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Addis Ababa University, School of Graduate Studies, Department of Earth Sciences

Characterization of Aquifers and Hydrochemistry in Volcanic Terrain of Central Ethiopia

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

Advisor: Tenalem Ayenew (prof.)

By: Mekdes Nigatie Enideg

June 2012

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EARTH SCIENCES

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June, 2012

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Acronyms

AAU: Addis Ababa University

AAWS: Addis Ababa Water and Sewerage Authority

ABGREP: Adaa-Becho Groundwater Resource Evaluation Project

GSE: Geological Survey of Ethiopian

MoWR: Ministry of Water Resources

RA: Residual Alkalinity

TDS: Total Dissolved Substances

WHO: World Health Organization

WWDE: Water Well Drilling Enterprise

WWDSE: Water Works Design and Supervisor Enterprise

BH: Bore Hole

CSP: Cold Spring

EC: Electrical conductivity

E-W: East-West

HDW: Hand Dug Well

M.a.b.sl: Meter above Sea Level

Abstract

This thesis work aimed to characterizing the different aquifer systems and their hydrochemistry of volcanic aquifer in central Ethiopia which encompasses Upper Awash, Jema, Mugher and Guder River basins surrounding the city of Addis Ababa.The area can be divided in to three geomorphologic features (zones): central gentle slopes and plateau, western, northwestern and northeastern deep gorges of Blue Nile, Guder, Muger and Jema rivers and low elevation area, and elevated picks of mountains and ridges. The main rainy season of the study area is from June to September. The recent Quaternary deposits, Quaternary basalt, Tertiary basalts, ignimbrites, rhyolites, trachytes and Mesozoic sediments are the stratigraphy of the area from youngest to oldest. The hydrogeological classification is done using qualitative and quantitative approaches. On the basis of hydrogeological characteristics of lithologic units and different data collected from different organization, the classification leads to different aquifers and aquiclud. High productive porous aquifers of sandstone (T=100-500 m^2/d, Q=5-25l/s). High productive fissured and/or karst aquifers of limestone (T= 50-100 m^2/d Q=2-5 l/s). High productive fissured aquifers of Tertiary and Quaternary basalt (T=100-500 m^2/d, Q=5-25 l/s). Moderate productive fissured aquifers of Aiba basalt Lower ignimbrite and aphanitic to Medium grained vesicular trachyte and trachy basalt (T=50-100 m^2/d, Q=2-5 l/s), Moderate productive porous aquifers of sandstone and Quaternary deposits, (T=50-100 m^2/d, Q=2-5 l/s) Low productive aquifers of Entoto rhyolite and trchyte (T=1-10 m^2/d and Q=0.05 l/s) and aquiclud or minor aquifers with limited ground water resources. Moreover, different types of maps and their analysis result indicate widely variable aquifer characteristics. Hydro chemical data shows that evolution of major ions, such as Na, K, Ca, Mg, SO4, NO3 and HCO3 and analyze some physical parameters PH, TDS and Conductivity, water types. The result shows that the dominant water type is bicarbonate especially Ca-Mg-HCO3, Ca-Na-HCO3 and Ca-HCO3. The water quality analysis mad based on Florid, Chloride, Nitrate and Total Dissolved Solids (TDS) results approved the potential of groundwater contamination in the area. Generally the ground water of the area is suitable for domestic use. However, there are also exceptions which are susceptible for pollution and needs proper follow up of its quality.

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CHAPTER 1

INTRODUCTION

1.1. Background

Water is essence food and the basic component of life. The need for water is strongly ascending and has diversified purpose, which is not only important for drinking purpose but also vital for any development activities. It is the most essential resource affecting municipal, agricultural and economic activities. Any development is related either directly or indirectly to water utilization. But it becomes more complex due to population growth, urbanization and industrialization.

More than 98% of the available global fresh water is ground water (Fetter, 1994), which is one of the most precious resources that nature has provided and occurs under the ground in rock unit (s) that can store and transmit water at the rates fast enough to supply reasonable amount to wells. There are various types of aquifer which are composed of various types of rocks. An aquifer in a given area could be a rock of sedimentary, igneous, or metamorphic origin depending on the degree of interconnection of fractures, joints, bending; planes grain size, grain sorting (degree of assortment), orientation of grains and the prevailing hydro geological condition, etc. Ethiopia consists of a large variety of metamorphic, sedimentary and igneous rocks with diverse aquifer characteristics .The study area dominantly consists of volcanic rocks. As per the information from Addis Ababa and surrounding cities municipality, water supply is gained from ground water source. Besides, all industries, factories, flower farms, and many other activities are currently using ground water for their water consumption.

Many of us depend on ground water for our very existence. Ground water is a precious and most widely distributed resource of the earth. Unlikely any other mineral resource, it gets in annual replacement from the meteoric insight. In spite of its huge water resources, Ethiopia is frequently affected by drought and the people are not food scoured. These problems, to some extent, are related to underutilization of existing water resources and resource management. It is obvious that for the full utilization of existing water resources, good understanding of hydro geological systems that control the evaluation of potential water resource of an area is highly important. Such understanding could also help water managers to understand the impact of climatic variability and aquifer pumping on water resources.

In the study area, surface and ground water are the most important water supply for the community. But information on ground water recharge, storage, circulation and chemical evolution is barely known. A picture of ground water recharge and factors that influence ground water circulation and its chemical evolution aquifer is lacking. The ground water development in this study area was conducted without a good understanding of its role in the characterization of aquifer and hydro chemistry of natural water.

In area where surface water is not available, ground water is the second alternative for irrigation purpose, if the demand for the irrigation and ground water potential is promising without negative environmental effect. To use water for drinking purpose, the water should be analyzed in terms of quality and quantity. The water supply needs chemical, physical and bacteriological analyses.

Water which is absolutely pure is not found in nature. Even water vapor condensing in the air cations solids dissolved salt, it seeps up other materials from the air and becomes more contaminated on reaching the ground, running on the surface and percolating through the various strata of the soil and rock. Some contamination may be removed by passage through the soil as result of infiltration and adsorption and exchange reactions, some may be removed in the surface water by sedimentation and biological activity; specific engineered processed in the treatment plants may remove some of them.

This research is addressing the effective mutilation of the water resources of the area by giving due attention to aquifer characteristics and their hydro chemistry of volcanic rock protecting the resource from contamination and recommending possible development activities. It is believed that this research will play an important role toward the sustainable use of water resources in the area.

1.2. Objectives of the Study

1.2.1. General Objectives

The principal object of the research is to systematically characterize the different aquifer systems and their water chemistry in central Ethiopia which encompasses Upper Awash, Jema, Mugher and Guder River basins surrounding the city of Addis Ababa.

1.2.2. Specific Objectives

- Characterization of aquifer systems and aquifer units in the study area.
- Understanding the hydrogeology of the area providing with classification of water bearing layers based on qualitative and quantitative parameters.
- Determine groundwater flow direction in the area.
- To understand the hydro chemical and water quality evolution in the aquifer systems
- To map the hydro chemistry of the basins

1.3. Significance of the Study

The research findings are assumed to have the following contributions. The results may:

- Be helpful to planners in the development and management of aquifer characterization and aquifer related works in volcanic rock terrain.
- Be useful to propose the mechanism of sustaining and obtaining the maximum benefit from the aquifer(s) in volcanic rocks terrain i.e. without affecting the aquifers.
- Help to schematize and characterize the geochemical processes and water quality distribution of the area.
- Be use full to Earth science students, researchers and research institution such as universities they can gain empirical evidence from the research work

1.4. Research Methodology

The activities undertaken included:

- Reviewing the available literatures related to the title.

- Reviewing the available previous works in the basins.
- Collecting boreholes and springs data from different organization. To make a map of the distribution of water points, potential of aquifer and ground water level contour line for reconstruction of the ground water flow direction.
- Pumping test data and geological log of the well from the study area were collected from different organization
- Data processing: the help of Aquachem 3.4, Arcgis 9.3, Global Mapper-12, Sulfer-8 and other computer codes to make easy of bulk data management and facilitate the analysis, and interpretation of results.
- Collecting and analyzing of seasonal water chemistry of ground water and surface water from existing data base and some primary water sample.
- Understanding and mapping of the geologic and hydro geologic set-ups

1.5. Literature Review

The area has been studied by various authors; however, most of the studies were concentrated at the southern part of the study area. The northern part is poorly studied. Some of the works conducted in the area are described below.

Abenezer Kefeni (2007). Hydrogeochemical Evaluation in the Ambo-Weliso area. Unpublished MSc thesis, AAU.

Andarge Yitbarek (2010). Hydrogeological and Hydro geochemical Framework of Complex Volcanic System in the Upper Awash River Basin, Central Ethiopia. University of Poitiers, France, unpublished, PhD. Thesis.

Berhau Melaku (1982). Investigating the General Hydrogeology of the Upper Awash Valley Which Includes, the Akaki River Catchment

Berhan Gizaw (2002). Carried out Detailed Assessments on the Hydro chemical and Environmental Investigation of Addis Ababa Region.

Esayas Tilahun (2008). Hydro chemical and Characterization of Natural Water in Addis Ababa Area, Unpublished MSc thesis, AAU

Tesfay cherent (1993). The Volcanic Rocks of Addis Ababa were characterized by extensive aquifer with fracture permeability and moderate productivity.

Fanuel's Seyoum (2007). Aquifer Characterization of Addis Ababa and the Adjacent High land.

Tilahun's Azagegn (2008). Findings reveal the Hydro Geochemical Characterization of Aquifer ystems in Upper Awash and Adjacent plateau using geochemical modeling and isotope hydrology.

Water work design and super vision enterprise (WWDSE), (2008). worked on evaluation of water resources of the adda'a and Becho plains ground water basin for irrigation development project.

Bisrat Lema and Amaha Athnafu (2007). Conducted Hydrogeological mapping of south eastern part of the Jema river basin.

The technical hydro geological report of Addis Ababa (2010). Deals the hydro geological description of different litho logical unites ground water occurrence and hydro chemical interpretation of ground and surface water points.

Tamiru Alemayehu et al. (2005). Hydro geochemical and lake level changes in the Ethiopia rift, hydrogeology journal.

Seifu Kebede et al. (2004). Groundwater Recharge, Circulation and Geochemical Evolution in the Source Region of the Blue Nile River, Applied Geochemistry.

CHAPTER 2

DESCCRIPTION OF THE STUDY AREA

2.1. Location

The study area is found in central Ethiopia within Oromia national regional state, Amhara national regional state and Addis Ababa city administration. In the north mugger river basin, in the west Guder River basin and in the east Jema River basin and in the south upper awash basin are found in the study area. The total cachement area is 44,522 km^2.

