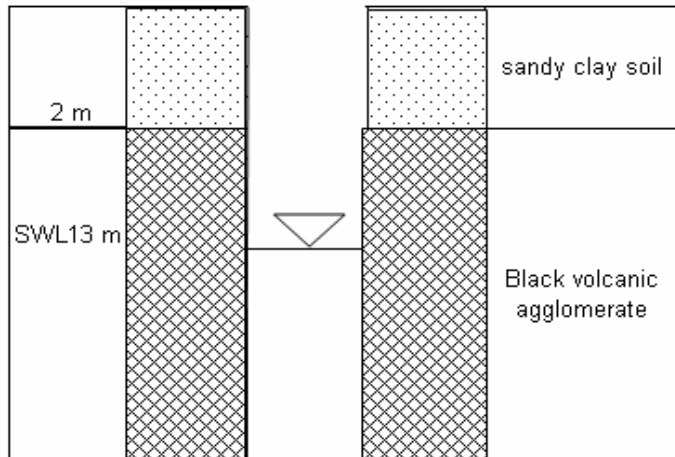
Annex II. Well log - lithology for Daka Hora-Kelo well (near Lake Abijata)

Depth Lithology Well Lithology Formation name



Annex III . Well log - lithology for Gerbi farm well (Near Lake Ziway)

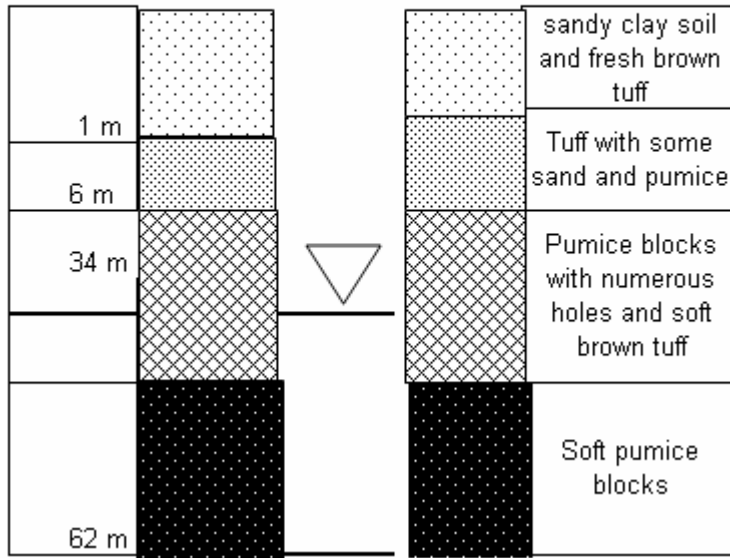
Depth Lithology Well Lithology Formation name



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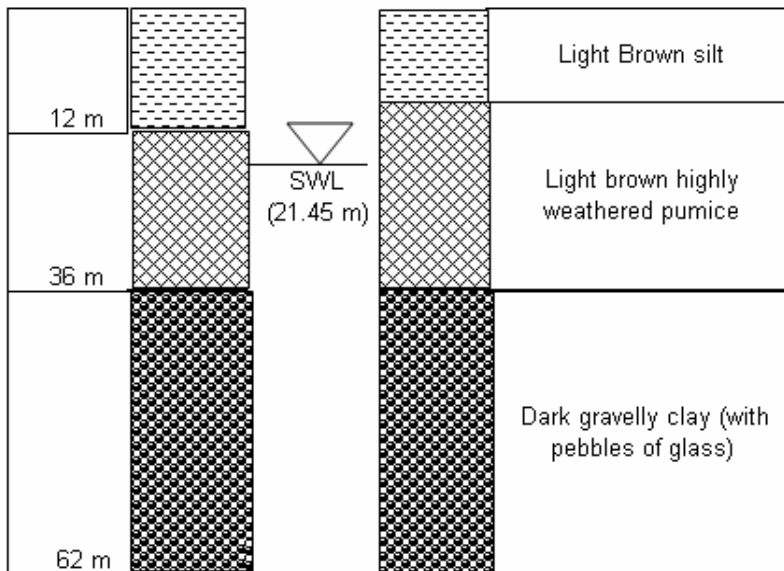
Annex IV . Well log - lithology for Ziway prison well (in Ziway town but a bit far from Lake Ziway)

