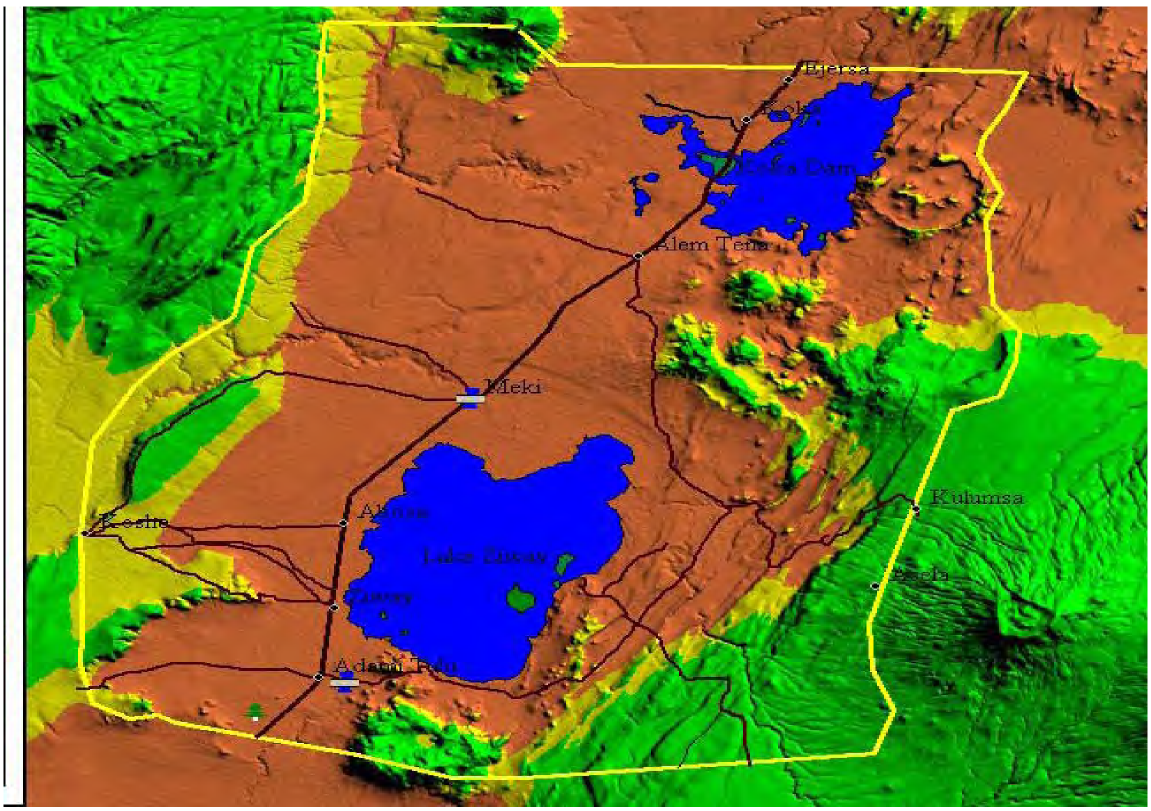
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

GROUNDWATER FLOW SYSTEM AND HYDROCHEMISTRY OF ZIWAY-KOKA CORRIDOR IN THE MAIN ETHIOPIAN RIFT.



A THESIS SUBMITTED TO THE SCHOOL OF GRADUTE STUDIES OF ADDIA ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDROGEOLOGY.

ABIYU KEBEDE

FEBRUARY 2007
ADDIS ABABA

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Table of Content

Content *page*

ACKNOWLDGMENTS.....i

ABSTRACT.....Vii

1. INTRODUCTION ..... - 1 -
1.1. GENERAL ..... - 1 -
1.2. PREVIOUS WORK..... - 2 -
1.3. OBJECTIVE OF THE STUDY ..... - 3 -
2. STUDY SITE DESCRIPTION..... - 5 -
2.1. LOCATION , ACCESSIBILITY AND AERIAL EXTENT ..... - 5 -
2.2. CLIMATE ..... - 6 -
2.3. TOPOGRAPHY ..... - 7 -
2.4. DRAINAGE..... - 8 -
2.5. POPULATION..... - 9 -
2.5.1 Human ..... - 9 -
2.6. GROUND WATER DEVELOPMENT..... - 10 -
2.6.1. Public Consumption..... - 10 -
2.6.2. Irrigation ..... - 11 -

3. GEOLOGY ..... - 12 -
3.1. REGIONAL GEOLOGY ..... - 12 -
3.2. GEOLOGY OF THE STUDY AREA..... - 15 -
3.2.1. MAIN RIFT..... - 15 -
3.2.2. SYN-RIFT ..... - 17 -
3.3. GEOLOGICA STRUCTURE 22
3.3.1. Fault..... 22
3.3.2. Jointe and Fracture..... 22
3.3.3. Caldera 22
3.3.4. Fissure, Cones and Domes 22

4. SURFACE WATER HYDROLOGY 25
4.1. SURFACE WATER HYDROLOGY 25
4.1.1. AWASH RIVER..... 25
4.1.2. MEKI RIVER..... 25
4.1.3. BULBULA RIVER..... 26

4.1.4. KATAR RIVER 26
4.1.5. LAKE ZIWAY 26
4.1.6. KOKA DAM 28
4.1.7. ELEN LAKE 30

5. H Y D R O G E O L O G Y 31
5.1. GENERAL 31
5.2. Hydrogeological units and aquifer systems 32
5.2.1. AQUIFER FORMATION 34
5.2.2. AQUIFER TYPES, DEPTH AND LATERAL EXTENT 36
5.3 HYDRAULIC CHARACTERISTICS 37
5.3.1 Pumping test type and duration 37
5.3.2. Hydraulic conductivity 43
5.3.3. Transmisivity 45
5.4. GROUNDWATER SOURCES INVENTORY 45
5.4.1. Hand dug wells 45
5.4.2. Boreholes 46

6. GROUNDWATER FLOW SYSTEMS 48
6.1. GENERAL 48
6.2. GROUND WATER SOURCE, RECHARGE AND DISCHARGE 49
6.2.1. Ground water Source 49
6.2.2. Groundwater Recharge 49
6.2.3. Groundwater Discharge 51
6.3. GROUNDWATER MOVMENT 51
6.3.1. Flows in the vicinity of Koka Dam for shallow aquifers 52
6.3.2. Flows in the vicinity of Lake Ziway from shallow aquifer System 53
6.3.3. Flows in the vicinity of Lake Ziway from Deep aquifer System 55
6.3.4. Flows with in the corridor in Shallow aquifer System 56
6.3.5. Flows with in the corridor in Deep aquifer System 59
6.3.6. Flows with in the corridor from hand dug Wells near to lakes 63

7. H Y D R O C H E M I S T R Y 65
7.1. GENERAL 65
7.2. SAMPLING SITES AND METHOD 67
7.3. IN-SITU PARAMETERS MEASURED IN THE FIELD 68
7.3.1 PH (hydrogen ion activity) 69
7.3.2. Electrical conductivity (EC) 70
7.3.3. Total dissolved solids (TDS) 72
7.3.4. Redox Potential (EH) and Temperature 73
7.4. CLASSIFICATION AND PRESENTATION OF LABORATORY MEASURED PARAMETERS 74

7.4.1. GRAPHICAL PRESENTATIONS.....74
7.4.1.1. Box and Whisker for Major ions chemistry.....75
7.4.1.2. Piper diagram and Water types..... 77
7.4.1.3. Schoeller semi-logarithmic diagram.....82
7.4.1.4. The Spatial Distributions of the Major Ions Compositions.....82
7.4.2. SPATIAL TRENDS OF THE CHEMICAL PARAMETERS OF WATER SAMPLES IN THE STUDY AREA 86
8. S Y N T H E S I S.....96
9. CONCLUSIONS AND RECOMMENDATIONS.....102
REFERENCE.....107
APPENDIX 111

LIST OF FIGURE

Figure 2.1. Location Map of the Study Area.....6
Figure 1.2. Topographic map and the geomorphic features.....8
Figure 2.3. Shaded relief maps with Main drainage of the corridor.....10
Figure 3.1. Geological Map of the study are area.....19
Figure 3.2. Geological Cross-sections along Line X-X'.....20
Figure 3.3. Geological Cross-sections along Line C-C'.....20
Figure 3.4. Geological Cross-sections along Line A-A'.....21
Figure 3.5. Structural Map of the study area.....23
Figure 5.1. Analysis of well by using pumping test data for Areta well.....40
Figure 5.2. Analysis of well by using pumping test data for Denebe well.....41
Figure 5.3. Hydrogeological Map of the studied corridor.....44
Figure 5.4. Distribution of Hand Dug wells along the lakes.....46
Figure 5.5. Distribution of Deep and shallow wells with in the corridor.....47
Figure 6.1. Recharge and discharge zones from elevation contours.....50
Figure 6.2. Groundwater flows near to Koka dam for shallow aquifer.....53
Figure 6.3. Ground water flowsin the surroundingof Ziway Lake from Shallow wells.....54
Figure 6.4. Ground water flows in the surrounding of Ziway Lake resulted from deep wells.....56
Figure6.5. Ground water flows with convergent and divergent

Zone resulted from shallow well…………58
Figure 6.6. Groundwater flows direction resulted from deep well…………60
Figure 6.7. Groundwater flow direction from deep well data and detail frequency of vector map…………61
Figure 6.8. Difference in GW flow direction between shallow and deep wells……63
Figure 6.9. GW flow direction of HDWs along the lakes…………64
Figure 7.1 Water sampling sites…………68
Figure 7.2. Trend of pH in the area form HDW & certain boreholes…………69
Figure 7.3. Trend of pH in the area for all water…………70
Figure 7.4. Electrical conductivity Map…………71
Figure 7.5. TDS Map…………72
Figure 7.6. Semi-log plot of major ions concentration of Ground Water…………76
Figure 7.7. Semi-log plot of major ions concentration of Surface Water…………77
Figure 7.8. Piper plot of all water sources…………78
Figure 7.9. Piper plot for all Boreholes…………80
Figure 7.10. Piper plot of all Geothermal Water…………80
Figure 7.11. Piper plot of all Hand dug wells…………80
Figure 7.12. Piper plot for lakes water…………81
Figure 7.13. Piper plot for rivers water…………81
Figure 7.14. Piper plot for spring water…………81
Figure 7.15. Schoeller plot of all water sources…………82
Figure 7.16. The distributions of major cations and anions in groundwaters……… 84
Figure 7.17. The distributions of major cations and anions in groundwaters………. 86
Figure 7.18. Lateral trend of Chloride from all water sources…………88
Figure 7.19. Lateral trend of Sodium from all water sources…………89
Figure 7.20. Lateral trend of Bicarbonate from all water sources…………90
Figure 7.21. Lateral and vertical distribution of Fluoride…………94

LIST OF TABLES

TABLE 4.1. Physico-Chemical analysis of Lake Ziwa…………28
TABLE 4.2. The Koka Reservoir Data…………29
TABLE 5.2. Aquifer Parameters (Areta well)…………42
TABLE 5.2. Aquifer Parameters (deneba well)…………42

LIST OF PHOTOS

PHOTO 4.1. Partial View of Lake Ziway with its islands……………………………………………27
PHOTO 4.2. Partial View of Koka Dam……………………………………………………………………30
PHOTO 7.1. Dental and skeleton fluorosis effect…………………………………………………92

LIST OF APPENDICES

APPENDIX 1-Field measurements for HDWs……………………………………………………………I
APPENDIX 2-Reading in UTM and SWL fro deep and shallow wells…………………………IV
APPENDIX 3-In-Situ Water quality parameters measurements ………………………………VI
APPENDIX 4-Physico-Chemical Analysis result for Shallow and deep aquifer………VII
APPENDIX 5-Spatial Fluoride distribution in the Main Ethiopian Rift Valley…………..X
APPENDIX 6-Satellite image of the studied area………………………………………………………XI
APPENDIX 7- Lithological log……………………………………………………………………………L1-L10

Abstract

The studied corridor, part of the Main Ethiopian Rift, has been delineated so as to include eastern and western escarpment, floor of the rift, and the Lakes Ziway & Koka Dam. All of which has the total aerial coverage of almost 6000 sq. Km.

Geological coverage of the studied area is dominated by Lacustrine deposit at the floor of the rift, which is followed by other sub formation.

Integrated methodology and approaches are conducted to observe the groundwater flow system and to determine hydrochemistry (water potablity) of the corridor. Both of which are interrelated each other and brought the same output.

Groundwater flow system are considered as shallow and deep aquifer cases and the output indicate that the existence of flows in a separate way in the two systems. For the deeper case, groundwater migrates from southern to northern part of the study corridor which is disproving/ rejecting the previous work. For the shallower case, groundwater migrates from north western to south eastern of the corridor.

Hydrochemical data shows: evolution of major ions, water types, potablity of water for human consumption, fluoride lateral & vertical distribution, which is the main problem in the Ethiopian Rift, and direction of groundwater flow.

Graphical presentations of the physical and chemical parameters of the water samples provide a good deal of information on the characteristics of ground water flow systems, recharge and discharge zones, and evolution of major ions in the corridor.

Appropriate software like Global Mapper, Surfer, ArcView, Aquifer Test, Aquachem, AutoCad and others employed to facilitate analyses and interpretations of the data in order to get the output.

CHAPTER ONE

INTRODUCTION

1.1. GENERAL

The Ethiopian Rift System, which is part of the east African rift system and divided in to South-western rift zone, the main Ethiopian rift and Afar.

The main Ethiopian Rift (MER), which is the extension of East African rift, divides Ethiopian into north-western plateau and south-eastern plateau extends for about 650km from South-western rift zone from the south to the Afar depression to the north and its average width is about 80km. The main Ethiopian Rift forms a NNE-SSW trending graben between the Ethiopian and Somalia plateaus and characterized by extensional faults which are associated with various volcanic episodes. A number of studies reported that the main Ethiopia rift with intense faulting in N-S, NE-SW

NNE-SSW direction was developed due to extension processes associated with mantle plume activities.

The study corridor is part of MER which consists of a rift lake-Ziway and an artificial Dam-koka for the Hydropower and irrigation purpose. Most part of the study area is on the floor of the rift and covered by Lacustrin sediments together with other geological formation. Awash river which is the basis for the construction of the Dam, Meki River which feed to Lake Ziway, Bulbula and katar rivers outlet of Ziway lake are the existing and observing rivers with in the study corridors. Marsh and Swampy area also observed near to koka Dam and Ziway Lake.

Because of Volcanic and tectonic process, the area contains scenic topographic features, fertile soil, Surface and ground water potential. Although most of the farmers in the rift floor depend on seasonal rains, irrigation in small skim techniques are being developed to cultivate farmlands close to the lake and the Dam. Currently flower farm is the growing horticulture industry in the study area by using lake water (Share Ethiopia-the largest flower farm in the country) and ground water in the adjacent area of the reservoir (Red Fox). Even though the demand of fresh flower for domestic and international consumption is ascending, the way they produce by using chemicals is directly polluted both surface water and ground water.

Determination of Groundwater flow direction within the corridor is one of the objectives of the study so as to solve the scientific problems together with comparative water quality of the area to recommend the water quality standard based on WHO in order to solve community based problems.

According to the previous work (Tesfay Charnet,1982), there is groundwater divide between Lake Ziway and Koka Dam near to Meki town or around 125 km driving from Addis to Ziway. On the other hand, the reservoir floor of Koka Dam is a discharge area for local and regional ground water flow (Silesh Mamo, 1995).

In-situ water quality measurements have been conducted in the field together with sampling of water to get physio-chemical analysis result from laboratory. Concentration of Fluoride in the study area is very high and major source of fluoride in the rift valley water is considered to be the dissolution of acid volcanic rocks, which are rich in fluoride. Its concentration has a great impact on the tooth of children and Spinal cord of old men and women.

1.2. PREVIOUS WORK

The study area is merging two basins, the lakes region and the Awash basin. Even though these basins are extensively and separately studied by different researcher on regional to detail geological, hydrogeological, and hydrological and hydrogeochemistry, the complexity of the area has not yet got a solution.

Among the works, Berhane Melaku, (1982) hydrogeology of the Upper Awash Basin Upstream of Koka Dam. Getahun Kebede,(1987) Hydrogeology of Nazret Area. Kazmin,V, and Seife Michael B.(1978) Geology and Development of the Nazret Area, Northern Ethiopia Rift. Tsegaye Abebe, (1987). and Giday Wolde Gabriel,(1990) have yielded important clues and information about the geological and hydrogeology of the area.

More valuable works related to the Koka dam reservoir hydrological balance & leakage phenomena, and paths were done by Sogreah/FAO (1975). Meachem, (1972), Gibb, (1975) who revised Meachem works, and Halcrow. These authors from reservoir hydrological balance view point considered leakage loss through the whole reservoir bed sediments but their assumption has been disprove by Sileshi Mamo, (1995) and on his conclusion the potential leakage area is known to be in the right north east shore of the lake along the intensive fault but the rest part of the lake including its bed are received water from regional and local area.

Tesfaye Chernet, 1982. Hydrogeologic map of the lakes region (with memo).
Tesfay Chernet, (1978 & 1985). Hydrogeology of the Lakes Region and Hydrogeology of Ethiopia and water Resources Development respectively.
Tenalem Ayenew, 1998. The hydrological system of the Lake District basin, central main Ethiopian rift. Ph.D. Thesis, ITC Publication, 259pp.
Tenalem Ayenew and Tamiru Alemayhu, 2001. Principle of hydrogeology
Tenalem Ayenew, 2002. Recent changes in the level of Lake Abiyata, Central Main Ethiopian Rift. Hydrological science 47 (3), 493–503.
Even though the current study use the necessary data from the previous work, the expected result, the geological Map, Hydrogeological map and any other new out put of the corridor is updated by the author.

1.3 OBJECTIVE OF THE STUDY

GENERAL OBJECTIVE

- Determination of groundwater interaction and its flow direction between Lakes region and Koka basin.
- Comparable determination of Hydrochemistry (water quality) in the study area (Main Ethiopian Rift) for the utilization of human consumption by using Physio-chemical analyze of sampled water.

SPECIFIC OBJECTIVES

- To determine groundwater level by using ground water contour map (using static water levels of Hand Dug wells, deep & shallow Boreholes).
- To show the regional and local flow systems of ground water in the Corridor.
- To prepare new geological map with in the selected corridors (lake Ziway and Koka Dame).
- To prepare hydrogeological map of the study corridors
- To study the different aquifer parameters and mapping them.
- To map and determine the concentration of Fluoride with in the studied corridor.
- To suggest how to plan, develop and environmentally safeguard the water resources in the areas.

1.4 RESEARCH APPROACH AND METHODOLOGY

The project work began with primary and secondary data collection in the field as well as in the office and all relevant available data related to geology and tectonics, hydrogeology, hydrology, hydrochemisrty and well data inventory has been acquired.

The activities undertaken included:

- Literature review, survey and analysis of previous works in the study area and around the corridors.
- In-situ test of water chemistry, lithology description, sampling ground water using systematic geo-traverse.
- TDS, Chloride, Sodium and Bicarbonate mapping of the corridors so as to show the flow direction of the ground water of the study area.
- Interpretation of satellite imagery of the area.
- Laboratory analysis of water in order to observe the existing cat ion & anion and determine comparative water quality of the selected area of the rift.
- Interpretation of data in accordance with the field observation, literature and laboratory analysis.
- Using Remote Sensing and Geographical Information System Methods for preparation of maps.

CHAPTER TWO

STUDY SITE DESCRIPTION

2.1. LOCATION , ACCESSIBILITY AND AERIAL EXTENT

The study corridors is located in central Ethiopia and with in the Main Ethiopian Rift which is range from Km 90 at the small village called Ejersa in the north to km 190 at the town of Bulbula in the south along the asphalt road running from Addis Ababa to Shashemene. Its lateral variation varies a little far from Koshe in the west to Asela in the east.

Geographically it is bounded with in the limits of 7^{0}43'–8º33'N latitude or 854542-945885 UTM (ADNDA) and 38º29'–39º17' E longitude or 443174-531360 UTM (ADNDA) (Fig 1). With an aerial extent and perimeter of 5376Km^2 and 304Km respectively.

The area is accessible through an Asphalt road, which goes from Addis Ababa to Awassa. There are all weather, seasonal gravel roads and natural rift floor, which go from major town to different direction in the study area and have a good connection that enable to access in every direction to villages, small towns and almost to all constructed water schemes which are motorized Boreholes, Wind mills, Hand pump boreholes and Hand dugs. All of this accessibility is because of the nature topographical appearance of the rift floor together with the constructed roads.

With in the corridors the accessible towns and small villages are Ejersa, Koka, Kintiri Alem Tena, Ogolcha, Meki, Ziway, Koshe and bulbula.

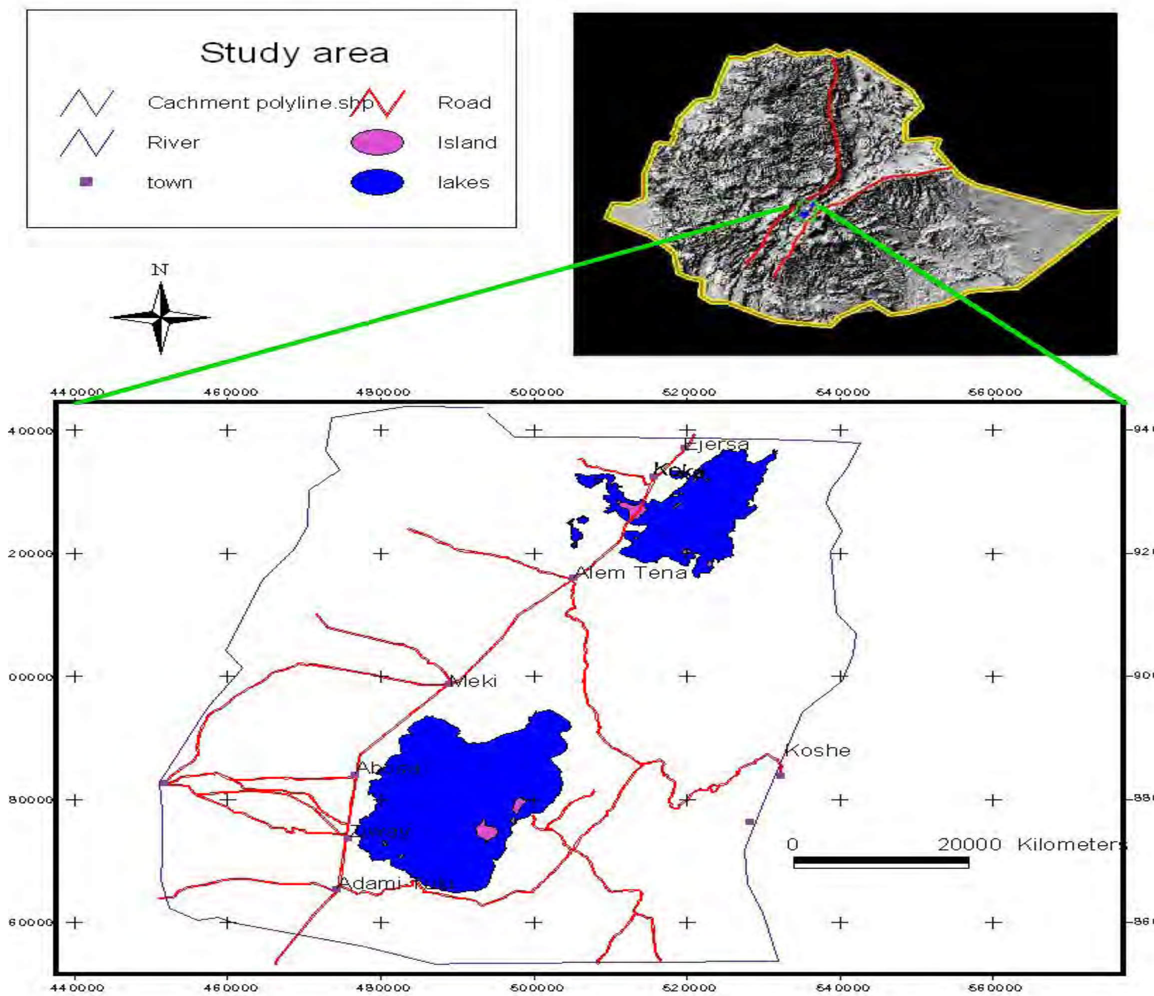


Figure 2.1 Location Map of the Study Area

2.2 CLIMATE

The Climate is generally semiarid in the study area. The mean precipitation is no more than 650 mm in the vicinity of Lake Ziway and for that of koka rises a little of 700-800 mm which was reported in the Hydrogeological map of Nazret sheet.

Rainy and dry periods in the study area are reported to be June to September and October to February, respectively. In the month of March and May small rains occur. When this study was in progress, the intensity and duration of rain fall with in the study area and other part of the country was unexpectedly very high. This uncommon situation of the precipitation has to be considered though out the study.

The highest and the lowest mean monthly temperature were 27^0C and 18^0C respectively while the main daily air temperature was 21.60C. Mean annual temperature of 21.25^0C and 19.95^0C were also reported to Koka and Wonji stations and the annual daily temperature for 1985 was 20.32^0C.

Mean monthly evaporation rate is generally reported to be much higher than the mean monthly precipitation both in the koka and wonji station the whole rift valley (sileshi, 1995,).

2.3 TOPOGRAPHY

The topographic appearance of the corridors is dominantly covered by the rift floor of low altitude vary as 1590 meter above sea level (m.a.s.l) to 1770 m.a.s.l and the western and eastern part of it, has small portion of rift escarpment and a little part of high lands. (Fig.2)

Existing mountain with in the corridors are Zik Wala, Bericha & Bora and Aluto Volcano which are concentrated on the Northern, Central and southern part of the study area respectively. Based on their altitudinal range or peaks range they can be ascend as Aluto - Bora (2085 m.a.s.l) - bericha (2505 m.a.s.l) -Zik Wula (2939 m.a.s.l). Lowest elevations with in the area are Koka Dam level (1589 m.a.s.l), Lake Ziway level (1637 m.a.s.l.), and gorges just like that of Awash and Meki Rivers.

Relative to the western margins, the eastern rift margin is marked by deep gorges and canyons due to the existence of large regional marginal fault system.

Calderas are observed in the study corridors at the eastern part of Koka Dam called GEDEMSA, south- eastern part of Lake Ziway called Gademota Caldera.

With in the two water body, Lake Ziway - Koka Dam, the floor of the rift slightly elevated away from each water body and form highly elevated mounts called Bora and Bericha along them, the previous investigator consider it as the ground and surface water divide.

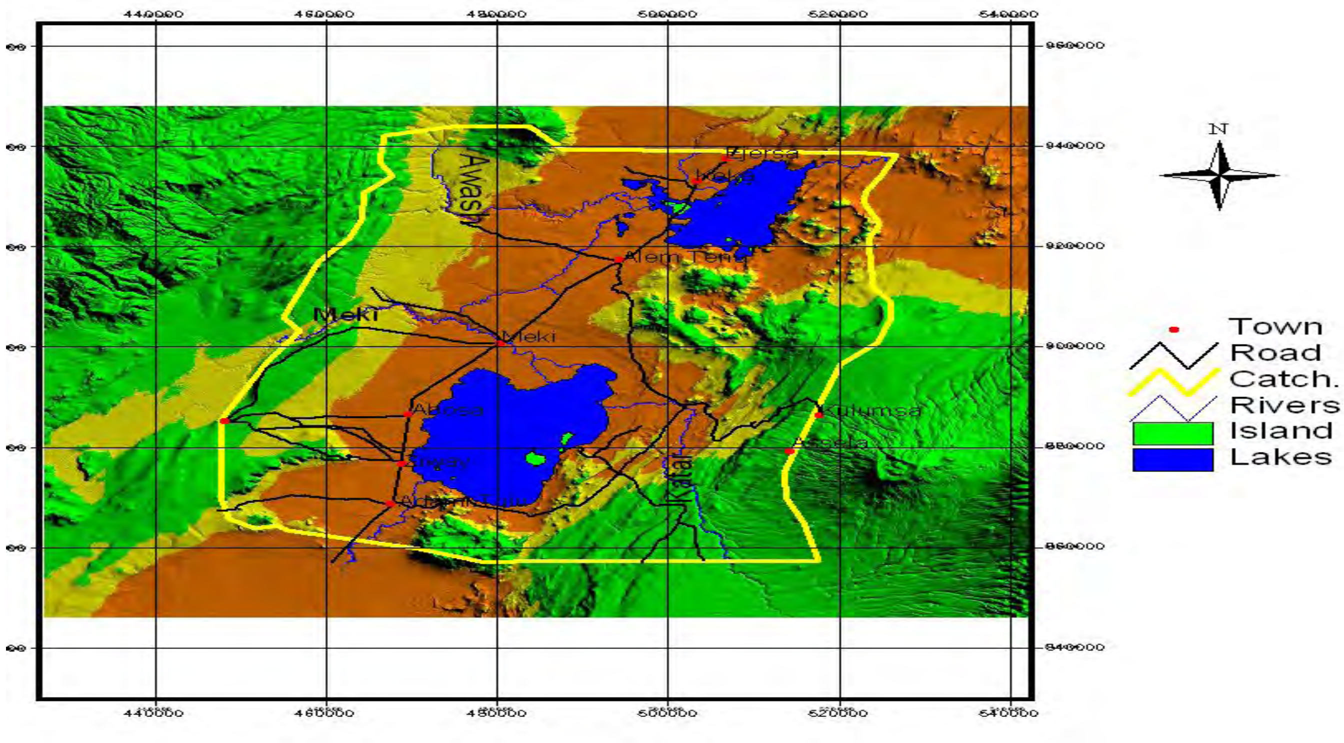


Figure 2.2 Topographic map and the geomorphic features

2.4 DRAINAGE

Awash, Meki, Katar and Bulbula are the main and crucial rivers for scientific and economical purpose which are drained the study corridor.

Awash River, economically important for Hydroelectric power and irrigation, flows southeast from high mountains at the western margin of the main Ethiopian rift, west of Addis Ababa, in a relatively steep gorge up to 25 km up steam of the koka Dam with very low gradient. Immediately downstream from the Koka Dam, the Awash River formed relatively deep gorge on the up faulted and fault dissected horst, and meanders up to Awash Melkasa. The river has relatively narrow course/out let across Hippo fault scarp, at Wonji Gorge.

Meki river is one of the feeding river to the lake ziway on its north western part which raise from the gurage high land about 462 hectares of land is currently under cultivation using Meki River and its tributaries up stream of Meki town (Alemu, 2006) other than this the river contribute large sand deposit and supply to different town including Addis Ababa.

Katar River is another feeding river on the eastern part of the lake Ziway which raise from the Arsi high land. Large scale irrigation was started in Katar catchment in mid 1980’s by Katar irrigation Project. Since then, irrigation demand has been increasing by using the river and its tributaries.

Bulbula River is an out let for Lake Ziway on the south western and as feeding river for Lake Abyata.

Generally, tributary drainage are fine dendritic to sub-parallel. Patterns are controlled by topography and structures. Drainage density is generally low as shown.

2.5 POPULATION

2.5.1 Human

The total population in the study area was estimated based on the Statistical Abstract, 2005, prepared by Central Statistical Agency. Accordingly, the population size of the catchment’s area is about 1,970,451 as of July 30, 2005.

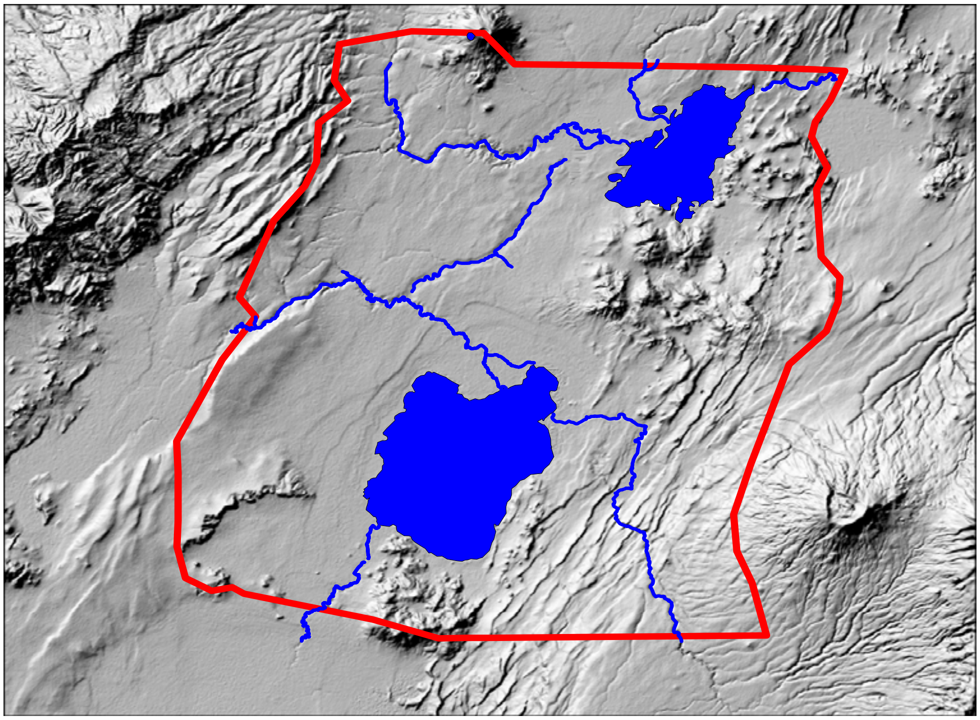


Figure 2.3 Shaded relief maps with Main drainage of the corridor

2.6. GROUND WATER DEVELOPMENT

2.6.1 Public Consumption

In the northern part of the study corridor, the main source of water for public and livestock watering is the Koka Lake and the Awash River. The hot thermal groundwaters and springs are often used for washing, livestock watering and curative purposes.

Kintiri, small town on the west of the Dam, its groundwater totally thermal in nature and water consumption for the community is drained from koka towm which has one borehole a little far from Kintiri.

Central and southern part of the study corridor; water for the public consumption is developed from ground and lake water. Alem Tena, Meki, Abosa, Ogolcha, Adami Tulu and Koshe extract ground water for drinking. Ziway town's community use both Ground water and lake-Ziway surface water for public consumption. Regarding to the water quality, almost all part of the study area, fluoride concentration is beyond its normal concentration and affect the communities health.

2.6.2 Irrigation

Irrigation scheme is highly observed in the area particularly in the vicinity of Lake Ziway and Koka Dam so as to produce flower, sugarcane, tomato, onion and vegetation. Since the irrigation in this area is a year-round process, its effect on the water level is magnified, especially during times of low precipitation and high evaporation (Zinabu and Elias, 1989). Several rivers that flow into one or more of the rift-valley lakes have been diverted for irrigation. The rivers Meki and Katar and the Bulbula and Gogessa rivers, which flow into Lake Ziway and Lake Abiyata, respectively, are being used for irrigation. This practice has caused water level subsidence in both lakes because of the reduced inflows.

Out of environmental impact, irrigation also causes surface and ground water pollution. Flower farms Red Fox and Share Ethiopia discharges highly polluted water on the vicinity of Koka Dam and Lake Ziway itself respectively.

CHAPTER THREE

GEOLOGY

3.1 REGIONAL GEOLOGY

The geology and stratigraphy of the study area was studied by different groups and researchers. The present study of the geology of the study area is based on field observation by taking traverse, observing geological logging of wells in different part; review of previous work and by referring geological map which is published by Geological Society of America at a Scale 1:200,000. (Tsegaye Abebe, Piero Manetti, Macro Bonini, (2006) and others).

According to Kathy Stewart and Nick Rogers (1996), magmatism and extensional processes, which resulted in the MER and sea floor Spreading in the red and Gulf of Aden, is related to Afar Plume. Ebinger and Sleep (1998) have also conducted that uplifting, magmatism and extensions in Ethiopia and East Africa is attributed to a single plume activity beneath Ethiopian plateau (Afar Plume).Extensional processes commenced after volcanic activities in Ethiopian plume activities.

Geological map also included in this study shows that the nature of consolidated and unconsolidated material comprising the area being investigated. It shows the rock type and the distribution of geological structure. The cross section also displays to show the various formations, their thickness, and stratigraphic relationships to other formation.

According to Giday Woidegebriel et al. (1990), the MER development is related to volcanism. They believed that the initial rifting began in the Oligocene-early Miocene, and the stages of MER development are proposed:

- In the late Oligocene nearly Miocene the first Tertiary Volcanism dominated by basaltic rock occurred, which forms a Series of half graben with opposed border faults of greater than 60̃ dip.
- In middlẹ Miocene an important volcanic event occurred which is associated with the edification of the main Ethiopian Rift and it is dominated by Rhyolitic rocks.
- In Late Miocene- Early pliocece another very large volume basaltic eruption occurred, whichfrd was associated with the full development of the MER by forming or evolved into symmetrical grabens.

- Finally in the Pleistocene Volcanism dominated by Rhyolitic rocks occur which is the youngest and associated with the rift reorientation and the formation of the Wonji Fault Belt which is the active axis of the Main Ethiopian Rift.

Wonji Fualt is the most active part of the MER which shows a graben with in a large graben or a rift with in a rift and are oriented NNE-SSW like that of MER. The MER extends from south of lake Chamo in Southern Ethiopia to the lake Abbe area in Central Afar.