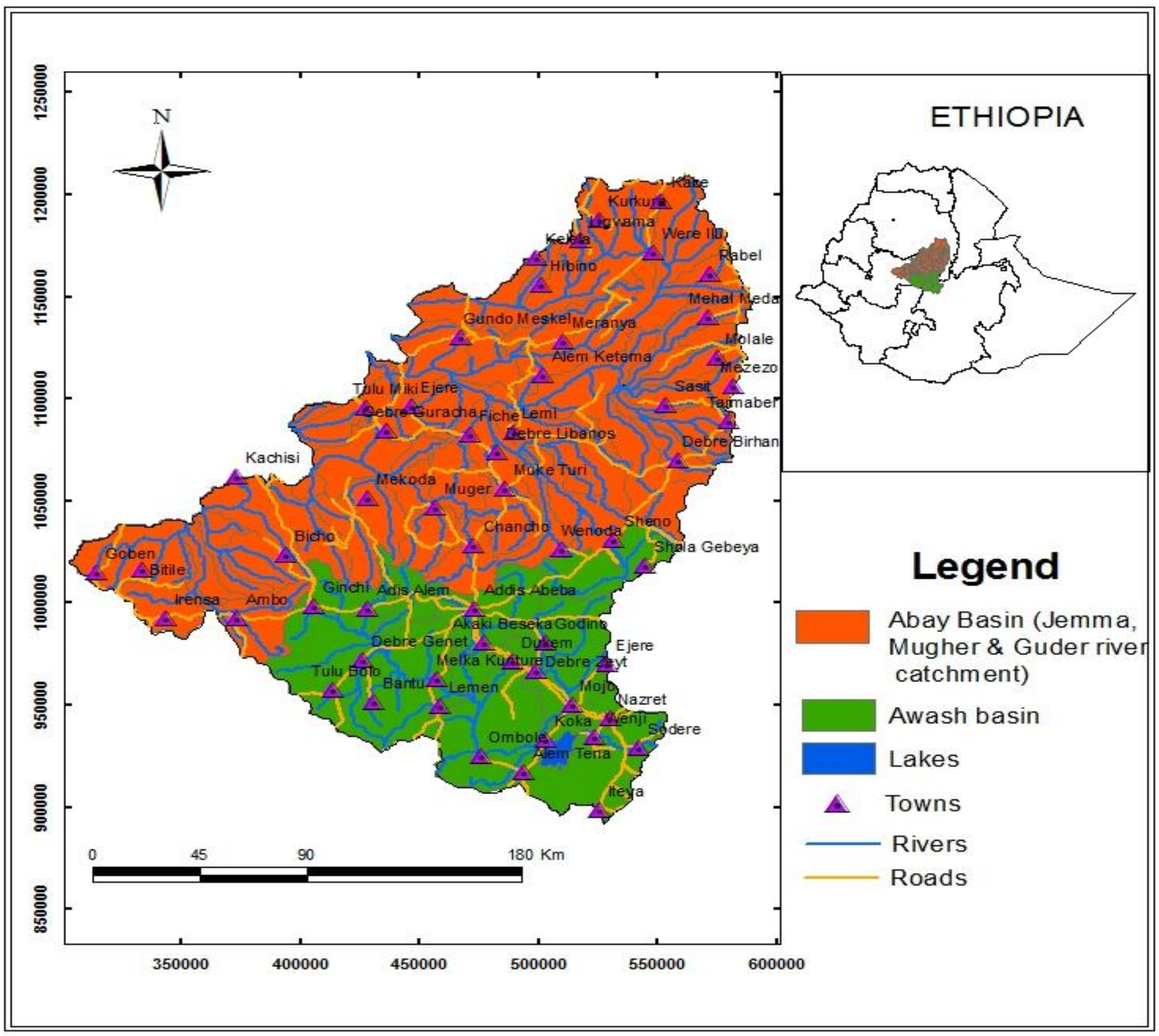

Figure 1: Location map of the study area

2.2 Geomorphology

The morphology of the study area is bordered in the east by Adaa-Becho, in the north by Jema, Muger river gorges, in the west by Guder River and in the south by mt. ziquala and koka dam. Inside the study area, there are voluminous ridges of acidic volcanic locations in which some of them are highly affected by recent faulting, like Entoto, Wochcha, Fori, Bedegebaba, Menogsha, Guji and many others.

There is high elevation variation within the study area ranging from 700-3500 m.a.s.l. The area can be divided into three geomorphic zones based on variation in elevation, morphological setting and topographic setting.

2.2.1. Blue Nile-Jema-Muger-Guder River Gorges and low elevation area

This physiographic zone covers the north eastern, the north western and southern part of the map area. It is characterized by development of deep gorges; steep slope and escarpment of the Blue Nile, Jema, Muger, and Guder Rivers. The elevation ranges from 700-2200 m.a.s.l. The lowest altitude of the zone is recorded inside Blue-Nile River at the north western part of the area which is about 700 M.a.s.l. This zone is dominated by quaternary sediments at the bottom, Mesozoic sediments as the escarpments and tertiary volcanic specially basalt which is hexagonal columnar joints at the top part. The drainage system is dendritic and with a number of perennial and intermittent rivers forming deep gorges.

2.2.2. The Central Plateau

This physiographic zone covers wide area of map. It is characterized by flat plain covered by recent deposit, gently slopes, and undulating terrain covered by tertiary volcanic rocks basalt and ignimbrite and quaternary basalt and sediments. The altitude ranges from 2200-2800 m.a.s.l. The region is desiccated by some big river and small streams such as Awash, holeta, duber, aleltiu, legedadi and sokoro. In this zone, there is numerous numbers of lineaments and most of them have NE-SW alignment. The drainage pattern shows parallel to dendritic. Most of the rivers in this zone flow to the Blue Nile basin and the rest flow to Awash basin.

2.2.3. Entoto-Chelelka-Guragudda-Wechecha-Chilmo Mountains

This region is located in the south eastern, south western and northern part of the study area at Entoto, chelelka, guraguda (near Fiche), wechecha and chilmo (north of ginchi) areas. This region forms dominantly E-W and N-S trending ridges and mountains picks of tertiary volcanic (basalt, trachyte, trachy basalt, rhyolite and ignimbrite). The altitude of this zone is greater than 2800 and reaches up to 3400 m a.s.l. on Chelelkaa and Entoto riges. The maximum altitude is 3500 m.a.s.l at Gura Guda mountain picks. This zone forms especially Entoto and Chilmo mountain ridges, the surface water divide between Blue Nile and Awash River basin.

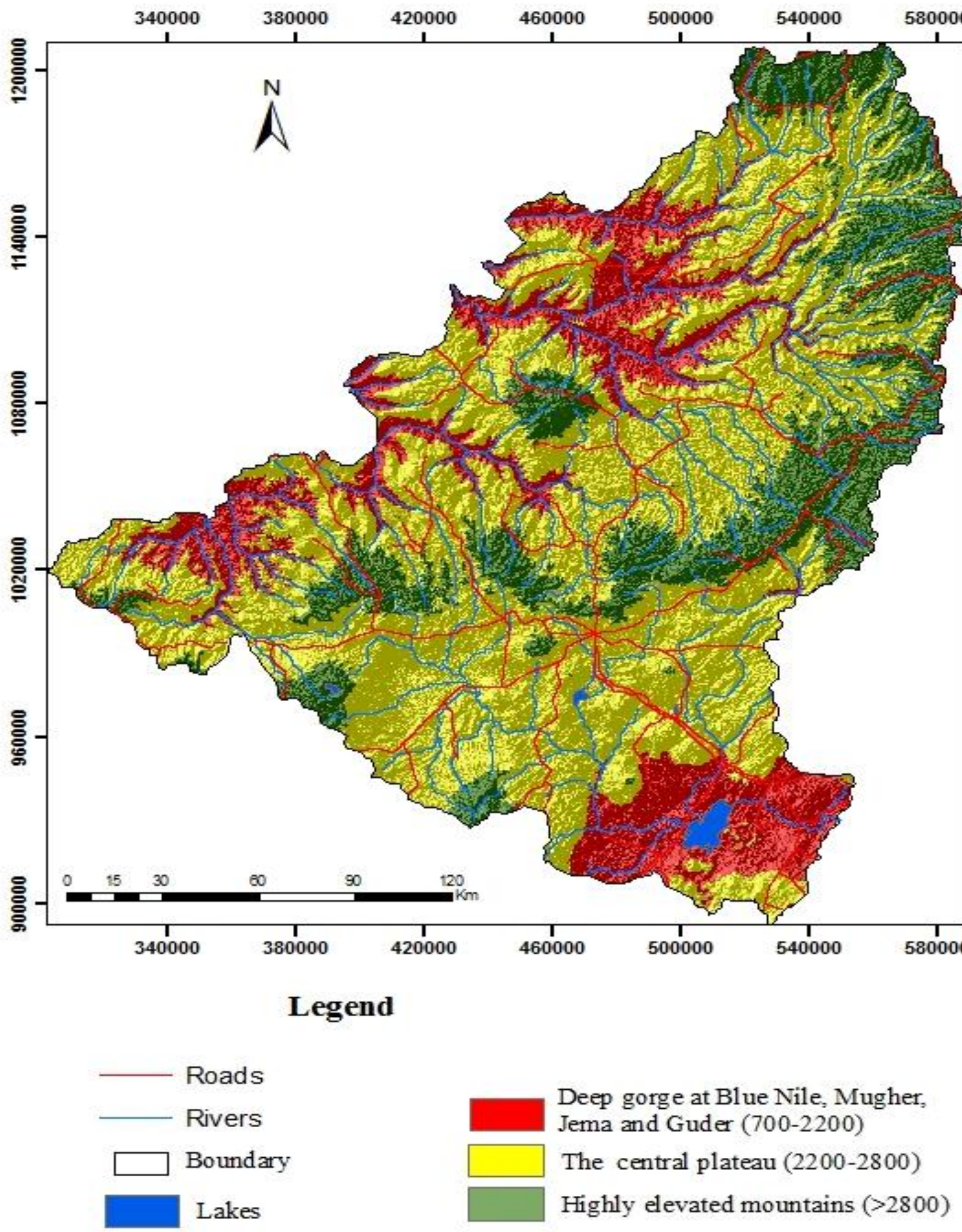

Figure 2: geomorphology map of the area

2.3. Climates and Hydrology

2.3.1. Climate

A climatic condition in Ethiopia is highly influenced by Altitude. The climatic regions of Ethiopia are summarized in the following table.

Climate regions		Mean annual temperature(0c)	Attitude of regions(m.a.s. l)	Present in study area
Kure	Alpine	10 and below	3300 and above	Present
Dega	Temperate	10-15	2300-3300	Present
Weniadega	Subtropical	15-20	1500-2300	Present
Qolla	Tropical	>30	800-1500	Present
Bereha	Desert	>40	Less than 800	Absent

Table 1: General Climatic Regions of Ethiopia (Daniel Gamachu, 1977).

The study area has all the climatic regions. Dominantly temperate climatic regions represent the area followed by subtropical. Tropical climatic region in the study area is found in the deep Gorges of Blue Nile, Guder, Mugger and Jema where the vegetation cover is sparse with some tropical acacia trees and grass. The highly elevated mountains and ridges are dominated by alpine climatic region. Accordingly the climate of study area of central Ethiopia is typically characterized by two distinct seasonal weather patterns. The main rainfall season in the study area is from June to September, but there is relatively small rainfall during the month of March and April and the dry season which covers the period from October to May.

For this study the monthly mean average meteorological measurements were collected from National Meteorological Agency. It includes the monthly mean total RF, the maximum and minimum Temperature for all stations.

Climate station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nob	Dec
Mean Rain fall												
AddisAbaba Bole(1999 2009	17	43	67	89	83	121	254	284	175	37	9	7
Fitche(1973-2005)	15.2	51.1	40.2	70.7	110	260.3	286.3	285	140	14.2	3.9	9.1
Filkilk(1972-2005)	40.8	31.3	51	61.4	56.7	150	350.7	309.6	130.9	40.8	9.6	3.1
Chancho (1998-2007)	39.8	26.3	46	56.4	50.7	154	355.7	319.6	127.7	45.8	10.6	5.1
D/Berhan	11.2	41.1	37.2	60.3	50.9	811.6	232.7	235.9	110	15	7.7	4.4
Mean temperature												
Addis Ababa Bole (1999-2009	8.3	17.3	18.25	18.5	18.5	17.15	16.4	16.2	16.2	16.2	15.15	15.2
Fitche(1973-2005)	13.5	14.5	15.15	15.5	15.53	15.15	13.5	13.15	13.5	12.525	12.51	13
Filkilk(1972-2005)	20.3	21.5	22.2	23.1	23.5	22.52	20.3	19.52	20.3	19	18.53	19.5
Fincha(1998-2007)	18.5	19.3	19.45	19.2	19.5	18	16.5	16.25	16.53	17	17.1	17.4
Kachise	16.2	17.4	17.5	16	16.51	15.5	13.5	13.53	14.51	14.4	15	15.45

Table 2: Mean climatic elements at key stations

2.3.2. Hydrology

Two major basins constitute the study area, Abay and Awash basin, of which Abay basin cover 80 % of the study area. Rivers like Zegawedem, Silm, Weserbi, Tiliku all drain North East to Jema River, which is one of the biggest tributary of Abay River. Small Rivers like, Aleletu and labu drain south to Muger River. Whereas Tilikulemen, Dilo, Sibilu and kolobo drain to the north towards Muger River, which later joins Abay River and Fichle, Foka and Yade flows directly to Abay River. The Kale, Chelelkai, Degaga and Dongage Rivers drain the western part of the area to Guder River which is tributary of Abay River.