Depth (m) Lithology Well Lithology Formation name

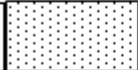

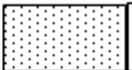
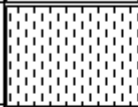
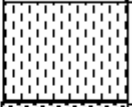
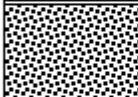



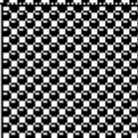
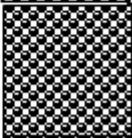

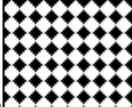


Annex V. well log - lithology for Bulbula Well (in Bulbula Town)

Depth (m) Lithology Well Lithology Formation name



**Annex VI. well log - lithology for Wayyo School
(between Meki and Abosa)**

Depth (m)	Lithology	Well	Lithology	Formation name
2.5m		 BWL 33m		Top gray clay soil
7 m				Pumice
16 m				Volcanic ash
33m				Tuff
42m				Black fine sand
61 m				Sand with some volcanic

**Annex VII. Location of some of the hand dug wells
for domestic purposes**

No	Name	Location	Elevation
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		Eaasting	Northing	
1	Bashune	469992	888330	1664
2	Ziway Tourist Hotel	468438	875637	1648
3	Serto	469115	880788	1644
4	Jaletu	469171	881996	1641
5	Like	469411	883391	1649
6	Abiti	469565	885259	1656
7	Denanso	469668	885586	1666
8	Kemal	469731	885922	1654
9	Haweno	469717	885980	1662
10	Yemaneh	471629	891219	1664
11	Adi Alemu	472647	893143	1666
12	Firdu	471916	891555	1650
13	Zergaw	471490	891736	1668
14	Oda Bokota	478429	903034	1687
15	Well No 3 (St mary)	480611	901627	1674
16	Graba Jarso	478088	902657	1683
17	Well No 1 (Near Briddge)	480410	900579	1666
18	Gaddise	480297	900063	1662
19	Awash Hotel (Meki)	479210	899745	1665
20	Abebe (Ziway)	468443	875684	1650
21	Aneno	465640	862317	1661
22	Adami Tulu No 1	467535	865258	1656
23	ADAMI Tulu No 2 (LVIA)	467854	869444	1654
24	Desta	460815	854043	1604
25	Abdulkadir	460819	854086	1612
26	Safewo	460759	854162	1607
27	Yasin	460808	854200	1609
28	Amare	460502	853945	1613
29	Idasa	460731	853951	1609
30	Kabeto	460355	853971	1610

AnnexVIII. Location of some of the hand dug wells for irrigtion purposes

No	Name	Location		Elevaton
		Eaasting	Northing	
1	Negewo	478354	897128	1642
2	Abu Geda	478201	897217	1644

3	Yohanis 1	478126	897150	1642
4	Biyo	477029	896814	1648
5	Uba	476791	896881	1644
6	Negashu	478216	897371	1642
7	Abu Geda 2	478317	897329	1640
8	Yohanis 2	478129	897304	1644
9	Yosef	478049	897291	1647
10	Iyasu 1	478058	897127	1645
11	Iyasu 2	477921	897197	1646
12	Iyasu 3	477969	897300	1643
13	Denbel	477843	897292	1641
14	Zewdu	477798	897537	1657
15	Abay	477937	897636	1654
16	Yohanis 3	477825	897118	1644
17	Yohanis 4	477763	897233	1644
18	Samuel	477678	897170	1648
19	Roba	477511	897400	1652
20	Tesfaye	477551	897610	1649
21	Abe	477438	897668	1652
22	Korme	477575	897212	1647
23	Yishak	477631	897176	1646
24	sategni	477535	897177	1648
25	Solomon	477666	896959	1645
26	Tadese	477526	896995	1646
27	Roba	477423	897091	1644
28	Idaa	477397	897124	1645
29	Korbu	477385	897037	1646
30	Biru	477336	896628	1642
31	Tedecho	477180	896701	1642
32	Shibiru 1	477157	896764	1644
33	Shibiru 2	477093	896857	1644