The study area is situated with in the floor of the Central and North sector of the main Ethiopian Rift.The central part of the MER itself is more than 175Km long and 75km wide, widening to wards the northeast and narrowing south ward (Mohr, 1967)

Cenozoic rocks of the central sector divided into six chronostratigraphic units from Oligocene to Quaternary, according to Giday Waldegabriel et.al (1990) and the classification is based on K/Ar ages and lithologic correction. As follows:

Stratigraphic sequence in the Central Sector of the Main Ethiopian Rift

UNIT	EPOCH	AGE
Wonji Group	Quaternary	< 1.6 Ma
Chillalo Trachyte	Middle to Upper to Pliocene	< 1.6-3.5
Butajira Ignimbrite	Upper Miocene to Middle Pliocene	3-3.5 Ma
Guraghe Basalt	Middle to Upper Miocene	8.3-10.6 Ma
Sheble Trachytes	Upper Oligocene to Middle Miocene	12-17 Ma
Kella Basalts	Lower Oligocene to Upper Oligocene	12-17 Ma

Kazmin and Seifemichael (1978) mapped the North Main Ethiopia rift between 80-90^0Nlatitude, and39-$40^0$30Elongitude, at a Scale of 1:250,000. They reconstructed the following stages/episodes of volcanic activities.

.

- Nazret Group Volcanic eruption associated with the first of rift development since 9ma.

- Nazret Ignimbrite expantion and trachytic volcanic at the right shoulders, between 4.5-3.5 Ma (second stage of rift development. This is followed by Bofa basalt eruption (3 or 3.5Ma) that overlies Nazret Group
- Dino ignimbrite eruption, between 2-1.5 Ma ago, during the third episode of rifting
- Wonji Group Volcanic activities associated with wonji faulting (less than 1.6Ma), after Bofa Volcanic activity.

Earlier, Di Paola (1972) identified nine volcanic centres in the Ethiopian Rift Valley between 7000' and 8040' latitudes north, from north to south, they are:

1. Zik Wala Volcanõ Located about 20Km SW of Mojọtown and made up of several thick and viscous alkali trachitic lava flows.

2. Boseti-Gudda and Boseti-Bericcia Volcanic Complex-Located about 15km east of Nazaret town, close to the eastern escarpment and consisting mostly of very recent pantelleritic obsidian lava flows associated with pumice and ashes.

3. Gadmsa Caldera Volcano This is located adjacent to the Wonji sugar estate farm and formed mostly by rhyolitic with pumice and ignimbrites.

4. Bora-Bericcio volcanics Complex- lacated between Koka Lake and Ziway Lake close to the eastern escarpment. The volcanics are formed in late Pleistocene-Holocene and cosist of two large volcanic centers (Bora and Bericho) associated with a great number of smaller volcanic foci and with sub historical limited fissure eruptions. Most of the products found in this area are silicic pyroclastics. Two of them is located on the central part of the study area and consists of alternances of pumice and ash.

5. Chillalo Volcano- located about 30km east of Lake Ziway, on the eastern escarpment and mostly constituted by thick alkali trachytic lava flows.

6. Badda Volcano-located just east of Chilallo and majority of the products are alkali trachytes.

7. Aluto Volcano- located between lake Ziway and Lake langano, clos to the eastern escarpments of the wonji fault Belt and constituted by silicic pyroclastics such as pumice flows, pumice falls and ashes, with subordinate rhyolitic lava flows, mostly obsidians.

8. Lake Shalla Caldera-located along the Wonji Fault Belt and the caldera cuts mostly ignimbrites pumice deposits of “Sillar” type and some rhyolitic lavas.

9. Corbetti Caldera-lacated between lake shalla lake Awassa, along the axis of the rift (Wonji Fault Belt) and mostly consists of pumice flows and pumice falls with subordinate obsidian lava flows.

3.2 GEOLOGY OF THE STUDY AREA

Dominante geology of the study area is lacustrine sediments of sand and silt with abondand components of volcanic origin and their age is less than 500Ka. Eventhough these sediments cover the largest part of the study area, there are also Wonji Basalt, Bora-bericha Lacustrine Sediments, Zikwala Trachayte, Chefe Donsa Pyroclastic Deposits, Bofa Basalt, Nazret Pyroclastic Rocks, Gedamota slop deposits, Aluto Volcanics and Jimma Volcano. A composite stratigraphy of the area has been reconstructed based on secondary datas specially Tsegaye Abebe, (2006), well log data and field investigation.

All the above mentioned formation can be categorized and classified on the basis of MER characters which include Main-Rift, Rift-shoulder and Syn-Rift.

3.2.1 MAIN RIFT

3.2.1.1 Wonji Basalt (Wba,Wbb) (Pleistocene-Holcene < 1.6 Ma)

This group found on the south-East part of the study area and dominated by alkaline to olivine lava flows with minor tholeiites, hawalites and benmoreites. Scoria cone,fall-out deposite, plagioclase porphyry basalt lava also seen with in the group.

The maximum exposed thickness of basaltic lava flows is 10m, from water well drilling cuttings at wonji suger head quarter, it was observed that red scoria occurs between 22-28m underlying unconsolidated lacustraine sedments and dark olivine porphyry basalt is found between 28-48m. The age of the group ranged Pleistocene-Holocene (<1.6 Ma).

3.2.1.2 Bora-Bericha Rhyolite (Pleistocene-Holcene < 1.6 Ma)

This group is surrounded the Wonji almost in all direction with variable lithological formation that characterize by peralkaline trachytes and rhyolites with comenditic and pantelleritic affinity of the central volcanos such as Bede Gebabe, Baseti, Gedemsa, Bericha, Bora and Tullu moye.

Sub division of the Group:

- Pyroclastic deposites,fine ash falls and flows with exposed thickness of>200m and which is the dominante of the group including Bora and Bericha mountain and Gebemsa caldera
- Comenditic and pantelleritic lava flows and domes with exposed thickness of about 50m
- Pheatomagnetic phreatomagnetic deposite which dominated on the north-east flank of the Gedemsa Caldera with the exposed thickness of 10m.
- Obsidian lava flows and domes with exposed thickness about 50m.
- Porphyritic glassy trachayte lava flows with maximum exposed thickness of 20m.

Age of this group is the same as that of wonji basalt.

3.2.1.3 Lacustrine sediments (Ls) (<500Ka)

These are the largest portion of the study area predominantly sand and silt with aboundant components of volcanic origine. In the rift, these deposits exist in the vicinity and beneath the beds of Lake Ziway and koka dam mixed with volcanoclastics. The sediments have a varied lithology related to their mode of origin whether they were inactive lake deposits, water deposited volcanic ejecta or coarse sediment introduced into the lakes by flood events (Tenalem Ayenew, 1998).Drilling Cuttings, from borehole with in this formation indicate as follows and its thickness also estimated at about 600m.

3.2.1.4 ZiK Wala (1.28-0.85 Ma)

This group is found on the North-west part of the study area with an elevation of 2039m. Its lithology range from dark gray, aphyric to phyric lava flows with interbebbed pyroclastics. At the hill of this formetion there is a small lake called Zik Wala Lake. The age of Zik Wala Mountain is 1.28-0.85Ma.

3.2.1.5 Chefe Donsa Pyroclastic Deposites (CDp) (2.54-1.7 Ma)

It has coverage of South-west, North-west and south –east of the study area which is unwelded to poorly welded, volcanic ash flow and fall deposits.The formation is mixed with Nazareth group like rhyolitic, trachytic lava domes and welled pyroclastic flows. Their thicknesses vary from a few meters to 40m.

3.2.1.6 Bofa Basalt (3.5-1.6 Ma)

This is the smallest formation of the study area on the North-east part surrounded by wonji basalt,Bora-bericha rhyolites.Its rock are plagioclase phyric basalt lava flows withsubordinate fine grained and and Scoriaceous varities.

3.2.1.7 Aluto volcanics

This group representing multiple flows dominated by pumice, ash recent obsidian flows. Coarse pumice interbedded with sediments encountered in drill holes at Aluto caldera represent sub aqueous ignimbrite flows. The predominated of pumiceous sediment indicates that there was intense rhyolithic volcanism during the late period of sedimentation. Aluto caldera is reported to be older than Corbetti and shala Caldera (Tenalem Ayenew, 1998).

3.2.1.8 Gedamota Slope Deposite

This is composed of very thin alluvio-colluvial,volcanic clastic and fluvio-deltaic deposite,resting erosively on older deposits. On the Gedamotta slopes, this unit is represented by alluvial sand and gravel, overlain by alluvially reworked fine-grained greyish tuffs which are located on the west of Lake Ziway.

Gedamota rhyolite is on early Pleistocene alkaline and per-alkaline rhyolitic lava flow and bedded tuff. The Gedamotta ridge is the relict of a large Caldera. After the collapse, the centre of the caldera has been margin exists. The eastern side might have collapsed and has been subsequently buried (Tenalem Ayenew, 1998).

3.2.2 SYN-RIFT

3.2.2.1 Nazareth Pyroclastic rocks (Npc, Npb)

This group found on the North-west, South-west and North-east part of the study area with variable lithological distribution distribution like rhyolite and trachytic lava domes associated with lava flow, perealkaline pantelleritic welded pyroclastic flows and and small coverage of welded peralkaline pantellertic pyroclastic flows with sparse intercalated basaltic lava flows.

According to some Drilled wells in the area, the above geological formation has been conformed.

Rhyolite found within Gedemsa caldera underlying pumice deposit. Pumice deposit is underlain by Rhyolite at different sites in the NW and west outer rim of Gedemsa caldera. Pumice deposite is overlain by rhyolite and underlain by Ignimbrite at the NW inner wall of Gedemsa caldera. Drilling wells around Koshe town (south-western part of the study area) indicate the existence of lithic pumaceous pyroclastic which is vary from highly weathered to slightly fractured in the depth coverage of 196m-243m. These formations correlated with pyroclastic and Basaltic lava flow in the above geological map.

Geological Logging of a Borehole near to Alem Tena shows that, top brownish clay Soil, Volcanic ash, tuff with volcanic ash, welded ignimbrite (39-93m). Ignimbrite is overlain by surface geology which observed in the above geological map.

Well drilling near to Meki town 12Km and 5Km south and north of the town shows that Pumice, volcanic ash, tuff, Sand with volcanic ash and black sand, tuff with volcanic ash, welded tuff & ignimbrite from 7-60m and 11-52m respectively. These formations correlated with Lacustrin deposit of the geological map in the above.

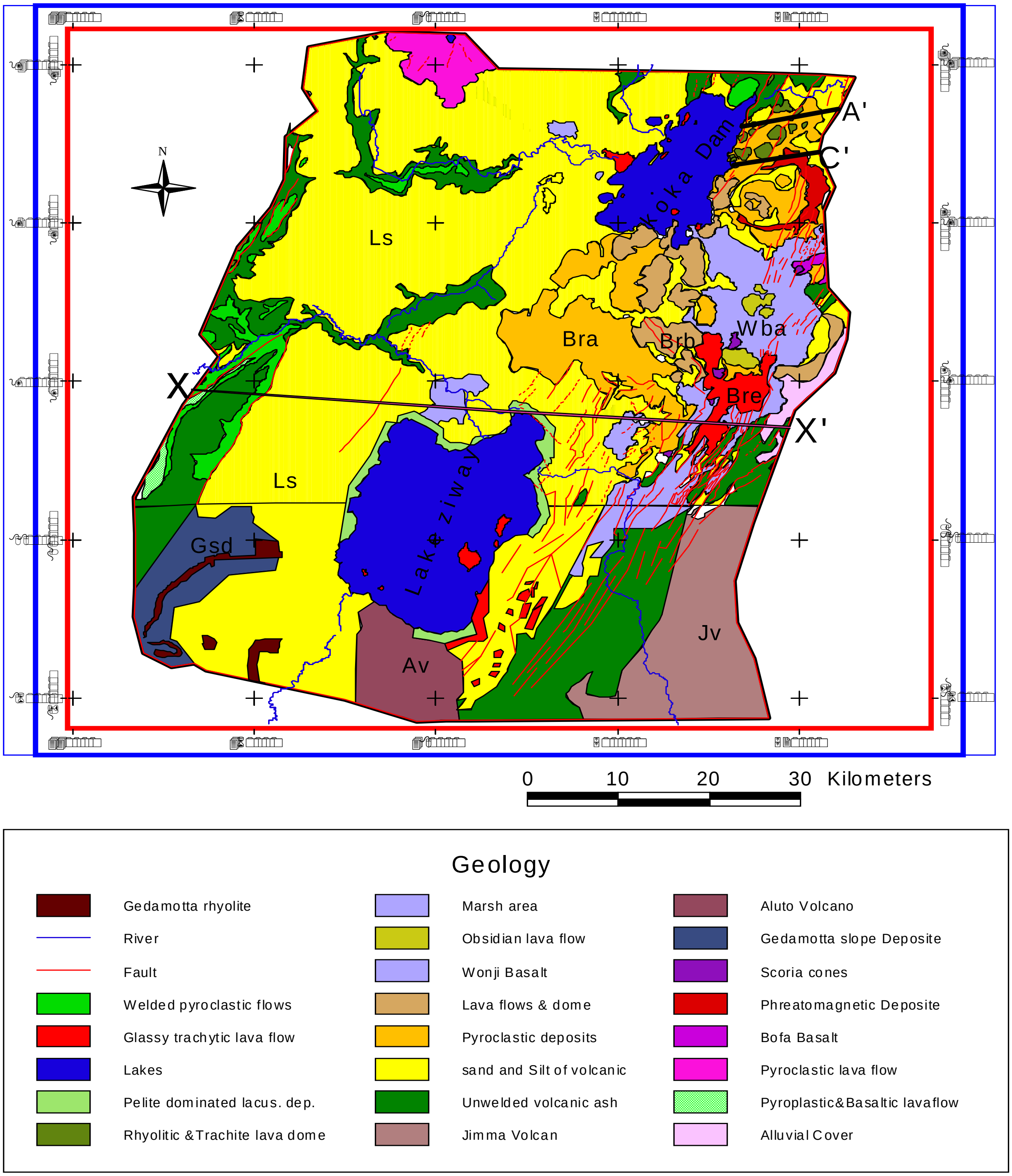


Figure3.1 Geological Map of the study are area.

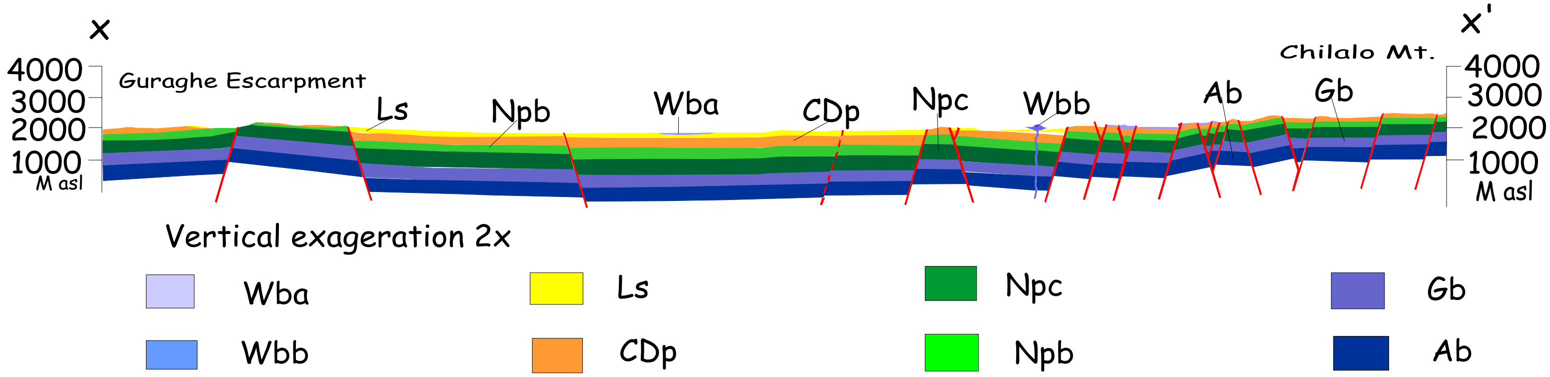


Figure3.2 Geological Cross-sections along Line X-X'

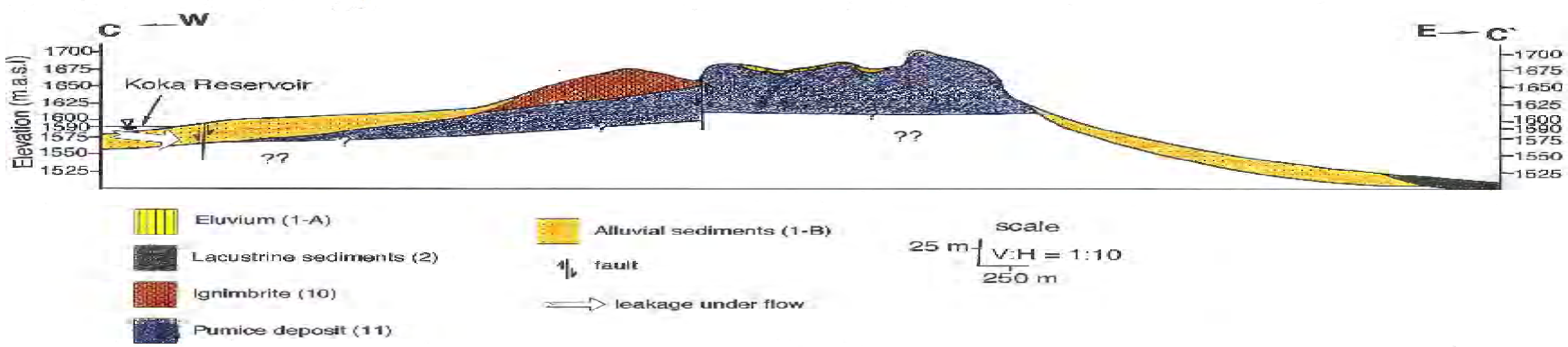


Figure3.3 Geological Cross-sections along Line C-C'

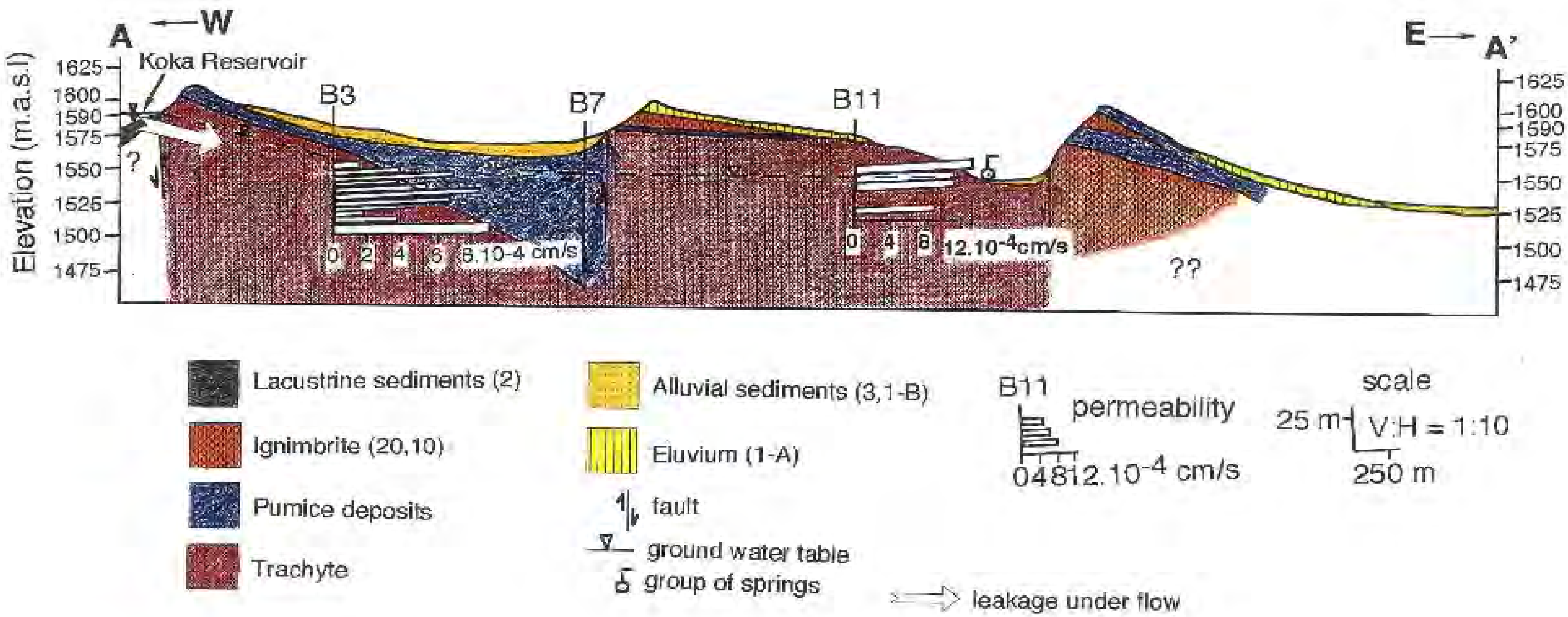


Figure3.4 Geological Cross-sections along Line X-X'

3.3 GEOLOGICA STRUCTURE

The main existing geological structures that have been observed in the studied area include: faults, joints, fractures, calderas, fissures, Cone and Domes.

3.3.1 Fault

The area is intensively divided by a number of minor and major normal faults running almost parallel to each other in a NNE-SSW direction and is usually arranged in “en-echelon” fashions, which belong to the Wonji Fault belt and form graben- horst structures. The faults dissect almost all units outcropping in the area and recent volcanism like Bora and Aluto has been observed to be associated with these faults. Faults are concentrated north-easter part of the study area. Even though their extent is not that many considerable, uncertain and certain faults are observed on the north-western part of the area to Zik Wala Mountaiṇ.

3.3.2. Jointe and Fracture

Jointing and fracture are abundant in welded ignimbrites, rhyolites and recent basalts of the area.

3.3.3 Caldera

Calderas present in the area are the Gademota caldera, Gedemsa caldera and Haya and caldera which are located south-west of Ziway lakes, eastern and south-eastern part of Koka Dam respectively.

3.3.4 Fissure, Cones and Domes

Fissure, Cones and Domes are mainly concentrated along with wonji Fault Belt on the the N-E and S-E part of the study area. The volcanotectonic history of the studied area is part of the volcanotectonic history of the MER and can be summarized as follows based mainly on the available literature (Di Paola, 1972, Giday woldegabriel et,al, 1990).

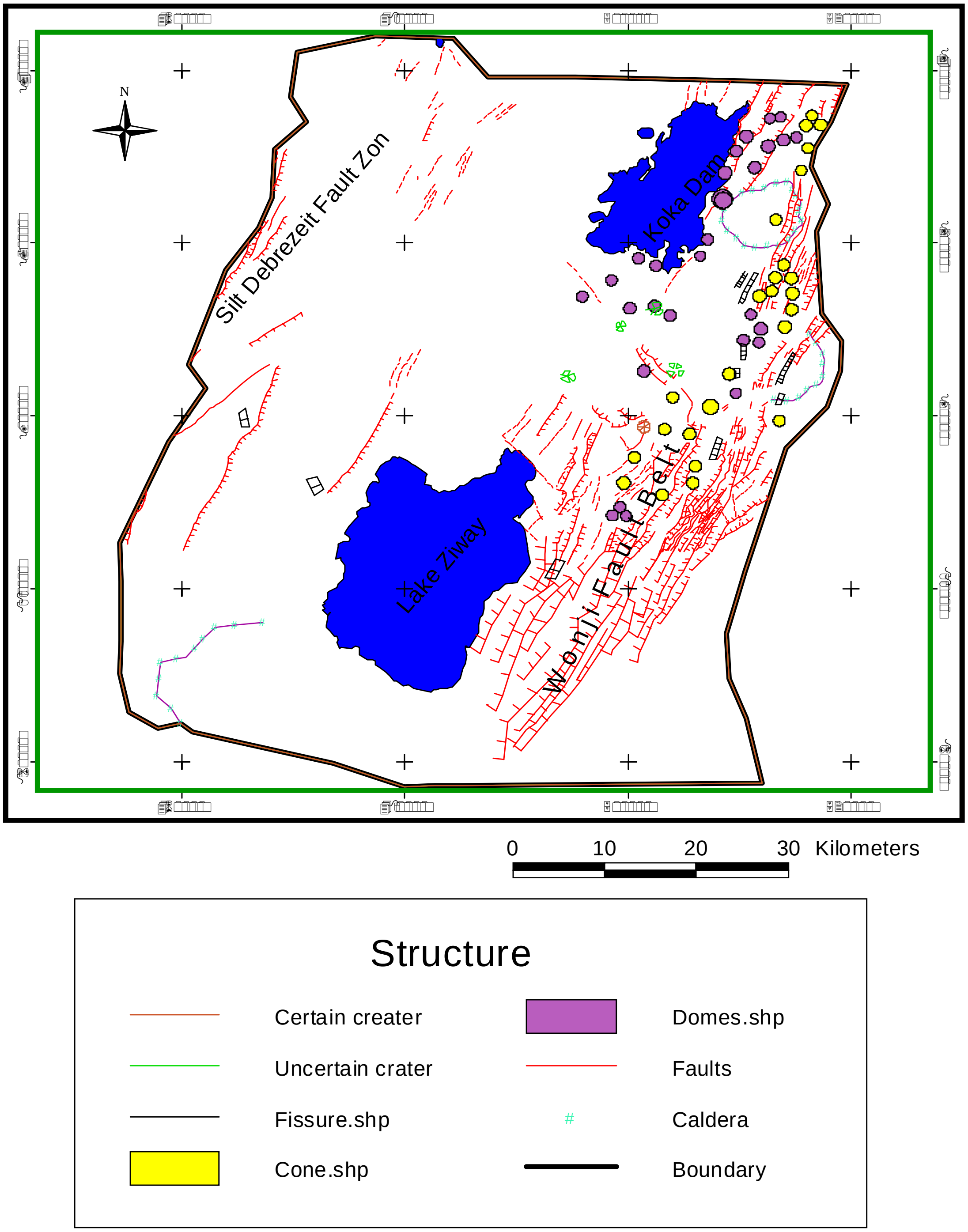


Figure 3.5 Structural Map of the study area

The area has been affected by volcanism since pliocene with fissure eruptions and growth of individual volcanoes, and volcano tectonic activity was episodic.

The eruption of trachytes around Chillalo and Assela occurred in the beginning of the period followed by major border faulting, of the Wonji Fault Belt: following or accompanying the above faulting ignimbrites was erupted associated with pumice, which is highly affected by major faulting. Next the rising of basaltic lava flows occurred, which were also affected by major faulting. This was followed by the emplacement of acidic volcanic lavas. The pumice and rhyolites of Bora and Obsidians of Aluto are the result of this event. Finally minor faulting event occurred, which resulted small cliffs and step faults.

Lacustrine sediments represent the youngest unit in the area which was deposited starting from the time of emplacement of ignimbrites up to the present day.

CHAPTER FOUR

SURFACE WATER HYDROLOGY

4.1. SURFACE WATER HYDROLOGY

Due to natural and manmade action, lakes and rivers are there as the surface water. Lakes included Ziway which is one of the largest rift valley lakes, Koka Dam which is an artificial reservoir constructed based on Awash River and Elen Lake which is a small lake on the western part of Lake Koka. Major Rivers are Awash, Meki, Bulbula and Katar.

4.1.1. AWASH RIVER

The Awash River flows southeast from High Mountain at the western margin of the Main Ethiopia Rift, west of Addis Ababa around Holeta where it collects discharges of many small springs emerging from slopes of trap basalt and ignimbrites (Berhane,1982), in a relatively steep gorge up to 25 Km upstream of the Koka Dam with very low gradient. Immediately downstream from the Koka Dam, the Awash River formed relatively deep gorge on the upfaulted and fault dissected horst, and meanders up to Awash Melkasa. In the downstream area of the dam, minor ephemeral and intermittent stream often flowing only for 3 wet months (July, August and September) feed the Awash River. Internal drainage areas also exist around Gedemsa Caldera area. (Sileshi Mamo, 1995)

The river has relatively narrow course/out let across Hippo fault Scarp, at Wonji Gorge. The Awash River descends from Awash Melkasa, downstream of Wonji Sugar Estate, NE ward with low gradient, except at some volcanic ridge and scarps, to the southern Afar depression where it terminates into the lake Abe, at the border to Djibouti. (Sileshi Mamo, 1995).

4.1.2 MEKI RIVER

Meki River is the feeding river to the Lake Ziway that radiated from the gurage highland and its dischare is highly affected by amount of precipitation around Butajira area. It drains on the unwelded volcanic ash, Lacustrin sedments (sand and Silt) and wonji basalt formation from the highland to the Lake Ziway respectively. The river is highly known as a source of sand deposit in the building construction industry.

4.1.3 BULBULA RIVER

Bulbula River is interconnecting Rift Lakes that starts from the largest Rift Valley Lake-Lake Ziway and terminate into the Lake Abayata. Now a days Bulbula’s discharge is decreasing and its reflection is also observed on the lower amount of Lake Abayata.

4.1.4 KATAR RIVER

Katar River is another feeding River for the Lake Ziway that starts from the Arsi highlands and compares to the other Rivers in the corridors, its drainage system is denser. As already mentioned, the river has be irrigated together with its tributary in the highlands so as to produce tomato, cabbage, onion and papaya as well as in the lowland too.

4.1.5. LAKE ZIWAY

Lake Ziway is the largest lake in the basin. It lies in a shallow down faulted depression (on the average 4m) flanked in the east by a large basalt field. It is feed by the Meki and Katar and overflows to Lake Abiyata via the Bulbula River (Silishe, 2006)

The lake is relatively of low salinity and is the only lake used for irrigation purpose. The lake has a potential of irrigating 1700 ha but presently it is irrigating about 1000 ha (HALCROW, 1992). In addition to this the lake is used for fishing and has a potential of 3000 tone fish per year (Atkins & Partners, 1965).The lake has four species of fish, namely, Perch, Crap, Cat fish and Barbus (local names being Koreso, Dude, Ambaza and Bilcha respectively).There are also different kinds of water birds. Some emergent plants are also observed in the littoral zone of the Lake.

Photo 4.1 Partial View of Lake Ziway with its islands

The lake has a total average surface water inflow, including the direct precipitation, of 1028 mcm (million cubic meters) per year. The annual average water loss from the lake by evaporation, run off through Bulbula river and water loss for irrigation is amounts to 1102 mcm. But with this water balance the level of the lake remained constant indicating the inflow of groundwater to the lake (Tenalem Ayenew, 1998).

Lake Zway is 26 km. long and 18km, wide and highly eutrophicated and has five islands of Tulugudo, Gelila, Funduro, Tedecha and Debresina.

The physico-chemical Analysis of Lake-Ziway with different Parameters with in different part of the Lakes is: (Source from Oromia Water quality control Office)

Table 4.1 Physico-Chemical analysis of Lake Ziway

Parameters	Samlple-1	Samlple-2	Samlple-3
Turbidity	165FTU	164 FTU	169 FTU
Colour	1325 Pt-co	1353 Pt-co	1390 Pt-co
PH	9.08	9.1	8.98
Temperature	24.1^{0} c	22.1^{0}c	21.8 ^{0}c
TDS	213mg/l	210 mg/l	208 mg/l
Conductivity	426 **μ** /cm	420**μ** /cm	416 **μ**/cm
Total Alkalinity	202 mg/l as $CaCo_3$	196mg/las $CaCo_3$	197mg/las CaCo
Bi-Carbonate	202 mg/l as $CaCo_3$	196mg/las $CaCo_3$	196 mg/las $CaCo_3$
Hardness	84 mg/l as $CaCo_3$	90mg/l as $CaCo_3$	81 mg/las $CaCo_3$
Ca-Hardness	48 mg/l as $CaCo_3$	49mg/l as $CaCo_3$	35 mg/las $CaCo_3$
Mg	36 mg/l as $CaCo_3$	41 mg/l as $CaCo_3$	46 mg/las $CaCo_3$
Fe^{2+}	0.76 mg/l	0.81 mg/l	0.89 mg/l
Mn^{2+}	0.007 mg/l	0.008 mg/l	0.009 mg/l
PO_4^{3-}	0.18 mg/l	0.14 mg/l	1.15 mg/l
SO_4^{2-}	18 mg/l	19 mg/l	18 mg/l
NO_3^-	Nil	Nil	Nil
F^-	1.05 mg/l	0.95 mg/l	1.01 mg/l
CI^-	-	_	26 mg/l
Salinity	-	_	2.6 ppt
DO	-	5.25 mg/l	5.45 mg/l

4.1.6. KOKA DAM

The Koka dam is the only artificial Dam that regulating the Awash River in the Upper valley and the koka release together with the downstream joining streams supplies water for existing 69,000 ha of farm in the lower Valley. During drought years,water shortage is often encounter even for the existing farms. And the reservoir water was operated according to the Hydropower demand. But currently it has come to be used as per the downstream irrigation water requirements. (Sileshi Mamo,1995).

The Koka reservoir is exhaustively suffering from silt sedimentation. Siltation rates of 26.4 Mm^3/yr and 25 Mm^3/Yr were estimated for the years 1969-81, and since 1981, respectively.

Water Level (M)	**Storage hm^3**	**Area KM^2**
1576	0	0
1577	5	25
1578	20	49
1579	50	65
1580	110	78
1581	200	90
1582	320	103
1584	590	130
1586	905	159
1588	1250	191
1590	1670	225
1596	2970	319

Table 4.2. The Koka Reservoir Data.

Spill way level = 1585m

Maximum Operating Level =1590.7m

Minimum Operating level = 1580.7m

The reservoir is loosing its water through evaporation and ground leakage. Average annual evaporation loss of 309.9 Mm^3 was estimated by Halcrow, 1989.The recharging water from surface and Sub-surface aquifer in to the Dam is common in all part of its surrounding except in the North eastern shore of the Lake where dense fault observed and in which the reservoir potential leakage occur. (Sileshi Mamo, 1995).

Halcrow, 1989 has proposed rising of the Koka dam by 1 to 3 meters. Every meter rise in the water level is supposed to add over 178Mm^3 of storage capacity, and can increase the reservoir life by probably a minimum of 7 years.

4.1.7 ELEN LAKE

Lake Elen is the smallest lake in the study corridors found on the western part of Koka dam. Its fluoride concentration is very high relative to other surface water.

The community around the Lake have highly affected tooth and Spinal cord because of the higher concentration fluoride from the hand dug wells near the lake which is the only source of water for public consumption. According to the local community near to Bericha Mountain (directly South of Koka), the ground water comes from the Lake Elen (from western to Eastern part) and that is why water near to Bericha is high Fluoride concentration. But the water that comes from Koka side (northern part) is relatively small in the concentration of fluoride. It is easily observes the groundwater direction in the hand dug wells near to bericha that comes from western part.

The lake has been also irrigated for the production of different vegetations

Photo 4.2 Partial View of Koka Dam

CHAPTER FIVE

H Y D R O G E O L O G Y

5.1 General

The occurrence, distribution and movement of groundwater in the sub surface is mainly depends on the hydrogeological parameters like porosity and permeability of the geological formation called Aquifer. In addition to these, size of openings or interstices and their shape, arrangement, interconnection, and continuity are others hydrogeological properties that governs ground water occurrence.

Rock formations and the openings are the results of primary geologic processes (primary porosity) and secondary processes that modify them, either increasing or decreasing their porosity (as secondary porosity) and permeability.

The other main controlling factors of groundwater distribution in rocks are lithology, structure and grain size.

Volcanic rocks, due to the difference in mineralogy, texture and structure, its water bearing potential varies. Groundwater circulation and storage in the volcanic rocks depend on the type of porosity and permeability formed during and after the rock formation. All rock structure possessing a primary porosity may not have necessarily permeability: i.e. without the original interconnection, the primary porosity may not give rise to the primary permeability, but later connection, by means of weathering or fracturing may results a secondary permeability.(Tamiru Alemayehu,2006)

Volcanic rocks resulting from explosive magmatic activity like pumice falls and scoria have very high intergranular permeability while in lava flows, primary permeability is mainly due to jointing at the time of flowing, on cinder cones and spatter cones, weathering mostly have a negative effect on permeability by filling the openings, while in tuffs and ignimbrites it may have a positive effect by separating different layers forming these rocks. (Haile Gashaw, 1995).

Basic volcanic rocks like basalts are generally rich in cavities (formed due to high mobility lava flowing for more time and space before solidifying and thus escaping lot of gasses) and contraction cracks; and as such, may became permeable and sources of underground water (S.G. Garg, 1983). On the other hand,

Acidic volcanic rocks may or may not contain ground water although generally they possess interstices. The reason is that the interstices may be filled up with ash and other material, and hence uncertainty. Pyroclastic rocks associated with lava flow are generally porous. However, their permeability varies depending on the interconnection of the pore spaces (Davis et al, 1966).

Openings in volcanic rocks include gas cavities, porous flow textures & structures, openings between included rock fragments, and interstices in tuffs & breccias. Fractures are the principal openings in such rock types. Large fractures, usually few in number, are produced by deep-seated earth stresses and may extend to great depth; and small near-surface fractures may occur in great numbers (Nockolds, Knox, Chinner, 1979).

Large spatial variation in the permeability of rocks is a common feature of fractured volcanic terrain due to differences in the degree of fracturing .In contrast to geological bodies which are frequently determined by their stratigraphic characteristics and/or lithologic composition, spatial variation of hydrological bodies (aquifers and aquitard) can be partly or entirely independent of lithologic properties in a highly fractured environment (krasny, 1997).

The most important features governing the groundwater flow and storage in volcanic rocks are the following: (Tamiru Alemayehu, 2006).