Small Rivers like Berga, Holeta; Jemjem, Geforsa and Legedadi all drain south to join Awash River. The drainage pattern is dominantly dendritic with some streams having parallel pattern.

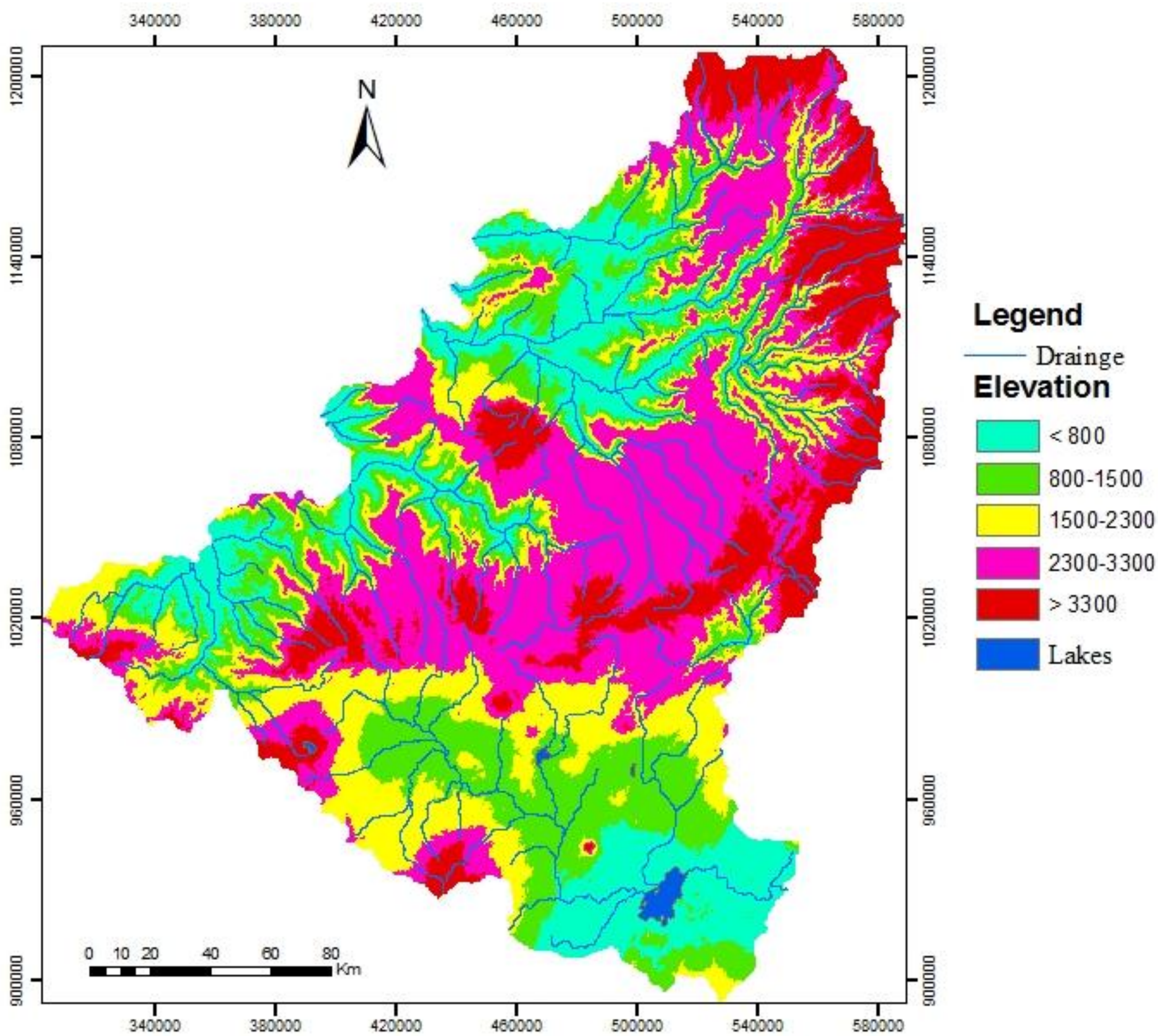

Figure 3: Drainage pattern of the area

The surface water hydrographs of almost all river gorges are of similar type with one peak discharge which is in the rainy season, where there is surplus of water. The runoff at Blue Nile, Awash and Mugher Rivers shows a high fluctuation. The runoff peak in Blue Nile River in one or two months (July or August) with a sharp ascending and descending curves (Figure 4)

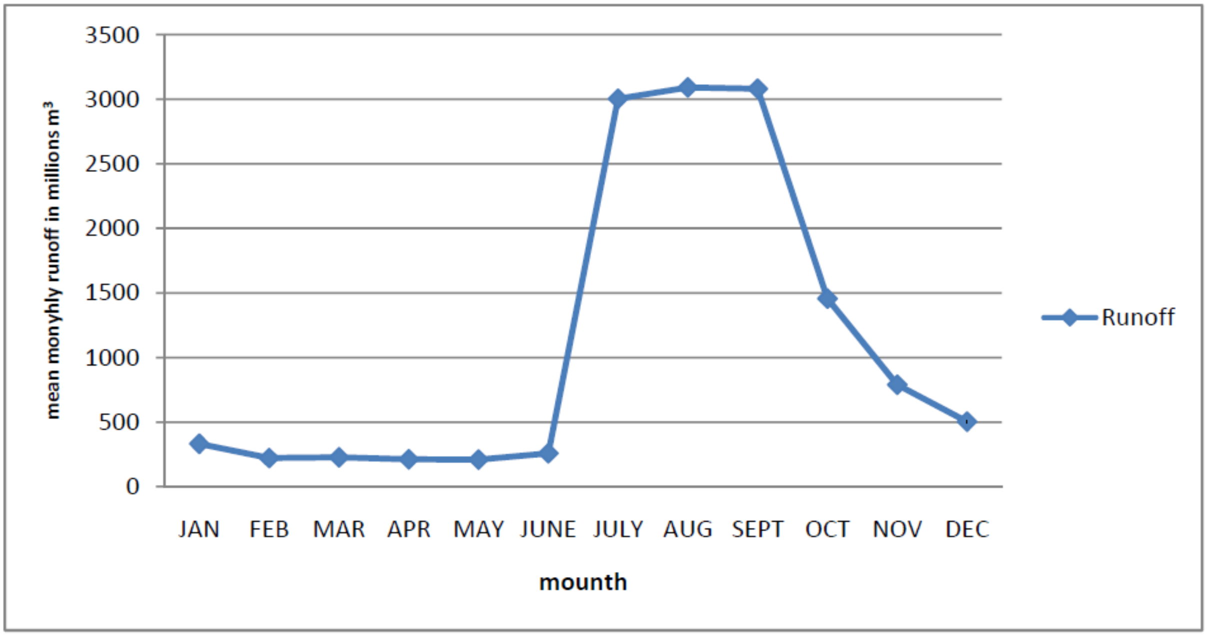

Figure 4: Mean monthly runoff Blue Nile near Kessi (1956-2004).

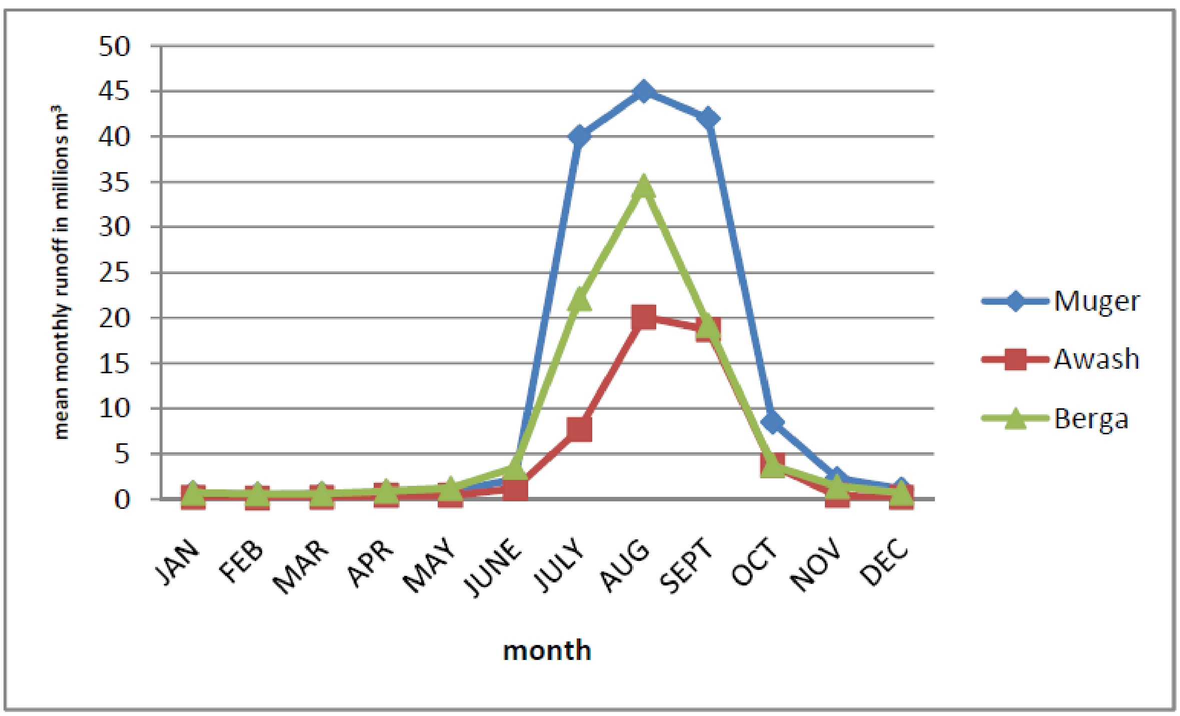

Figure 5: Mean monthly runoff Awash River near Ginchi, Mugher and Berga River (1993-2004).

The awash has a relatively lower river discharge and run off compared to Mugher and Berga rivers. This Seems due to data taken from Awsh is at its upstream course

CHAPTER 3

GEOLOGY

The major geological formations and tectonic features of the research area were adopted from the Report of ABGREP WWDSE (2008) and technical hydro geological report of Addis Ababa (2010). The geo-structural findings are summarized as shown below.

3.1 Regional Geology

Ethiopia can be divided in to four major physiographic regions, widely known as the western plateau, southeastern plateau, the Main Ethiopian Rift (MER) and the Afar Depression (AD). The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleocene period and Tertiary volcanic rocks with related sediments. The Precambrian basement exposures are found in the north (Tigray), in the west along the Sudan border (Gojam, Wollega, Illubabor, and Kefa), in the south (Sidamo and Bale) and in the east (Harerghe). The Precambrian rocks of Ethiopia are consisting of high-grade gneiss, metamorphosed volcano sedimentary rocks and associated ultramafic bodies and intrusive ranging from mafic to granitic composition.

The outline of the geological history of the Afro-Arabian countries – Ethiopia is believed to be in the group – was sketched by Pierre Gouin (1979) as follows:

At the end of the Precambrian era, the crystalline basement complex of the present Afro-Arabian swell had been above sea level for a long time and remained for another 370 million years until the end of Paleozoic era. Such a long period of erosion and denudation left the earth's surface almost completely penplaned.

Crustal motion started in the beginning of Mesozoic era. During the late Triassic and early Jurassic periods, a regional epi-orogenic sinking of the crust commenced causing a progressive transgression of the ocean from the south east that is, from the Indian Ocean coast of present day Somalia in the general direction of Lake Tana in the North West

Ethiopia.This downward crystal movement, associated with a sedimentation process, started a cycle of marine transgression and recession of Mesozoic sea. Within this large epi-continental sea, extensive layers of sediments were deposited to form hundreds of meters of rocks consisting of sandstone, shale, gypsum, limestone and other varieties of sedimentary rocks.

The crustal movement was reversed into the upward motion during the late Jurassic period, which brought the crust's surface up to sea level by marine regression in late Cretaceous period. The regional uplift resulted in wide spread crustal fracturing during the early Tertiary period. The crystalline and sedimentary rock layers were fissured mostly along or in the vicinity of the zone of maximum uplift, thus allowing outpouring of molten lava to cover the older rock layers.

Major fault displacement along the Rift Valley was initiated during middle Tertiary period. Subsidence of large crystal blocks along steeply inclined fault zones created grabben type depressions along the rift valley and at Lake Tana. Significant volcanic activity was associated with the formation of grabben and young volcanic rocks cover the old Tertiary volcanic in many depressions.

Present day tectonic activity occurs along the Rift Valley as evidenced by numerous earthquakes. More recent volcanism, associated with tectonic activity, had been concentrated within this structure along the edge of the adjoining plateau. The geological setting of the study area and its vicinity is representative of:

The Mesozoic era transgression and regression event depositions of sediments, like Adigrat sandstone, which rests uncomfortably on the crystalline basement rock, Abay beds composed of gypsum and shale units, Antalo Limestone which conformably overly the Abay beds, Amba Aradam sandstone; Tertiary and Quaternary volcanic units includes:

The Blue Nile basalts, Amba Aiba basalt, Alaji rhyolites, Tarmaber basalt and Rift volcanic.

3.2. Local Geology

Various lithologic units ranging from:

- Mesozoic sedimentary succession;
- Tertiary age groups of acidic and basic volcanic rocks;
- Quaternary age groups of acidic and basic volcanic rocks and lacustrine and alluvial deposits;

3.2.1. Mesozoic Sedimentary Rocks

According to the geological studies conducted so far, the Mesozoic sedimentary rock formations are further classified into four major classes as shown below from older to younger.These are Adigrat Sandstone (lower sand stone**),** Abay Beds, Antalo Limestone and Amba Aradam Sandstone. There are outcrops of the Mesozoic sediments in different parts of the study area which includes northern extreme part in Guder, Muger, Jema, Debrelibanos areas and in central zone in Ambo and Kela areas.

Adigrat Sandstone (lower sand stone)

The unit is exposed in north western, western, south western and central part of the area. It forms the cliff of Blue Nile, Guder and Muger river gorges below the volcanic or the Mesozoic lime stone. Succession mostly consists of sand stone with very thin intercalations of silt stone, mud stone and some pale soils. In most cases it develops primarily structures like lamination and cross bedding. The degree of weathering and fracturing is high in the toppart

Plate 1 : Thick lower sandstone exposure at Blue Nile gorge.

Abay Beds (gohatsion formation)

This formation is mainly exposed in the northern, central and north eastern part of the study area following the Blue Nile, Jema and Muger river valley forming steep slope cliff. Assiged (2007) mentioned that the nature of the contact with overlying limestone is sharp while with the underlying sand stone is gradational.

This formation composed mainly of gypsum and mud stone. There is an intercalation of lime stone at the base and shale towards the top (Assiged, 2007). It is slightly too moderately weathered and compact. The dominant types of rocks in this formation are mud stone, silt stone and shale. However, there are multiple beds of different intercalations. It exhibits high degree of weathering. The main structures are laminations, cross laminations, ripple marks and bedding.

Lime stone (Antalo Lime stone)

This unit is exposed in the Northern, Northeastern, and Central and western parts of the area. It is mainly out crop at the Blue Nile, Jema and Muger river valleys. Most of the time lime stone forms cliffs. However at some places it shows gently sloping ridge. The contact with the underlying mud stone formation is gradational which is marked by silt stone layers followed by calcareous silt stone, silty lime stone and gradually to lime stone. However, the contact with the underlying gypsum unit is sharp (Assiged, 20007). This formation is characterized by alternating beds of Marl. There are also shale intercalations which are frequent towards the bottom. At places, higher degree of weathering is observed, the precipitation of the secondary materials such as calcite and silica are observed along fractures and weak zones. Assiged (2007) mentioned that the petrography study indicated that this lime stone has a range of texture from mud stone to wack stone and pack stone.

AmbaAradam Sandstone (upper sand stone)

This unit is exposed in the northern eastern and central part of the map area, with in Jema, and Muger river valleys. In most out crops, this unit forms cliffs. The maximum thickness measured is about 328m. The thickness gently decline from east to west (Assiged, 2007). It has a sharp and unconformable contact with overlying basalt while with the underlying unit it has gradational contact. The sand stone unit exhibits wide range of compositional variation ranging from the top part yellow color, well stored, medium grained to red color, conglomerate cross bedded sand stone at the middle. The bottom part is dominated by jointed, fine grained white sand stone. This unit is slightly weathered at the top and highly weathered at the bottom. In general it exhibits coarsening up ward sequence.

Plate 2: Contact between Tertiary volcanic and upper sandstone at Zigawedem river gorge.

3.2.2. Tertiary volcanic Rocks

Tertiary volcanic rocks are divided into Paleogene and Neogene age sequences.

a) Paleogene Rocks

Blue Nile Basalt

This unit is thick basaltic flows and outcrops in the Abay gorge uncomfortably overlying the Mesozoic sediments. It is alkaline basalt with columnar joints of wider spacing forming vertical cliff. According to Kazmin (1979), the age of this unit is Paleocene-Oligocene (69-23 Ma).

AmbaAiba Basalt

This unit is exposed in northern and central parts of the map area in river valleys and canyons. It mainly forms steep slope cliffs and sometimes gentle slope. The contact with the underlying sand stone is characterized by abrupt nature. On the other hand there is a red limonite of 3 meter thickness at contact with the overlying pyroclastic (Assiged, 2006)

In this unit there is vertical compositional variation. The top of part is made up of columnar Jointed, cliff forming, and relatively fresh aphanitic basalt. In general this basalt is characterized by well-developed columnar Joints with hexagonal faces, and cliff forming. The maximum thickness measured is about 350 meter around shenhea-cheka locality (Assiged, 2007)

Ashangi Basalt

The Asangi basalt is exposed in the northern part of the area representing the oldest fis sural flood basalt next to the Blue Nile basalt volcanism in the northwestern plateau. It is strongly weathered, crushed and predominantly consisting of alkaline basalts with inter bedded pyroclastic and rare rhyolites and is commonly injected by dolerite sills and dykes. According to Kazmin (1979) the age of this unit is Eocene-Oligocene (55-24 Ma).

Alaji Rhyolite

This unit is exposed in the northern central part of the study area area. It is consisting of rhyolites, ignimbrites and subordinate trachytes. Obsidian bearing rhyolites are common in the study area. The obsidian composition at Segnogebeya area gives rise to the dark gray color. The age of this rock unit is Miocene, 33-15Ma (Kazmin, 1979).

B) Neogene Rocks

Addis Ababa Basalt

This unit is mapped by Kebede and Tadess (1990) at 1:25,000 scales and the basalts area classified in to different units based on their texture and compositions. For the purpose of the present mapping scale they are mapped as one unit. This unit is fine to coarse grained basalt composed of olivine and plagioclase phenocrysts. In most part of the outcropped area it is relatively thin (20m) lava flow overlying the ignimbrite. The age of the Addis Ababa basalt is 7.5-4.5 Ma (Chernet et al. 1998 and Morton et al. 1979).

Addis Ababa Ignimbrite

This Ignimbrite is outcropped in most part of the plane area around Addis Ababa and the Becho plane. It is composed of welded tuff (ignimbrite) and non-welded pyroclastics fall (Ash and tuff). It is grayish to white color and when welded it exhibits fiamme textures, elongated rock fragments of various color. Around the Legadadi plane and melka kunture area the thickness of this unit reaches up to 200m (exploration drill data). In the Becho plane area it is covered by thin 5-7m thick residual soil developed from the same rock. The age of this unit is 5.11-3.26 Ma (Morton et al. 1979).

Nazeret Unit

This unit is mainly exposed in the southeastern part of the area mapped area and forms rift floor. It consists of a sequence of welded per alkaline rhyolitic ignimbrite. The unit comprises numerous rhyolitic and trachytic domes. Rock fragments and crystals, generally broken, are abundant; alkali feldspars, quartz and amphiboles are the most common crystals. The age of this unit is 5.4 to 3.11 Ma (Morton et al. 1979).

Akaki Basalt

This unit is outcropped at Daleti, Abasamuel Dam, Akaki and Dukem area. It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows. Both the basalt and scoria is quarried for construction around Akaki and Dukem area. The thickness of this unit around Akaki is 202m (exploration drilling data). The age of the Akaki basalt is 2.9-2.0 Ma (Chernet et al. 1998 and Morton et al, 1979).

Olivine- plagioclasephyric basalt (TarmaberMegzezebasalt)

This basalt is exposed in southern, central, and northern part of the map area. It mainly forms gentle slope plateau lands resulted from fissural eruption. In some localities extensive ridges and mountains (such as Cheleka Mountains and chilmo) are also observed. It is observed to overlying uncomfortably over upper sand stone and conformably on the lower ignimbrite. It exhibits stratified layers with varies compositions and structures. The layers are fine to very coarse grained, aphanitic to porphyritic and sometimes very coarse grained porphyritic and vesicular basalt, intense fracturing, columnar jointing and spheroid weathering are very common features.

C) Central Volcanoes Unit

Entoto Rhyolite and trachyte

The Entoto mixed rocks are found in the southern eastern part of map area. This unit constitutes rhyolite, trachyte, ignimbrite, pyroclastic rocks and sediments. All the rocks are highly weathered and jointed with few layers of agglomerate at some places. There is a red backed soil development at the contact with the under lying basalt. This lithological unit is highly affected by joints trending E-W and N 29^{o}. It forms high mountain chain called Entoto trending E-W (Assiged, 2007)

Aphanitic to medium grained vesicular Trachyte (Wechecha-Furi-yere Trachyte and Trachy basalt).

This formation is exposed in south western and south eastern part of the map area. It is found over lying tertiary basalt marked by a thick paleosoil and it is also occurred by forming big mountains such as Furi, wechecha and yerer. It has aphanitic to medium grained texture with vesicular varieties mostly at it is lower part. Mostly the trachyte and the trachy basalt are found alternatively layered with the trachyte being dominant. At its lower part it shows columnar jointing and is affected by two sets of joints (Assiged, 2007).

Tulu Rie Basalt

This unit is outcropped in the southeastern part of the mapped area and forms NE trending escarpments. It is lava flow coarse grained basalt with olivine and plagioclase phenocrysts with rare clinopyroxene. The age of this rock is 2.7 to 1.44 Ma.

Chefa Donsa Unit

The ChefaDonsa volcanic rocks units are outcropped at the east, north east, south and west extreme parts of Debrezeyt. They are consisting of fall deposits (ash, tuff and pumice) and poorly welded ignimbrites of rhyolitic composition. At places in the Dukem and Mojo river valleys they are observed under the lacustrine deposit. The age of this unit ranges 2.24 to 1.71 Ma (Morton et al. 1979). This unit is covered by patches of Quaternary olivine basalt.

3.2.3. Quaternary volcanic rock and sediments

3.2.3.1. Quaternary Volcanic rocks

This unit is exposed in south eastern and north eastern part of map area. The southern part is dominantly olivine basalt. In most case out crops in boulder form, vesicles filled by secondary materials area observed. It forms mainly ridges with maximum thickness measured about 50 meters (Assiged, 2007).

The northern part is dominantly trachyte and trachy basalt having aphanitic and porphyritic texture. It is exposed forming topographically high domes and stains at Gara, Guda, Degeem and yabeno. In this unit, sheeted and layered flow structure is observed at the top of the dome and it’s oriented in E-W direction. With shallow dip angle ($22^o/35^0$) (Assiged, 2006).

Weliso Ambo Basalts

This unit is outcropped at the western and northern extreme parts of the mapped area. It is a lava flow composed of porphyritic basalt with large crystals of plagioclase, olivine and pyroxene, basalt breccia’s and minor tuff. In the area of Weliso it is scoraceous basalt.

Ziquala Trachyte

Ziquala trachyte is isolated, well preserved cone standing about 1300m from the surrounding plane area, located in the southern part of the study area. It has a summit caldera 1.5 km wide and partially filled by water. The Ziquala trachyte is coarse grained and petro graphically composed of an orthoclase, sanadine, minor clinopyroxene, phenocrysts and glassy alkali feldspar groundmass. The age of the Ziquala trachyte is 1.28-0.85 Ma (Morton et al., 1979).