- Vertical permeability due to primary and secondary fractures.
- Horizontal permeability due to horizons containing openings due to the lava flow and gas expansion during solidification.
- Occurrence of impervious horizons and dikes

5.2 Hydrogeological units and aquifer systems

The existing hydrogeologic units in the study corridor are volcanic rocks that are subjected to varying degrees of secondary activities like weathering, fracturing and faulting which intensively divided the area by a number of minor and major normal usually arranged in "en- echelon" fashion, which belongs to the Wonji Fault Belt. This fault together with others, dissect almost all outcrop units with in the area. Comparing to the primary structure, secondary one has a significant role in the circulation and distribution of groundwater in the study corridor.

As of a witness of this, lithological logs of Boreholes with in the area shows that the aquifer formation system is weathered and fractured which is classified as low, moderate and high.

The major water bearing formations in all of the boreholes of deep and shallow wells are welded & fractured ignimbrites weathered & fractured pyroclastic deposited, fractured lithic pumaceous pyroclastic deposit, alluvium (silty-sand Gravel) and highly and slightly fractured basalt.

The aquifer system of the corridor varies laterally and with depth as it is understood from the field observation and Secondary borehole data history indicated. More than 172 HDW investigated in the field by taking in-situ data measurements and most of which is in the vicinity of Lake Ziway and Koka Dam their depth vary from 1m near to lakes to 29m with in the Towns and indicating the existence of shallow aquifers system. Secondary borehole data history which includes motorized and windmills confirms the existence of deep and shallow aquifers and their depth is varying as of 34 to 268m.

In the study corridor, the aquifer formation is generally categorized as follows depending on their primary porosity, variable degree of weathering and fracturing:-

1. Aquifers mainly characterized by primary permeability in rocks which include: lacustrine sediments, alluvial, pumice falls and scoria cones. These deposits usually represent important aquifers in many places within the area.

2. Aquifers mainly characterized by secondary permeability due to rock fracturing and weathering. This group consists of ignimbrites and tuffs; the permeability of these rocks mainly depends on the intensity of faults and fractures. In places of intense faulting and fracturing they are good aquifers.

3. Aquifers characterized by both primary and secondary rock permeability. In the area this group includes: basaltic lava flows, rhyolitic pumice flow and obsidian lava flows. Generally these rocks form moderate to good aquifers, in places of intense faulting and fracturing they are very good aquifers.

5.2.1. AQUIFER FORMATION

Depending on the above aquifer formation, the following four Hydrostratigrahic units are identified in the study area.

Classification of lithostratigraphic units into hydrostratigrahic units requires information on the hydraulic characteristics of rocks. Even though the hydraulic conductivity of the different volcanic sequences of the Ethiopian rift valley is poorly understood, lithological description, existing secondary data and the field hydrogeological & geological mapping have been used as a basis for classifying Hydrostratigrahic units. These are:-

- **LACUSTRINE DEPOSITE (UNCONSOLIDATED DEPOSITE)**

The lithologic groups found in this unit are ignimbrites overlain by lacustrine sediments. Thickness of the lake sediments ranges from 40 meters to more than 200 meters and on the average they are 40-50 meters thick (Tesfaye Chernet , 1982). In wonji area about 50m thick lacustrine deposite with clay at the top and sandy to gravel and pebble at the bottom was reported. Drill bore holes near to the area shows of 3 to 6 l/s yields, 0.1, 1, 9 l/s/m specific capacities, and estimated transmissivity (m/d) of 20.36,6.09, 0.2 were also reported.

Lacustrine deposits extending between the northern part of Modjo and west part of Koka Dam have been known with 0.75 l/s to 12.8 l/s yields, 0 to 30.5m draw downs and 0.06 l/s/m to 2.4 l/s/m specific capacities. Permeability values vary from 0.1 m/day to 88.15 m/day. This deposit, in the vicinity of Lake Ziway is relatively lower in value than the above mentioned values.

The aquifer is generally fine to medium grained sand and coarse sand, some times pumiceous, silty and tuffaceous. These aquifers have generally moderate to high permeabilities (Figure 5.3).

Unconsolidated Lacustrine and subordinate alluvials and fluvio-lacustrine deposite of the Gedemsa caldera area are generally taken as moderate to high permeability.

Lacustrine deposit mapped in the north eastern of the reservoir shore is shallow and thus the permeability of the underlying Nazret Ignimbrite aquifer is taken in order to get representative values. Only shallow (2m) perched aquifer was observed in these lacustrine deposit. (Sileshi Mamo, 1995).

These aquifers have large coverage in the studied area and are mostly part of the shallow aquifers system, as confirmed form lithological log in some wells; this is also part of deep aquifer system.

- **BASALT**

The Basaltic unit is coinciding with the NNE-SSW en-echelon faulted structure in the Wonji fault belt. The unit is recent and associated with Hawaiitic Flows, Scoria and Cinder Cons. All of them are vertically and horizontally jointed, vesicular and scoraceous and densely faulted with variable degree of weathering and fracturing. Accordingly, their permeability values rang from high to very high (Figure 5.3) and these aquifers is associated with the deep aquifers system.

- **DIFFERENTIATED IGNIMBRITIC AND WELDED TUFFS UNITS**

The unit includes Gedemsa Ignimbrite, Upper Pleistocene Fissure Ignimbrite, Ignimbrite underlies in lacustrine Sediments and, Nazret group Ignimbrite.

These rocks have variable permeabilities. In the Koka shore areas, they are faulted and jointed with different sets, the main ones having orientation to the north west and north east. Joints especially the north east trending ones are open, relatively wider and widely spaced and interconnected. The other is fine but interconnected.

Ital Consult, 1970 has measured field equivalent permeabilities of 10^{-4} cm/s to $1.9 * 10^{-3}$ cm/s to these ignimbrites.

Welded tuff also observed as an aquifer as inferred from lithological Log in different part of the study area like Gedemsa Ignimbrite and around Alem Tena in the shallow and deep aquifer system (Sileshi Mamo, 1995, Tenalem Ayenew, 1998).

Permeabilities are generally low to moderate in all units.

RIFT VOLCANOES AND VOLCANIC RIDGES

They were mapped as mountains in the northern part of Lake Ziway, at Aluto and Gademotta ridge.

Very recent Comenditic Obsidian Domes and Flows ,Obsidian and Lithological Domes and Flows of peralkaline Rhyolitic Compostion, Pyroclastic Deposits Constituted by unwelded pumice and Ashes of peralkaline Rhyolitic Composition, Thinly Bedded “Wet Surge” Deposits, pyroclastic Deposits Constituted by Unwelded peralkaline Rhyolitic pumice & ashes and Others.

These rocks generally have low to very low permeabilities.

5.2.2. AQUIFER TYPES, DEPTH AND LATERAL EXTENT

Regarding to the nature of the aquifers there are two in types, shallow and deep, existing in the study area. (Sogreah, 1965).

On the other hand, a single and continuous aquifer in the study area in the regional scale, with semi confined nature owing to variation in lithologies. (PROGINT, 1988).

Ital Consult confirmed that areally homogenous and isotropic volcanic aquifers.

In the view of motorized boreholes logs, aquifer parametric values, geology and tectonics as well as geomorphological evolution of the aquifer rocks and the river Awash itself, it is believed that a regional conduit or confined type of fracture volcanic aquifer with regionally ascending hot mineralized thermal ground water which rises to the level of discharge that had once presumably been regionally adjusted to the level of the Awash River in the northern part but later have been disturbed by younger faults giving the present setting.(Sileshi Mamo,1995).

The author also agree in the Sileshi’s work but according to the field data observation, there is evenly distributed HDWs from Bulbula river (south) to that of Awash River(north) and the same is also true from west to east with an average depth of 18m.

An additional enforcing reason is that observation of the seasonal disturbance of water table of dug wells. This disturbance is thought to arise in response to seasonal changes of surficial processes like precipitation that is directly recharge to the surrounding Lakes (from which the HDW feed) and the shallow aquifer. Recharge to these aquifers is thought to come from downward seepage through the unsaturated zone. According, in addition to the regional aquifer system, local unconfined, perched and semi confined aquifer deposited and overlain the regional aquifer with varying hydrostatic pressure.

Generally, the aquifers are of two types in terms of depth, extent and types. These are:-

- First type is shallow unconfined type; its lateral extent is not regionally extended relative to the confined one. On the average, their depth can be as deep as 60m with different aquifer formation including Lacustrine sediments (sand plus Gravel which is the dominant), sandy volcanic ash, weathered volcanic rock, quartz sand and welded ignimbrites. All of these aquifer formation has variable lateral extent without considering the geology.(ANNEX--)
- Second type is deep confined with regional lateral extension, its depth is start running from 60m to deeper with variable aquifer formation including weathered and fractured ignimbrite and weathered scoraceous basalt (dominant) and Sandy volcanic ash. The first two is the dominant.

5.3 HYDRAULIC CHARACTERISTICS

Depending on inventory in the field and secondary data from appropriate offices, more than 85 deep and shallow boreholes and many HDW are located in the study corridors. For the boreholes, the necessary boreholes history/well compilation report is not properly compiled in the offices but from Meki Catholic Church, Meki rural and Agricultural development offices, Saba Engineering, Hydro water well drilling & Engineering, and Oromia water quality control center, the physico-chemical analysis, SWL & Total depth of about 55 boreholes have been obtained. For HDW, the corridor have been extensively duged by hands in the vicinity of lakes (Koka, Elen, Ziway) and Towns (Kintri-hot water, Aboso, Ziway, Bulbula) among which only 170 HDWs' parameters have been measured.

5.3.1 Pumping test type and duration

Most of the boreholes are pumped at a constant pumping rate for duration of 24 hours, and discharge rate and draw down measurements are made on the pumping wells and some of the wells pumped at a step and recovery tests for about 72 hours. Observation wells (monitoring wells) are absent in and around the study area (not common in

Ethiopia) but for analysis purpose in some wells, ideal observation borehole near to the main well has been considered. The absence of observation wells near by functioning water wells in the schedule of the work limits the possibility of deducing the effects of local hydraulic conditions in and near the pumping well such as measurements of storage coefficient that strongly influence the draw down in the well and interpret the aquifer system of the area under influence.

In almost all tests, steady sate or equilibrium is reached and data analysis is made using a suitable well-flow equations developed for such a condition. Most of the analyses were made using the formula developed by Cooper and Jacob, 1946 on the Aquifertest soft ware. This soft ware also helps for the generation of hydraulic conductivity of different wells in the studied corridor. As representative well in the area, the following two wells pumping recording analyzed. For the first well (Areta) constant rate test pumping was carried out at a discharge rate of 9 l/s for duration of 720 minutes. Within this period the drawdown of the water level was 3.1 meters on the average and the water level recovered 75% within 120 minutes.

Theis, Cooper-Jacob time - draw down and Moench Fracture Flow analysis methods were used for the interpretation of the pumping test data.

According to the analyses result the hydraulic parameters of the aquifer are presented below:

A) Time - Draw down analysis (Theis Method)

- Transmissivty – 1.35E-3 m^2/s
- Conductivity – 5.62E-5 m/s
- Storativity – 5.87E-2

B) Time - Draw down analysis (Cooper - Jacob Method)

- Transmissivty – 1.87E-3m^2/s
- Conductivity – 7.80E5 m/s
- Storativity – 1.71E-2

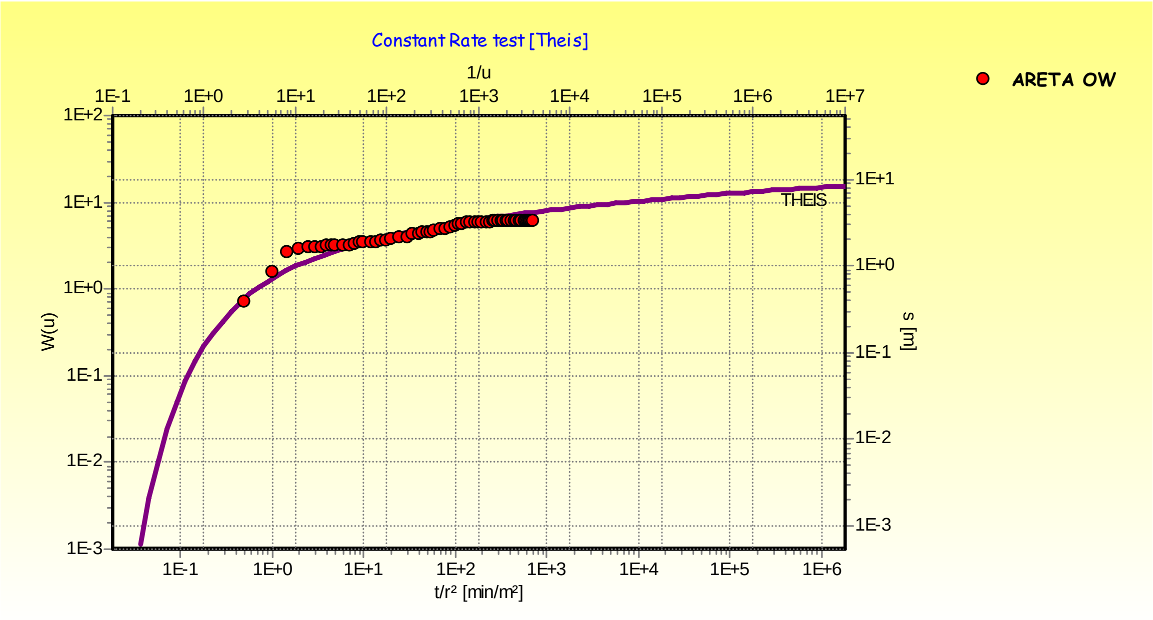
C) Moench Fracture Flow analysis

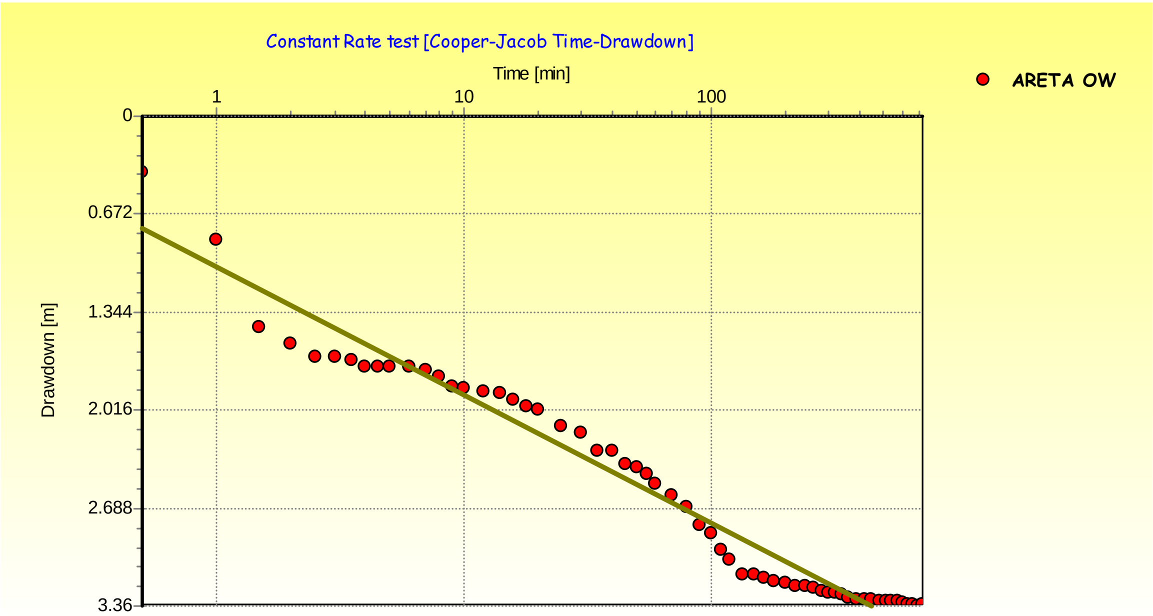
- Transmissivty – 1.41E-3m^2/s
- Conductivity – 5.88E-4 m/s
- Storativity – 1.54E-2

D) Theis Recovery Analysis

- Transmissivty – 1.65E-3 m^2/s
- Conductivity – 6.86E-5 m/s

Graphical plots of the above mentioned data as follows:





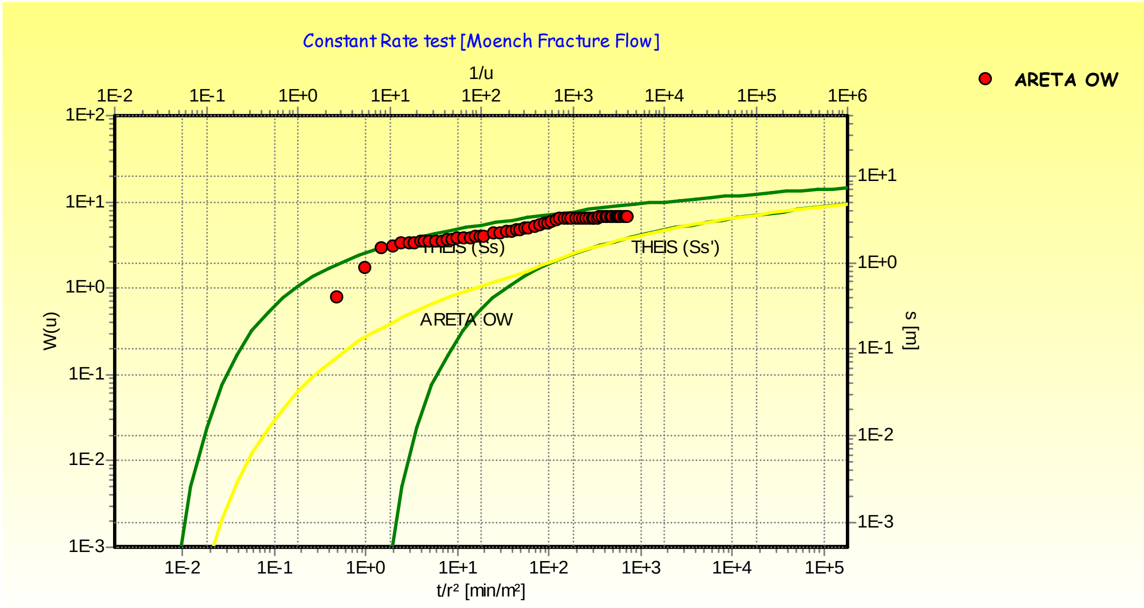


Figure 5.1 Analysis of well by using pumping test data for Areta well

In Theis curve, the field measurements are plotted as t or t/r^2 along the x axis and S along the y-axis. The data analysis is done by matching the line drawn through the plotted absorbed data to the Theis curve. Accordingly, almost all analyzed graph in the above graphs coincide with the Theis curve which confirms that the well fulfills the assumption that has been settled by Theis.

For the second well (Deneba) constant rate test pumping was carried out at a discharge rate of 3.85 l/s for duration of 900 minutes. Within this period the drawdown of the water level was 1.84 meters on the average and the water level recovered 100% within 3 minutes.

Theis, Cooper-Jacob time - draw down and Moench Fracture Flow analysis methods were used for the interpretation of the pumping test data.

A) Time - Draw down analysis (Theis Method)

- Transmisivty – 7.46E-3 m^2/s
- Conductivity – 3.24E-5 m/s
- Storativity – 3.11E-2

B) Time - Draw down analysis (Cooper - Jacob Method)

- Transmisivty – 1.28E-3m^2/s
- Conductivity – 5.57E-5 m/s

C) Moench Fracture Flow analysis

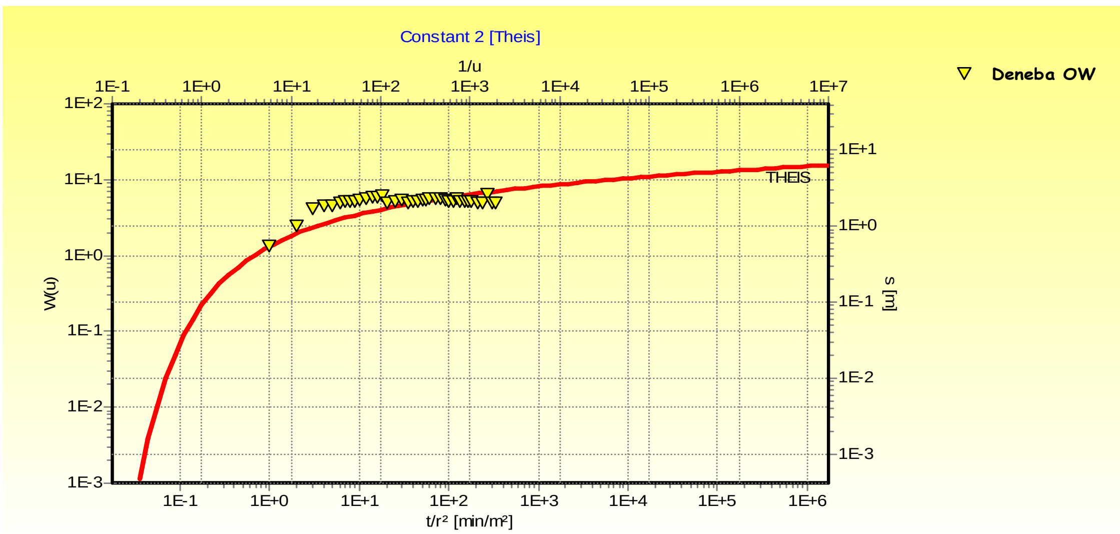
- Transmisivty – 7.46E-4m^2/s

- Conductivity – 3.24E-5 m/s
- Storativity – 7.78E-1
-

D) Theis Recovery Analysis

- Transmissivty – 7.05E-4 m^2/s
- Conductivity – 3.06E-5 m/s

Graphical plots of the above mentioned data as follows for the first two are:



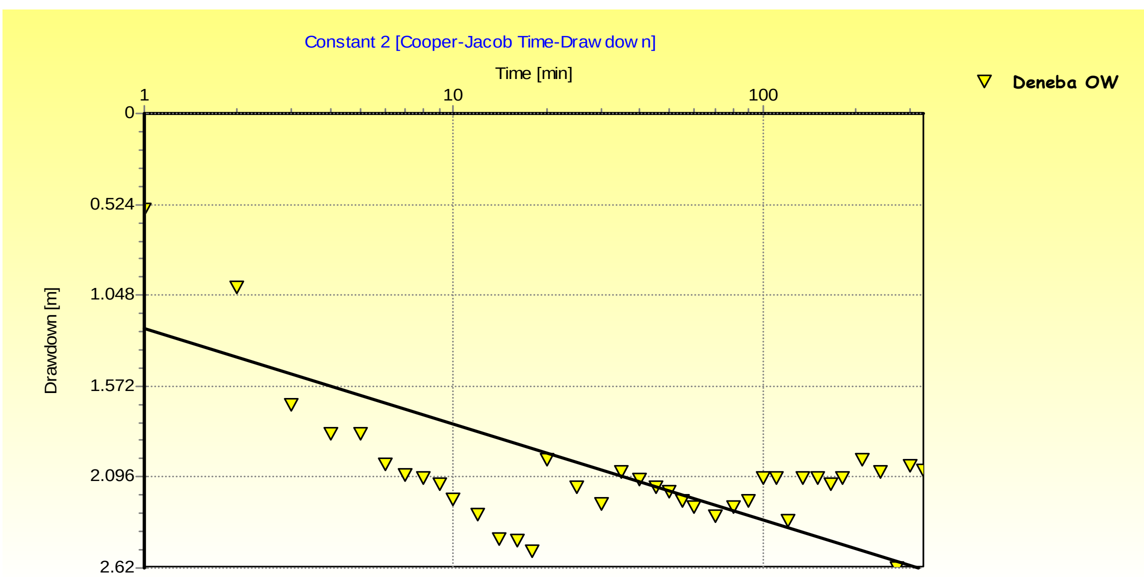


Figure 5.2 Analysis of well by using pumping test data for Denebe well

According to the Cooper-Jacob time - draw down graph, the draw down of the well is not uniform as Areta but the Theis graph shows that this well also falls with in an acceptable assumption of Theis.

For the purpose of comparison, the aquifer parameters obtained are tabulated below.

Where T = Transmissivty S = Storativity C = Conductivity

Analysis Method	Constant Rate test		
	T m^2/s	S	C m/s
Theis, Time-Drawdown	1.35E-3	5.87E-2	5.62E-5
Cooper-Jacob, Time-drawdown	1.87E-3	1.71E-2	7.80E-5
Moench Fracture Flow	1.41E-3	1.54E-2	5.88E-5
Theis Recovery	1.65E-3	-	6.86E-5

TABLE 5.1: AQUIFER PARAMETERS (ARETA WELL)

Analysis Method	Constant Rate test		
	T m^2/s	S	C m/s
Theis, Time-Drawdown	7.46E-4	3.24E-5	-
Cooper-Jacob, Time-drawdown	1.28E-3	-	5.57E-5
Moench Fracture Flow	7.46E-4	3.24E-5	-
Theis Recovery	7.05E-4	-	3.06E-5

TABLE 5.2: AQUIFER PARAMETERS (DENEBA WELL)

For the Areta well sandy gravel is the main shallow aquifer, it is believed that this formation is a good aquifer as far as the other hydrogeological conditions are favorable. For the purpose of evaluation, the average Transmissivty and Conductivity of the Constant Rate Test is considered since the pumping duration is longer to get relatively reliable result.

Taking the average Transmissivty and Conductivity values into consideration, 1.57 $10^{-3}m^2/s$ and 6.54 x 10^{-5}m/s respectivly and the observed water level drawdown, the recovery time of the water level and the geology of the aquifer, the aquifer encountered can be classified as very good performing aquifer. And for that of Deneba, because of loss of circulation, no sample were collected and aquifer formation identification is difficult but from the pumping test data the average Transmissivty and Conductivity values are 8.69 x10^{-4} m^2/s and 4.31 x10^{-5} m/s respectively.

5.3.2 Hydraulic conductivity

Hydraulic conductivity is the volume of water that will move though a porous medium in unit time under a unit hydraulic gradient though a unit area measured at right angle to the direction of flow (Kruseman, 1989), or it is governed by the size & shape of the pores, the effectiveness of the interconnection between pores, and the physical properties of the fluid. If the interconnecting tubes are small, the volume of water passing from pore to pore is restricted and the resulting hydraulic conductivity is quite low.

Based on the hydraulic conductivity data collected from 6 wells (Appendix) in the vicinity of Ziway Lake and Hydrogeological map for Koka dam, the various formations in the area have been classified to groups of High to very high, Moderate to high and Low to moderate and very low to low permeabilities .As shown on Fig 5.3 there is a variation in the permeability of rocks especially in the eastern escarpment where there is high contrasting role of the rift faults (as conduits or barriers of groundwater) where as most permeability of the rift floor falls in the moderate to high range.

Based on this the following hydrogeological maps build which are similar to the geological maps considering rock types but other valuable hydrogeological formation is also included like ground water level contour, aquifer hydraulic parameters, water points and ground water flow direction, wells position which the pumping test representative and black spot of different size which shows variable permeabilty corresponding with geological formation etc.

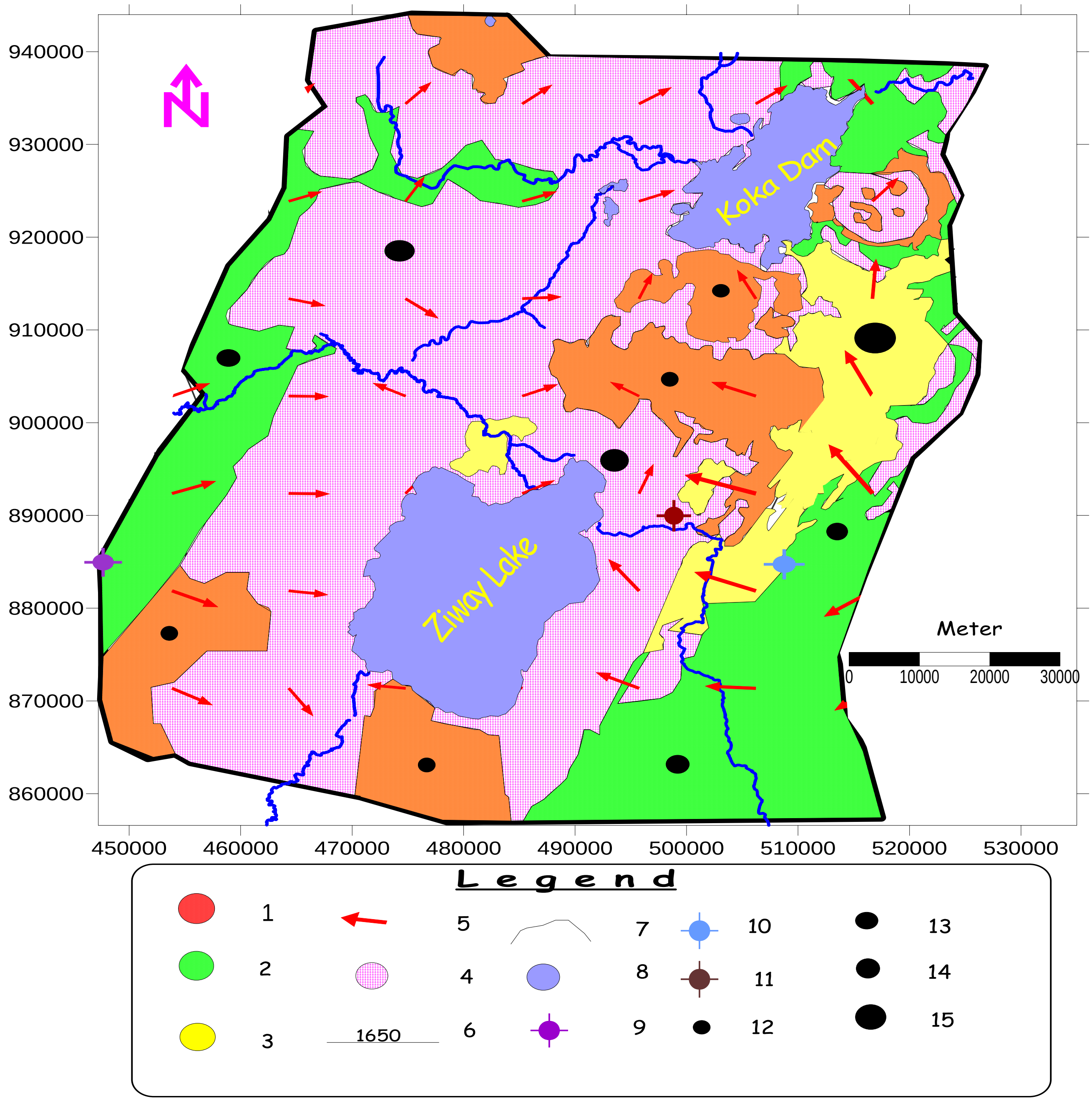


Figure 5.3 Hydrogeological Map of the studied corridor

1= Rift Volcanoes and Volcanic ridges, 2 = Ignimbrite, tuff, local rhyolite and Basalt, 3=Basalt and local Ignimbrite, 4=Ignimbrite covered with lacustrine deposit, 5= Groundwater flow direction, 6= Groundwater level contour, 8= Lakes, 9= Koshe well, 10=Deneba well, 11= Areta well, 12= Dot representing very low to low permeability of the surrounding formation, 13= Low to moderate, 14= moderate to high, 15= High to very high (1=12, 2=13, 3=15, 4=14,).

5.3.3 Transmisivity

Transmisivity is the product of the average hydraulic conductivity K and the saturated thickness of the aquifer. Consequently, transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer. As mentioned in the above, all the transmisivity of the studied well derived from pumping data using the aquifertest software to characterize the aquifer. The representative wells of transmisivity values mentioned in the above tables (Table 5.1 and 5.2)

5.4. GROUNDWATER SOURCES INVENTORY

5.4.1. Hand dug wells

A plenty of Hand Dug wells are founded within the study corridor for public & livestock consumption, small & large scale irrigation and washing purposes in the vicinity of lakes and towns. Among which around 170 hand-dug wells have been inventoried in the field during the pre feasibility phase of the program. Except few, in the majority of the dug wells abstractions are carried out by pulley system. Depths of the dug wells vary from 3-33m with variable static water levels of 1m - 21m.

The dominant aquifer formation is known to be lacustrine deposit in the northern, central and southern parts which is concentrated along the main asphalt road. Fractured basalt slightly weathered and fractured rhyolites and trachytes are the formations in the eastern part of the study area but is formation mostly characterized for deep aquifer system of the studied area.

Most of the dug wells provide a perennial source of water and however, yield is substantially decreasing during dry season. The seasonal fluctuation of the static water levels in most of the wells is highly attributed to the direct recharge condition from precipitation into the well which intern indicates the unconfined nature of the aquifers.

Most of the dug wells are constructed in the discharging zones/rift floor parts of the study area.

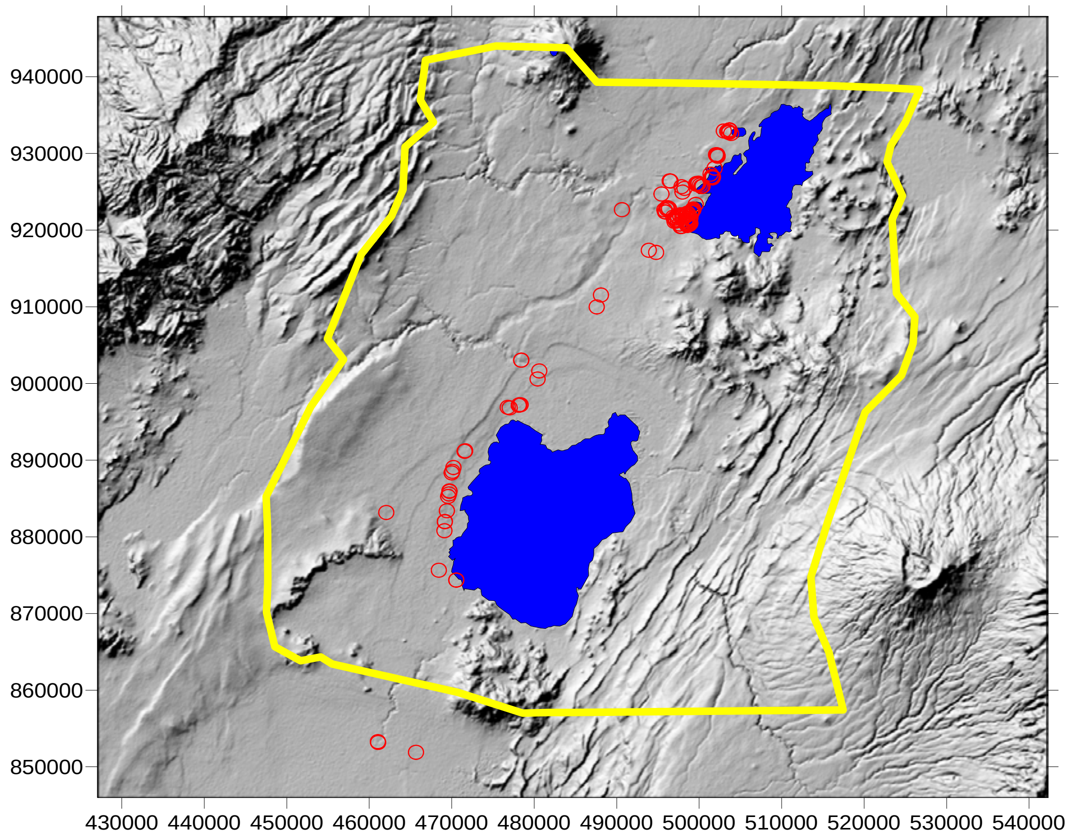


Figure 5.1 Distribution of Hand Dug wells along the lakes

5.4.2. Boreholes

Both deep and shallow boreholes are drilled in the study area by Governmental, non Governmental and private Drilling Company. There are about **48** deep boreholes where the depth varies between 61-268m and 38 shallow boreholes of 33-60m depth range. The deepest borehole has a depth of 268m drilled at the northern part of the study area near koka Town. Most of the deeper boreholes are fitted with submersible electrical pumps and the others boreholes are equipped with Indian mark II, III, and Afrideve hand pumps and Windmill pumps.

The main aquifer formations of the boreholes are Lacustrine deposit, weathered and fractured Basalt, ignimbrite, rhyolites & trachytes and welded tuff having a variable thickness and variable weathering and fracturing intensity. The static water level of the wells lies within the range of 8.6m for shallow well of 24m total depth to 256m for deep well of 268m total depth. Aquifer thickness, specific capacity, drawdown and yield of the aquifers lie between 5- >33m, 0.02-7.4 l/s, 0.25-19.63 m and 0.97-21.6 m^3/hr respectively.

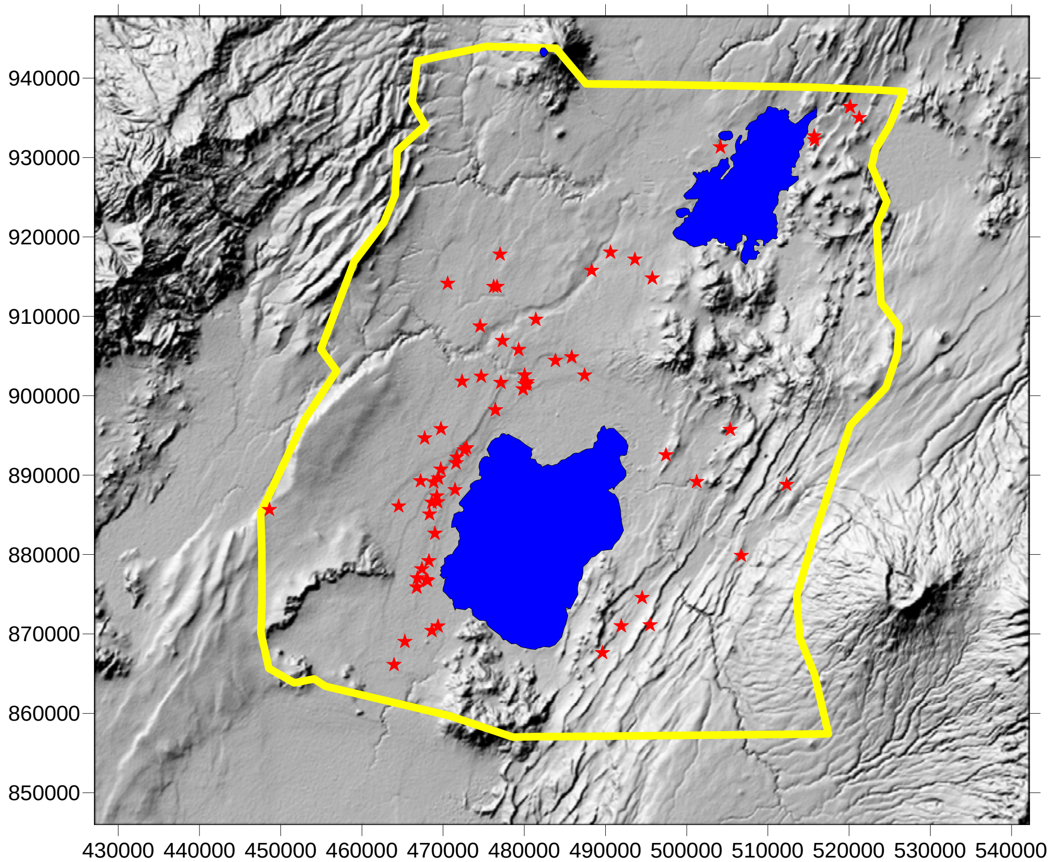


Figure 8.2 Distribution of Deep and shallow wells with in the corridor

CHAPTER SIX

GROUNDWATER FLOW SYSTEMS

6.1 GENERAL

Groundwater moves into various soil and rock formations by means of infiltration and percolation through interconnected void spaces, along micro cracks between grain boundaries and in large-scale fractures in response to differences in fluid pressure and elevation after the water comes from recharging area and/or from the preciptation processes. These movements are governed by well-known Hydrogeologic parameters like hydraulic conductivity and hydraulic principles of Darcy’s Law.

Groundwater flow system could be local, intermediate or regional flows depending on different factors like recharge area, lateral & vertical extent and thickness of aquifers. In turn it depends on effective porosity and permeability of the aquifers itself.

Extent of flow system is depend on the recharging area, in which recharge area may be discharged in the nearest topographical low area as local flow.

Thickness and extent of aquifer can also limit or extend the ground water flow system as local or regional. If the geological formation of the aquifer is laterally and vertically extends with the necessary effective parameters, the ground water flow system could be regional, or else it could be local.

Regarding to the depth, regional groundwater flow is in most case deeper than that of the Local flow system.

In the flow system of water in the subsurface whether it is local or regional, there may be an ideal vertically impermeable layer as a boundary called Groundwater divide across which there is no flow. For the case of surface water divide, the principle is the same, but in this case, topographically elevated area can be considered as surface water divide.

As of the hypothesis, ground water flow may follow the slop of surface morphology, if so, in some case, surface and ground water divide May overlaps one on the other. In both case, surface and ground, the water moves in opposite direction from the divide.

6.2. GROUND WATER SOURCE, RECHARGE AND DISCHARGE

6.2.1. Ground water Source

Main ground water source of the study corridor is adjacent high relief provinces which included Guraghe and Arsi highlands and available/surplus water from precipitation which is estimated to 134.15mm and 175.74mm for koka and Wonji stations. (Sileshi.1995)

6.2.2. Groundwater Recharge

Most of the study corridor covered by the floor of the rift and partly surrounded by highlands from which water moves to the study area. From the previous authors, it is proposed that, there are local descending fresh & cold, and deep ascending regional hot mineralized thermal water circulating in the study area.

According to Myboom, 1966a and Toth, 1966, there are five basic types of indicators of recharge and discharge areas: which include topography, peizometric patterns, hydro chemical trends, environmental isotopes, and soil and land surface feature. Among these indicators, topography is the simplest (Figure 10) and peizometric measurements are the most direct (Freeze and Cherry, 1979)

Recharging to the local fresh water comes from:

- Precipitation in the area and adjacent high relief provinces whose shallow run off reach the area.
- Spring and Seeps that flows down to the saturated zones.
- Irrigations water and Seepage from canals.
- Awash, Meki, Katar and Streams where theses cut and cross fractures and faults.
- Koka (north-eastern part) and Ziway (southern part) on some portion of their bed.

Recharge to the saturated zone can take place through the pediments, escarpments, river banks, river lines, soils and sediments, and along fractures and faults.

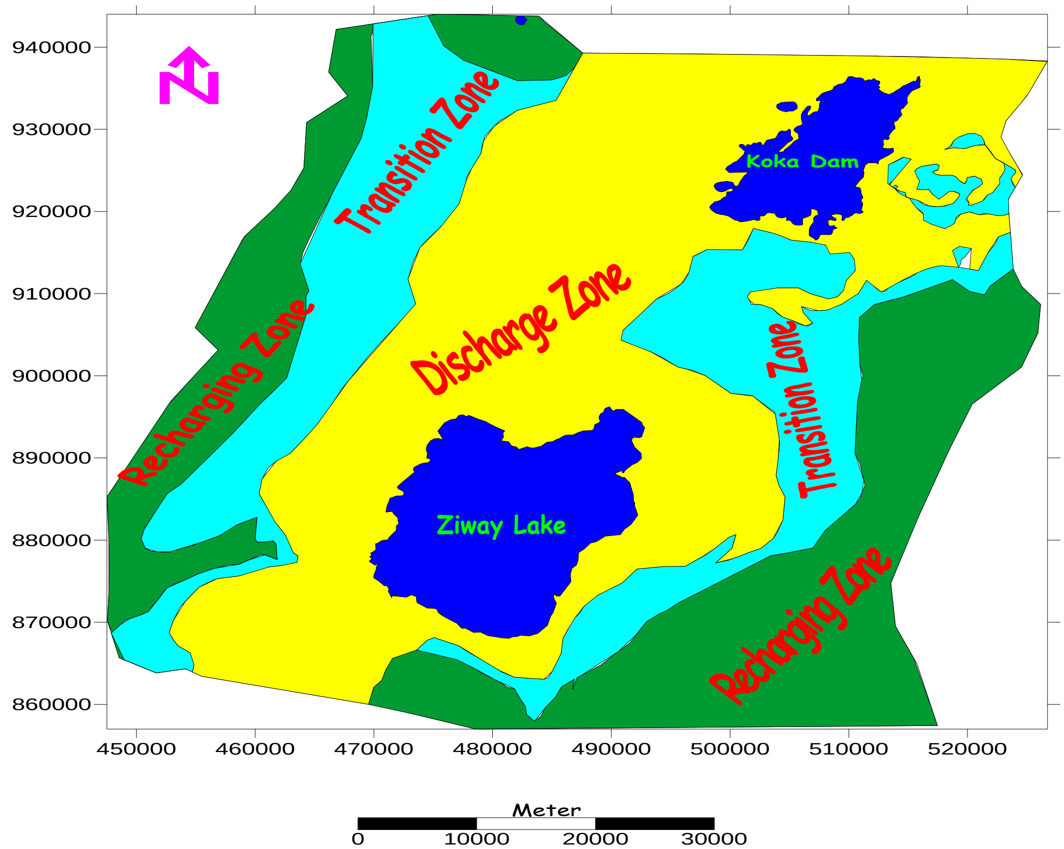


Figure6.1 Recharge and discharge zones from elevation contours (Topographic)

The deep regional thermal water with temperature greater than 40^{0}c is reported by some authors to be of geothermal origin and while raising it mixes with local meteoric water of 25-300c.The mixing water in the ratio of 3:2 was reported for the Aluto-Langano area. It is also reported that geothermal fluids in lake districts is rise to the level above the ground water piezometric level.

The idea of geothermal source was supported by the presence of anomalous temperature, boron, ammonia, methane, hydrogen and other gases.

On the other hand, some previous authors believed that there is deep recharged meteoric water which is heated by conduction from the cooling acidic rocks. While up flowing to the surface, this water looses heat to the contact rocks.

To prove these further isotopic and noble gases studies are essential (Sileshi.1995)

6.2.3. Groundwater Discharge

The area is also considered as discharge zone, even though received water from highlands as rechargeable zone, it also discharges through evaporation, plants transpiration, domestic & industrial uses, through boreholes, hand dug wells, springs development, springs, seeps, and base flow to the rivers, as well as by under flow to the downstream of adjacent area.

According to Sileshi, the actual evapotranspiration of 829.76mm and 636.76mm are estimated respectively for Koka and Wonji station.

Additionally, the water table contour map helps to locate ground water recharge and discharge areas. The flow vector lines (fig. 5.6 & 5.7) tend to diverge from recharge areas and converge toward discharge areas. The convergence of the vector lines is clearly seen in the north-east parts of Lake Ziway, and the divergence of the flow lines is observed in the north-west and eastern part of Lake Ziway for shallow aquifer system. These zones also observed for deep aquifer system (Fig.6.7)

6.3. GROUNDWATER MOVMENT

Ground water movement is from highlands (recharge area) to lowlands (discharge area) or from high elevation to low elevation even in the absence of discharging and recharging zone.

In the rift, the localization of groundwater is strongly controlled by the rift faults. They have two contrasting role in the movement and occurrence of groundwater.

- First, majority of faults are conduits to groundwater flow, in places these open faults allow significant amount of preferential groundwater flow parallel and sub-parallel to the rift axis.

  In the rift valley the direction of groundwater is strongly governed by the orientation of faults, which is often perpendicular to the regional groundwater contours in the highlands and escarpments. It was found that these axial faults govern strongly the subsurface hydraulic connection of the rift lakes and the river-groundwater relations. Some rivers disappear in these open rift faults as in the case of rivers coming from the Arsi highlands feeding lakes Langano and Shala.

In the rift floor, significant groundwater flows through local palaeochannels. An example to this is the palaeochannel along the Bulbula River, which connects lakes Ziway and Abiyata (Tesfaye Cherenet, 1982; Tenalem Ayenew, 1998). Isotopic and hydrochemical techniques also supported the subsurface connection of these lakes.

- Secondly, in contrast to the high hydraulic conductivity of the rift fractured volcanic, some faults act as barriers of groundwater flow. This is a common case in areas of rift-in-rift structures where the faults deep against the topographic slope forming local grabens and horsts. Beyond the barrier faults most volcanic rocks do not form large extended aquifers, even if they are highly permeable. The barrier faults form local swampy areas. (Shimels, 2006).

Ground water flow in the study area can be categorized as:

- Flows in the shallow aquifer for both vicinity of Koka Dam and Lake Ziway,
- Flows in the deep aquifer for both vicinity of Koka Dam and Lake Ziway
- Flows in the Dug wells near to the lakes
- And also along the corridors itself (in between the lakes).

6.3.1 Flows in the vicinity of Koka Dam for shallow aquifers

As confirmed from the previous works and the current study, ground water flows towards and away from the surrounding of Koka Dam. The dam also received ground water though its bed which consists of slightly consolidated lacustrine deposit, which is covered by thin silt sediment, has moderate to high permeability in the area of unconfined aquifer nature.

The reservoir area seems discharge area for local descending ground water, and the deep regional ascending ground water head seems stabilized at the level of reservoir floor.

According to the previous work and the current study, it is confirmed that the dam receiving water from south, north and north-west of the surrounding and in turn discharge to north-eastern of the dam as the potential area for leakage of the dam.

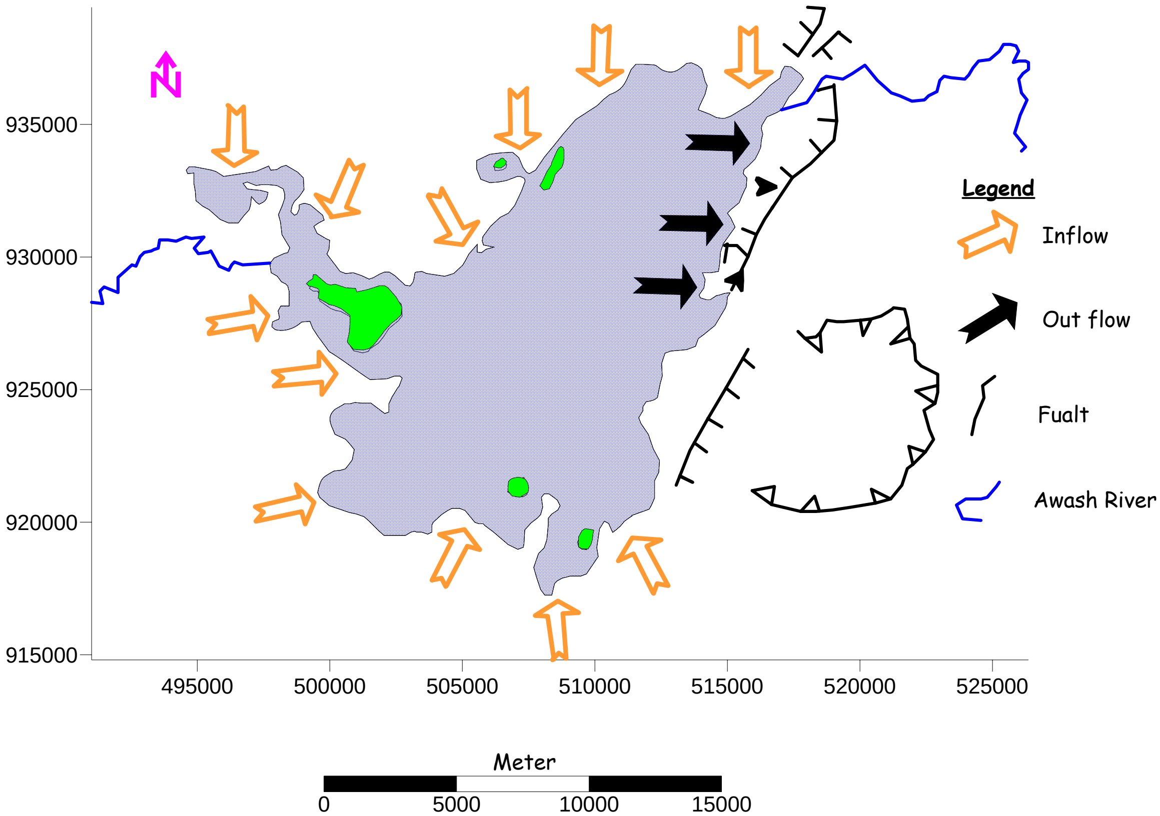


Figure6.2 Groundwater flows near to Koka dam (Modified from Sileshi, 2000) for shallow aquifer.

The reservoir area was a permanent marsh before impoundment and this suggests ground water discharge but previous water balance data for the reservoir show high negative leakage value, which evidence high ground water inflow into the reservoir, more than ground water discharge at the peripheries or shore areas.

Water depth in the Koka dam may not receive regional deep groundwater which could be supported by high aquifer temperature found below Koka town.

6.3.2. Flows in the vicinity of Lake Ziway from shallow aquifer System

Field static water level measurements of open shallow wells, secondary data collection in the appropriate offices in Addis Ababa, Ziway, Meki and Nazareth, helps to get enough and evenly distributed shallow wells data which are **48** in number that vary in depth from 18m to 60m (the deepest among the shallow wells) in the study area.

As of standard for shallow wells, the author considers that from 15 to 80m shallow wells. In this aquifer system, as also shown in discharge-recharge figure, the main recharge area is eastern part from which water migrated to Lake Ziway with the help of extensive structures that facilitate fast circulation and movement of ground water.

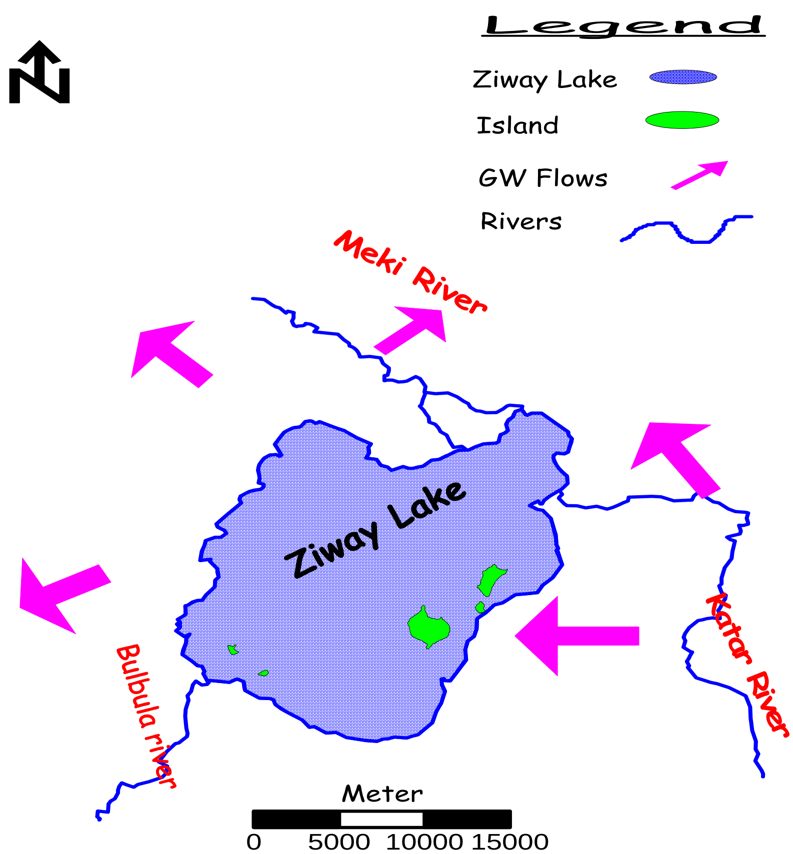


Figure6.3 Ground water flows in the surrounding of Ziway Lake from Shallow wells

As shown in the figure above, other part of the lake, discharge water to the northern, western and north western part from the shallow aquifer system and vicinity of Ziway Lake. Water that came from Gedamota rige and other part of Guraghe highland may sink dawn to the deeper aquifer than that of the shallower that is way shallow aquifer discharges towards Gadamota.

From the shallow aquifer system the lake also loss water in its northern part that might came from the other rift lakes in the southern of the lake ziway which may radiate to the koka dam.

Since, the lake is shallow (≈ 9m depth), the regional deep groundwater may not have impact on level rise.

6.3.3. Flows in the vicinity of Lake Ziway from Deep aquifer System

In this deep aquifer system also enough and almost evenly distributed deep wells data has been collected so as to determine ground water flow with in the corridors. Around 44 deep wells data obtained as they vary in depth from 81 to 410m (deepest well in the northern part of the study area).

In this system, the water comes from recharge area of both escarpment and highlands (fig.6.4) towards the lake Ziway.

Ground Water that rises from Guraghe highlands may sink dawn in its path and added to the deep aquifer, in turn, it radiate to the floor of the rift (Ziway Lake).

Ground Water that rises from eastern part, the Arsi highland, also discharges though the floor of Lake Ziway because of fast circulation of ground water due to intensive and extensive rift faults.

Flow direction in the northern part of Lake Ziway is the same for both shallow and deep aquifers system. In this case, the two aquifers may or may not merge along their path from norther part of Lake Ziway to the southern part of Koka Dam. Additional studies on aquifer characterization recommended to proven these.

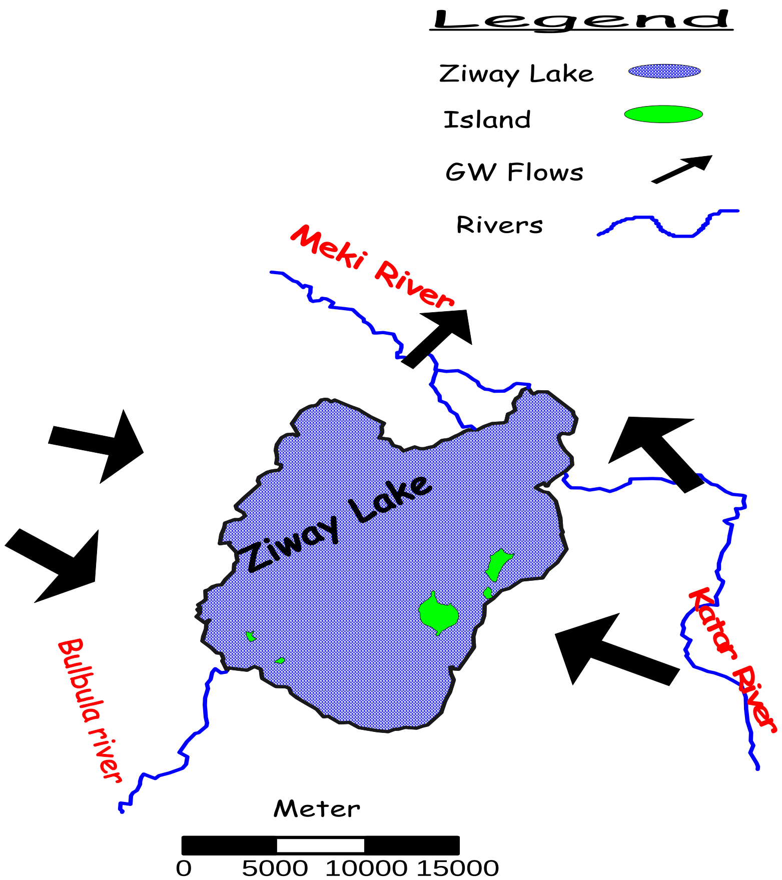


Figure6.4ground water flows in the surrounding of Ziway Lake resulted from deep wells

6.3.4. Flows with in the corridor in Shallow aquifer System

According to the shallow aquifer system, in the figure below, several parameters observed like regional and local ground water flows, divergent and convergent zone, local ground water divide.

- **Ground water flows**

By using surfer and Global mapper software together with shallow wells data, it is possible to determine the ground water flow direction from shallow aquifer system, which is depressed with in the corridors. North-western and south eastern part of the study area is the main source of water that migrated to different direction. The lakes themselves also act as the source in the eastern and western, north-western & northern part of Koka dam and Lake Ziway respectively.

Ground water that moves away from the eastern part of Koka Dam along with the Awash River is considered as potential leakage area of the dam.

Ground water also moves away from the vicinity of Lake Ziway after receiving from Arsi highland and its escarpment in which obviously faults are conduits to groundwater flow.

Ground water flow directions between the two lakes are more or less perpendicular to their axis or the corridor, that is the water that radiated from the Guraghe highland and its escarpment pass in south-eastern orientation by crossing the corridors to the eastern part of the study area.

Local groundwater flow leads to regional flow in most part of the area as observed in the figure below but in some case, the local flow disturb the regional one like in the divergent zone.

Divergent and Convergent Zone

Ground water contour map with the appropriate perpendicular vector map can determine divergent and convergent zones. According to the displayed map below, if the ground water contour map forms circular lines, it is either divergent or convergent zone.

Divergent zone is a specific area where the water starts to flow to any other area of different direction and consider as recharging zone, in the corridor, there are two divergent zones in the north-west and south-east part of the study area on the basis of shallow aquifer system, which may probably because of recharging of water from the highlands.

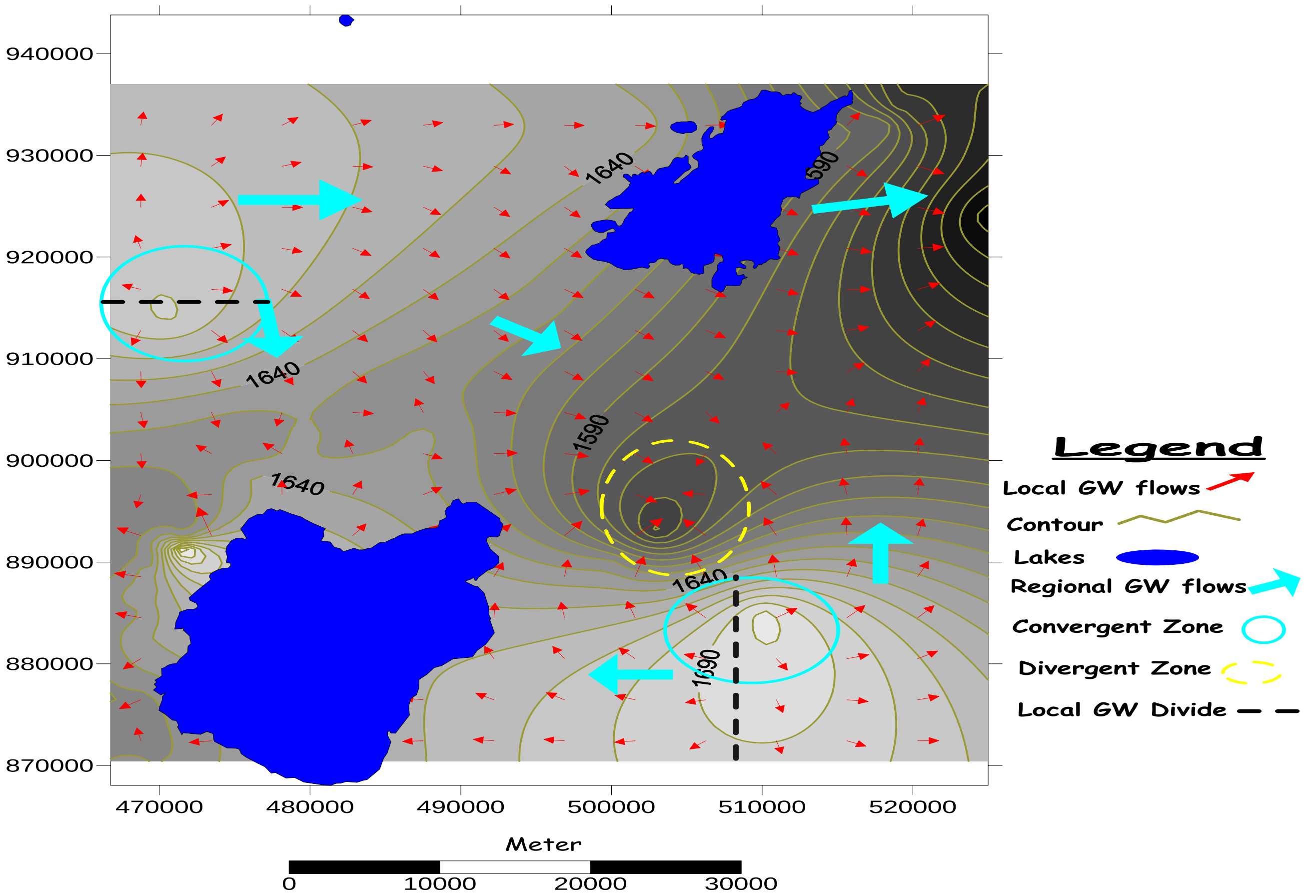


Figure6.5 Ground water flows with convergent and divergent Zone resulted from shallow well

Other than the topography, if the water potential of a specific zone is relatively high, it has plenty of contribution for existence of divergence zone.

Convergent zone is specific area where the water flows toward specific zones that comes from its surrounding of any other direction and consider as discharging zone. From the figure above, there is only one convergent zone in the study corridors which is located north-eastern part of Lake Ziway or southern part of Koka dam. At this convergent zone, water comes from almost all direction of the area. Existence of convergent zone may depend on several factors among which structure is the main one. Accordingly, the area where convergence observed in the study corridors is dominated by structures.

- **Local ground water Divide**

Groundwater divides are imaginary and vertical impermeable boundaries across which there is no flow (Freeze and Cherry, 1979) or the flow is in the opposite direction of these ideal lines. The divide can be generated from ground water contour map and vector map which is perpendicular each other, specially vector lines shows opposite direction representing ground water flow direction. This imaginary line may be locally or regionally extends from one direction to the other direction, in the study corridor, for shallow aquifer system there are no ground water divide which exists in the extended form. But in most case, in the zone of divergence, there are also local water divide which may not consider as a divide. In this study, such a divide is observed at the divergent zone. This may because of faults which act as barriers of groundwater flow sometimes.

6.3.5. Flows with in the corridor in Deep aquifer System

Existence of deep aquifer system can be confirmed from deep wells data that vary in depth, the deepest well in the area has 410m well depth.

Ground water flow direction in this deep aquifer system, unlike the shallower, has relatively clear distribution of water migration that radiating from the escarpments to the floor of the rift (Fig. 6.6).

As hypothesis from the previous authors, there are deeply ascending regional hot mineralized thermal waters which starts its journey from southern part of Lakes Region to the northern part. It is originated as geothermal and mix when rising with local meteoric water. This assumption can also confirm as:

- First, from existing data collecting from field and appropriate office together with soft ware like Surfer and Global Mapper, the following ground water contour map and vector map displayed in order to get the flow direction of ground water in the corridor. As a result, by using different vector map frequency, the resulted map of deep aquifer system has been obtained which clearly indicate the flow direction in the corridor towards koka dam.

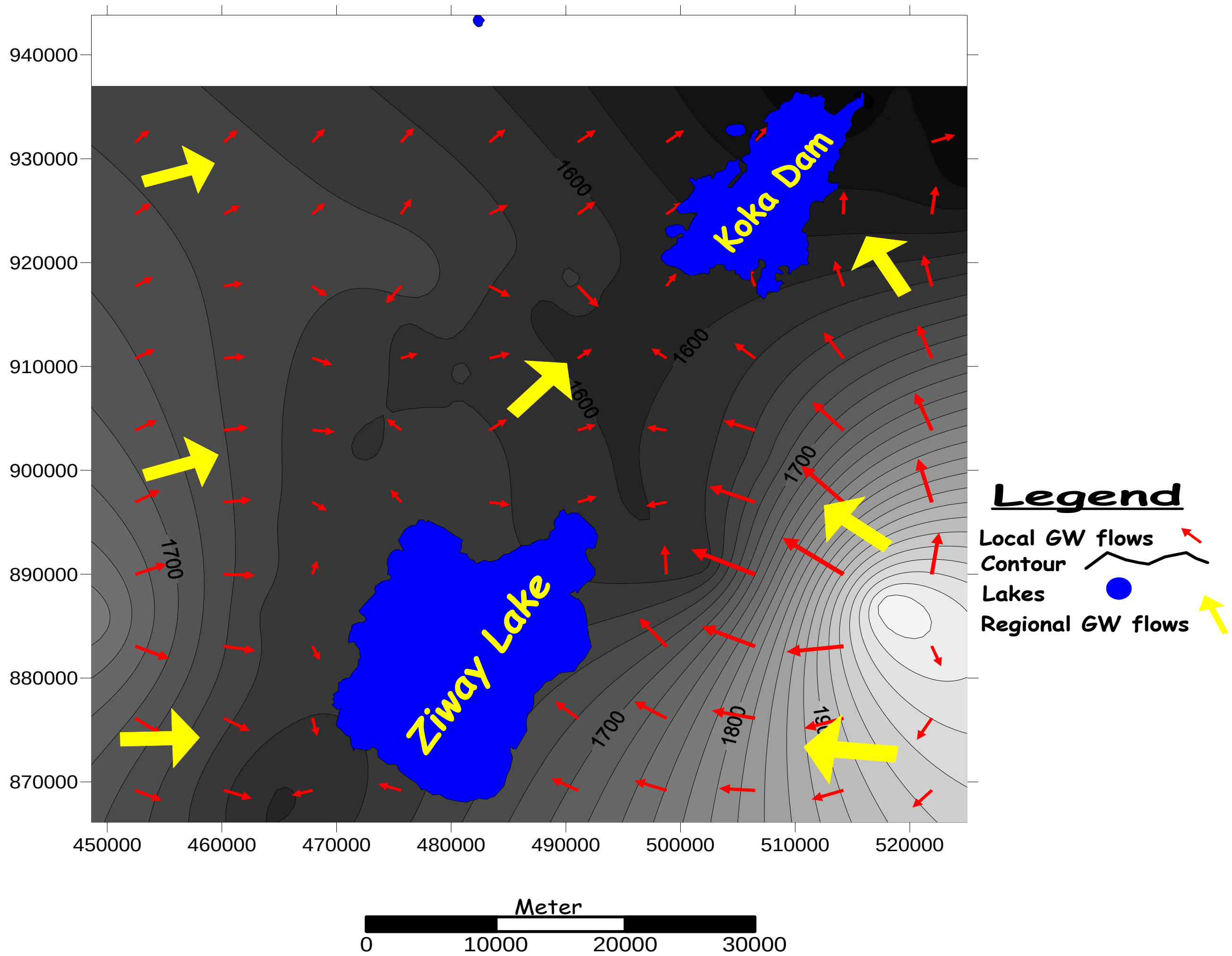


Figure6.6 Groundwater flows direction resulted from deep well

The flow direction indicated in two systems with high and low frequency of vector map of the same data to clearly observe the flow direction, the overall orientation of these frequencies (the high frequency-the yellow vector and low frequency-the red one) are correlated with the above hypothesis with respect to the flow direction of ground water. Depending on it, ground water with in the corridor is migrating from the southern part (probably from lakes region to be geothermal origin) to northern part.

- Secondly, comparing the depth and temperature of the hot mineralized thermal water of the two zones, the lake districts and the Koka, supporting the flow direction in the above figure. Geothermal fluids in the lake districts were reported to rise to the level above the ground water piezometric level with a temperature of greater than 55^0c. But in the northern part, Koka vicinity-Kintiri small town, geothermal fluid is sampled by the author which is relatively in deeper manner 17-25m with a variable temperature of 48-50^0c. As sourced from Lake District, the temperature in the northern is relatively lowered because its mix with meteoric water in its path moves in the northern. The depth also has a significant difference; geothermal fluid is observed in the level above the ground in the Lake District but in the northern part it is relatively deeper, this is because the regional aquifer may inclineding dawn in the northern part.

- Thirdly, the geomorphology of the lakes show altitude variation which is inclined dawn to Koka Dam (1589masl) from Lake Ziway (1637masl) which may be reflected on the deep aquifer system that facilitate the ground water flow to northern of the corridor.

Taking into consideration the small vector map frequency, it helps to clearly observe detail ground water flows direction and divergent & convergent Zone with in the study corridor which is important to generalize the flow direction of the ground water in the study corridor. (Fig. 6.7). As seen in the figure below, the deep aquifer system has clearly observable ground water flows that migrate from the western and eastern part of the escarpment to the floor of the rift and with in the rift, it can be generalized that flow direction from northern part of Lake Ziway to southern part of koka dam which could be part of the regional water flow (larger blue vector map prepared by manual, not based on the data, to generalized the detail or local flow). Like the shallow aquifer, there is also observable local divergent & convergent zone distributed with in the study area.

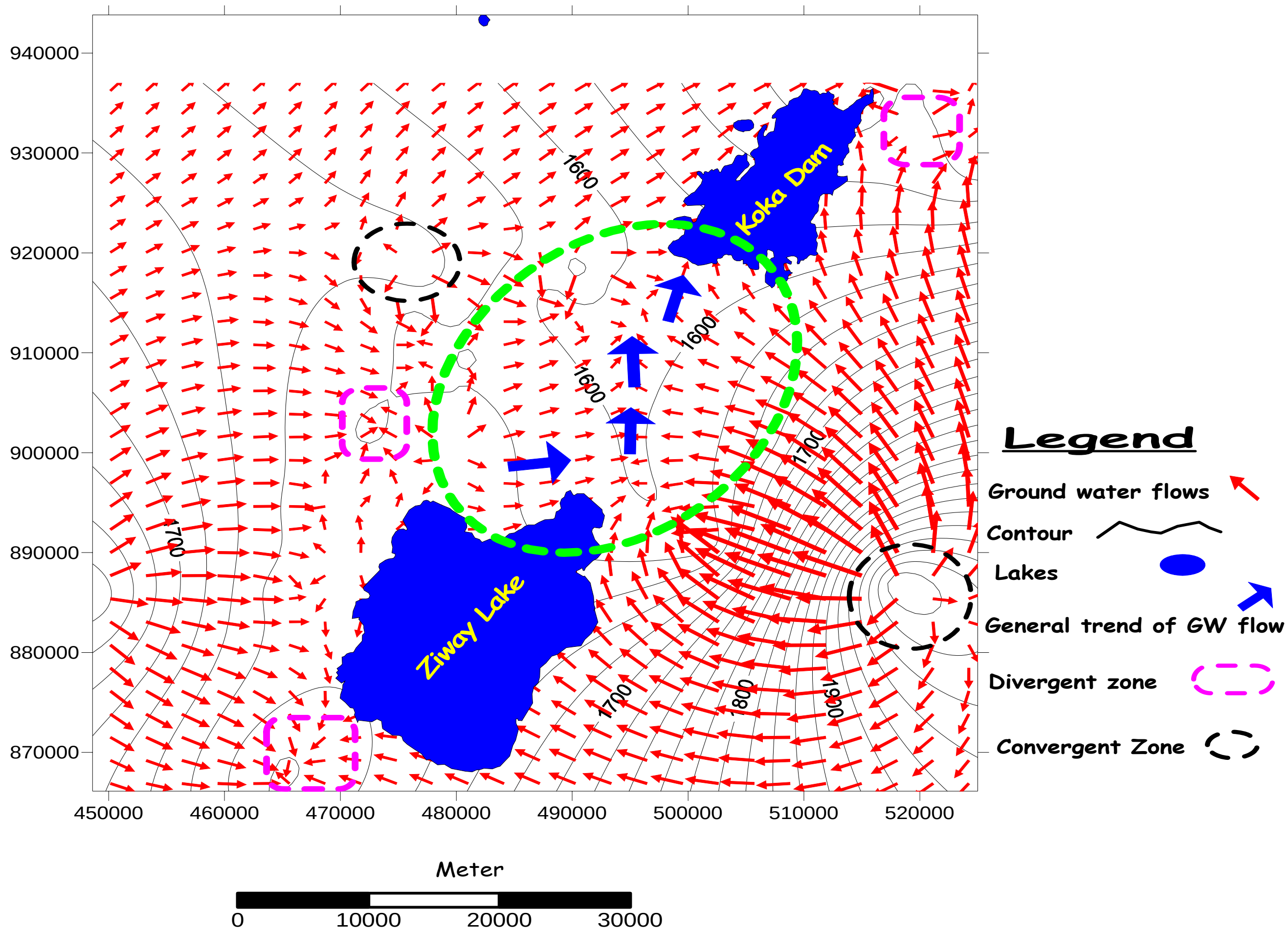


Figure6.7. Groundwater flow direction from deep well data and detail frequency of vector map

Comparing these out put to that of the previous one, the current out put has different value in terms of ground water flow direction. According to other author, there is surface and ground water divide that is running in between the two water bodies by crossing there axis which is almost located 125km driving from Addis to Ziway along the asphalt road near to lacustrine outcrop and its specific GPS reading at this asphalt road read is E 484020 and N 904911.