Bede Gebaba Volcano Units

This unit is a circular volcanic complex outcropped north of the Ziquala Mountain with maximum elevation of 400m above the surrounding plane. Its morphology dominated by the occurrence of several coalescent caldera structures. Spatter cones and basaltic lava flows belonging to younger Bishoftu Volcanics are present in the central part of the volcanic complex. Pumice and lavas show a composition ranging from rhyolites to minor trachyte. According to Gasperon et al (1993), the lava contains microphenocrysts and rare phenocrysts and quartz as well as scattered plagioclase and clinopyroxene set in glassy to microcrystalline groundmass.

Bishoftu Volcanic Unit

This unit forms a NNE trending belt outcropping mainly in the central flat areas of Debrezeyt. In the Bishoftu Volcanic spatter and cinder cones with associated tabular basaltic lavas flows and phreatomagmatic deposits are distinguished. The basalt is vesicular and coarse grained with olivine phenocrysts. The phreatomagmatic deposits are mainly consisting of surges and highly fragmented deposits associated with maars and tuff ring.

3. 2.3.2. Quaternary Lacustrine and Alluvial Deposits

Lacustrine Deposits

The lacustrine deposit is particularly distinguished in the Adaa plain of the Lakes region. They are fine grained deposits, thinly stratified and often contained volcanic matrix; whose thickness ranges from 5 to 8m. More thickness is reported in the groundwater well drilling reports. In these successions volcanic layers are frequent and become predominant and coarse grained near by the maars.

Alluvial Cover

The alluvial cover mainly out cropped above the Tertiary Volcanics on the plateaus and Becho Plain and the alluvial unit is deposited in northern, north eastern and western parts of the study area along Jema, and Muger river valleys. Its texture varies from sand to silt size.

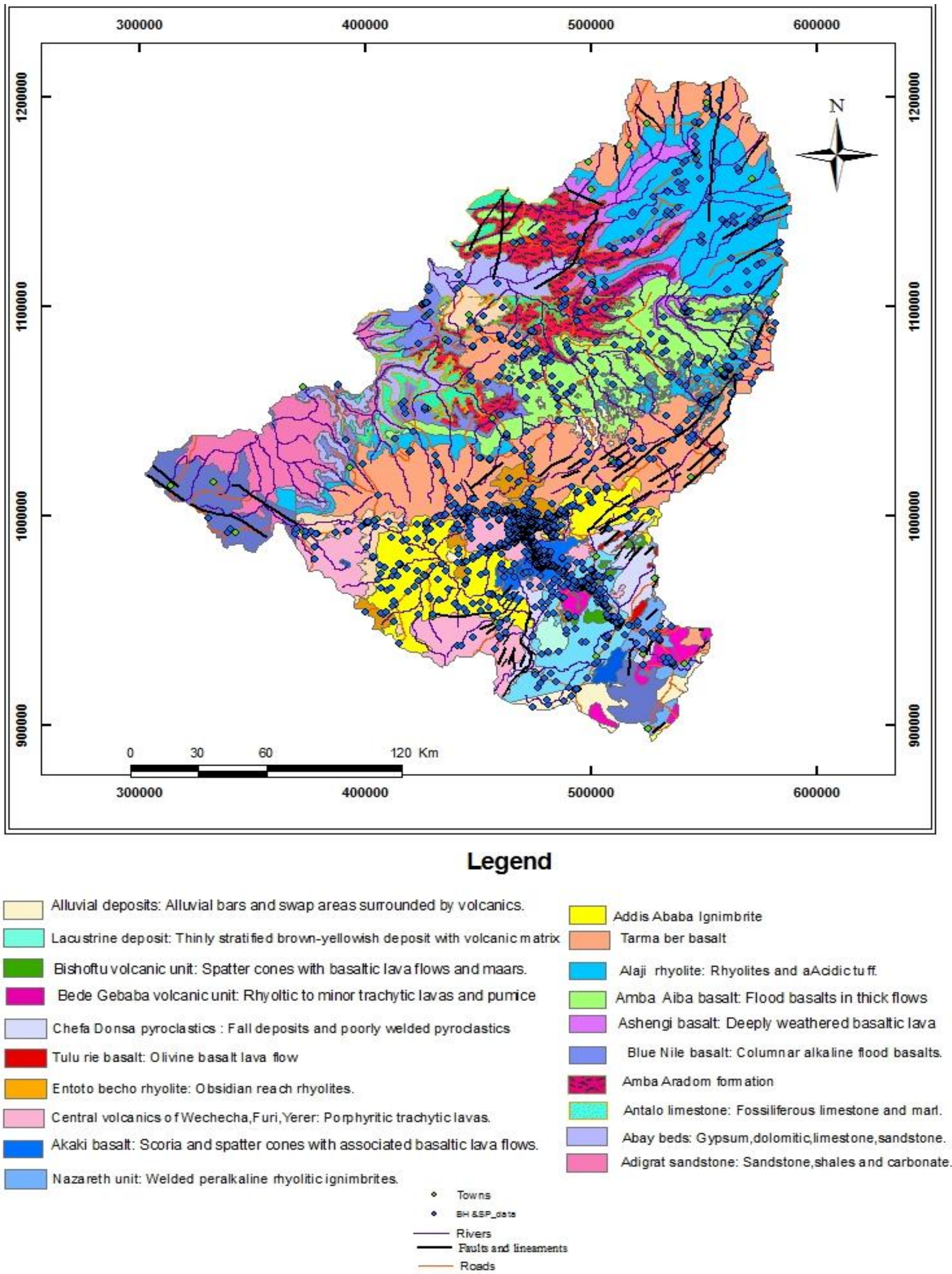

Figure 6: Geological map of the area Combined from Ethiopian geology and ABGREP Report WWDSE (2008)

CHAPTER 4

HYDROGEOLOGY

Hydrogeology can be defined as the study of ground water with particular emphasis given to its chemistry, mode of circulation and relation to geology environment (Davis & DeWiest, 1996). The occurrence of ground water is mainly influenced by lithology, geological structures, and geomorphology and climate conditions. Lithology, geological structures and geomorphologic setting of the area strongly influence the quantity, quality and movement of groundwater. Since the climate condition throughout the area seems uniform, it has the same effect through the entire area. The geology of the area provides usable ground water and good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers. Fractures, joints and weathering surfaces of different lithological units play a vital role in facilitating the infiltration amount and rate and also ground water flow.

The majority of productive aquifers are characterized by their high degree of weathering and intense fracturing. Fractured volcanic rocks and karst limestone are the major potential rock units for storage and movement of ground water. In addition, the intergranular pour spaces of sandstone and alluvium also have significant role in occurrence of ground water. The main recharge for ground water of the area is precipitation, although surface water and Perennial River and streams are also act as local recharges.

4.1 Hydro Geological Classification /Characterization

The classifications of different lithological units are made based on hydro geological characterization of various rock types. This classification is also based on existing data. This study used the qualitative and quantitative parameter to classify the hydro geological unites in to aquifer/aquitards system. Since the quantitative parameters such as permeability, transmissivity, aquifer thickness and yield are not sufficient to make classifications, it is obligatory to assess the qualitative parameters in order to achieve on complete classification. The qualitative classification is based on the ground water point data and pump test data, the major hydro geological units are characterization into pours, fissured and/or karst permeability and impermeability rocks.

4.1.1 Qualitative Parameters

Hydro geological units with porous permeability

The ground water is available in the porous of unconsolidated sediments. The quaternary alluvium and Mesozoic sand stone represent dominantly the porous materials. The ground water availability and flow is mostly dependent on grain size, sorting, cementing material and thickness of deposition.

Hydro geological units with fissured permeability

Most of the tertiary volcanic and Mesozoic limestone has fissured characteristics of permeability. The weathered and fractured surfaces play a significant role in ground water accumulation and flow. Majority of the tertiary volcanic are highly jointed and fractured but they are filled by secondary filling materials, which are a barrier for ground water flow.

The lime stone of the study area has dominant character of karst permeability. Fractures and joints of limestone though dissolution of minerals by water lead to the karst formation. The degree of interconnection and the type of karstifcation tends to influence occurrence and flow of ground water.

Hydro geological units with impermeable nature

The fresh, massive and very limited fractures surfaces give the very low permeability and limited ground water occurrence characteristics. Mesozoic sediments of Mugger mudstone, siltstone and Gohatsion formation have such characteristics.

4.1.2. Quantitative Parameters

The quantitative data division of lithological units is based on the hydrogeological characteristics of various rock types, such as permeability, aquifer thickness and yield obtained from different organizations.

4.2. Aquifer classification of the area

Based on the above qualitative and quantitative hydrological criteria and geomorphologic setting the different lithological units are classified in the following aquifer and aquiclud system.

4.2.1. Extensive and highly productive porous aquifer

This hydrological unit is exposed in the Blue Nile and Guder River gorges localized western the study area. E.g Mesozoic sand stone, the lower sand stone occurs by forming cliffs on the escarpment of Blue Nile and Guder River as well as their tributaries. While the Paleozoic sand stone forms gently sloping and undulating terrain inside the gorges. The hydraulic property of this aquifer is mainly characterized by the thickness of variation of the formation, grain assortment and size, cementing material, the availability of primary pour spaces, extent and degree of weathering and also the presence of well-developed fractures. Mesozoic sand stone possess both primary and secondary permeability for ground water movement and occurrence. The main water bearing horizon is constituted by interstitial spaces. In addition, the ground water occurrence and movement is governed by secondary fractures and joints which enhanced the porosity and permeability. However, in some places precipitates from percolating water readily close such pour spaces and reduces the permeability of the aquifers. In the study area the bedding plains of Mesozoic sand stone are dipping towards flow direction of rivers and gorges, where many springs follow such pattern. The presence of conglomeratic layers in the lower sand stone indicates as positive impact on the hydraulic property of the aquifer. According to GSE this formation has ranges of aquifer parameters of: T=100-500 m^2/d, Q=5-25l/s.

4.2.2. Extensive and Highly Productive Fissured and Karast Aquifer

This hydro geological unit is localized in northwestern and western parts of the map area at Blue Nile, Guder, and Mugger River valleys (E.g. Antalo lime stone). The Antalo limestone possess both primary and secondary porosities but the productivity of this unites is highly dependent on the secondary porosity (fractures). Fractures, joints and karsts are the common features. That plays a significant role in ground water occurrence and movement. The surface of Antalo limestone is the study area is highly fractured and jointed and they are sources of several springs.

Circulation of water through these fractures and joints enlarges the openings increase permeability and tends to create karast features. Thus the development of karst is the result of solution and leaching of lime stone through interaction by acidic rain water. These cavities found below the water table yield. Permanent springs with good discharge. The Antalo lime stone forms deep aquifers in the gorges of Jema and Muger, through karst goes to deeper. However, there are springs emerging in hill side of Jema and Muger gorges through fractures and at the contact with shale or underling gypsum (T= 50-100 m^2/d Q=2-5 l/s).

4.2.3. Extensive and Highly Productive Fissured Aquifer

- (Olivine –plagioclase phyric basalt (Tarmaber basalt)
- Quaternary basalts of central Ethiopia

This aquifer is exposed in central, northern and southern plateau and covers most part of the study area. It forms plateau and undulating terrain with elevated ridges, central volcanoes. This formation has T=100-500 m^2/d, Q=5-25 l/s.

Olivine_ plagioclase physical basalt (Tarmabermegzeze basalt)

This unit possesses very good secondary porosity and permeability. The scoraceous lava flow nature of unit is highly favorable for ground water storage and movement. The permeability is highly dependent on the degree and depth of fracturing and occurrence of joints development on Tarmaber basalt gives to the good hydraulic property of the aquifer. Most fractures due to faulting are responsible for emerging of many springs. In some places the development of thick soil act as good recharging media to his aquifer by hold the precipitating water which will percolate later through fractures to the aquifer. Columnar joints developed on Tarmaber basalt act as ground water discharge features at topographic breaks when enhanced by weathering. The vesicular and scoraceous nature of this basalt gives to its high water bearing characteristics. The ground water manifestation of this aquifer occurs as spring, borehole, and dug well. The springs from this aquifer are almost perennial throughout a year. Most of these springs normally emerge through fractures and at the contact with underlying impermeable layers having a relatively big discharge. There are also a number of deep and shallow wells that penetrates Tarmber Basalt up to 200 meters. In addition, in highly weathered shallow depth there are hand dug wells with relatively good discharge.

Plate 3: Fracture developed on Tarmaber basalt (left) and spring on it (right)

Quaternary basalts of central plateau of Ethiopia

These units are localized to southern, northern and western part of the map area. They have good water bearing characteristics with a variable mode of occurrence. Mostly their vesicular nature and boulder forming characteristics makes them a good aquifer with good ground water occurrence and movement. However, the vesicles are filled by secondary materials; weathering process gives them a relatively good permeability. In northwestern part of map are this unit forms domes and hills and have poor ground water availability instead they act as good recharge area to the underlying aquifer. In general they are classified as medium to high productive aquifers. Drilling in this aquifer is more than 250 meters in Addis Ababa city and to its vicinity may have a probability of getting hot water with high electric conductivity. Boreholes around Ayat, Hilton and Felwuha are good representatives for such phenomena. This aquifer is recharged by direct perception and small rivers and its recharge the under lying ignimbrite.

4.2.4. Extensive and Moderately Productive Porous Aquifer

This hydro geological unit exposed by scattering in the northern, eastern, central, western and southern part of the area. The formation has (T=50-100 m^2/d, Q=2-5 l/s) (GSE report). It comprises:

- Quaternary deposit (alluvium and Elluvium)
- Upper sand stone

Quaternary deposits

The Quaternary alluvium is exposed along the river valleys of Jema, and muger and also in old river depressions, at the base of mountains. This unit is one of the most important sources of shallow ground water. It has relatively good permeability and productivity, since the texture ranges from sand to coarse gravel with loose and undifferentiated grains. The alluvial sediments are mostly recharged by infiltration from perennial rivers and streams. In some places the grains of the sediments show poor sorting resulting in a very low productivity. The alluvial fans at the bottom of mountains show good porosity and permeability and are extracted by shallow dug wells for community water supply. The permeability porosity and their thickness of the alluvial fans decrease away from the mountain. There are a number of dug wells and few shallow wells drilled these units for the purpose of community water supply. There are also some perennial springs emerging from the alluvium depositions at salayish locality inside Jema River gorge having discharge 5 l/s. The elluival soils of the plateau are represented by silty to clay soil. There are numerous dug wells that gain water from these units but during dry seasons the water level of dug wells will decrease and become dry, due to the evaporation of shallow ground water.

Amba Aradam Sand stone (Upper sand stone)

This hydro geological unit is situated in deep gorge of Jema, and Muger rivers. It has both primary and secondary porosities. But the main water bearing part is constituted by interstitial spaces. It is holding capacity is determined by the degree of consolidation and assortment, grain size and cementation. This joint does not have important role in the occurrence and movement of ground water due to the presence of infilling secondary materials and poor interconnection. The recharge from the overlying tertiary volcanic rocks percolated through the pours of the interstices and emerges as spring at the contact with the underlying Muger mud stone. Most of the ground water points are springs that come out at the contact with impermeable mud stone. There were neither shallow nor deep wells. This reason could be due to the rugged topographic and cliff forming nature of the unit.

4.2.5. Extensive and Moderately Productive Fissured Aquifer

This unit is exposed in south eastern, north eastern and western part of the map. It forms plateau and localized ridges in the south eastern and cliffs in the escarpment of gorges. These formation has (T=50-100 m^2/d Q=2-5 l/s).

- Aiba Abia basalt
- Lower ignimbrite
- Aphanitic to medium grained vesicular trachyte and trachy basalt

AbiaAbiaBasalt

The intensive fracturing and highly weathered surface are major features for ground water bearing character of this aquifer. The vertical joints with hexagonal faces are enhanced by irregular sets of fractures which facilitate the ground water flow. Potential yield of this aquifer varies throughout its out crop. This is due to the variation in the frequency, intensity and distribution of the fracturing system. In addition, mode of occurrence and topographic setting also affects the yield of many springs within this effects the yield of many springs within this aquifer.

However, there are primary porosities such as vesicles and cracking joints the permeability would be very low and have very little role in ground occurrence and movement. This is due to the poor interconnection of vesicles which will reduce the ground water movement and occurrence. So the primary porosity of abia basalt has very little input in the productivity of the aquifer. However, in some places the cracking joints are enhanced by weathering and fractures with farther increased the vertical permeability. Such phenomena lead to the availability of few springs at river canyons and gorges. Spring at Wedenbi Ensarro locality with dry season discharge of 2.5 l/s emerged from columnar cracking joints and weathered surface is a good example. The potential water bearing horizon of this unit is concentrated to the fractured and weathered surfaces. Springs at locality of Dahana, Jegolo Gendeberet and CisoAbabuGuduru are resulted from such phenomena. Most of the springs emerge through these fractures at the topographic breaks.

Aphanitic to medumgraind vesicular trachyte and trachy basalt (wechecha-yere-foru trachyte and tracky basalt) /lower ignimbrite

This unit is localized to wechecha and yerer are forming ridges and domes. The hydraulic conductivity, permeability and storativity of this unit are very low, since there are no well-developed fractures and joints that are use full for ground water occurrence. But, there are springs at Wechech Mountain with mean dry season discharge of 2.7 l /s. The ignimbrite layer, most of the time covers the plateau area and acts as a confine layers for the underlying basalt aquifer. Many deep wells penetrate this unit shows massive and poorly fractured lithology. But, very near to the ridges and domes, the thickness of the formation increases and it may be difficult to penetrate in to deeper aquifers. The qualitative and quantitative evaluation shows moderate permeability and water bearing capacity.

4.2.6. Low Productive Aquifer

This aquifer comprises:

- Inter layers of ignimbrite, welded tuff & Ash
- Entoto rhyolite &trachyte
- Aphanitic to porphyritic trachyte

These hydro geological units are localized to southern part of the study area at Entoto locality, north of Addis Ababa. These formation have T=1-10 m^2/d and Q=0.05 l/s. It forms steep slope ridges and a relatively localized flat terrain .This unit is highly weathered at the top part while massive and fresh at the lower part. But occasionally vertically developed fractures are seen in rhyolite and trachyte inters beds. This fracture in combination with weathering surface tends to give the water bearing characteristics of the aquifer. In some places the occurrence of tuff interconnection holds water from precipitation and leads to the appearance of spring with low yield through the pore space. The discharges of springs from this aquifer at localities of Entoto Mariam, Gebrechefie and Yenguswuha range from 0.5 to 0.05 l/s.

There are also a number of springs with relatively small discharge coming out through fractures and weathered part of rhyolite and trachyte. Almost all springs are located on hill side and emerged as topographic break. Most of the precipitating water leaves the area as run off with very little infiltration due to the sleep slope topographic nature of the Entoto ridge. As result, there is little ground water stored except the appearance of small yielding springs.

This low productivity aquifer serves as a recharge zone to the Addis Ababa city aquifers (quaternary and tertiary basalt and lower Ignimbrite). But at the foot of the ridge there is a possibility of ground water occurrence along the manifestation of NS fault line. The borehole drilled along these faults have an artesian nature with very high yield of 100 l/s (reported by WWDSE; 2008, Ada Becho ground water potential evaluation project). Since the well has multi layered aquifer, the probable main aquifer would be the underling basalt. But, the tendency of drilling anther bore hole could be risky due to the topographic setting and shallow circulation of ground water. In general these units act as both recharge and discharge area. However it's recharging characteristics to the surrounding aquifer is more significant and act as a surface water divide between Blue Bile and Awash basins.

4.2.7. Aquiqulid

This unite is exposed in the western, north western, central and south eastern part of the study area. The hydraulic properties, permeability and transmissivity of this unit are very poor, since there are no well-developed fractures and dissolution cavities that are useful for ground water occurrence. But, it acts as in permeable layer and responsibility for occurrence of the springs at the contact with overlying limestone in Muger gorge and its tributaries. It comprised of Abay beds, Chefe Donsa Pyroclastics and Nazareth unit (Welded ignimbrites).

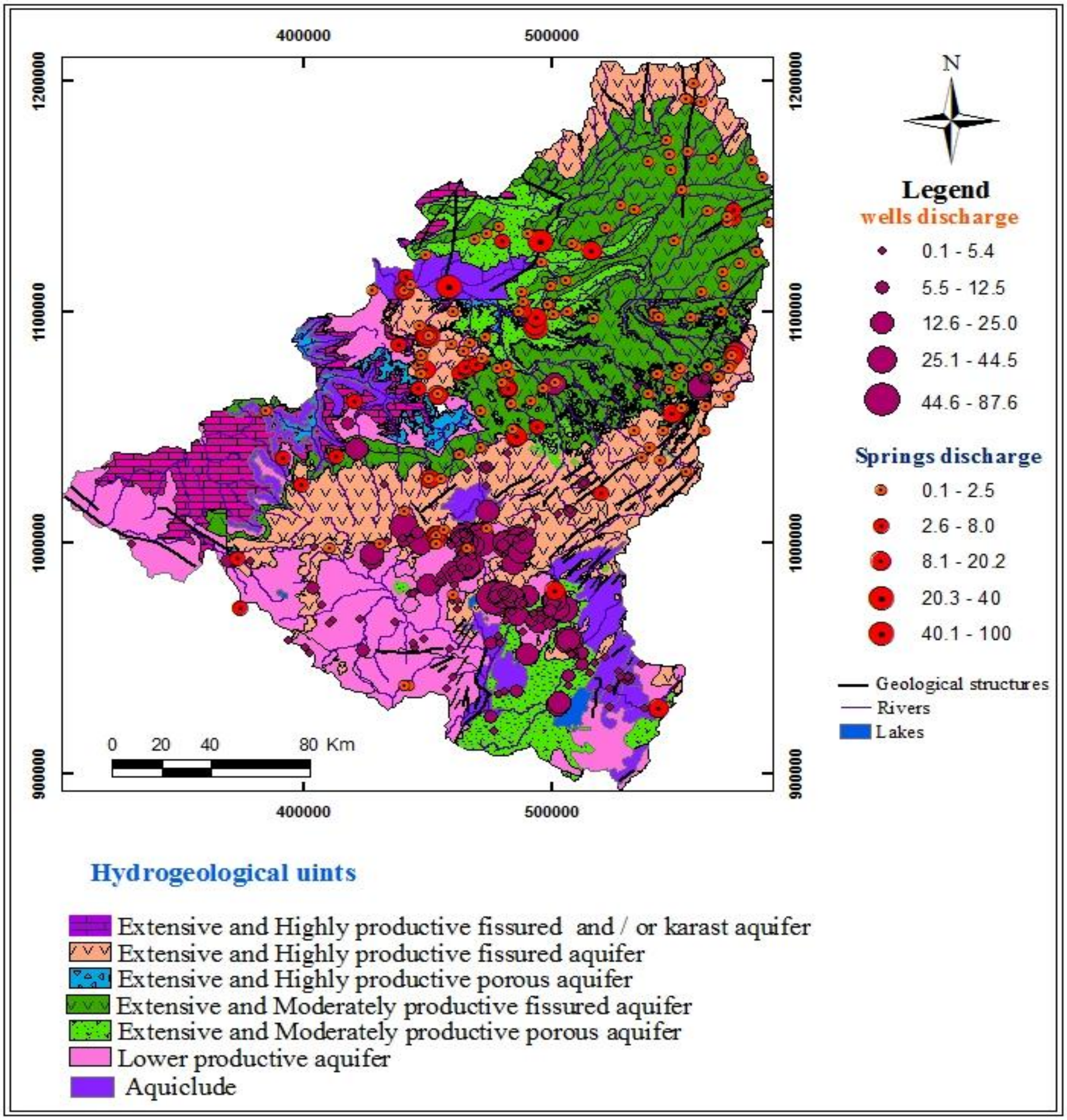

Figure 7: Hydrogeological map of the area, combined from Ethiopian hydrogeology and ABGREP Report WWDSE (2008).