In the current study, prepare the standards for shallow and deep wells data for the determination purpose of ground water flow direction and interpret each of them separately as observed in the figure 6.5 and 6.6.

Separate flow direction can be clearly seen by overlaying the two aquifer flow system together with in the area as shown in the figure 6.9.

In this case, the shallow aquifer flow direction in the eastern, north-east, central and north-west part of the study area is different from that of deep aquifer.

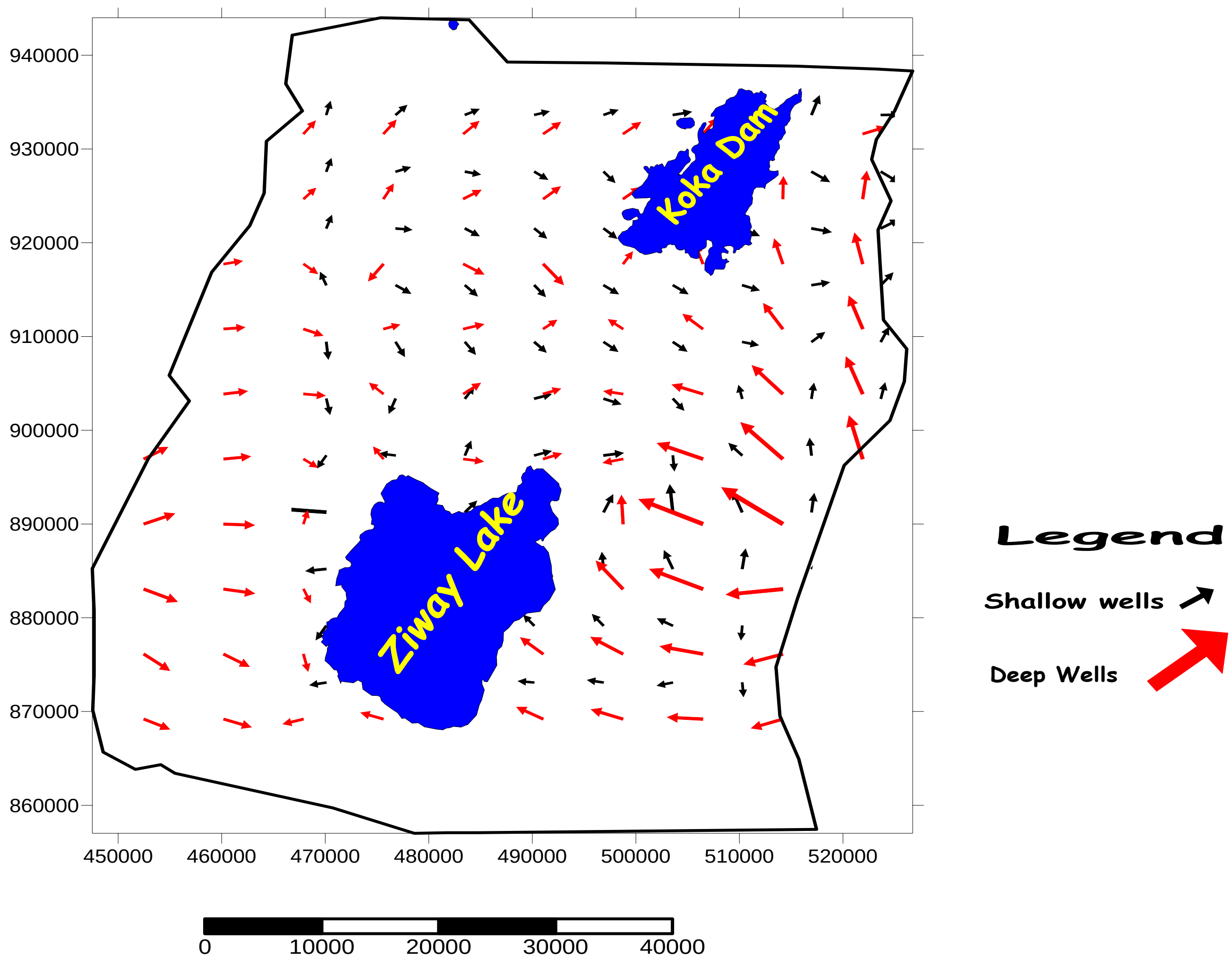


Figure6.8. Difference in GW flow direction between shallow and deep wells

6.3.6. Flows with in the corridor from hand dug Wells near to lakes

From hand dug wells which mostly concentrated along the lakes (Ziway and Koka) has been measured different in situ parameters including GPS and SWL. Taking the altitude from GPS reading and SWL directly from 254 hands dug wells which have been visited in the field at the data collection phase of this study. Most of them are located south-western and north-western part of Koka dam and Lake Ziway respectively, which has crucial significant for small scale irrigation around the lakes. Groundwater flow direction from these data display in the figure below.

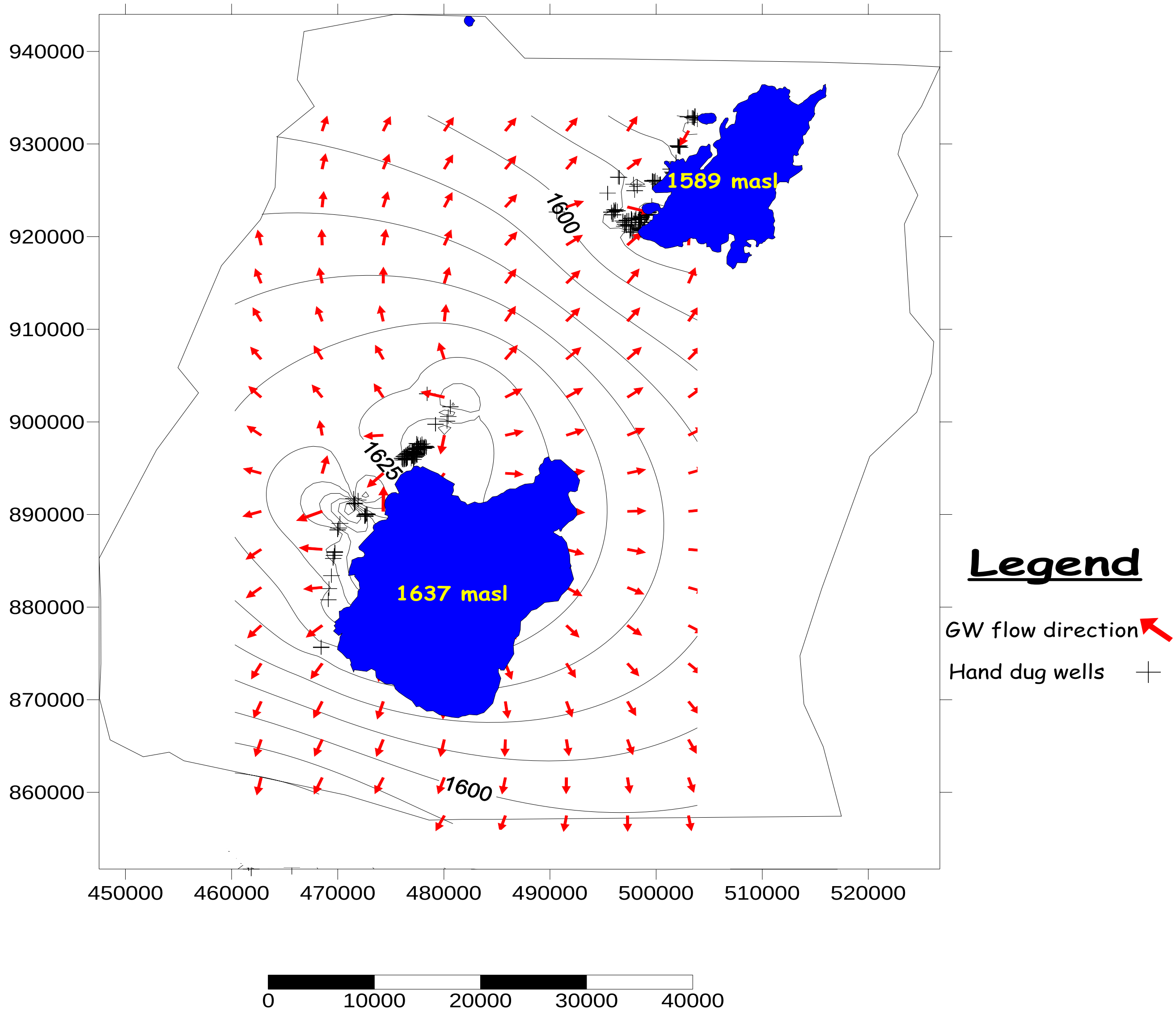


Figure 6.9. GW flow direction of HDWs along the lakes

Groundwater flow direction from HDW data in the above map shows that from Lake Ziway (1637 masl), which relatively elevated, to Koka dam (1589 masl). Not only in this direction, in other direction of lake ziway, ground water is discharged to south ,east, west, south-east and south-west.

CHAPTER SEVEN

H Y D R O C H E M I S T R Y

7.1 GENERAL

Nearly all groundwater originate as rain that infiltrates through soil into flow systems in the underlying geological materials. The soil zone has unique and powerful capabilities to alert the water chemistry, as infiltration occurs through this thin, biologically active zone. In recharge area the soil zone undergoes a net loss of mineral matter to the flowing water. As groundwater moves along flow lines from recharge to discharge area, its chemistry is altered by the effects of a variety of geochemical processes. As groundwater moves along its paths in the saturated zone, increasing of total dissolved solid and most of the major ions normally occur, in the shallow groundwater in recharge area is lower in dissolved solids than the water deeper in the same system and lower in dissolved solids than water in shallow zones in the discharge area.

According to Chebotarev (1955) and two hydro geologist in the Soviet Union developed groundwater tend to evolve chemically toward the composition of seawater. They observed that this evolution is normally accompanied by the following regional changes in dominant anion species:

Travel along flow path ----------------->

$$HCO_3^- \text{----->} HCO_3^- + SO_4^{2-} \text{---->} SO_4^{2-} + HCO_3^-$$

$$SO_4^{2-} + CL^- \text{---->} CL^- + SO_4^{2-} \text{---->} CL^-$$

Increasing age------------->

These changes occur as the water moves from shallow zone of active flushing through intermediate zones into zones where the flow is very sluggish and the water is old.

These chemistry variations along its flow paths are very important for generation of hydrochemical data which are applicable for the conceptualization of groundwater flow pattern (dynamics), Standardization of water quality in various natural geological and hydro geological systems.

Conceptualizations of groundwater flow systems in small watersheds has been demonstrated by Toth (1963) which has importance to hydrochemical analysis in hydrogeology along with simple two dimensional numerical groundwater flow model.

Winter (1978a) presented the use of Groundwater flow models coupled with hydrochemical methods in understanding the groundwater-surface water interactions in Lake Watershed systems. A more comprehensive coverage of the study and interpretation of chemical characteristics of natural waters and their use in hydrological studies have been provided by Hem (1970), Stumm & Morgan (1970) and Appeleo & Postman (1993).

Standardization of water quality based on World Health Organization can also generated on the basis of Hydrochemical data which in turn helps to categorized water for human, industrial and irrigation purpose.

As an objective of this section, the Pysico-chemical analysis, which is considered as hydrochemical data, result of different water source like boreholes, Hand dug wells, cold & hot spring, rivers and lakes water are helps for the determination of ground water flows direction along the corridor. In its approach, as ground water moves from place to place, the chemistry of water changes due to, displacement & replacement reaction beteewen ions, duration and interaction between rock and water. Variation of ionic concentration in this aspect soundly important for determination of flows, among these ions Na, Cl and TDS are the most common.

The analysis also crucial for the recommendation of water quality of the study area for human consumption comparing to WHO standard. Special emphasis on the concentration and spatial distribution of fluoride has been given. This is because the study area has large coverage of the rift floor which is highly affected by the fluoride due to dissolution of acidic volcanic rocks. The tooth of children and spinal cord of old men and women affected by fluoride, in most part the area its concentration is beyond the standard limits of WHO. Now a day, different diflouridation techniques by chemists, physician & hydro geologists cooperating with GO and NGO like CRS has been conducted to solve this community problems (see below).

7.2. SAMPLING SITES AND METHOD

The distributions of boreholes, hand-dug wells, springs, rivers, lakes and geothermal have been examined in a view to identify reference areas, to give a representative geographical and hydro geological sample distribution. Their distribution consisted of a total of 140 samples all from recharging, discharging and transition Zone. Their particular numerical distributions are 61,50,13,7,5 and 4 for borehole, HDW, spring, rivers, lakes and geothermal respectively

The method involves the withdrawal of water from pumping boreholes sufficiently in order to insure that the sample represents the groundwater that feeds the well and in situ measurements of pH, Eh, EC, TDS and Temperature has been conducted.

Samples are batch type collected at particular time and places. These kinds of samples represent the composition of the source at that particular time and place. However, when a source is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then the sample may be said to represent a longer time period or a large volume, or both, than the specific point at which it was collected. Accordingly, the physico-chemical analysis which analyzed by the previous author also included in this study.

The samples are collected by a polyethylene plastic bottle that are the I.A.E.A standards which has the advantage of not breaking when they are completely filled as can be the case with glass bottles after temperature changes and were reached to the laboratory at easier risk within few days and laboratory measurements are then carried out in Addis Ababa University and SABA Engineering P.L.C.

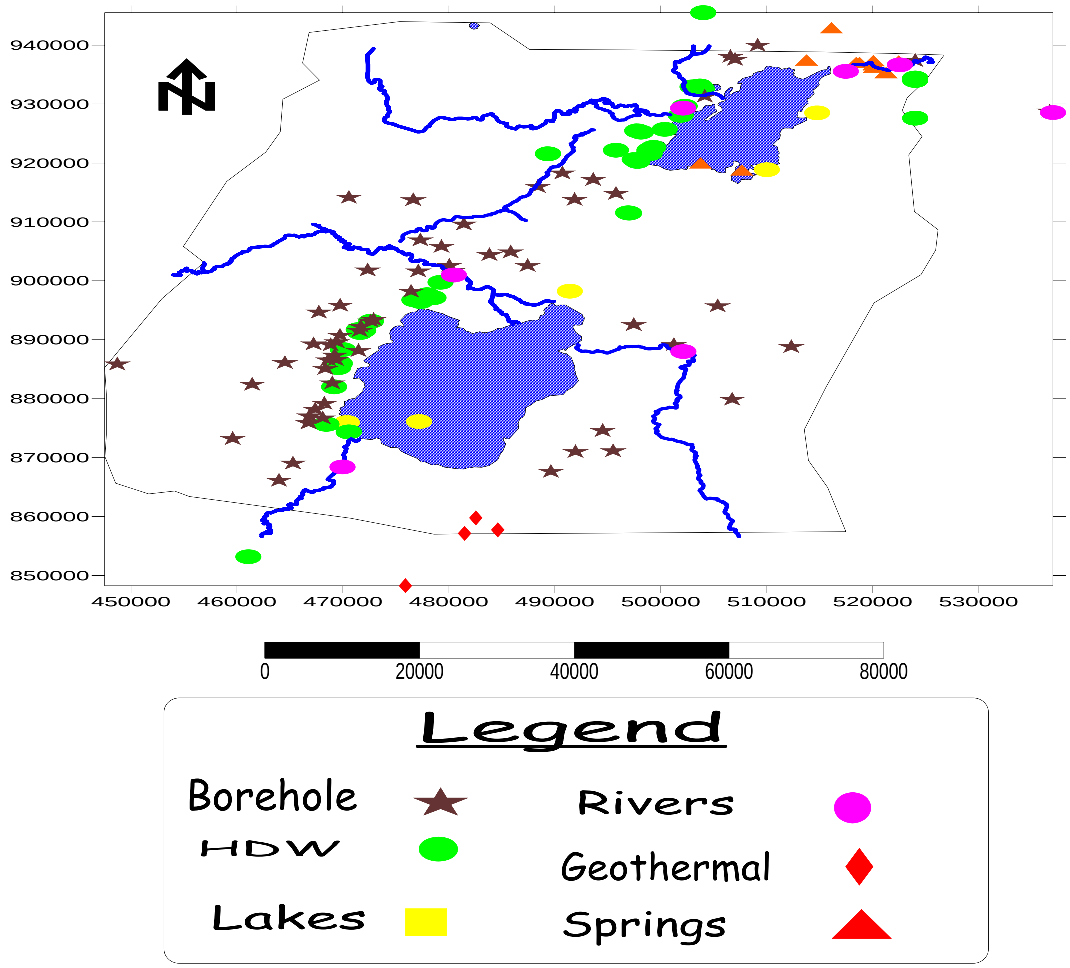


Figure 7.1 Water sampling sites

7.3. IN-SITU PARAMETERS MEASURED IN THE FIELD

In-situ measurements in the field are very common for the parameters which easily altered by the environment or surrounding atmosphere like PH, EH, Temperature Conductivity and TDS. These parameters in the field measured using check-temp to measure temperature, conductivity meter to measure conductivity, redox potential and TDS, and PH meter for PH. These geochemical analyses also measured in the laboratory as obtained from secondary data and previous author, and together with in the current result discussed below.

7.3.1 PH (hydrogen ion activity)

According to Hem, 1992, Hydrogen ion of natural waters mainly fall between 6 to 8.5 and it is controlled by interrelated chemical reactions that produce or consume hydrogen ions. The main once are the reaction of acidic solutes and hydrolysis reaction.

The field measurements of PH values of the studied area near to the lakes and the surrounding of small towns which ranges between 6.44 to 8.2 and therefore, PH values of water in the area can consider as neutral.

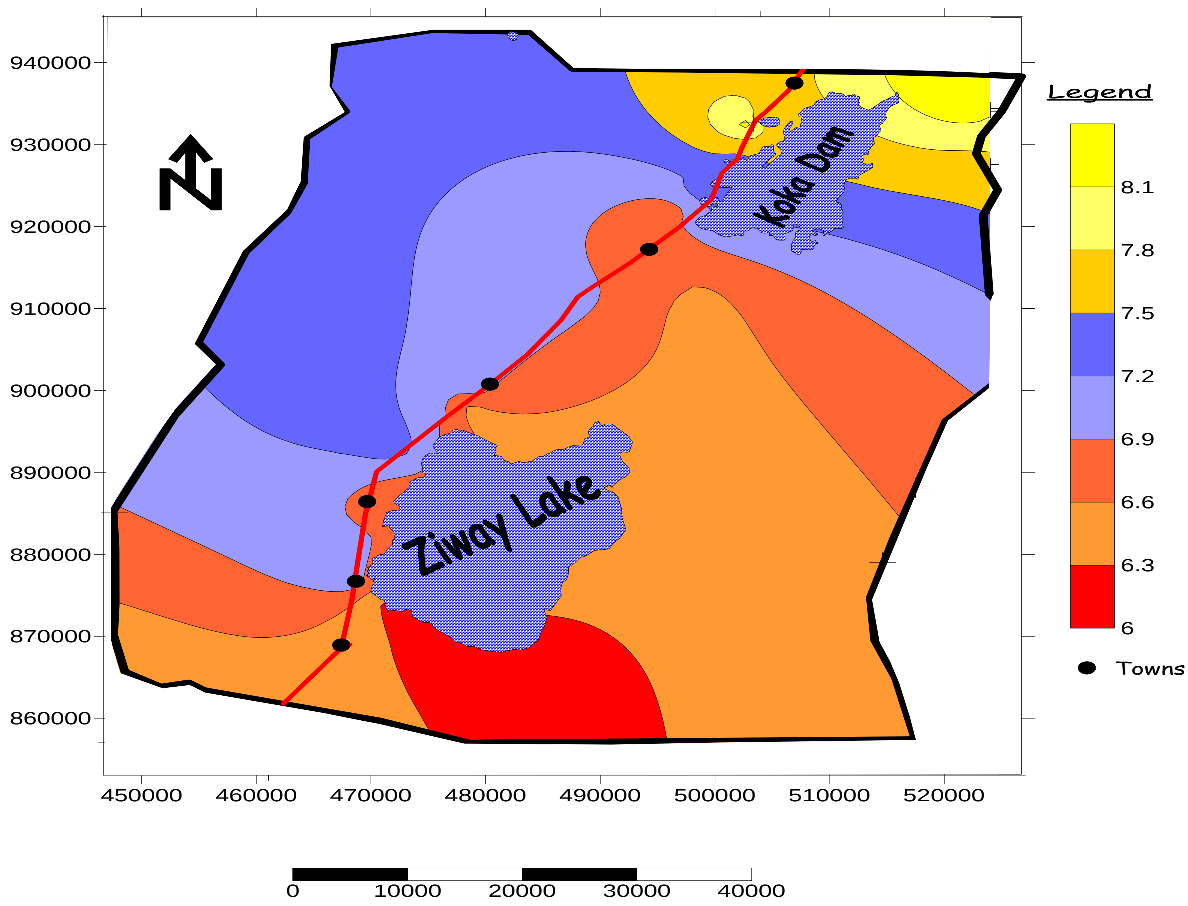


Figure7.2. Trend of pH in the area form HDW & certain boreholes

As observed in the above figure, moving along the corridor, PH distribution ascending in its concentration from the northern of Lake Ziway to north-west of koka dam, reflecting of water movement which also agrees with HDW flow direction in fig.6.10.

Field measurements and reading from laboratory of boreholes, hand dugs, spring, lakes and rivers of all water with in the studied area displayed below. Unlike the above figure (Fig.7.2), uniform distribution of PH values is not detected, this may because of mixing of different water sources with in different depth, but the overall PH values of the corridor can easily observed.

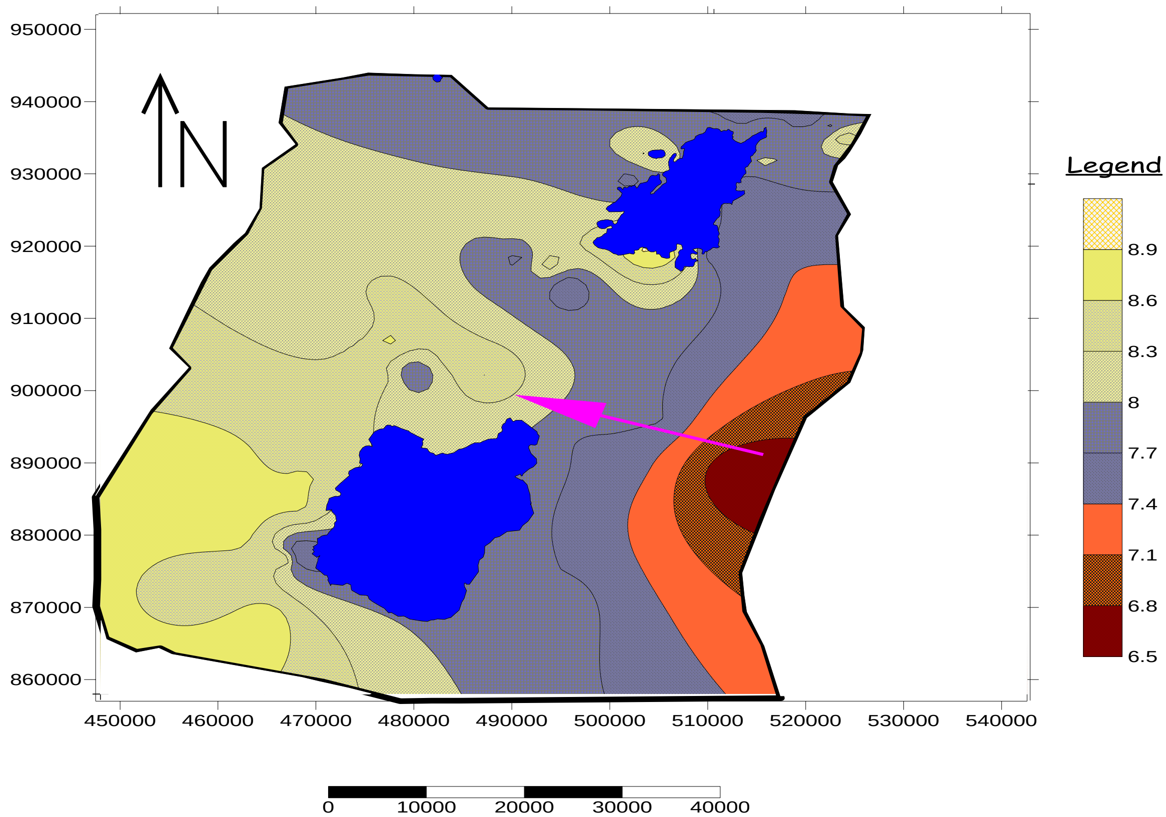


Figure7.3. Trend of pH in the area for all water

Even if the overall distribution is not uniform, the water that comes from the eastern part indicated that the concentration of PH increasing along the water flow direction which also confirmed in the water flow system.

7.3.2. Electrical conductivity (EC)

Electrical conductivity of water is its ability to conduct an electric current at a specified temperature and it is usually measured in micro siemens per centimeter or micromhos per centimeter (Weast, 1968). The values of EC increase with temperature, between 20^0c and 30^0c, an increase in 1^0c, increases the EC by two percent on the average (Hem, 1992).

The presence of charged ionic species in solution makes the solution conductive. As ion concentrations increase, conductance of the solution increases; therefore, the conductance measurement provides an indication of ion concentration.

It is apparent that the relationship between electrical conductivity and ionic concentration of water is direct, and most of the data set fit a straight-line regression closely (correlation coefficient= 0.6).

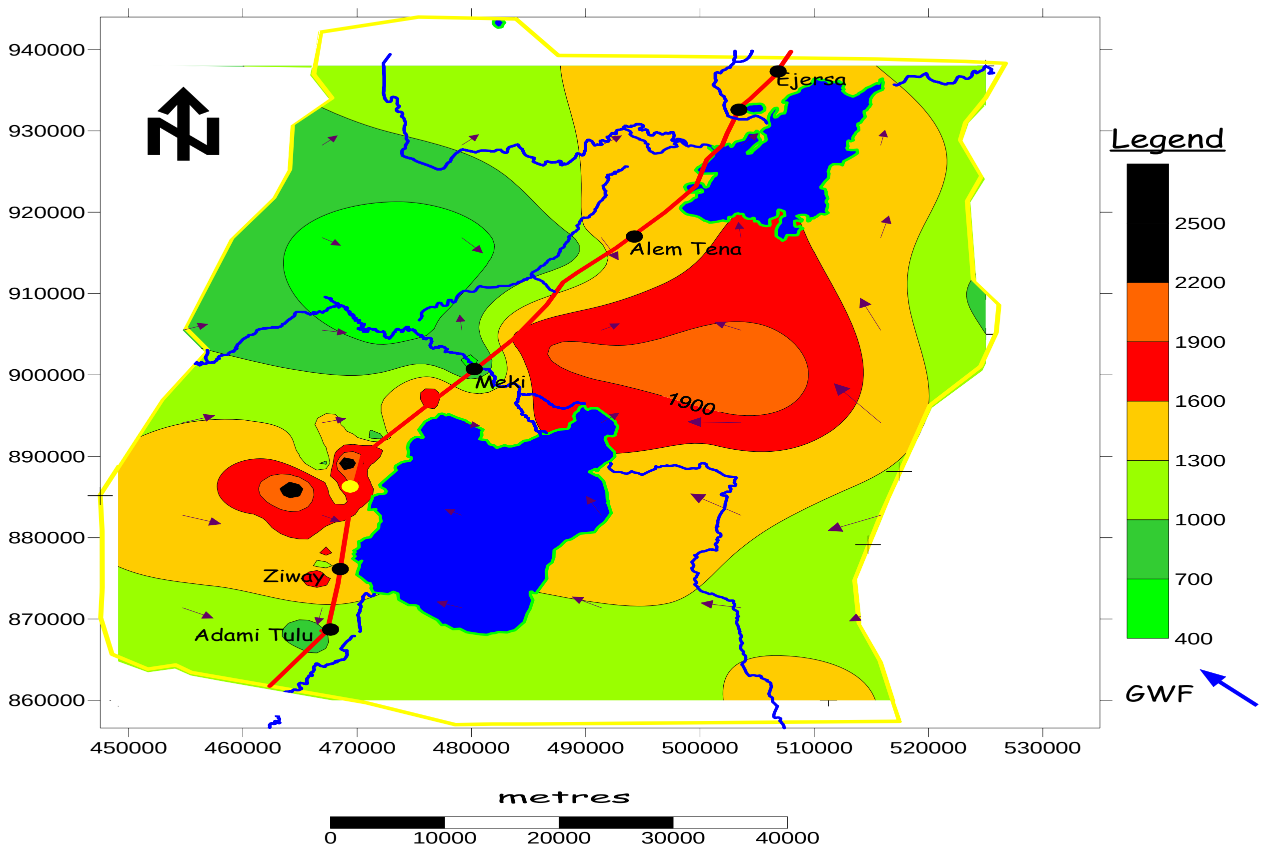


Figure7.4. Electrical conductivity Map

Electrical conductivity values show significant variations with the different sources of water. It has been observed that most of deep boreholes have a higher EC values and these values are progressively decreasing for shallow source of water.

On Fig.7.4 sharp increase in EC towards the rift implies that there is a general groundwater flow from the highlands towards the rift valley in both directions. The EC also varies within the rift waters which show the northward flow in the rift. The arrow symbols are vector maps prepared using surfer to show the regional deep groundwater flow from low EC to the higher. The regional flow system supports the results of major ion traced flow path.

7.3.3. Total dissolved solids (TDS)

Total dissolved Solids included all solid material in solution, whether ionized or not. As it is related to the sum of the concentration of all ions, it is directly related to the electrical conductivity. TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine.

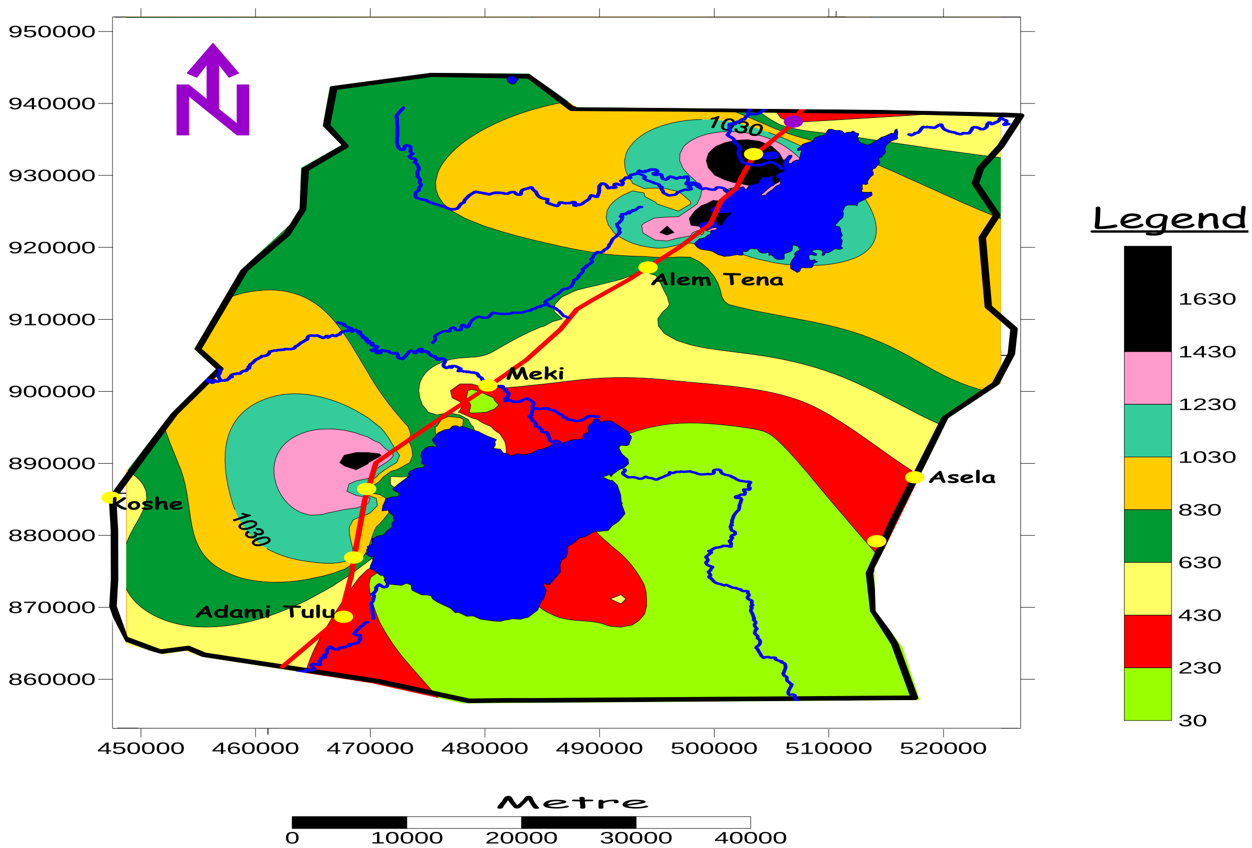


Figure7.5. TDS Map

Thus, the total concentration of dissolved solids can be used for simple classification of water (Tenalem Ayenew & Tamiru Alemayehu, 2001)

TDS map of the studied area shows its distribution with in the area. The concentration is increasing from north of Ziway along the corridors to Koka dam with an increasing order of 230ppm, 430ppm, 630ppm, 830ppm, 1030ppm respectively which can coincide with ground flow direction.

High TDS observed in the western and north & south western of Ziway and Koka respectively. This could be:

- Because of high irrigation activity in the lakes vicinity with artificial fertilizer.
- Other anthropogenic effects as the areas are urban and Semi urban.
- Because of thermal aquifer, there may be high degree of water-rock interaction in the vicinity of Koka reservoir.
- Or/and any other Geological and Hydrogeological factors such as formations

7.3.4. Redox Potential (EH) and Temperature

For chemical reactions in which electrons are transferred from ion to the other one (redox reactions), the oxidation potential of an aqueous solution is called the Eh

High Eh is generally the direct result of dissolved oxygen in the water. (Drever, et.al. 1997).

EH was measured in the field and the values analyzed and interpreted by corresponding software but most of the out put not fitted with the expected result, this is because, during measurements in the field either the apparatus was not normal or it fatly react with the atmospheric oxygen.

Temperature also other parameters measured in the field by using conductivity meter. In most case, shallow ground water are normally characterized by a temperature which is strongly affected by the type of overlying surface environment. In the area, almost all wells have the same depth with same climatically situation but shows temperature variation. Temperature of the area ascending when moving to Koka at the maximum of 55^0c which has a relation with regionally ascending thermal water that migrating from southern part of lakes region and create thermal aquifer around Koka Dam that doesn’t have any relation with the Dam. Wells with SWL on the average 4m very near to the Koka Dam, have thermal water.

7.4. CLASSIFICATION AND PRESENTATION OF LABORATORY MEASURED PARAMETERS

The spatial variability observed in the composition of the major ions can provide highlight to aquifer heterogeneity and connectivity as well as the physical and chemical processes controlling water chemistry. Generally the approach is to divide the samples in to hydro chemical groups, which are group of samples with similar chemical characteristics that can then be fitted with location. Verification that systematic variations along the flow path are related to reactions between ground water and surrounding formation which can provide the hydro chemical evolution trend for the study area. This is crucial for interpreting the spatial variations of water chemistry (so as to determine potablity of water) and defining ground water flow direction along the corridors and characterization of the hydrologic systems.

By using Aquachem Software, it is tried to use some of the many available graphical and statistical methodologies to classify the water samples including Piper diagram, Pie Chart, Box & whisker, Stiff diagram, and Schoeller plot.

7.4.1 GRAPHICAL PRESENTATIONS

An important task in groundwater investigation is the compilation and presentation of chemical data in a convenient manner for visual inspection. For this purpose several commonly used graphical methods are available from simplest to complex one like Stiff diagram, Pie chart, Box-whisker, and piper diagram & Schoeller respectively.

Most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species (Hem, 1989) and all the graphical methods use a limited number of parameters, usually the available data, unlike the statistical methods that can utilize all the available parameters.

7.4.1.1 Box and Whisker for Major ions chemistry

Water is naturally balanced in terms of the existing cation and anion (Na, K, Ca, Mg & CL, SO4, CO3, and HCO3) but because of its distribution, occurrences and movements with in geological formation, the neutrality of water disturbed. On the study area, variable dissolved solids observed together with major ions concentration.

Major ions concentration on the surface and in the ground water shows great variation as can be seen in the figures below, which shows that the minimum, maximum and mean concentrations of the major cations and anions of groundwaters (from boreholes, cold springs, hot springs, dug wells and geothermal wells) and Surface Water (Lakes & River waters) in the study area.