4.3. Determination of Aquifer Parameters from Pumping Test Data

As cited in Tenalem (1998), the classification of the Lithostratigraphic unit into hydro stratigraphic units requires information on the hydraulic characteristics of rocks. The hydraulic characteristics of the different volcanic sequence of the Ethiopia poorly understood. Data on specific capacity and transmissivity values have been obtained from existing boreholes.

Transmissivity of an aquifer measures how much water can be transmitted horizontally. It is the product of the hydraulic conductivity times and the thickness of the aquifer (Driscoll, 1986).Transmissivity (T) is a hydraulic parameter of an aquifer that is known employed in most groundwater flow equations to understand the flow dynamics and is generally estimated from pumping tests (Freeze & Cherry, 1979). Spatially variable aquifer parameters are often available, yet appropriate data that covers wide area uniformly are lacking due to the fact that the cost of performing a large number of aquifer tests is relatively expensive and time consuming. Thus, simple and inexpensive parameter estimation methods that may cover extensive areas are often preferred.

In fact such approaches require quantification of one or more easily measurable aquifer parameters. One such aquifer parameter that is easy to measure is the specific capacity (Sc) of a well, which is the ratio of pumping rate (Q) to drawdown (s) in the well. The fact that Sc is correlated with hydraulic-flow properties (Theis, 1963) can simplify parameter estimation mainly because Sc values are more abundant in groundwater databases than values of T or hydraulic conductivity (K), and offer another approach to estimate hydraulic parameters of aquifers. Most of the formation shows a wide variation in transmissivity values. These variations indicate complex geological and hydro geological situation of the area. The volcanic sequence of the area exhibits a similar wide range of variation in transmissivity. Because of variations in the degree of fracturing a marked heterogeneity in aquifer characteristics exists both laterally and with depth in the study area.

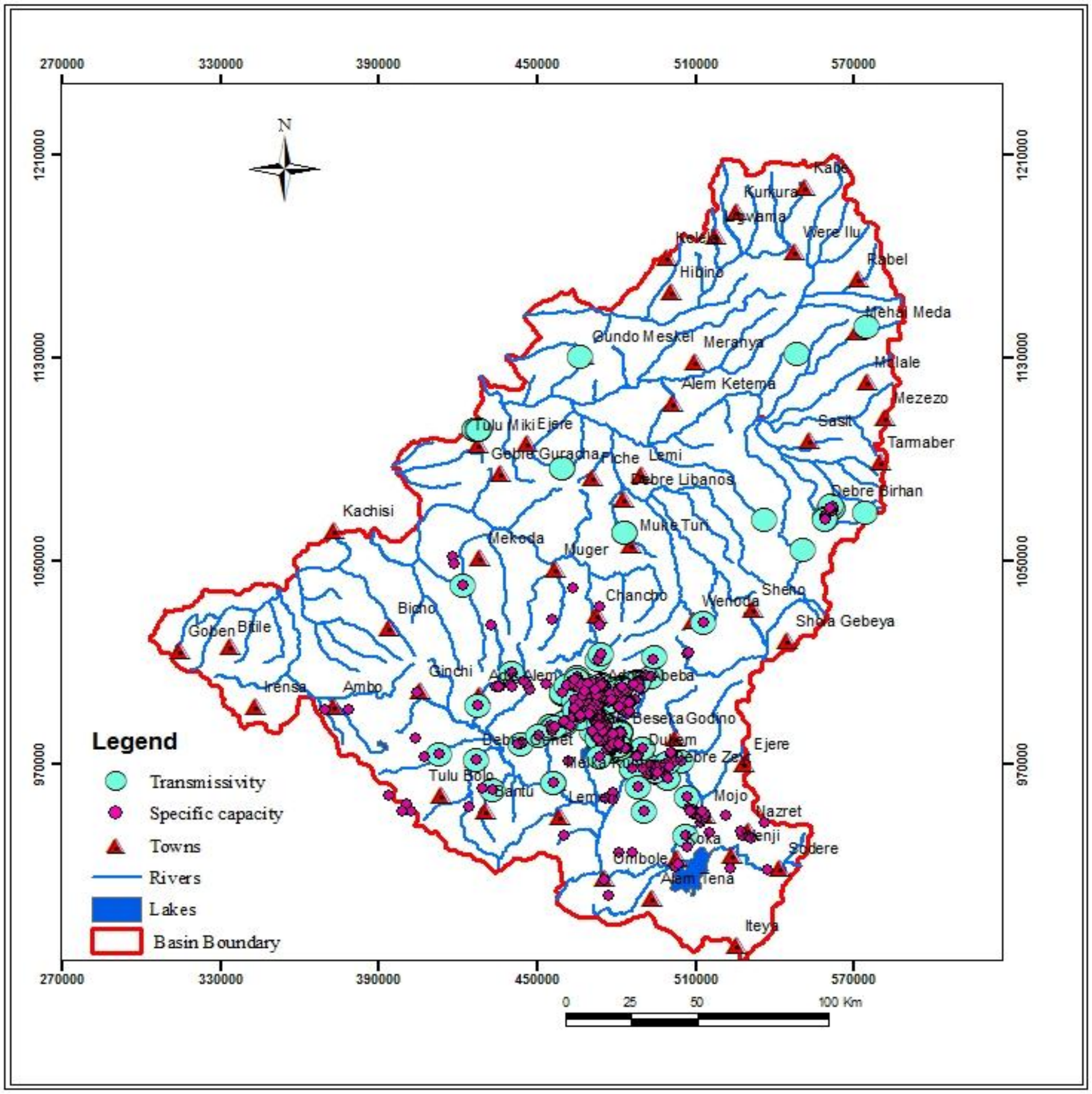

Figure 8: *Transmissivity and specific capacity data points*

4.4. Ground Water Potential (Aquifer potential)

Since the study area is situated in the central plateau and highlands of Ethiopia, there is a relatively good rain fall throughout a year and the people are largely dependent on a rain fed agricultural syste. However, in areas where there is no sufficient rain fall and during dry season, ground water is a good alternative resource of water for agriculture. In the study area the utilization of ground water for irrigation purpose is not common. But, there is small scale irrigation using several intermittent and perennial rivers that drain ground water.

It is also hard to say the development of ground water for community water supply is sufficient. There is a shortage in community water supply even in towns. There fore it is better the ground water potential in terms of hand dug wells, drilled deep wells and spring development.

Potential of aquifer in Sedimentary Rocks should be done by spring development. Since this aquifers and sand stone and lime stone are out cropped in deep gorges of rivers and occur as ridges. Potential of aquifers in volcanic Rocks are mainly based on spring development drilling of shallow and deep well. Spring development is best in the areas where there is appearance of spring due to topographic break. Development of Aquifers in Alluvial/ Eluvium sediment is mainly based on hand dug wells and shallow wells. The alluvium and windiest of deep gorges and the alluvium deposition of the plateau area are drained by direct precipitation, recharge from small intermittent and perennial streams. The ground water circulation in this aquifer is shallow. So digging of hand dug wells is the best way for small community water supply.

4.5. Hydrogeological Structures

Structural features, such as fractures, joints and faults, the geometrical properties of the geologic system produced by deformation or crystallization (Freeze, 1979), may provide secondary hydrological properties to the various rock bodies, notably increased water transmissivity .

The hydrological structure describes the configuration of aquifers within the geological environment. It determines the ground water circulation from the recharge area, along percolation and circulation pathways (ground water reservoir) to the drainage area. The North part of the area is structurally simple and occasionally tectonized whereas the southern part of the counry is highly tectonized and is complex in structure since its vicinity to the main Ethiopia Rift margin. The main structures encountered in the area are Faults Joints, Lineaments and dikes.

Faults

There are few normal faults in the area. They are mainly found in north eastern, north western and southern part of the area. The dominant faults are those associated with the MER trending NE-SW faults. They are also N-S and S-W faults. They cut Mesozoic, sedimentary and tertiary Basalts. The NE-SW and N-S faults are act as good ground water conduits in the north western and southern part the study area.

Lineament

The major lineaments in the study area trend NE-SW lineaments being dominant in the area and they are parallel to the structures of the rift or the rift margin. Most of the lineaments follow trend of linear of ridges, mountains and mainly river valleys and streams. The length of lineaments varies from few meters to about 12km. (Assiged, 2006; Matebie meten et al. 2007).

Joints

Joints are widely observed in tertiary basalts and upper sand stone. The E-W and NW trending joints are more common on the upper sand stone. Most of the joints are filled by secondary material such as calcite, iron oxide and silica and feldspar. The occurrence of many springs at the foot of the former and thermal water along the latter may indicate the conductive nature of this fault.

Dykes

These features are more observable in northern and central part of the area cutting the basalt Mesozoic unites. They are parallel and oriented in the NE direction with maximum width about 2 meters (Assiged, 2006). Its composition varies from pyroxene phyric to aphanitic and vesicular basalt. In general, dykes are barrier to ground water circulation but in relative term, the surface of basic dykes is fractured and slightly weathered. As aftermath, dykes may have some contribution for ground water circulation.

4.6. Aspects of groundwater recharge and discharge

4.6.1. Ground Water Recharge

The major source of recharge to the ground water is highly sloping plains of the study area. In addition, different perennial rivers and streams of the area recharge the local ground water. Most of the hand dug wells and shallow wells placed along the rivers and streams are recharged by such condition in dry season. The locality deposited alluvium along the Jema and Muger Rivers are recharged by corresponding Rivers. The highly elevated areas of Entoto, wechecha, chilmo, chelelka and other locally developed ridges are the possible source of recharges to the ground water of adjacent plateau and hill foot aquifers.

There are three types of recharge

Direct recharge: water added to the groundwater reservoir in excess of soil moisture deficit sand evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone.

Indirect recharge: it is percolation to the water table following runoff and localization in Joints, as ponding in low lying areas or through the beds of surface water sources such as Rivers, Lakes and Reservoirs.

Localized recharge: resulting from horizontal surface concentrations of water in the absence of well-defined channels.

Assessment of the mechanism and amount of recharge is fundamental for sustainable groundwater resources utilization and management. However, estimating the different recharge processes is not simple. It requires understanding the various processes that affect recharge and quantifying the spatial and temporal variability. Unfortunately, there is no direct means of measuring groundwater recharge at regional and sub-regional level.

Recharge estimation requires accounting the different factors. These include:

- Topography and geology
- Precipitation (intensity, duration, spatial distribution)
- Runoff and ponding of water

- Rivers (rivers flowing into and leaving out of the area under consideration, rivers Gaining water from or losing water to the aquifer, etc.).
- Soil zone (nature of the soil, depth, hydraulic parameters, variability of the spatially and with depth, rooting depth of the soil, and cracking of soil on drying out or swelling due to wetting)
- Unsaturated zones between soil and aquifer (flow mechanism through unsaturated zone, zones with different hydraulic conductivity, etc.)
- Ability of aquifer to accept water and variation of aquifer condition with time

All the three types of recharge can be identified in the region. However, direct recharge and indirect recharge from rivers are the most important ones.

4.6.2. Ground Water Discharge

Ground water discharge areas are located on gently sloping and undulating plateau, inter mountain depression and at the middle and bottom of high cliffs of deep gorges. In most places, the ground water discharge areas are indicated by the appearance of springs. A lot of springs emerge at the weathered and fractured parts of topographic break, inter mountain depressions and high cliff of deep gorges. It is observed that the discharge of this groundwater is due to the presence of thin impermeable layers in the middle or the discharge top parts of ridges different, in hydraulic conductivity resulting from lithological variation along cliff variation in the extent of weathering of the same rock along cliff and variation in degree and extent of fracturing. Generally, low areas can be considered as discharge area. But, there also some exceptions such as in highly elevated Entoto ridges where the appearance of springs is common. This is most probable due to the above mentioned reasons. So it should be emphasized that the topographically of this ground water is due to the presence of thin impermeable layers in the middle or elevated ridges can also act as discharge areas in addition to their recharge media.

Discharge map (fig 10) for different aquifers based on the analysis of existing data as well as those gathered for the research. The data for characterization of aquifers requires intensive data collection on: lithology, static and dynamic water levels, screen leangth, total draw dawn, etc. for the confined and semi confined aquifers.