In the case of groundwater, Sodium is the dominant cations followed by calcium and magnesium, and bicarbonate is the dominant anions which also followed by Cl and SO4. Major cations concentration descending uniformly from Na, Ca, and Mg in the groundwater of the study area (Fig.6.7).

The dominance of Sodium in the study area is likely to be attributed to the dominance of the acidic volcanic, mainly ignimbrite, rhyolite and pumice.

Calcium is also sourced from many igneous rock minerals, especially in the silicates of pyroxene, amphibole and feldspars. In the volcanic the main sources of these ions come from the basic volcanic.

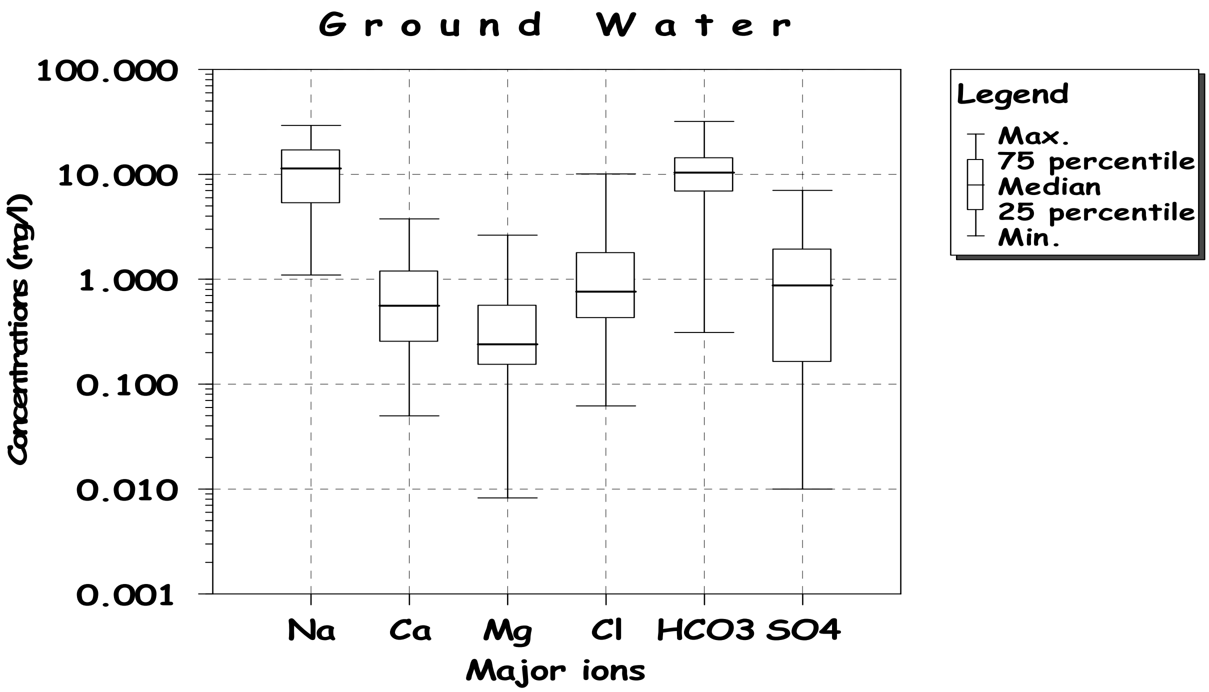


Figure7.6. Semi-log plot of major ions concentration of Ground Water

Magnesium is typically a major constitute of the ferromagnesian minerals such as olivine, pyroxene and amphiboles, which from basic rocks and has small concentration in the.

The dominance of Bicarbonate in the study area is likely to be the reaction of dissolved CO_2 with rocks dominated by minerals with Na, K-Silicates common in acidic rocks.

Other anions, CL and SO_4 more importantly sourced with an association of sedimentary rocks, volcanic gases from geothermal fields may also introduce Cl in the groundwater system and in some rift lakes. Some unusual high Cl in the rift lakes is likely to be related to the influence of geothermal fields.

High SO_4 waters in the Main Ethiopian Rift are probably attributed to the effect of local lacustrine deposits associated with evaporates (Tenalem Ayenew, 1998).

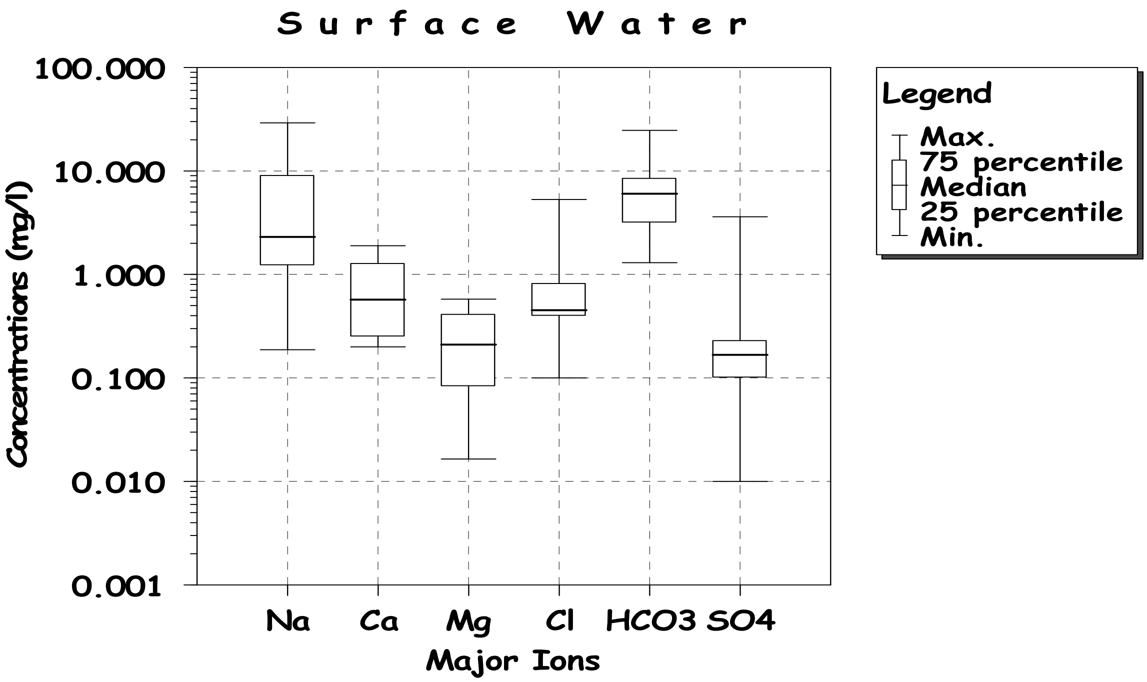


Figure7.7. Semi-log plot of major ions concentration of Surface Water

In the case of surface water, (fig.7.7), the dominance of cations and anions have same as the groundwater (Na for cations and HCO_3 for anions) but the distribution, and maximum & minimum values completely vary.(ANNEX…).

Therefore, there is a high variation of dominant cations and anions species both in groundwater and surface water samples. This ionic variability reflects the existence of different hydrogeological process that is crucial to trace groundwater flow paths in the study area

7.5.1.2 Piper diagram and Water types

Piper diagrams permit the cations and anions composition of many samples to be represented on a single graph in which major groupings or trends in the data can be discerned visually and also showing the effects of mixing two waters from different sources. The mixture of the two waters will plot on the straight line joining the two points. The intersection of lines extended from the two sample points on the triangles to the central rectangle gives a point that represents the major-ion composition on a percentage basis.

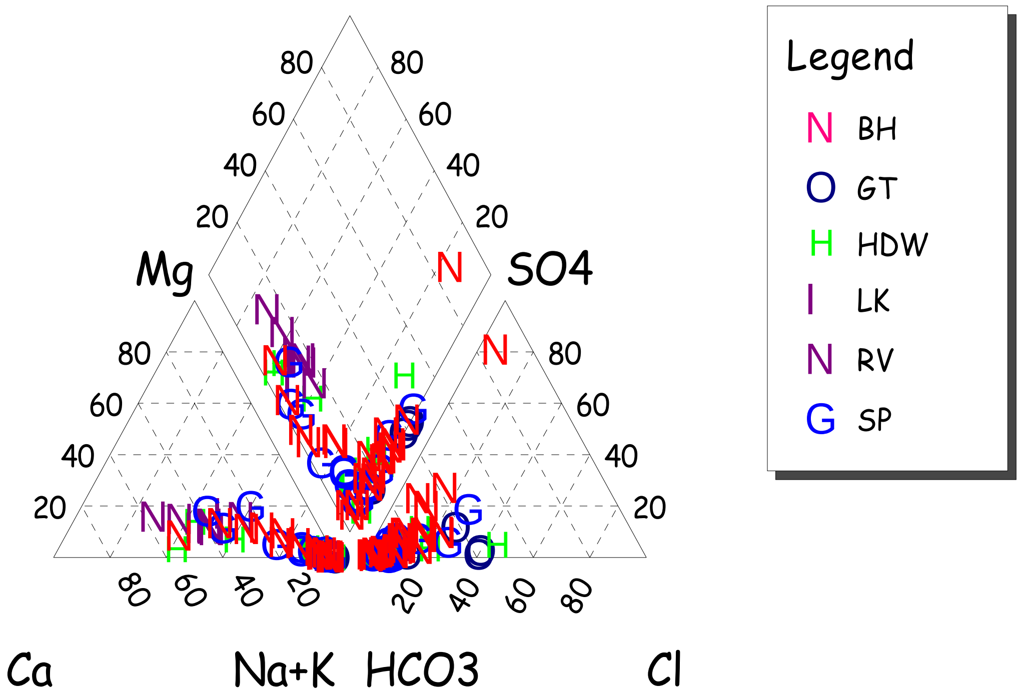


Figure 7.8. Piper plot of all water sources

From this point, lines extending to the two adjacent scaled rectangles provide for representation of the analysis in terms of two parameters selected from possibilities, in this case, total major-ion concentration.

In the Fig.7.6, all cations concentrated nearly on calcium and sodium bar line reflected to in the central diamond shaped rectangle, at same situation, all anions nearly concentrated to bicarbonate bar line reflected to the central diamond shaped rectangle. The two major cations and anions simultaneously reflected on the rectangle and forming intersection which is representing of water point. The reflection values in the central rectangle concentrated on its bottom apex showing the Na + K + HCO_3 + CO_3 Values and slightly diverted to the left boundary of the rectangle to indicate the value of Ca and Mg. Accordingly, the water is Na-Ca-HCO_3 and Ca-Mg- HCO_3 types.

In addition to all water source together, piper diagram also important to display each water source of more than one sample. In the figure below, six piper plots observed which are representing Borehole, Geothermal, hand dug well, lakes, rivers and spring.

Lake Sample positions on the piper plot (Figure7.10) represent the fresh Lake Ziway and Koka dam waters. The dominant cations in these lakes waters are sodium followed by calcium and magnesium, and the dominant anion is bicarbonates. These lakes waters fall in the Na–Ca-Mg-HCO_3 type in the Piper plot.

In the majority of waters from the rift floor boreholes (Figure 7.7), spring (Figure7.12) and dug wells (Figure7.9); sodium dominate their cations species followed by Calcium & magnesium and bicarbonate dominate their anions. These groundwaters fall in the Na–HCO_3 and Ca-Mg-HCO_3 type in the Piper plot and most of them have moderately high TDS.

Geothermal (Figure7.8) sample located in the piper diagram shows the dominant of ions of Na and HCO_3 which is followed by SO_4 and the water types are Na-SO4 - HCO_3.

Rivers water sampled in the piper diagram (Fig.7.11) indicated the dominance of Ca and Mg as cations and HCO_3 as anion and its water types is Ca-Mg- HCO_3.

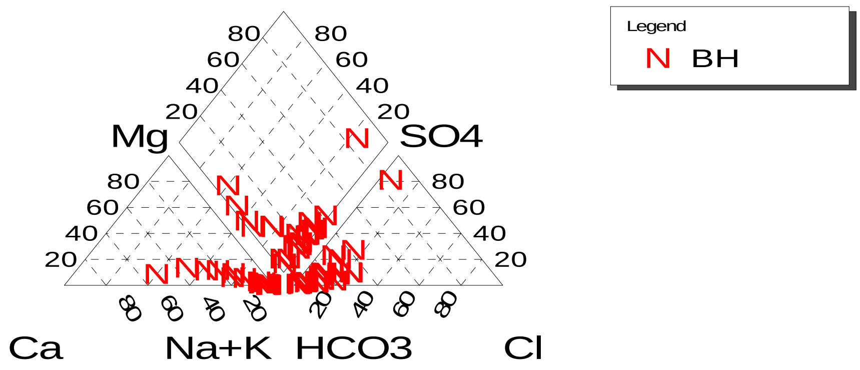


Figure 7.9. Piper plot for all Boreholes

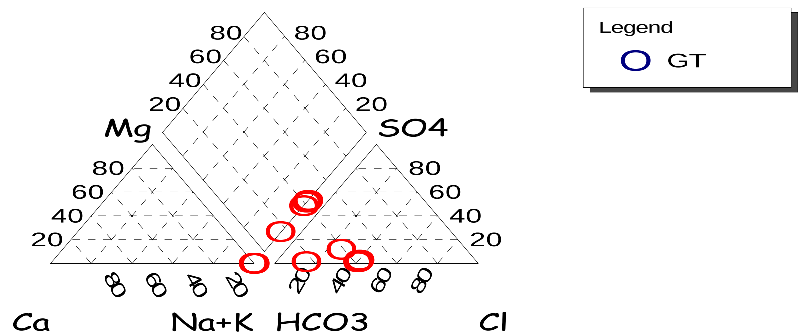


Figure7.10. Piper plot of all Geothermal Water

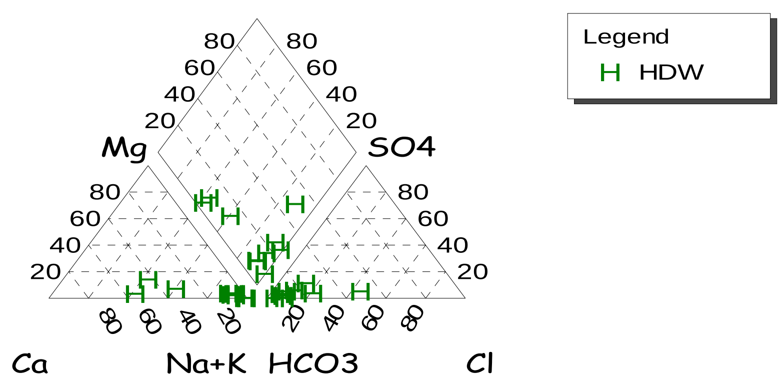


Figure7.11. Piper plot of all Hand dug wells

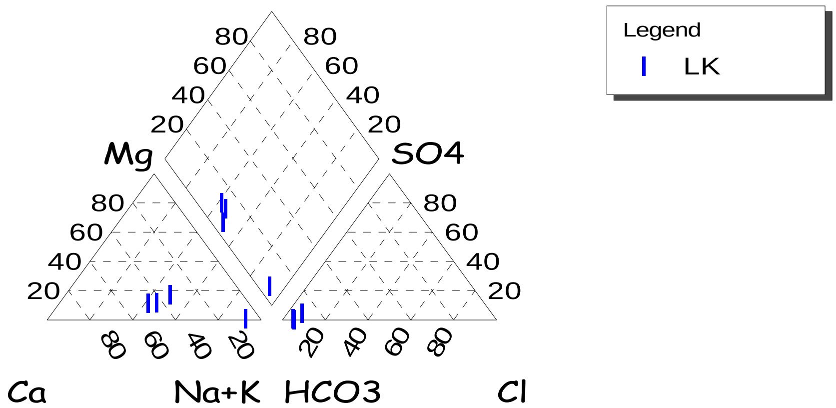


Figure7.12 Piper plot for lakes water

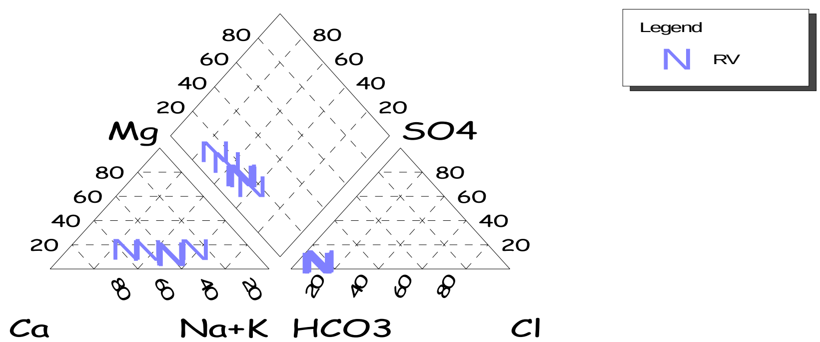


Figure7.13 Piper plot for rivers water

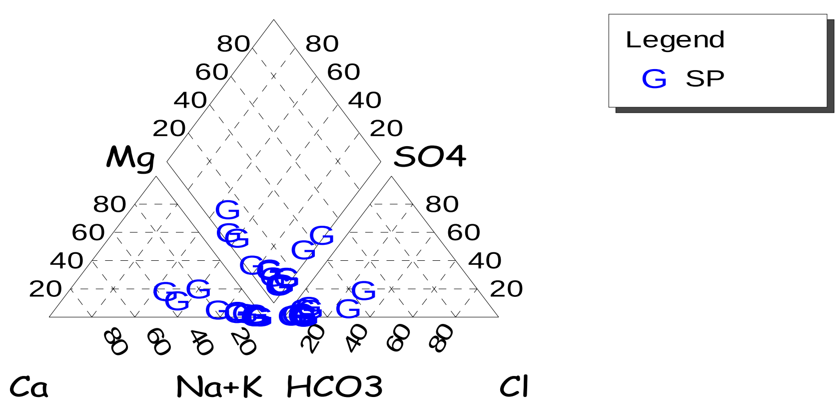


Figure7.14 Piper plot for spring water

Some wells show a similar hydrochemical signature to the nearby lake waters (Ziway Lake). This shows that there is interconnection between the rift groundwaters and the lake waters in the shallow depth.

The hydrochemical signature similarity is also evidence for the subsurface migration of lake waters and the subsurface interconnection between the lakes.

7.4.1.3 Schoeller semi-logarithmic diagram

The Schoeller semi-logarithmic diagram shows the total concentration of the cations and anions and it allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated.

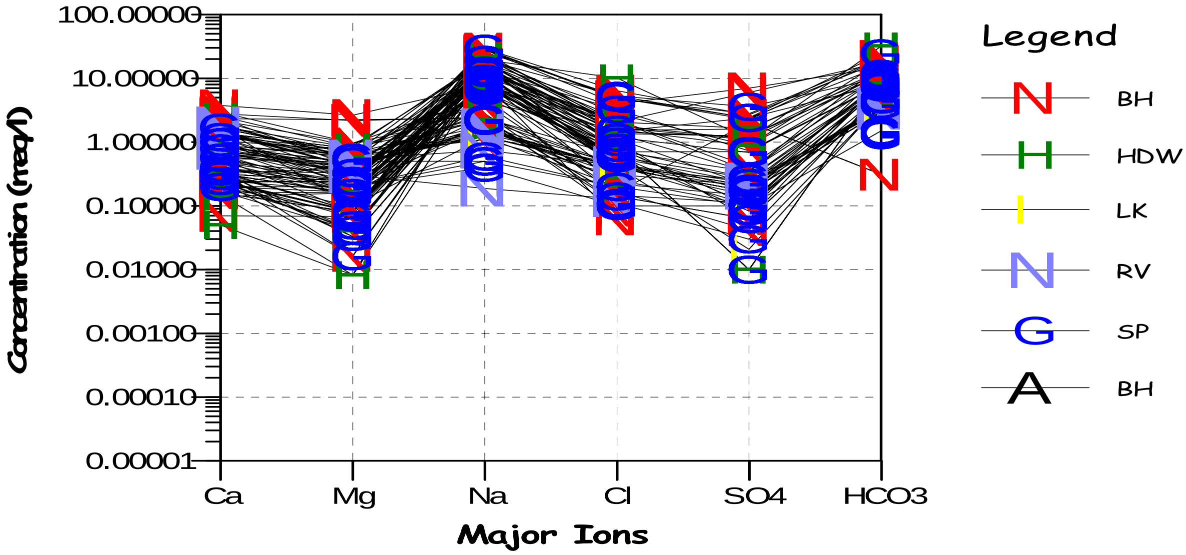


Fig. 7.15 Schoeller plot of all water sources

Sodium from cations and Bicarbonate from anions the dominant ions in the above figure as it also confirmed by other diagrams. Magnesium and Sulphate have lowest concentration in the cations and anions respectively.

7.5.1.4 The Spatial Distributions of the Major Ions Compositions

The wide spatial variations of the hydrochemistry of natural waters in this study has clearly demonstrated by preparing Stiff Pattern plots on the map using all scattered hydro chemical data in the study area (Fig 7.14). Stiff patterns visually allowing us to trace the flow paths on map (Stiff, 1995).

Fig.7.14 shows that there is clear systematic spatial variation in the major cations and anions concentrations of groundwaters following the regional groundwater flow directions. The difference is due to the rock-water interactions (related to litho logy and groundwater residence time), and the structural and geomorphologic settings.

The evidence that the systematic variations along the flow paths related to reactions between groundwater and the rock provides the hydrochemical evolution model for the area. In the area ionic composition of the water samples induces relatively variable chemical evolutions; waters are calcium, magnesium, sodium and bicarbonate dominated for the diluted waters on the highlands and the escarpment, and become sodium and bicarbonate dominated with a chloride increase for most concentrated waters in the rift valley (see the large symbols on the hydrochemical map). All the chemical evolution is towards a greater amount of sodium. The relative size of the stiff symbols on the highland and in the rift valley on the map demonstrates this evolutionary history (Fig.7.14).

On Fig.7.14 the sizes of the stiff symbol (which corresponds with the ionic concentration in the waters) is used to show the groundwater flow pattern in the area. The variation in the symbols size is related with the variations in the major ionic compositions of groundwaters.

The increasing trend in the size of the symbol from the northeastern of Lake Ziway towards south of Koka Dam indicates the groundwater flows along the increment of the size of Stiff symbols. The representative symbols in the western and eastern part of the corridor indicates low concentration of major ions due to absence of high rock-water interaction and fast circulation of groundwater but these symbols enlarge away from the margins of the corridors to indicate groundwater flow paths.

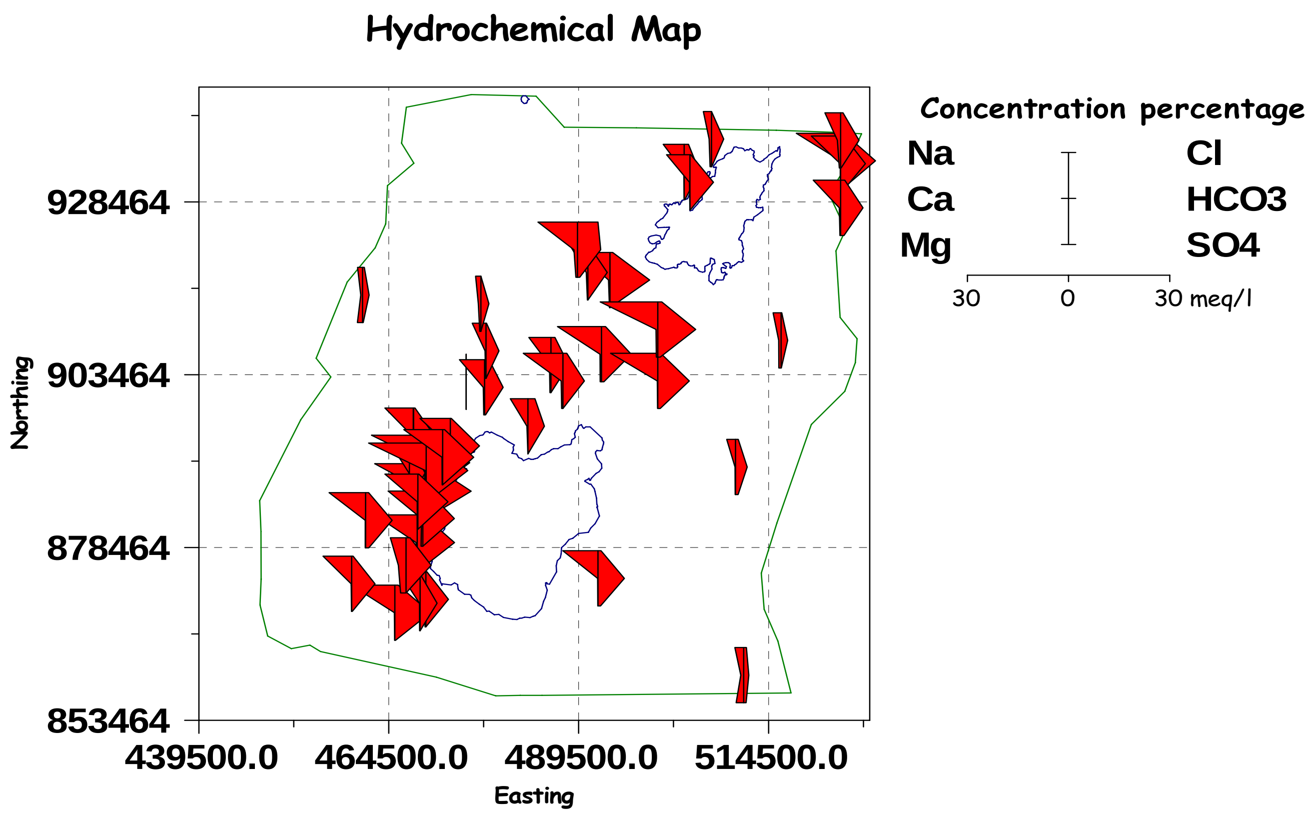


Fig. 7.16. The distributions of major cations and anions in groundwaters.

The sizes of the stiff symbols are almost uniform on the western, northwestern and southwestern of Lake Ziway and also disturb the uniform progressive trend of the symbols. This is may because; specific area characterized by extensive farming activity by using fertilizers and it is also public residence area(Meki, Abosa, Adami Tulu), there might be other anthropogenic effects that can raise the concentration of major ions.

Hydrochemical facies of spatial distribution can also observed by using pie chart which clearly shows concentration and distribution of major cations and anions together with their observable variation along the corridors.

Clear variation and distribution of concentration of major ions are very crucial for the determination of recharge and discharge area, groundwater residence time, flow path and neutrality of water.

As shown in the fig.7.15 below, pie charts representing deep borehole with its major ions concentration. Total distribution of major ions in the corridor dominated by Na and HCO_3 as a major cations and anions respectively and these ions shows stepwise increments in concentration from Lake Ziway to Koka Dam. Na due to replacement and displacement reaction by Mg & k, and because of its small radius allow to increases its concentration along the groundwater flow paths.

Cl also represented by specific color like the others in the pie chart which shows uniformly ascending trend in concentration from the borehole located southwest of Lake Ziway (873542N and 458500E) to other borehole located south of Koka Dam (nearly 911542N and 515500E).

According to hydrochemical evolution process, Cl is most conservative ion which is not active to react with others, as of the result, its concentration increases along the ground water flow paths.

Depending on these, increment of Na, HCO_3, and Cl concentration with in the corridor reinforcing the previous confirmation of ground water flow paths discussed in the flow System (Chapter Six).

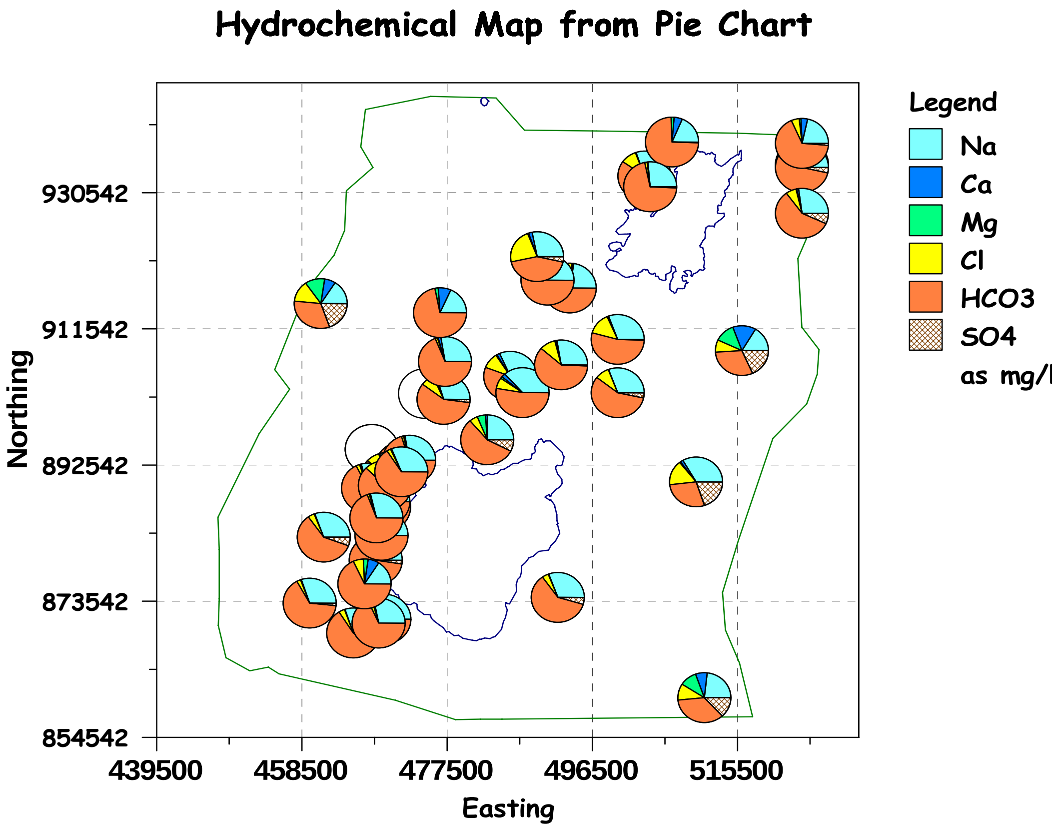


Fig. 7.17. The distributions of major cations and anions in groundwaters

Western and Eastern margin representative boreholes shows relatively small concentration in Na, HCO_3, and Cl indicating the recharging zone and not highly evolved water.

7.4.2 SPATIAL TRENDS OF THE CHEMICAL PARAMETERS OF WATER SAMPLES IN THE STUDY AREA

Many natural factors can affect groundwater chemistry; however, the primary factors include the lithological and hydrological properties of the geologic unit, a series of chemical reactions that have dissolved material from another phase, have altered previously dissolved components, or have eliminated them from solution by precipitation or other processes, the source and chemical composition of recharge water, and the amount of time the water has remained in contact with the geologic unit (residence time) all of these factors can affect the type and quantities of dissolved constituents in groundwater.

In addition to other ions like fluoride, the most abundant dissolved constituents measured are the major ions, which can be both positively charged (cations) and negatively charged (anions).

The spatial trend (evolution) of the cations and anions for each of the sources are separately plotted, and analyses are made on the basis of the trending direction and patterns so as to determine their contribution on the ground water flow direction and also potability of water for public consumption (by emphasis on rift floor problem-Fluoride)

7.4.2.1 Chlorine, Sodium, Fluorine, and Bicarbonate

Chlorine

Chloride is known by its conservative nature in the chemical evolution process and good indicator of the relative age of ground water compare to other major ions. Even though, more important source of Cl is association with sedimentary rocks, volcanic gases from geothermal fields may also introduce in the ground water system and in some rift lakes (Tenalem Ayenew, 2005)

In the study area, Cl shows variable spatial distribution and its concentration increase from different direction to wards the floor of the rift. This may follow groundwater flow direction (Fig. 7.16).

Away from the western part of the area, eastern part of Koka dam and along Ziway-Koka Corridor, Cl concentration show stepwise increments which reflect the flow direction of groundwater.

Running from Zik Wala Mountain to the south west of Koka, Cl shows special increment in its concentration which may related with the thermal aquifer beneath the area.

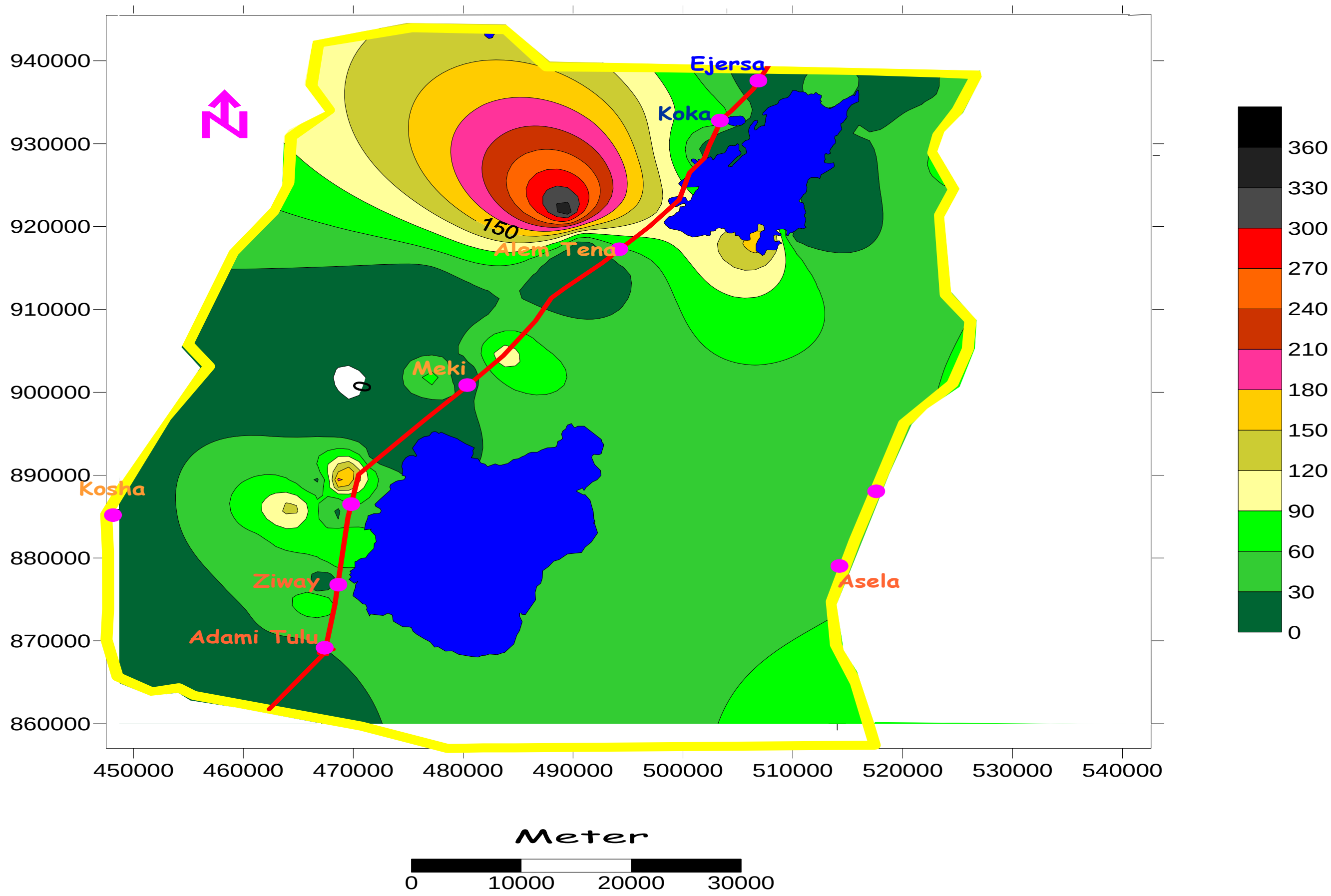


Fig. 7.18. Lateral trend of Chloride from all water sources

Cl varies from 0- >360Mg/L in the study area but according to WHO guidelines for drinking water quality 2003, the concentration of Cl has to be less than or equal to 250Mg/L. As of these, in terms of Chloride, most part of the area is safe for the drinking water quality except in the North West part of the area with high Cl concentration. (270-370 Mg/l).

Sodium

Na is one of the major cations characterized ion exchange chemical reaction during evolution process by Ca and Mg and passing though void space because of its small atomic mass (small radius).

Cations exchange is the chemical reaction frequently cited to explain the high percentage of sodium compared to calcium and magnesium in water (Lee, 1981; Woessner et.al., 1981, Wilson et.al., 1986). Cations exchange is a reaction in which the calcium and magnesium in the water are exchanged for sodium that is adsorbed to aquifer solids such as clay minerals, resulting in higher sodium concentrations (Hem, 1985).

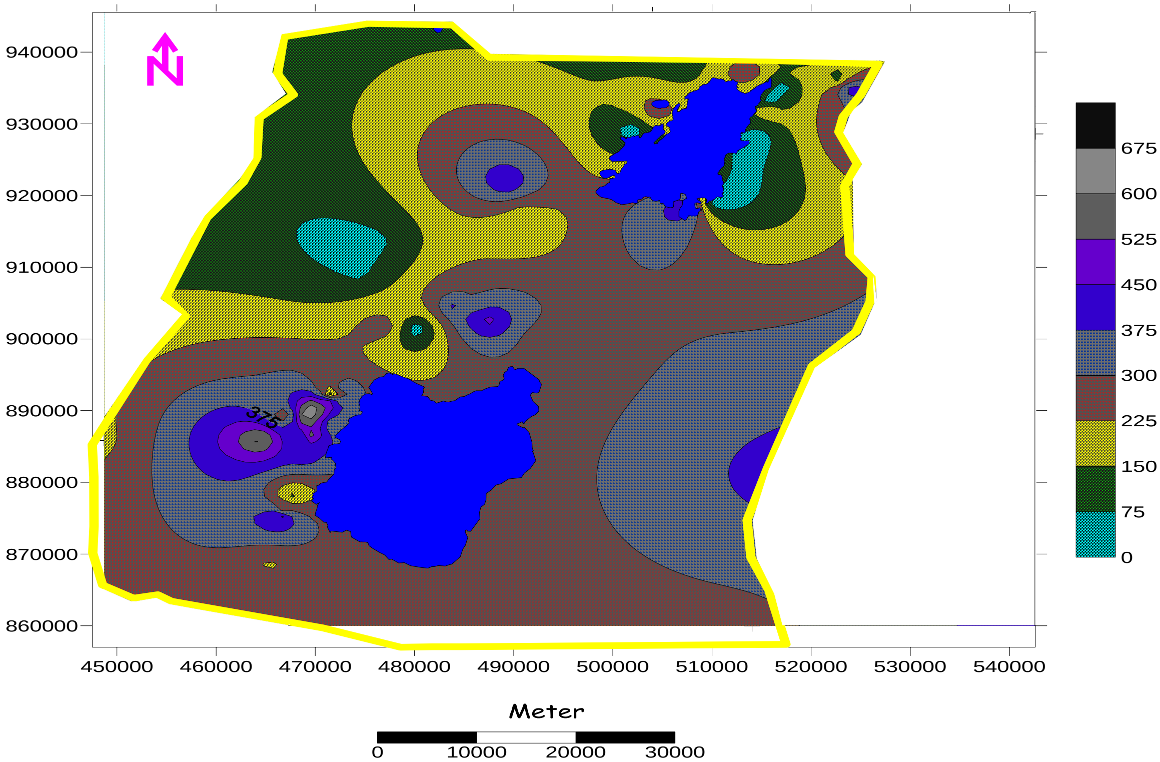


Fig. 7.19. Lateral trend of Sodium from all water sources

The generalized reactions are as follow (Hem, 1985)

Na2X + Ca2+ → Ca X + 2Na+

Na2 X + Mg2+ → Mg X + 2Na+ Where X = aquifer solid

Unlike other ions, Na not shows uniform trend in the studied area especially in the eastern part of the area. This may because of the geo-medias which are rhyolites and trachytes as Bora-Bericha Mountain and this specific area are highly affected by structure.

Na varies from 0- >675Mg/l in the study area but according to WHO guidelines for drinking water quality 2003, the concentration of Na has to be less than or equal to 200Mg/L. As of these, in terms of sodium, most part of the area is not safe for the drinking water quality except in the North West part of the area with low Na concentration. (0-275 Mg/l).

Bicarbonate

Fournier and Truesdell (1970) suggested that in geothermal system most of the HCO3 and part of the Na and K are produced by the reaction of dissolved carbon dioxide with the rock to produce mica or clay minerals and bicarbonate ions. Spatial distribution of HCO3 in the studied corridor shown in fig. 7.18 below.

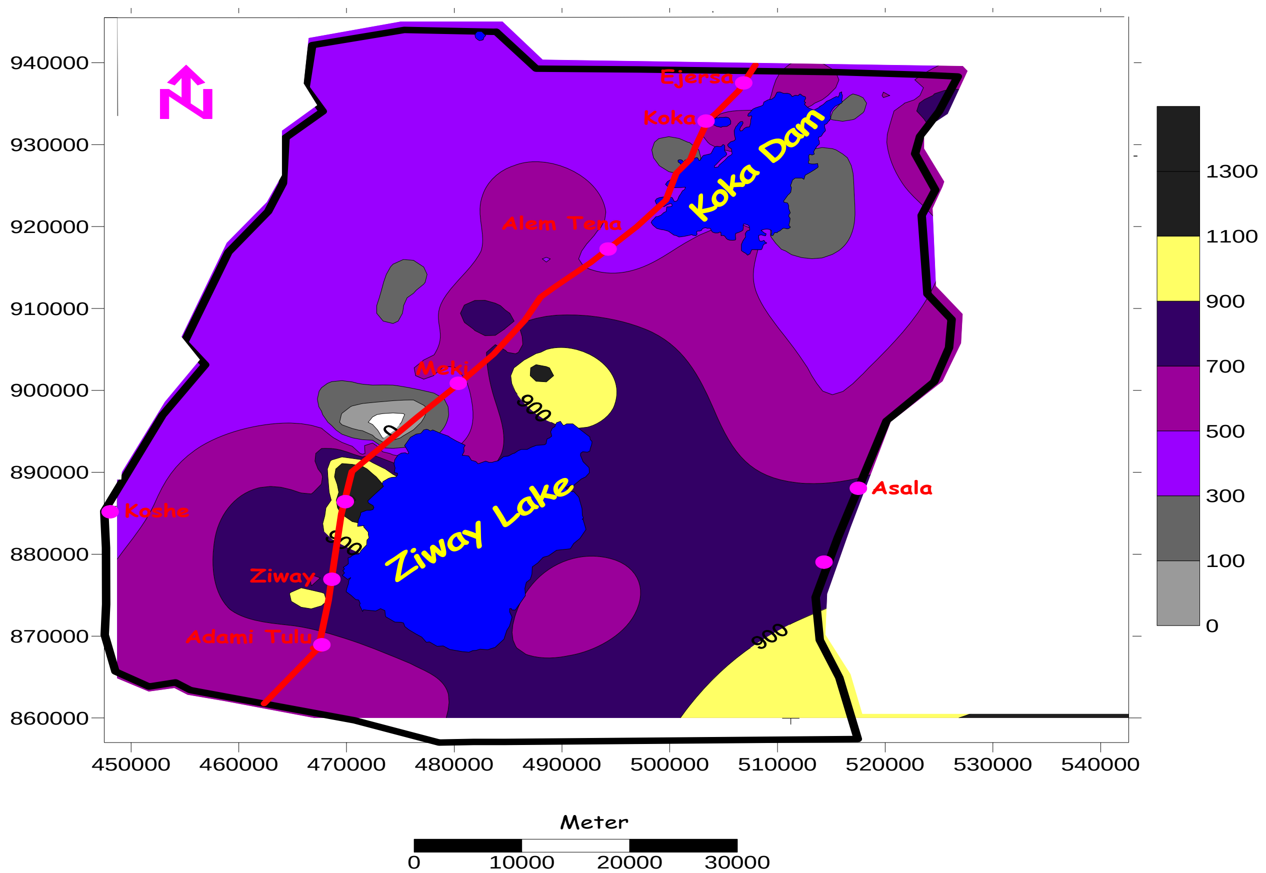


Fig. 7.20. Lateral trend of Bicarbonate from all water sources

Generally, Bicarbonate increase towards the floor of the rift from margins. Its concentration is higher and shows uniformity in the western than in the eastern part of the area which may be related with water circulation.

Discussion

Ground water associated with recharge is represented by water dominant in calcium, magnesium and sulphate with lesser amounts of sodium and bicarbonate. As the groundwater flows away from the source of recharge towards the rift floor, the interaction between water and rock increases. Sodic lithologic units are encountered as the ground water moves along a flow path, and calcium and magnesium ions are exchanged for sodium ions attached to aquifer solids. Anaerobic sulphate-reducing reactions also act on the groundwater as it moves along a flow path. Therefore, both reactions result in a decrease in calcium, magnesium and Sulphate and a corresponding increase in Na+ and HCO32-as groundwater flows away from the source of recharge and results in water that evolves to a sodium-bicarbonate-type in the deep geochemical zone.

As discussed in the hydrogeology chapter potentiometer contours suggest regional groundwater flow in the study area towards the floor of the rift and along the corridor of Ziway-Koka. This pattern is in a very good agreement with the apparent increase in dissolved solids concentrations of Cl- and Na+ spatial trend maps in the above.

Recharge and discharge zones inferred from elevation contours are better justified by the chemical evolutions of the chemistry of the waters. At topographically high locations and from shallow hand dug wells and high land springs, water from the shallow system probably represents recharge waters and the dominant ions are magnesium, sulphate and calcium with moderate amounts of bicarbonates and low concentrations of sodium.

At topographically low locations, ground water chemistry is dominant either in sodium and bicarbonate with lower concentrations of magnesium and calcium, or is dominant in magnesium and bicarbonate with moderate concentrations of calcium and sulphate.

Fluoride (Source, Problem and Techniques)

Source

In nature F comes from chemical weathering product of igneous rocks, magmatic emissions, atmospheric dusts from continental sources and industrial pollution (Hem, 1970). There is no agreement among researchers as to how the high F is introduced in to the groundwater and surface water bodies. According to Gerasimovskiy and Savinova (1969) the volcanic rocks of East Africa are richer in F than similar rocks in other parts of the world.

The most important sources are acidic volcanic rocks such as tuff, pumice and obsidian and emanations from geothermal systems (Tesfaye Chernet, 1982; Tesfaye Chernet et al., 2001)

High F in saline lakes of the East African Rift reflects the nearly complete removal of Ca by carbonate precipitation usually as calcium carbonate (Darling et al. 1996) probably from CaF2. Calcium exchanges in the lacustrine sediments also the probable source of F in ground water. These are two methods of Calcium depletion in the rift that may facilitate fluoride concentration.

Problem

Concrete available data from GO and NGO archives reveal that over 40% of deep and shallow wells and springs in the Rift Valley used for drinking have fluoride above the WHO optimal level of 1.5 mg/l for fluoride, which is the case for dental and skeletal fluorosis of children, and old men & women respectively.

According to extrapolating 2005 census figure reveal that out of the 10 million population of the rift valley almost 8.5 million (below 40 years of age) would be at risk of developing dental and skeletal fluorosis if they continue to depend on drinking water from wells with high fluoride concentration (Redda Tekle Haimanot, 2005).

Photo 7.1 Dental and skeleton fluorosis effect

Techniques

Ways of neutralizing high concentration of fluoride from human water consumption are using different techniques of defluoridation. Which are included Precipitation, Adsorption & ion exchange, Electrocoagulation, Reverse osmosis and electro-dialysis. Among which the most commons are:

Precipitation:-the use of chemicals for coagulation and flocculation followed by sedimentation and filtration. The chemical commonly used are aluminium sulphate, lime and alum, gypsum, lime, magnesite, dolomite or calcium chloride.

Adsorption and ion exchange:-Different media are used for adsorption and/or ion exchange of fluoride. The commonest media are activated alumina, clay as natural absorbent, granulated bone media and bone chair.

In the study area, a technical and socio-economical feasibility of three low cost water defluoridation methods has been evaluated at pilot scale by cooperation Addis Ababa University and CRS Ethiopia. These techniques are:

-Chemical precipitations by aluminum sulphate and lime.

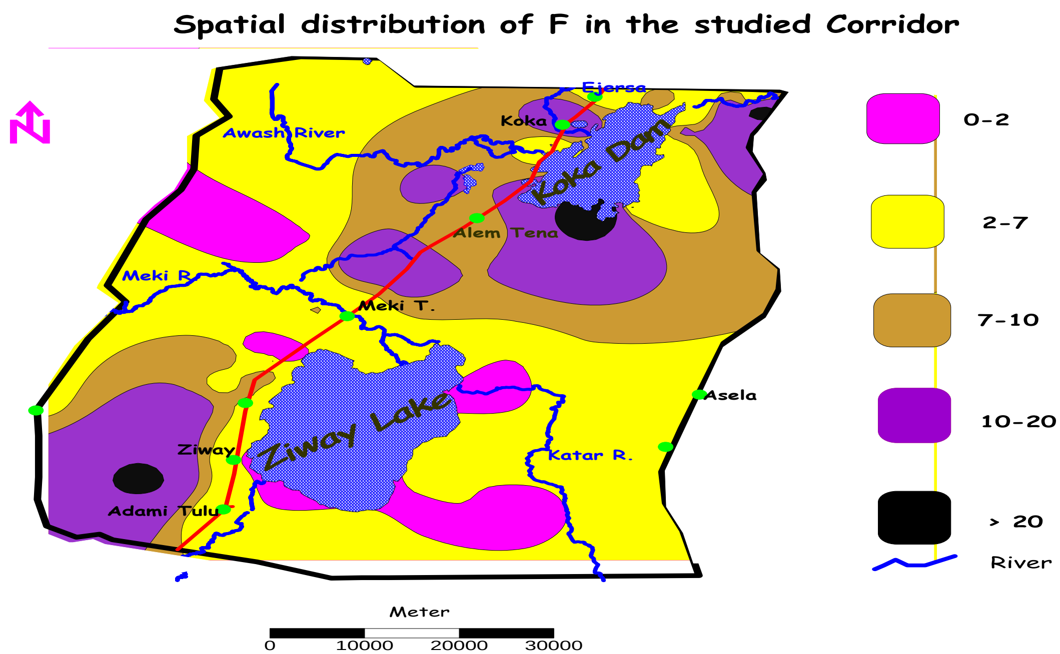
-Adsorption by bone char.

-Adsorption by clay minerals.

The result obtained on aluminum sulfate and lime so far indicates that the developed defluoridation unit could remove the fluoride concentration to the level below 3 mg/l. particularly, this method are promising relative to the WHO standards settled at 2003.

As observed in the field, in the defluoridation process, Nalgonda (lime & alum) is very common technique at household and community level, local people also accustomed the technique but in some place, the residue after the process, buried in the subsurface that directly link with Groundwater (around Ziway area-northern part).

In addition to lateral distribution of F, its concentration in vertical variation expressed planar form by using fluoride (mg/l) verses depth (m) (Fig.7.19). As it is shown, densely populated wells observed between 20-40m to reflect spatial arrangement of wells on the immediate North West part of Lake Ziway. Same thing is true for wells of 50-60m which is representing in the North West part of the Ziway Lake a little apart relative to the earlier.



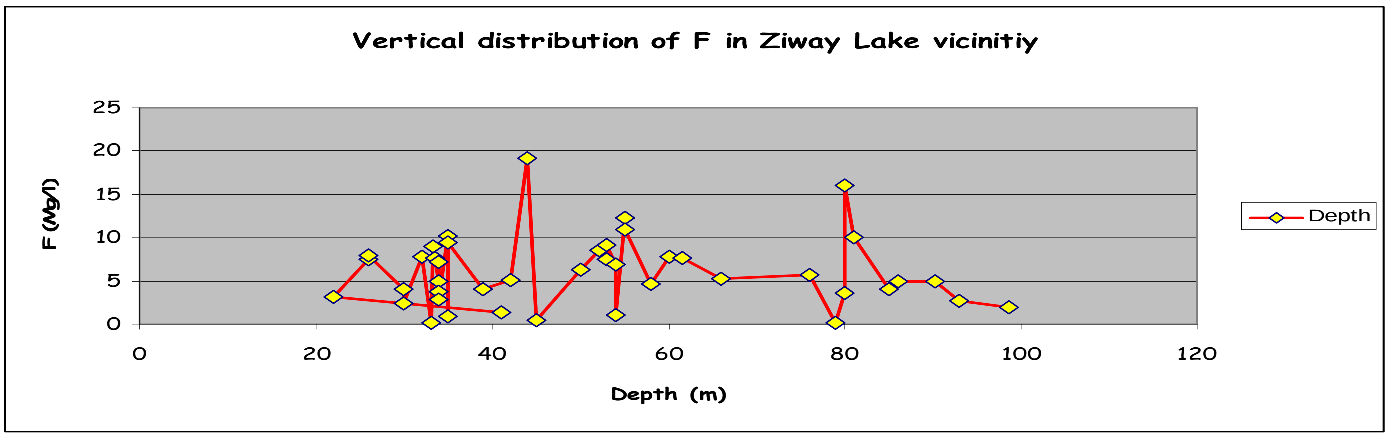


Fig.7.21. Lateral and vertical distribution of Fluoride

Well ,44m, between Koka and Ziway (relatively near to Ziway) representing the maximum F concentration (19.2 mg/l) among the displayed data in the above graph but the maximum concentration in the studied corridor is about 34.8 mg/l at the UTM reading of 524000E and 934400N.

From the above graph, by considering depth, two separate observations can be distinct. First, depth which range from 20-60m shows mixed types of concentration (high-low-medium, on the average higher relative to the second type). Second, depth which ranged from 60-100m (consider deep wells) shows clear decrement of F concentration except 80m which may be because of other process.

Water quality problems (for human consumption) observed in the studied area, because of fluoride concentration which is above the WHO optimal level, that can be solved or minimized by using techniques specially using Nalgonda. Others like bone cher, even though it is good to absorb F, not acceptable by the society from religion point of view.

As observed in the fig.7.19 the concentration of Flouride vary from 0.2 to 35mg/l and the dominance of concentration of the sub division in increasing orders are >20, 10-20, 7-10, 0-3, and 3-7mg/l. Accordingly, safe drinking water concentration (0-3mg/l) is falls on the dominance group in the area (second maximum) and it is recommended to consider lateral distribution of fluoride from map and the well depth also, to drill a well for human consumption in the studied area.

Even though, fluoride concentration is high in terms of lateral and vertical distribution of the studied area, its positive and negative influence on vegetation distribution is not clearly observed in this study. But, as observed in the field, the area which is reached in fluoride cultivated in a well manner with high products. Now a days number of irrigation projects in the studied area show significant increment.

CHAPTER EIGHT

S Y N T H E S I S

The studied corridor has been delineated so as to included certain part of the eastern & western escarpments, the floor of the rift and the lakes (Ziway and Koka Dam) having aerial coverage of 5371SqKm. The general objective of the study can be categorized in to two, solving the scientific and community based problems in the delineated area.

Ground water flow between Ziway and koka corridor rose dilemma among the researchers. Some of them concluded that, there are ground and surface water divide between lakes region and Awash basin and the others agree that there is regional ground water flow system in the deep aquifer system that migrate from southern part of lakes region to the Afar Tendaho area.

The current study considers this as scientific problem and tried to contribute some additional crucial point in order to confirm the movement of subsurface water that migrates regionally.

The area has a dominant coverage of the floor of the rift which characterized by high concentration of fluoride that affect the tooth of children and spinal cord of old women and men. Mapping of fluoride and determination of its concentration is included in the study in order to show the distribution and add significant amount of data in the defluoridation process in the studied area.

On the basis of these objectives, the study used different methodologies that could facilitate the study to reach the determined objectives. Among which collection of primary and secondary data together with literature review are the main one. The primary data collection includes: Deep, shallow, hand dug wells inventory in the field to collect in-situ parameters which included PH, EH, TDS, EC, Temperature, SWL, and location in UTM. Collection of water sample in the plastic bag and lithology description of the wells also part of field observation. Secondary data were also collected from the appropriate offices in Addia Ababa and regional level which includes: borehole history (SWL, log, and Pumping test data), and Physicochemical analysis.

The appropriate software like Global Mapper, Surfer, Arc View, Aqua hem, Aquifer Test, Auto cad, and XL stat together with the primary and secondary data was very crucial to approaching the methodology and determining: Ground water level contouring, three dimensional view of the study area, mapping of Geology, Structure, Hydrogeology, TDS, Cl, Na, determine recharge and discharge area and distribution of major ions & fluoride in the studied area.

Selecting representative traverses in the field, observing lithological log of wells and referring previous regional geological maps are some of the important methodology for preparation and description of the geology of the area. According to these parameters, the studied area characterized by different volcanic formations which includes: Wonji basalt on the north east and south east part of the studied area, Bora-bericha Rhyolites found in the area as mountain in the central and south west part, Lacustrine deposit (the dominant formation that overlay the ignimbrite) which vary as sand & silt with abundant component of volcanic origins with considerable lateral and vertical distribution and as mentioned in the geology part, there are other small formation (Figure 3.1).

These geological formations are partially good in water holding capacity on the surface. Hydrology of the area includes lakes, rivers and marsh areas. The lakes are ziway which is one of the rift lakes, Koka dam which is an artificial Dam for hydropower & irrigation purpose and Elen the smallest lake of the rift in the south western part of koka dam and has relatively high fluoride concentration that migrate toward Bericha mountain which is at the center between koka and Ziway.
Awash river is the largest in the study area and the main supply for the dam which starts from west of Addis Ababa around Holeta where it collects discharges of many small springs emerging from slopes of trap basalt and ignimbrites , in a relatively steep gorge up to 25 Km upstream of the Koka Dam with very low gradient.
Meki and Katar are other rivers which feed to Ziway Lake to northern and western part respectively and Bulbula is other river as an outlet form ziway lake to Abjita.

Some marsh area also exists in the western part of koka Dam, depending on the seasons, their water holding capacity varies.

Hydrology, precipitation, and hydrogeology of the area interlink one and the other which obey the hydraulics cycle. Hydrogeology or subsurface of water circulate in different geological formation which is characterized by porosity and permeability. Hydraulic conductivity, permeability, Transmissivty of the area has been determined from the pumping test data and the corresponding result mapped as the Hydrogeological map (fig. 5.3) which classified as very low to low (Rift Volcanoes and Volcanic ridges), Low to moderate (Ignimbrite, tuff, local rhyolite and Basalt), moderate to high (Ignimbrite covered with lacustrine deposit), High to very high (Basalt and local Ignimbrite) permeabilities. These permeability ranges has been related with aquifer formation of the area which mentioned in the brackets.

The aquifer distributions in the studied area are of two types: shallow and deep aquifer system. The shallow aquifer system ranged as far as 60m and the formation included: Lacustrine sediments (sand and Gravel), sandy volcanic ash, weathered volcanic rock, quartz sand and welded ignimbrites. The deep aquifer system has been observed below 60m deep and as far as 268m with in this range, the observable geological formations are weathered and fractured ignimbrite and weathered scoraceous basalt (dominant) and Sandy volcanic ash.

For the determination of hydraulic parameters, aquifertest software has been used and the corresponding graphs like Theis, Cooper-Jacob Time-drawdawn, Moench Fracture flow for the constant test displayed on this part and their output more or less coincide with the Theis standard (that Satisfies the Theis assumption).

According to these aquifer formations, and the existence of subsurface water, groundwater flow system has been investigated. For this study different methodology uses like field static water level inventory for shallow and deep aquifer to determine groundwater level contouring, Water sampling and analysis in the laboratory to get hydrochemical evolution of Cl, Na, HCO_3 & others and using the appropriate software like Surfer & Arc view for analysis purpose of the flow system.

The outputs of these methodologies are of two types which are flow system in the shallow and deep aquifers that shows different direction.

According to previous work, there is regional ground water flows system in the rift that migrates from the southern part of Lakes Region of rift valley to the northern rift part, Afar. He used the approaching of hydrochemistry and isotopes for both cases, the result indicate that there are regional groundwater migrations to the northern part.

Hydrochemistry shows evolution of water from Na-SO_4-Cl in the MER, its northern part and around Afar respectively. In turn the isotopes methodology also shows that depletion of O_{18} away from the MER to Afar.

The current study output agree with the above work using a little different methodology by considering the aquifer system into two shallow and deep, field SWL inventory and physicochemical analysis but not the isotopes.

Flow system in the deep aquifer system (Figure6.6) shows that the groundwater flows from southern part of the studied area to that of northern part without observing groundwater divide between Ziway and Koka unlike the other previous work. Evolution of Na, Cl and HCO3 reinforce the above flow system partially.

Flow system in the shallow aquifer a little differs from the deeper one (Figure6.5). In the shallow case, groundwater flow from the north western part to south eastern part of the studied area by crossing the corridors.

Flow system also consider in the vicinity of Ziway Lake and Koka dam for the shallow and deep aquifer system. According to the previous work and the current study, it is confirmed that the Koka dam receiving water from south, north and north-west of the surrounding and in turn discharge to north-eastern of the dam as the potential area for leakage of the dam.

In the case of ziway the main recharge area is eastern part from which water migrated to Lake Ziway with the help of extensive structures that facilitate fast circulation and movement of ground water, and the other part of the lake, discharge water to the northern, western and north western part from the shallow aquifer system and vicinity of ziway lake.

But deep aquifer system consideration in the lake vicinity shows no connection between lakes and the aquifer system. This is because the lakes are very shallow in depth relative to the depth of deep aquifer in the area.

Since, the lake is shallow (≈ 9m depth), the regional deep groundwater may not have impact on level rise of Ziway Lake. Even, water depth in the Koka dam may not receive regional deep groundwater which could be supported by high aquifer temperature found below Koka town.

Water that generated from these groundwater flow system can also determined in the laboratory to observe the Hydrochemistry part which is partly significant to determine water type, to show high concentration of fluoride, to determine major ionic distribution by using different graphical methods like Box and Whisker for Major ions chemistry distribution for groundwater and surface water, Piper diagram permit the cations and anions composition of many samples to be represented on a single graph, the Schoeller semi-logarithmic diagram shows the total concentration of the cations and anions and it allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated.

Hydrochemical maps also determined by using Stiff diagram (Fig. 7.14) and Pie charts (Fig.7.15) to shows the chemical evolution of major cations and anions.

The water types in the studied area are of Na-Ca-HCO_3 and Ca-Mg-HCO_3. For both surface and groundwater the dominant cations and anions are Na and Bicarbonate and it is possible to conclude that the general water type of the area is Na-HCO_3. Water types for different source are also determined lakes waters fall in the Na–Ca-Mg-HCO_3 type, rift floor boreholes, spring and dug wells fall in the Na–HCO_3 and Ca-Mg-HCO_3 type, Geothermal water Na-SO4 - HCO_3, rivers water has Ca-Mg- HCO_3 type.

In addition to water types, major ions evolution also determined by using hydrochemical data and presented by different graphs like Stiff and Pie chart in which clear evolution of ions can easily observed and it helps to observe groundwater flow direction. For the pie chart, the dominance of Na & HCO_3 and the progressive trend of Cl can be seen and is simple to deiced groundwater flow direction. In the stiff diagram, sizes of the symbols directly proportional to the concentration of major ions. Considering distribution of symbols size, in between Lakes, relative increments could be observed away from Ziway

Lake and to wards Koka Dam which supports the previous idea for the flow direction of groundwater from the southern part to the northern of the studied area.

Potablity of water needs special consideration for the concentration of major ions (in addition to fluoride) on the basis of WHO standard.

Na trends (Fig.7.17) has not shows uniform and/or progressive change along the corridor. This is because its concentration variation may be observed in the regional level rather than in such a small corridor, but the margins part of the studied area shows relatively better evolution of Na concentration that increases towards the floor of the rift (western part of the margins).

The vertical and lateral distribution of Fluoride has been examined by using its concentration distribution. Depending on concentration, fluoride classified as 0-3, 3-7, 7-10, 10-20, >20mg/l, according to WHO almost all concentration is beyond the standard values except the first one. High concentration of fluoride in the studied area observed in the southern part of Koka dam which probably comes from Elen Lake (it is characterize by high F concentration) and south west part of Ziway Lake

To make all water potable for human consumption it is better to pass thought defluoridation techniques. There are different methods of defuoridation techniques and the most common, suitable, available types are Nalgonda (lime & alum).

Generally, objective of the study is to determine flow direction and comparative water chemistry. Both of which are investigated, the flow system determined with different methodology which includes: SWL, in-situ parameters measurements & UTM readings in the field, and laboratory result analysis, as of this result, groundwater level contouring, PH, EC, TDS, Na, Cl, and HCO_3 mapped and their output is more or less the same that confirmed the groundwater flows in the northern part along the corridor which agrees with Panicky's work.

In the comparative Water chemistry part, water types of different source, evolution of major ions & their significant for water movement, fluoride concentration, its mapping and common defluoridation techniques are investigated and analyzed.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

Field well inventory, previous borehole history and hydrochemical techniques were applied to understand the groundwater flow system, the subsurface hydraulic links between the lakes (Ziway-Koka) and lateral & vertical distribution of fluoride. Interpretations of the graphical analysis coupled with the chemical analysis results of the hydrochemical data and results from analysis of flow system in the area are critically showed the hydrodynamics. From this approach the following conclusions have been drawn.

- Aquifers in the study area have two systems, the shallow and the deep system. The shallow aquifer formed near to the surface up to 60m depth and the deeper aquifer runs from nearly 63m to 268m as it is confirmed from lithological log and borehole history data.
- Aquifer formation are classified into four hydrostratigrahic units: lacustrine deposit, basaltic formation, differentiated ignimbritic & welded tuffs units and rift volcanoes and volcanic ridges.
- Hydraulic characters (hydraulic conductivities, permeabilities, and transmissivity) of the aquifers show variation and have been classified as very low to low, low to moderate, moderate to high and high to very high.
- The groundwater flow system in the aquifers varies a little in the shallow and deep aquifer cases (Fig.6.9). In the shallow case, groundwater flow from the northwestern to south eastern part of the studied area by crossing the studied corridor (Fig.6.5).
- In the deeper case, groundwater flow clearly observed when it migrates from southern to northern part of the corridor (Figs.6.6 & 6.7). It is believed that this water movement is part of the groundwater that migrats regionally from southern part of lakes region to the northern part of rift around Afar. This regional migration of water always fluctuate the level of Lake Shalla (the deepest Lake and may interact with regional flow) and no any contribution for other lakes like Lake

Abijita. This is because of their shallow depth, the regional water pass though deep aquifer system.

- Groundwater flow system of shallow aquifer in the vicinity of the Lakes was also investigated. It is confirmed that the dam receiving water from south, north and north-west of the surrounding and in turn discharge to north-eastern of the dam as the potential area for leakage of the dam.
- In the vicinity of Ziway Lake, the main recharge area is eastern part from which water migrated to Lake Ziway with the help of extensive structures that facilitate fast circulation and movement of groundwater and other part of the lake, discharge water to the northern, western and north western part from the shallow aquifer system.
- The two lakes (Ziway-Koka) have no interaction in the shallow (60m) and deep aquifer (>63m) system (Figs.6.5 & 6.6) but considering the flow system obtained from hand dug well in the vicinity of lakes, the groundwater flows from the lake Ziway to Koka Dam. Since both the Lake (1637masl) and the Dam (1589masl) are very shallow in depth and shows topographical variation, there might be a possibility of groundwater movement from Ziway Lake to Koka Dam.
- The field measurements of pH values of the studied area near to the lakes and the surrounding of small towns range between 6.44 to 8.2 and therefore, pH values of water in the area can consider as neutral. Moving along the corridor, pH distribution ascending in its concentration from the northern of Lake Ziway to north-west of koka dam (Fig. 7.2), reflecting of water movement which also agrees with HDW flow direction in Fig.6.10.

- Electrical conductivity (EC) values show significant variations with the different sources of water. It has been observed that most of deep boreholes have a higher EC values and these values are progressively decreasing for shallow source of water. On Fig.7.4 sharp increase in EC towards the rift implies that there is a general groundwater flow from the highlands towards the rift valley in both directions. The EC also varies within the rift waters, which shows the northward flow in the rift.

- TDS map of the studied area shows its distribution with in the area. The concentration is increasing from north of Ziway along the corridors to Koka dam with an increasing order of 230ppm, 430ppm, 630ppm, 830ppm, 1030ppm respectively which can coincide with ground flow direction.
- Field temperature measurements confirmed the existence of thermal aquifer in the vicinity of Koka that doesn't have any contact with the Dam. Shallow wells (SWL on the average 4m) near by the Dam have thermal water of higher temperature which completely varies from surface water of Koka Dame.
- Na and HCO_3 are the dominant cations and anions respectively for both surface and ground water in the studied corridor (fig. 6.6 & 6.7)
- The water types in the studied area are of Na-Ca-HCO_3 and Ca-Mg-HCO_3. As mentioned, for both surface and groundwater the dominant cations and anions are Na and Bicarbonate and it is possible to conclude that the general water type of the area is Na-HCO_3.
- Water types for different source are also determined, lakes waters fall in the Na–Ca-Mg-HCO_3 type, rift floor boreholes, spring and dug wells fall in the Na–HCO_3 and Ca-Mg-HCO_3 type, Geothermal water Na-SO4 - HCO_3, rivers water has Ca-Mg- HCO_3 type.
- The high spatial variations of major cations and anions follows systematic trend of groundwater flow paths (Fig.7.14 & 7.15). This reflects the different groundwater flow systems and the existence of hydrochemical evolution of waters along the flow path.
- Stiff diagram (Fig.7.14) shows the sizes of the stiff symbol which corresponds with major ionic concentration in the waters. The increasing trend in the size of the symbol from the northeastern of Lake Ziway towards south of Koka Dam indicates the groundwater flows along the increment of the size of Stiff symbols.
- The representative stiff symbols in the western and eastern part of the corridor indicates low concentration of major ions due to absence of high rock-water interaction and fast circulation of groundwater but the symbols being enlarge when away from the margins of the corridor to the floor indicating groundwater flow paths.

- Hydrochemical facies of spatial distribution can also observed by using pie chart which clearly shows concentration and distribution of major cations and anions together with their observable variation along the corridor (Fig. 7.15) Which are very crucial for the determination of recharge and discharge area, groundwater residence time, flow path and neutrality of water.
- Chlorine (Cl), Sodium (Na), Fluorine (F), and Bicarbonate (HCO_3) distributions in the studied area also investigated in a separate way so as to observe their evolution and water potablity degrees.
- Cl shows variable spatial distribution and its concentration increase from different direction to wards the floor of the rift. This may follow groundwater flow direction (Fig. 7.16). Cl varies from 0- >360Mg/L in the study area but according to WHO guidelines for drinking water quality 2003, the concentration of Cl has to be less than or equal to 250Mg/L. As of these, in terms of Chloride, most part of the area is safe for the drinking water quality except in the North West part of the area with high Cl concentration. (270-370 Mg/l).
- Na not shows uniform trend in the studied area especially in the eastern part of the area. This may because of the geo-medias which are rhyolites and trachytes as Bora-Bericha Mountain and this specific area are highly affected by structure. Accordingly, Na varies from 0- >675Mg/l in the study area but according to WHO guidelines for drinking water quality 2003, the concentration of Na has to be less than or equal to 200Mg/L. As of these, in terms of sodium, most part of the area is not safe for the drinking water quality except in the North West part of the area with low Na concentration. (0-275 Mg/l).
- Bicarbonate increase towards the floor of the rift from margins. Its concentration is higher and shows uniformity in the western than in the eastern part of the area which may be related with water circulation with in the area.
- Fluoride vertical and lateral distribution has been studied in the study corridor. Most part of the area has high F concentration beyond the WHO standard (1.5mg/l) and it needs defluoridation process in order to be potable for human consumption. Vertical distribution of fluoride in the wells shows significant variation. The concentration of fluoride in the shallow wells (60m) higher than the deeper one (>

65m). As observed from the figure7.19, the fluoride concentration in the shallow wells shows higher concentration (>19mg/l) but in the deeper case, its concentration lowering dawn below 5mg/l.

- It is strongly recommended to drill shallow wells than deep wells in the studied corridor for public consumption to minimize fluoride concentration (if there are no defluoridation processes).

For more detail understanding of the objective of the study, following recommendations are presented.

- Well compilation report should be properly compiled to get sufficient data on borehole history of the studied area.
- Observation pipes should be installed in the existing and newly constructed boreholes especially for the wells that could be significant for scientific purpose.
- Existing of the two aquifer system should be confirmed by Systematic sampling with depth and in relation to lithological log
- Other methodology like isotopes should be employed in future works for analysis of groundwater flow system along the corridor to confirm the out put of this work.
- Regional major ions evolution (including the study area) needs to be conducted to observe variation of water types which strongly indicated groundwater flow direction.
- Groundwater flow system in the vicinity of Koka Dam has to be investigated in detail manner so as to determine the relation between the Dam and shallow thermal aquifer.
- Vertical distribution of fluoride should be asses by using evenly distributed data so as to observe its concentration difference in the deep and shallow wells.

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This work is dedicated to:

My late Mother Emahoy Simegn Engida (1918-1998)

And

My Sister Mulu Kebede

DECLARATION

I, THE UNDERSIGNED DECLARE THAT THIS THESIS IS MY ORIGINAL WORK, HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY AND ALL SOURCE OF MATERIAL USED FOR THE THESIS HAVE BEEN DULY ACKNOWLEDGED.

ABIYU KEBEDE

SCHOOL OF GRADUATE STUDIES

FEBRUARY, 2007

The thesis has been submitted for examination with my approval as university advisor.

Tamiru Alemayehu (Ph.D) -----------------------

No.	Locality Name	East.	North.	Alt.Cali.	SWL	Water Ta.	Type of Sche.
1	Memre Teferi	503646	933035	1603	21.3	1581.7	HDW
2	Yeshi	503657	933057	1597	21.2	1575.8	HDW
3	Asallefech	503677	933056	1600	21.7	1578.3	HDW
4	Mariam Tsebel	502987	932925	1610	24.68	1585.32	HDW
5	Yergu	503412	932862	1609	20.1	1588.9	HDW
6	Getu	503411	932880	1609	20.2	1588.8	HDW
7	Mebrato	503424	932865	1609	20	1589	HDW
8	Yeshi	503523	932834	1607	20.9	1586.1	HDW
9	Eshatu	503602	932718	1617	23.4	1593.6	HDW
10	Wargn	503877	932594	1617	27	1590	HDW
11	Qcha	502252	929629	1591	5.1	1585.9	HDW
12	Shanko	502171	929686	1598	4.5	1593.5	HDW
13	Dhaqaba	502093	929748	1594	4.5	1589.5	HDW
14	Sidao	929830	502041	1595	5.85	1589.15	HDW
15	Wadago	502195	929810	1595	5.2	1589.8	HDW
16	Aadd	501876	928078	1601	11.5	1589.5	HDW
17	Girmma	501376	927291	1604	7.4	1596.6	HDW
18	Kasu 1	501509	926979	1593	6.2	1586.8	HDW
19	Kasu 2	501623	926932	1593	4.65	1588.35	HDW
20	Kasu 3	501679	926917	1600	3.3	1596.7	HDW
21	Kasu 4	501631	926804	1591	2.5	1588.5	HDW
22	Oda Bokota	478429	903032	1679	53.9	1625.1	HDW
23	Mariam sefer	480611	901627	1666	29	1637	HDW
24	Graba Jarso	478429	903034	1679	53.25	1625.75	HDW
25	Cort around	480410	900579	1658	49	1609	HDW
26	Midhagso	500255	925676	1600	6.6	1593.4	HDW
27	Negasi	499854	925969	1598	5.2	1592.8	HDW

No.	Locality Name	East.	North.	Alt.Cali.	SWL	Water Ta.	Type of Sche.
28	Zerihun1	499743	925997	1598	5.5	1592.5	HDW
29	Asefa	499657	926063	1597	7	1590	HDW
30	Zerihun2	499632	926005	1597	4.5	1592.5	HDW
31	Zerihun3	499668	925980	1601	5.6	1595.4	HDW
32	Meried	499921	926103	1596	3.15	1592.85	HDW
33	Tesfa	500095	925861	1602	5.3	1596.7	HDW
34	Daga	500416	925718	1598	2.96	1595.04	HDW
35	Urgecha	500365	925697	1592	4.67	1587.33	HDW
36	Billa	499585	923345	1601	11.7	1589.3	HDW
37	Sami	499263	922750	1597	8.9	1588.1	HDW
38	Baqala	499224	922560	1600	11	1589	HDW
39	Uga	499300	922638	1595	8.8	1586.2	HDW
40	Tolosa	499145	922427	1600	9.9	1590.1	HDW
41	Kawach	499101	922281	1597	9.7	1587.3	HDW
42	Badada	498941	921573	1599	7.1	1591.9	HDW
43	Raba	498869	921558	1597	7.2	1589.8	HDW
44	Nadhi	498519	921527	1596	8.7	1587.3	HDW
45	Esualelign	498519	921527	1597	7.6	1589.4	HDW
46	NomaneMN	498540	921502	1595	7.9	1587.1	HDW
47	Begenech	498387	921241	1597	7.4	1589.6	HDW
48	Temesgen	498369	921245	1596	7.2	1588.8	HDW
49	Neche	498521	921283	1598	7.33	1590.67	HDW
50	Temesgen	498369	921245	1596	7.2	1588.8	HDW
51	W/o Shite	498382	921816	1598	7.2	1590.8	HDW
52	Ayalew	498656	922108	1598	7.7	1590.3	HDW
53	Daniel	498470	922024	1601	6.8	1594.2	HDW

No.	Locality Name	East.	North.	Alt.Cali.	SWL	Water Ta.	No.	Locality Name	East.	North.	Alt.Cali.	SWL	Water Ta.	Type of Sche.
54	Goraw	498594	922128	1600	6	1594	85	Bekel	HDWB	499031	922432	1592	6.3	1585.7
55	Abiti	498354	921871	1597	7.1	1589.9	86	Nedi	HDWN	499061	922327	1589	6.4	1582.6
56	Beyene	498598	922219	1594	7.78	1586.22	87	Hadush	HDWH	498342	921051	1594	7.9	1586.1
57	Fitala	498100	922021	1603	8.63	1594.37	88	Hadush	HDWH	498440	920943	1602	7.9	1594.1
58	Gebre	498050	921812	1597	6.2	1590.8	89	Tolossa	HDWT	498459	920861	1598	7.6	1590.4
59	Adamu	497940	921819	1600	7.5	1592.5	90	Tolossa	HDWT	498509	920721	1599	8.4	1590.6
60	Birhan	497664	921967	1600	7.4	1592.6	91	Tullu	HDWT	498569	920596	1601	8.85	1592.15
61	Dessie	497728	921799	1598	7.2	1590.8	92	Gudeta	HDWG	498663	920644	1595	8.7	1586.3
62	Bekele	497664	921967	1599	11.5	1587.5	93	Wogi	HDWW	498698	920703	1597	8.5	1588.5
63	Yohannes	497425	921786	1602	8.4	1593.6	94	Medekiso	HDWM	498784	920712	1601	9.1	1591.9
64	Shambo	496865	921693	1596	8.4	1587.6	95	Geleshu	HDWG	498805	920755	1602	8.75	1593.25
65	Yohannes	497107	921564	1599	6.4	1592.6	96	Degaga	HDWD	498939	920869	1598	8.2	1589.8
66	W/Hanna	497018	921552	1598	7.4	1590.6	97	Mesfin	HDWH	497630	920791	1609	8.75	1600.25
67	Kunbi	497253	921772	1597	8.1	1588.9	98	G/meskel	HDWG	497748	920450	1606	11.2	1594.8
68	Mekikso	497975	924956	1605	12.85	1592.15	99	Ago Jillo	HDWA	497884	920464	1603	9.35	1593.65
69	Betei	498219	925435	1607	9.1	1597.9	100	H/maria	HDWH	497399	921257	1600	7	1593
70	Begashaw	497862	925658	1605	10.5	1594.5	101	H/maria	HDWH	497202	921175	1605	10.75	1594.25
71	Airba	496528	926391	1603	7.4	1595.6	102	Niguse	HDWN	497002	921125	1610	10.58	1599.42
72	Tewhibo	496427	926420	1602	6.6	1595.4	103	W/Hana	HDWW	497078	921330	1603	7.2	1595.8
73	Joba	495432	924705	1601	3.5	1597.5	104	W/Hana	HDWW	497015	921545	1601	8.5	1592.5
74	Ayanew	496031	922881	1606	7.3	1598.7	105	Feyso	HDWF	470081	888538	1672	32.83	1639.17
75	Fale	496178	922927	1605	6.8	1598.2	106	Gallelo	HDWG	470209	889035	1669	33.3	1635.7
76	Baddo	496348	922789	1600	3	1597	107	Negewo	Nosap.	478354	897217	1634	5	1629
77	Dema	496117	922718	1603	2.5	1600.5	108	AbuGed	Nosap.	478201	897217	1636	5.8	1630.2
78	Nebiy	490638	922657	1603	2.2	1600.8	109	TB	Nosap.	478126	897150	1634	5.45	1628.55
79	Hawas	495963	922357	1596	2.6	1593.4	110	Beshane	Nosap.	469992	888330	1656	32.7	1623.28
80	Medaso	495856	922368	1595	3	1592	111	Tesfaye	Nosap.	461077	853174	1590	10.1	1579.9
81	Ameni	495786	922643	1600	3.5	1596.5	112	Shuka	Nosap.	465669	851895	1589	11.5	1577.5
82	Hirut	499099	922409	1593	6.7	1586.3	113	Z Turist		468438	875637	1640	23.3	1616.7
83	Medega	499099	922378	1595	6.7	1588.3	114	Serto	Nosap.	469115	880788	1636	9.08	1626.92
84	Gerachew	499030	922394	1594	6.3	1587.7	115	Jaletu	Nosap.	469171	881996	1633	9	1624

No.	Locality Name	East.	North.	Alt.	SWL	Water Ta.
116	Like	469411	883391	1641	13.3	1627.68
117	Abiti	469565	885259	1648	19.6	1628.4
118	Denanso	469668	885586	1658	18.7	1639.3
119	Kemal Leta	469731	885922	1646	20	1626
120	Haweno	469717	885980	1654	20.4	1633.6
121	Yiheyis	471559	891143	1661	7.8	1661
122	Yemaneh	471629	891219	1656	31.1	1624.9
123	Negashu	478216	897371	1634	7.18	1626.82
124	Abu Geda	478317	897329	1632	6.2	1625.8
125	Yohanis	478129	897304	1636	6.38	1629.62
126	Yosef	478049	897291	1639	6.1	1632.9
127	Eyasu 1	478058	897127	1637	5.2	1631.8
128	Eyasu 2	477921	897197	1638	6.85	1631.15
129	Eyasu 3	477969	897300	1635	6.7	1628.3
130	Denbel	477843	897292	1633	6.8	1626.2
131	Zewdu	477798	897537	1649	9.8	1639.2
132	Abay	477937	897636	1646	9.56	1636.44
133	Yohanis 1	477825	897118	1636	6.9	1629.1
134	Yohanis 2	477763	897233	1636	7.7	1628.3
135	Samuel	477678	897170	1640	6.5	1633.5
136	Roba	477511	897400	1644	11	1633
137	Tesfaye	477551	897610	1641	11.6	1629.39
138	AbeQabqto	477438	897668	1644	13	1631
139	korme fole	477575	897212	1639	8.5	1630.5
140	Yishak	477631	897176	1638	7.65	1630.35
141	Sategni	477535	897177	1640	7.6	1632.4
142	Solomon	477666	896959	1637	5.1	1631.9
143	Tadese	477526	896995	1638	6.1	1631.9
144	Roba	477423	897091	1636	7.57	1628.43

No.	Locality Name	East.	North.	Alt.Cali.	SWL	Water Ta.
116	Like	469411	883391	1641	13.3	1627.68
117	Abiti	469565	885259	1648	19.6	1628.4
118	Denanso	469668	885586	1658	18.7	1639.3
119	Kemal Leta	469731	885922	1646	20	1626
120	Haweno	469717	885980	1654	20.4	1633.6
121	Yiheyis	471559	891143	1661	7.8	1661
122	Yemaneh	471629	891219	1656	31.1	1624.9
123	Negashu	478216	897371	1634	7.18	1626.82
124	Abu Geda	478317	897329	1632	6.2	1625.8
125	Yohanis	478129	897304	1636	6.38	1629.62
126	Yosef	478049	897291	1639	6.1	1632.9
127	Eyasu 1	478058	897127	1637	5.2	1631.8
128	Eyasu 2	477921	897197	1638	6.85	1631.15
129	Eyasu 3	477969	897300	1635	6.7	1628.3
130	Denbel	477843	897292	1633	6.8	1626.2
131	Zewdu	477798	897537	1649	9.8	1639.2
132	Abay	477937	897636	1646	9.56	1636.44
133	Yohanis 1	477825	897118	1636	6.9	1629.1
134	Yohanis 2	477763	897233	1636	7.7	1628.3
135	Samuel	477678	897170	1640	6.5	1633.5
136	Roba	477511	897400	1644	11	1633
137	Tesfaye	477551	897610	1641	11.6	1629.39
138	AbeQabqto	477438	897668	1644	13	1631
139	korme fole	477575	897212	1639	8.5	1630.5
140	Yishak	477631	897176	1638	7.65	1630.35
141	Sategni	477535	897177	1640	7.6	1632.4
142	Solomon	477666	896959	1637	5.1	1631.9
143	Tadese	477526	896995	1638	6.1	1631.9
144	Roba	477423	897091	1636	7.57	1628.43

UTM and SWL measurements Deep and Shallow Wells

No.	Comm.	Woreda	East.	North.	Altitude	Total Depth	Static WL	Water Ta.
1	Abossa	Adami Tulu	469329	886606	1667	35.3	30	1637
2	AdamiTuluCatholic	Adami Tulu	467229	889257	1652	60	34	1618
3	Edo Kontola	Adami Tulu	468994	882647	1657	37	18	1639
4	Elkana Metrofa	Adami Tulu	468331	885079	1661	47	34	1627
5	Garbi (ziway)	Adami Tulu	469375	870969	1639	36	23	1616
6	Garbi Gilgile	Adami Tulu	468615	870405	1653	45	30	1623
7	Wush Gulla	Adami Tulu	466766	875884	1649	56	42	1607
8	Haleku	Adami Tulu	465292	869031	1656	82	58	1598
9	Hesbawi Batele	Adami Tulu	468253	879184	1650	25	22	1628
10	Mago	Adami Tulu	468840	889117	1683	53	50	1633
11	Negalign	Adami Tulu	468613	886551	1673	40	32	1641
12	Semoye Chelemo	Adami Tulu	464528	886086	1687	100	55	1632
13	Shisho Tebo	Adami Tulu	463965	866111	1665	85	66	1599
14	Wolimabula	Adami Tulu	469229	887356	1668	36	35	1633
15	Woga Batele	Adami Tulu	466836	877030	1648	61	39	1609
16	Woga Gerbi	Adami Tulu	466761	875867	1659	73	44	1615
17	Ziway Prison1	Adami Tulu	467387	878170	1658	50	34	1624
18	Ziway Town	Adami Tulu	468098	876699	1642	33	30	1612
19	Ziway Catholic	Adami Tulu	467921	876815	1645	33	27	1618
20	Abonno 1	Dugda Bora	471685	892248	1663	50	35	1628
21	Abonno 2	Dugda Bora	467735	894651	1709	99	81	1628
22	Alem Tena Miss.	Dugda Bora	493616	917165	1659	93	61.5	1597
23	Ate Fnuri	Dugda Bora	472338	901801	1703	92	86	1617
24	AteMeti	Dugda Bora	474693	902440	1688	76	65	1623
25	Bada Gosa	Dugda Bora	469719	890729	1684	70	54	1630
26	Bofo	Dugda Bora	485837	904863	1674	75	55	1619
27	Chalaleki	Dugda Bora	472897	893411	1659	52	33	1626
28	Chalaleki Germeg	Dugda Bora	469737	895820	1714	110	79	1635
29	Choroke	Dugda Bora	471470	888142	1716	91	76	1640
30	Deriba Berbirsa	Dugda Bora	470565	914133	1736	63	54	1682
31	Grabr Garso	Dugda Bora	477113	901640	1681	75	60	1621
32	Graba Philla	Dugda Bora	483828	904419	1658	52	33.6	1624.4
33	Gura Germegi	Dugda Bora	472614	893146	1662	47	35	1627
34	Gussa 2	Dugda Bora	474552	908751	1713	120	93	1620
35	Korki Adi	Dugda Bora	476436	898195	1672	51	30	1642
36	Laluna Dero	Dugda Bora	479856	900827	1723	100	85	1638
37	Korki Adi	Dugda Bora	476436	898195	1672	51	30	1642
38	Laluna Dero	Dugda Bora	479856	900827	1723	100	85	1638
39	Koye jejeba	Dugda Bora	477019	917806	1728	123	78.5	1649.5
40	Meki Catho. Sch	Dugda Bora	480317	901410	1655	54	30	1625
41	Meki catho.com	Dugda Bora	480065	901461	1654	50	14	1640
42	Meki LVIA	Dugda Bora	480345	901718	1662	58	30	1632
43	Oda	Dugda Bora	480041	902595	1666	41	34	1632
44	Sera	Dugda Bora	479302	905792	1705	102	85	1620

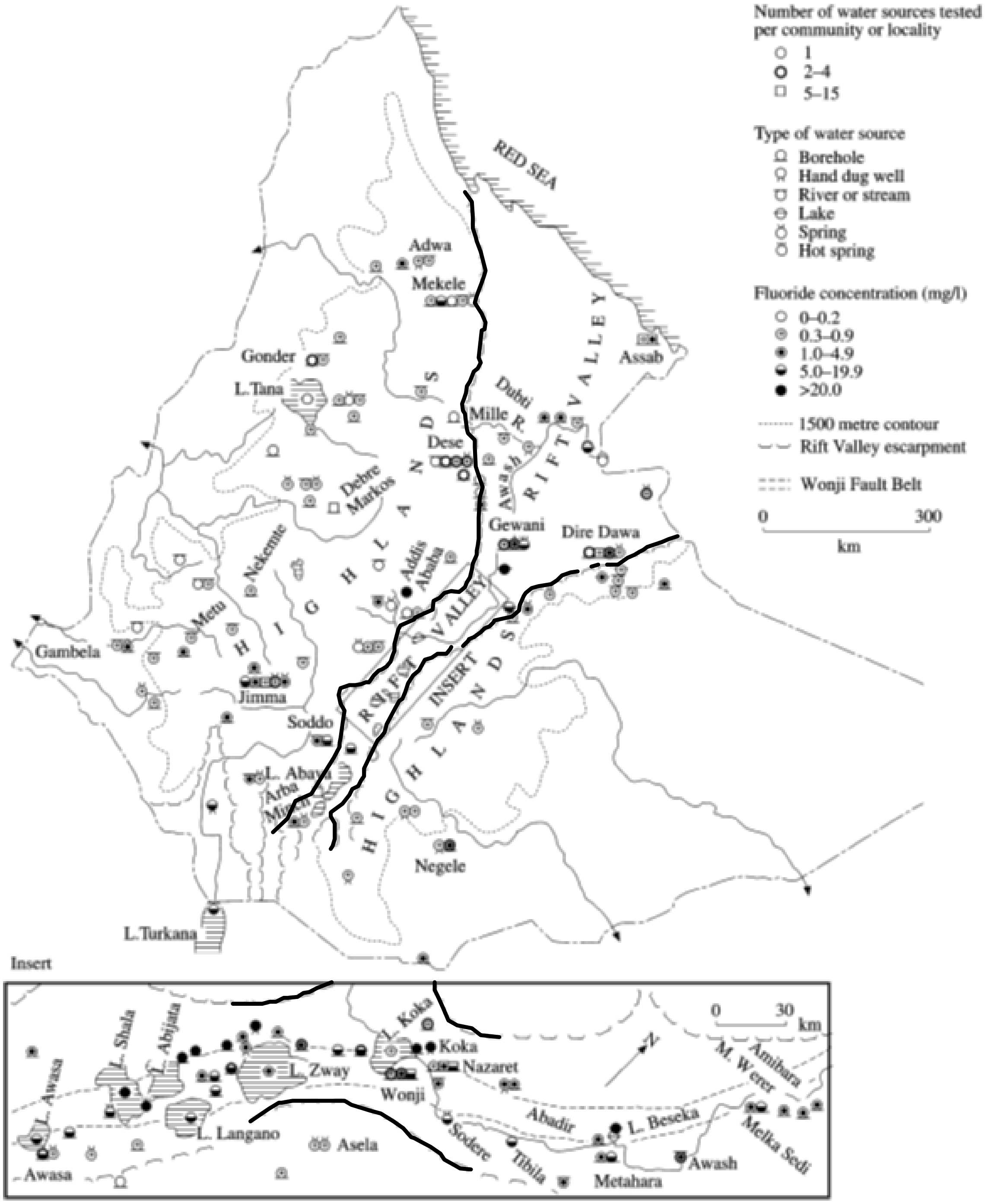
No.	Comm.	Woreda	East.	North.	Altitude	Total Depth	Static WL
45	Wekele	Dugda Bora	477309	906917	1699	91	80
46	Wolda Kocha	Dugda Bora	481416	909593	1701	105	80
47	Woyyo School	Dugda Bora	471590	891517	1764	60.5	33.2
48	Afana Kemene	Dugda Bora	476639	913734	1717	156	98.7
49	Langano	Dugda Bora	488390	915966	1646	81	52.1
50	Deko	Dugda Bora	491865	913779	1651	78	25.9
52	Dalota	Dugda Bora	490712	918262	1676	70	52.9
53	Koshe	Dugda Bora	495766	914798	1868	244	90.2
54	Afana Kemene	Dugda Bora	448714	885850	1717	151.3	100.5
55	Koka area	Lome	502000	933000	1600	70	45
56	Koka area	Lome	525000	924000	1550	76	56.6
57	Koka area	Lome	520000	937000	1531	60.7	
58	Koka area	Lome	520000	935000	1578	60.5	28.5
59	Koka area	Lome	517000	935000	1513	96.3	
60	Koka area	Lome	518000	933000	1589	60	
61	Koka area	Lome	518000	934000	1584	81.4	23
62	Koka area	Lome	519000	936000	1595	100.2	45
63	Koka area	Lome	518000	935000	1578	100	31
64	Koka area	Lome	517000	935000	1600	80	50
65	Koka area	Lome	518000	935000	1574	100.1	27
66	Koka area	Lome	521000	935000	1560	107	29
67	Koka area	Lome	520000	934000	1577	74	31
68	Koka area	Lome	519000	931000	1613	92	62
69	Koka area	Lome	519000	935000	1555	42.4	11
70	Koka area	Lome	525000	937000	1540	24	10
71	Koka area	Lome	525000	937000	1540	103.6	14.9
72	Koka area	Lome	525000	935000	1540	410	16
73	Koka area	Lome	525000	935000	1540	24.5	8.6
74	Koka area	Lome	526000	930000	1540	81	11
75	Koka area	Lome	525000	928000	1540	84	7.05
76	Koka area	Lome	523000	928000	1540	52	13
77	Koka area	Lome	535000	920000	1650	268	256
78	Koka area	Lome	510000	885000	1720	34	16.5
79	Koka area	Lome	518000	887000	2130	120	90
80	Koka area	Lome	525000	898000	2110	266	245
81	Koka area	Lome	500000	890000	1650	63	27
82	Koka area	Lome	502000	891000	1650	63.5	42.8
83	Koka area	Lome	503000	893000	1600	78	52.8
84	Koka area	Lome	507000	901000	1770	160	118
85	Koka area	Lome	518000	887000	2150	105	80

No.	Easting	Northing	PH	Eh (mv) ??	Temp.0 C	Cond. (us/cm)	TDS (mg/l)	Salinity (%)
1	503646	933035	7.25	20	55	1214	726	0.7
2	503657	933057	7.4	25	52.4	1230	730	0.7
3	503677	933056	7.79	44.4	47.6	1166	700	0.7
4	502987	932925	8.2	66.2	42.7	1400	833	0.8
5	503523	932834	7.8	48	52.6	1452	835	0.8
6	503877	932594	7.72	45	52	1051	6200	0.7
7	502252	929629	7.6	41	37.4	2140	1286	1.1
8	501876	928078	7.4	23.4	31.6	1600	961	0.9
9	500365	925697	7.34	19.2	27	4650	2.8	2
10	499300	922638	7.36	21	27	1615	961	0.9
11	498941	921573	7.1	1.6	22	1147	688	0.7
12	498869	921558	7	5.2	23	1300	780	0.8
13	496907	911543	6.7	-13.8	29.6	1077	640	0.7
14	497012	911486	6.45	9	26.5	1360	840	0.8
15	498124	925228	7.45	-27	33.8	910	551	0.6
16	495761	922161	6.8	7.8	27	1808	1550	0.9
17	497767	925451	7.2	17	28.4	1019	610	0.7
18	499004	922202	7.2	-6	27.3	1620	970	0.9
19	499004	922171	6.91	5.6	28.6	1545	924	0.8
20	498935	922187	7.12	2	27.9	1504	908	0.8
21	498936	922225	6.8	12.2	27.2	1653	986	0.9
22	498966	922120	7.01	6.6	27.7	1498	900	0.8
23	497535	920584	6.95	3	32.7	1144	690	0.7
24	497789	920257	6.95	8.4	29.9	1045	619	0.7
25	478550	897128	6.47	-13.4	27.1	650		
26	469992	888330	6.88	-29.1	29.6	2310	1380	1.1
27	470553	874349	6.29	-34.5	19.3	1672	101.3	0.4
28	470553	874349	6.78	-20.8	19.6	585	35	0.3
29	461077	853174	6.44	-0.7	22.8	795	480	0.6
30	468438	875637	6.87	-27.7	26	1332	800	0.8
31	469171	881996	6.96	-36	22.6	1540	930	0.8
32	469565	885259	6.8	-25.1	23.9	241	1437	1.2
33	469717	885980	6.78	-15.3	24.9	1108	667	0.7
34	471629	891219	7.03	-37	27.9	2380	1450	1.1
35	487583	909976	6.96	-33.6	22.1	1156	634	
36	488095	911530	7	-33.5	22.6	950	571	0.6
37	493894	917364	6.7	-17.3	29	1115	654	0.7
38	494783	917080	6.73	-17.7	30.6	1078	650	0.7
39	478058	897127	6.83	-10	23.4	6.11	3.67	2.6
40	477937	897636	6.56	-27	25	1003	589	0.7
41	477385	897037	6.9	-8	22.7	1485	900	0.8
42	477326	896469	6.7	-22.4	24.2	2780	1417	1.2
43	476745	896765	6.87	-10.6	24.2	818	490	0.6
44	472647	893143	7.32	-15		1425	860	0.8
45	471916	891555	7.2	-12	28.7	1685	1012	0.8
46	471490	891736	7.3	-18	28.7	1880	1318	1
50	468443	875684	7.05	-2	27.8	1143	689	0.7
51	479210	899745	6.97	-3.6	21.4	4070	2.44	1.8

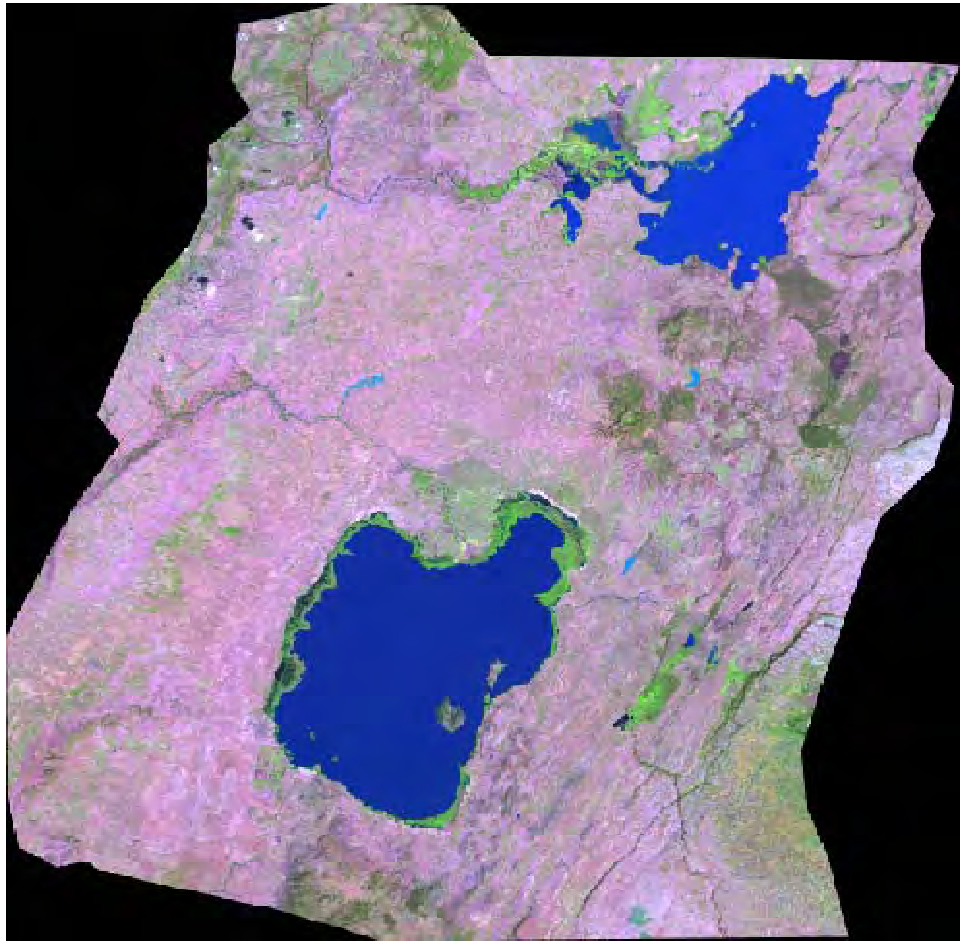
No	Easting	Northing	EC	PH @ 20^0	Carbo.	Bicar.	TH	Silica	Na^+	K^+	Ca^{++}	Mg^{++}	Cl-	NO_3	HCO_3	F	CO_3	SO_4	Fe tot
1	469329	886606	2162	8.5	80	1130	24	84.94	578	24.75	4.8	2.92	63.58		1378.6	4	48		0.37
2	467229	889257	820.2	8.5	28	388	24	74.4	204	9.9	4.8	2.92	15.2		473.3	3.75	33.6		0.34
3	459602	873206	1284	8.3	20	580	16	100	326.4	11.2	4.8	1	25.5	2.2	707.6	24	24	16.5	
4	468994	882647	1654	8.56	40	780	80	83.26	394.4	18.15	12.8	10.7	85.93	1.34	951.6		24		0.21
5	468331	885079	1483	8.69	80	740	28	90	374	16.5	6.4	2.92	15.88		902.8	7.19	48		0.21
6	461439	882406	1550	8.9	40	660	16	45	414.8	11.2	3.2	2	53.9		805	14	48	77	
7	466766	875884	1127	8.56	40	560	36	90.6	268.6	16.5	6.4	4.86	16		683.2	5.13	24		0.08
8	465292	869031	867.2	8.76	40	420	28	81.63	210.8	9.9	6.4	2.92	17.8		512.4	4.6	24		0.16
9	468253	879184	1270	7.69		620	32	94.69	178.5	14.85	75.4	32	69.98		756.4	3.13			
10	468840	889117	2697	8.6	120	920	20	80.8	671.5	24.75	4.8	2.92	227.1		1122.4	6.25	72	128	0.26
11	468613	886551	1494	8.8	80	720	12	89.4	387.6	14.85	3.2	0.97	33.9		887.4	7.75	48		0.02
12	464528	886086	2485	8.7	60	740	16	100	646	16.5	4.8	1	141.8	1.3	902.8	12.3	72	338	0.15
13	463965	866111	1045	8.76	80	480	24	87.35	258.4	11.22	6.4	1.94	20		585.6	5.25	48		0.12
14	469229	887356	1917	8.73	120	880	16	85.7	496.4	19.8	4.8	0.97	60	2.03	1073.6	10.3	72	14.4	
15	466836	877030	1150	8.55	40	560	40	85.7	268.6	14.85	9.62	3.89	20		683.2	4.1	24		0.02
16	466761	875867	1917	8.15		920	52	97.96	482.8	24.75	11.2	5.84	98		1122.4			42	0.03
17	467387	878170	1786	7.6			49		118	12.75	12.3	4.48	19.27			5			
18	468098	876699		7.5	600		64	90	251.6	19.8	19.2	3.9	21.3		732	2.4		nill	
19			1329	8.7	40	650	64	65.3	314.5	11.55	17.6	4.86	22		793	16	24		0.1
20	467921	876815																	
21			656.9	7.94		360	240	44.9	56.1	13.2	56.1	26.3	15.6		439.2	0.63			0.04
22	471685	892248	599.7	8.4	20	290	228	87.5	54.4	13.2	46.5	27.2	22	3.4	353.8	0.9	24		
23	467735	894651	1350	8.52	160	520	60	73.47	323	17.33	12.8	6.33	27.79		634.4	10	96	56	0.12
24																			
25	493616	917165	877	8.5	36	344	48	94	204	13.2	14.4	2.92	48	6.65	419.68	7.65	43.2		0.09
26	472338	901801	805.1	8.35	120	340	20	52.24	204	14.85	6.09	1.17	2.2	1.57	414.8	4.9	72		
27	474693	902440																	
28	469719	890729	2542	8.4	80	1020	36	85.7	646	28.05	9.62	2.92	175		1244.4	6.9	48	108	0.01
29	485837	904863		8.4	40	520	56	87.5	301.4	13.5	14.4	4.9	70.9	0.44	634.4	10.9	48		

No	Easting	Northing	EC	PH @ 20^0	Carbo.	Bicar.	TH	Silica	Na^+	K^+	Ca^{++}	Mg^{++}	Cl-	NO_3	HCO_3	F	CO_3	SO_4	Fe tot
30	472897	893411		8.4	80	800	48	100		454.9	27.7	9.6		0.01	19	0.2	976	97.6	
31	469737	895820		8.4	80	800	48	100		454.9	27.7	9.6	5.8		19	0.2	976	97.6	5.8
32	471470	888142	1258	8.4	40	500	32	87.7	299.2	16.5	11.2	0.97	63.98			5.63	24	54	0.33
33	470565	914133	576.6	8.1		320	196	96	64	11.88	59.3	11.7		5.64	390	1.03			0.01
34	477113	901640		8.4	40	460	52	112.5	285	15.2	12.8	4.9	78	0.2	561.2	7.8	48	20.1	
35	483828	904419	1686	8.5	90	610	88	75.6	399.5	20.4	9.73		122		744.2	7.65	108		0.24
36	472614	893146	1397	8.49	40	720	32	91.4	346.8	18.18	8.02	2.92	16.39		878.4	9.4	24		
37	474552	908751	429.5	8.1		230	100	81.6	64.6	5.94	28.9	6.8	4		280.6	2.75			
38			309	7.8		176	92	109.2	40.8	10.56	24.1	7.8	8.8		214.7	0.5			0.06
39	476436	898195	1703	8.3			7		191	11.7	1.4	0.83	13.6		8.86				
40	477019	917806																	
41	479856	900827	673	7.9	320		73	100	56.5	9.48	24	3.24	3		390	4.03		nill	
42	480317	901410																	
43	480065	901461																	
44	480345	901718	627	7.8			136		25.2	2.83	42	7.58	10.5			1.37			
45	480041	902595	715.5	7.62		400	156	72.24	115.6	13.2	43.3	11.7	5.2		488	2.9		5.35	0.03
46	479302	905792																	
47	469429	889602		8.4	30	1030	28	87.5	655	31.7	8	2	170.2	0.2	1257	9.2	36	134	
48	487429	902565	1983	8.65	60	980	76	73.88	484.5	36.3	17.6	7.78	69.18		1195.6	9	36		0.05
49	477309	906917	716	8.7	40	320	32	77.55	156.4	9.9	9.62	1.95	8		390	3.6	24		0.22
50	481416	909593									17.6	4.86	22		793	16	24		0.1
51	471590	891517	1696	8.4	160	790	28	96.8	442	26.4	6.4	2.92	34		963.8	9	96		0.03
52	476639	913734	406	8.4	12	196	92	101.6	61.2	5.6	25.7	6.8	8	1.08	239.12	1.9	14.4		0.08
53	488390	915966	785.5	7.8		400	24		190.4	6.6	6.4	1.9	16		488	8.5			
54	491865	913779							190.4	8.6	16	1.9							0.12
55	490712	918262	918.5	7.6		480	52		207.4	11.2	16	2.9	12	1.45	585.6	7.5			
56	495766	914798	846.8	7.4		400	48						36		488	7.5			
57	448714	885850					27		202.3	31	8.4	1.68	7.8		413			7	
58	515700	932200		8.17				100	228	16	5	0.8	36	0.24	566	12.9		3	

No	Easting	Northing	PH @ 20^0	Silica	Na^+	K^+	Ca^{++}	Mg^{++}	Cl-	NO_3	HCO_3	F	SO_4
59	515700	932700	7.8	17	33	5	29	5	13	0.31	187	1.7	5
60	520150	936350	7.87	88	208	13	5	1	29	0.52	517	10.4	5
61	520100	936400	7.89	87	204	13	5	1	29	0.49	517	10.3	5
62	520150	935950	7.92	92	223	13	4	0.9	30	0.26	542	13.1	9
63	521250	935000	7.88	99	208	12	4	0.6	25	0.76	482	15.5	34
64	520050	937050	7.43	97	185	12	6	0.4	22	0.45	479	9.63	4
65	518750	936750	7.62	122	146	21	16	4	23	0.7	443	4.47	8
66	518450	936750	7.79	119	178	19	7	0.4	20	0.28	478	5.98	11
67	514750	928500	7.51	18	34	5	30	5	13	0.02	182	1.73	8
68	510000	918850	7.58	18	36	6	27	5	14	0.02	184	1.88	8
69	524000	934400	8.82	91	505	18	1	0.1	60	0.82	1049	34.8	52
70	524000	934000	8.14	96	333	18	4	2	56	12	748	18	42
71	522550	936650	7.64	20	38	6	28	6	14	0.02	184	2.02	8
72	513750	937150	7.68	160	305	26	7	0.2	56	0.07	726	9.8	52
73	516100	942650	7.79	85	53	15	34	7	5	0.21	293	1.52	3
74	522450	937000	8.01	61	175	12	20	3	21	0.12	508	8.83	13
75	524250	943650	7.56	89	52	12	33	8	5	0.68	289	1.3	3
76	517650	941500	7.36	60	37	12	48	5	9	3.59	268	1.55	5
77	524000	937360	7.79	103	178	19	33	8	40	4.11	551	4.69	10
78	524000	927600	7.7	81	313	22	14	4	73	11	671	18.2	79
79	503400	932800	8.31	155	240	22	3	0.1	76	41	458	20	17
80	504000	945500	7.49	101	51	13	51	10	15	1.44	334	1.45	5
81	507000	937550	7.73	81	93	10	25	9	6	0.02	367	2.63	2
82	517450	935540	8.02	18	38	6	28	5	14	0.02	183	1.86	12
83	489350	921550	8.07	77	450	26	35	10	358	21	695	12.3	54
84	507650	918500	8.5	84	450	37	5	0.5	188	2.46	622	34.5	173
85	503750	919700	8.99	98	303	12	7	4	115	0.85	494	21.4	35
86	504150	931300	8.13	81	265	12	5	0.2	15	4	711	12.1	7



Fluoride distribution in the Ethiopian Rift



Satellite image of the studied Corridor

APPENDIX 1-Field measurements for HDWs

2-Reading in UTM and SWL fro deep and shallow wells

3-In-Situ Water quality parameters measurements

4-Physico-Chemical Analysis result for Shallow and deep aquifer

5-Spatial Fluoride distribution in the Main Ethiopian Rift Valley

6-Satellite image of the studied area

7- Lithological log

APPENDIX 2-Reading in UTM and SWL for deep and shallow wells

APPENDIX 3-In-Situ Water quality parameters measurements

APPENDIX 4-Physico-Chemical Analysis result for Shallow and deep aquifer

APPENDIX 5-Spatial Fluoride distribution in the Main Ethiopian Rift Valley

APPENDIX 6-Satellite image of the studied area

APPENDIX 7- Lithological log