In the research area, the geological time of volcanic rocks varies from Young Volcanic Pliocene to Alaji Series (Lower Miocene) and the age of the rocks younger towards the rift system. Moreover, the elevation of the area decreases to the rift as well. These variations of age and elevation affect the weathering and fracturing of volcanic rocks to give variable recharge and aquifer characteristics. Moreover, these structures are also affected the distribution of groundwater and its location in the area (e.g. Fliwoha Fault). All the above factors affect the groundwater distribution and aquifer characteristics of the area.

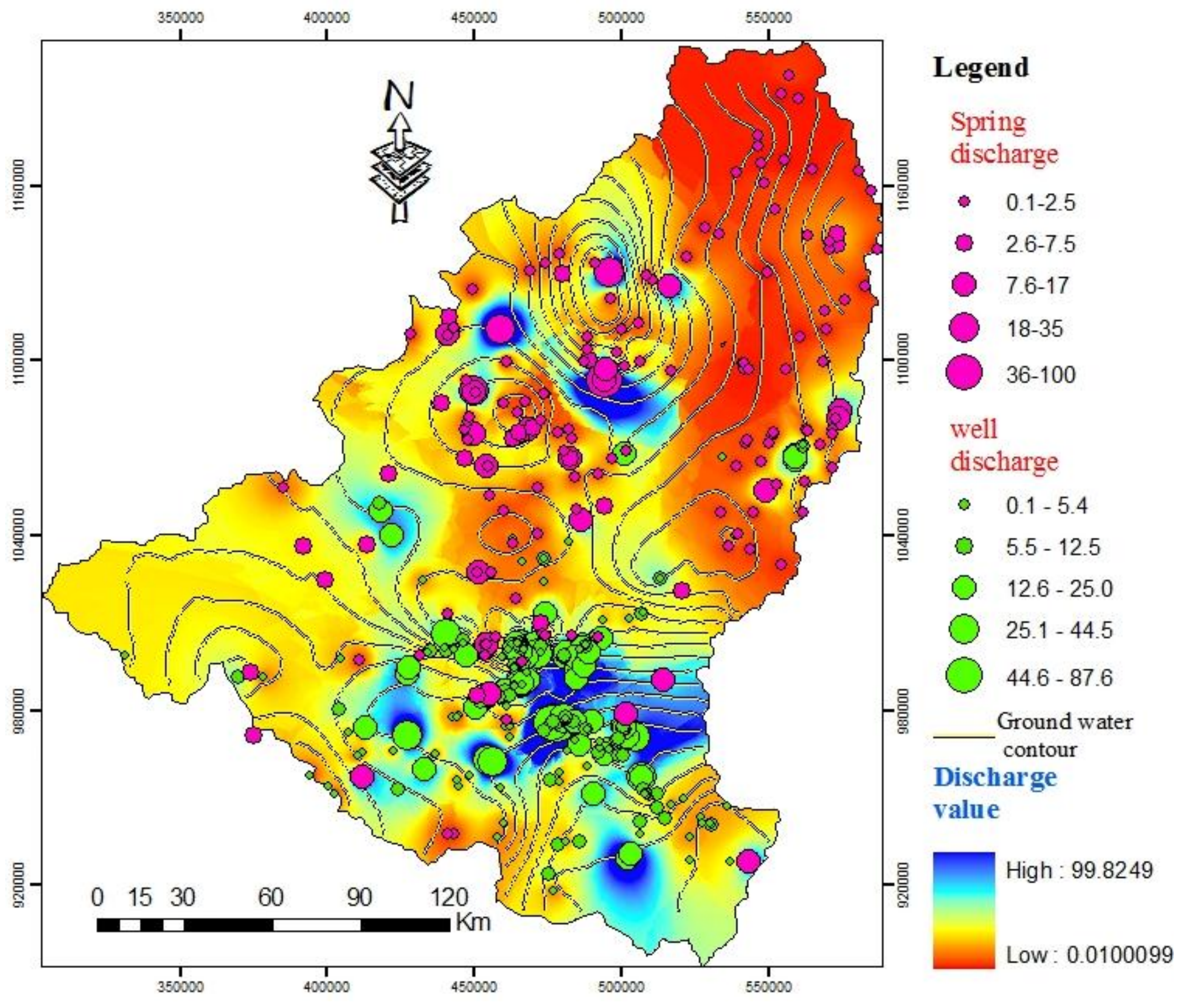

Figure 9 : Discharge map of the study area

Some important water points

A total of 1152 water points out of which 879 boreholes, 269 springs and foure surface waters are found in the study area. (Annex 2)

Springs

Most of the springs are located at hill side of deep gorges and ridges and slop breaks of undulating plateau. However, they are also some springs located at the flat land. The springs of the area are dominantly depression and fracture type. There are also springs with contact and karst nature. In most places the occurrence of springs follows the NE-SW and N-S trending faults and lineaments. They are found almost all types of lithologic unit with high variation in discharge. In the Hydro geological Reports of Addis Ababa map sheet NC-10 (2010), field inventory and reported data shows that the discharge in dry season period shows wide variation ranging between 0.05-35 l/s on basaltic aquifers, 0.01-1.5 l/s on ignimbrite, trachyte, rhyolite aquifers, 0.01-2.5 l/s for alluvial and elluival sediments and 0.02-40 l/s for Mesozoic lime stone and sand stone. Most of the springs at gentle sloping plateau and flat lands covered by high productive basalt aquifers are developed for community use.

Borehole

Almost all Boreholes drilled in the study area have water bearing units of basalt and ignimbrite/trachyte aquifers. Most of the bore holes have a total depth from 50 meters to 504 meters. The deepest Boreholes drilled penetrating fractured basalt and ignimbrite are concentrated around Addis Ababa city. Unfortunately on the central and north eastern plateau of the area shallow wells are dominant, but there are some deep wells drilled by WWDSE with promising yield on those areas. Collected data shows that the yield of boreholes increases as depth increases. In thermal water zone of Felwuha associated with the NE-SW trending fault which across Addis Ababa city, there are a number of wells with depth ranging from 90-300 meters. They are used for the bathing purpose. The well log data shows those boreholes penetrate the fracture basalt and encountered hot hotter after 50 meters penetration. Data from Addis Ababa water and sewerage agency (AAWSA) shows there are deep wells which reach up to 300 meters depth with the average yield about 25 l/s inside Addis Ababa city. The water bearing formation of these wells are fractured and weathered basalt and ignimbrite, whereas in central and northern plateau of the area datas shows a relatively shallow wells ranging from 58.8 to 96 meters at lemi and murkaturi with relatively low yield . So it is necessary to drill deep wells in those areas especially around Fiche and Gebreguracha to avoided water shortage in those towns. In general all existing data reveals that the static water for basaltic aquifer ranges from artesian to 60 meter below ground level. For ignimbrite/trarhyte aquifers the static water level ranges in between 5-100 meter below ground level.

Hand dug wells

The abstraction water using hand dug well is very common on the central and northern plateau of the area. Most of the hand dug wells are sunk on flat and gently sloping terrain on the recent deposits, alluvial fans and highly weathered basalt they are used for small community water supply. Most of them have a depth ranging from 10 to 25 meters below ground surface with average yield of 0.2 l/s.

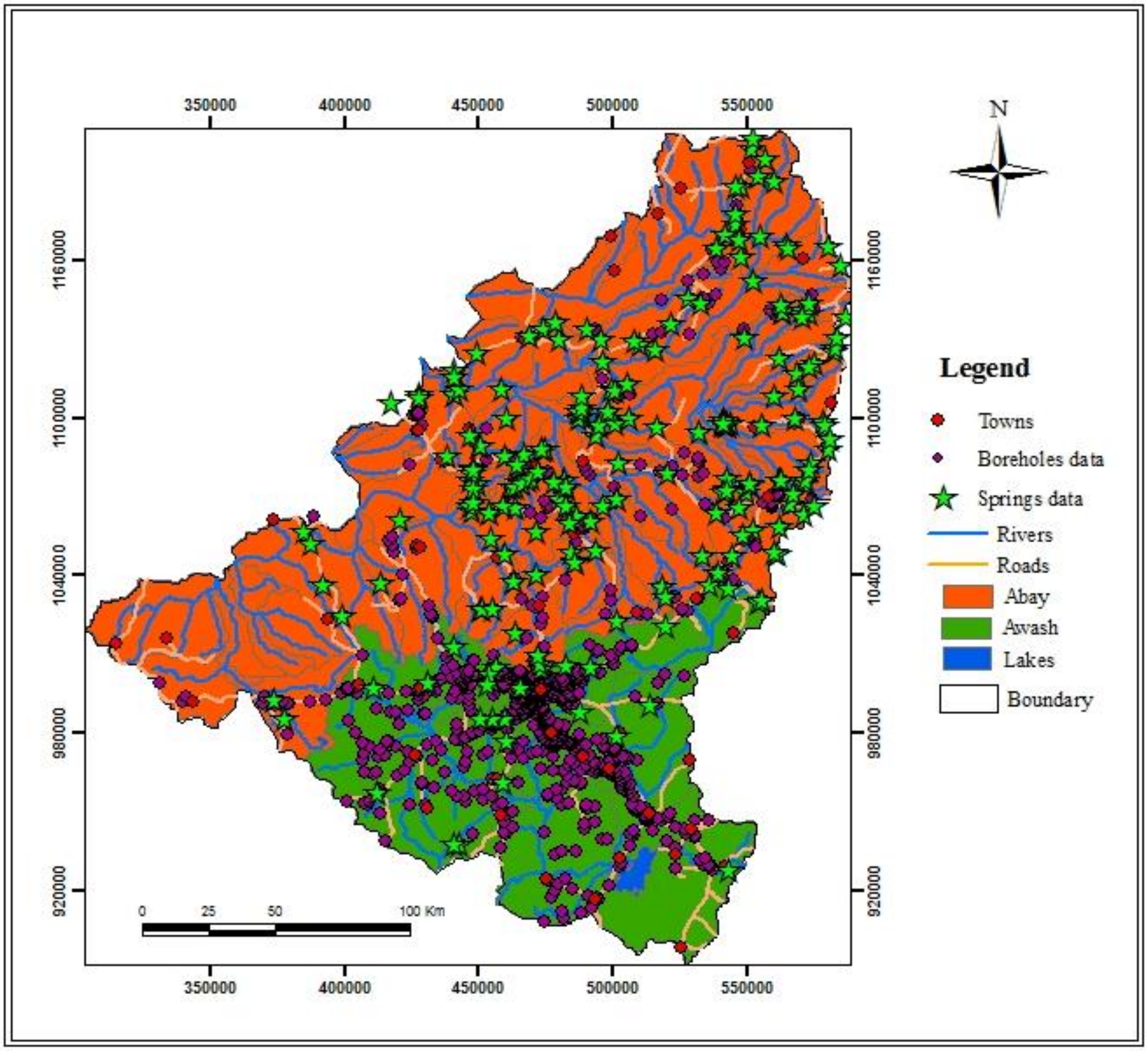

Figure 10: Location maps of Boreholes and springs

4.7. Ground Water Flow System

The ground water flow of the area seems to follows the surface water flow and it is highly dependent on the geomorphology and structures. Small intermittent and perennial rivers that feed local aquifer follow those alignment lineaments, where the ground water flow also follows such pattern. The direction of emergency of spring points on the tertiary volcanic and Mesozoic sediments are some show structurally controlled, indicating the structural tendency of ground water flow. It is also highly dependent on the surface water flows.

Variation in hydraulic conductivity of different rocks can also cause local deviations to the ground water flow. Hence there is complicated local ground water flow direction, due to the above mentioned factors. The general ground flow direction of the area shows two patterns as there is a contribution of two major basins (Abay and Awash basins). The ground water flow direction in plateau area of Abay basin tends to be toward North East and North West direction. In the Awash basin, the Southern part of the study area, the flow is towards the south to Akaki well field and main Ethiopia rift (MER). The trachyte, ryholite and ignimbrite ridges of Entoto, Ankorcha and Wechecha dominantly the basin mountain chains of chilmu, where the major E-W trending lineament which act as ground water as well as surface water divide between Blue Nile and Awash basins but there is a hypothesis of ground flow recharge flow Blue Nile basin to Awash basin through becho plain and legedade area (WWDS, 2008)

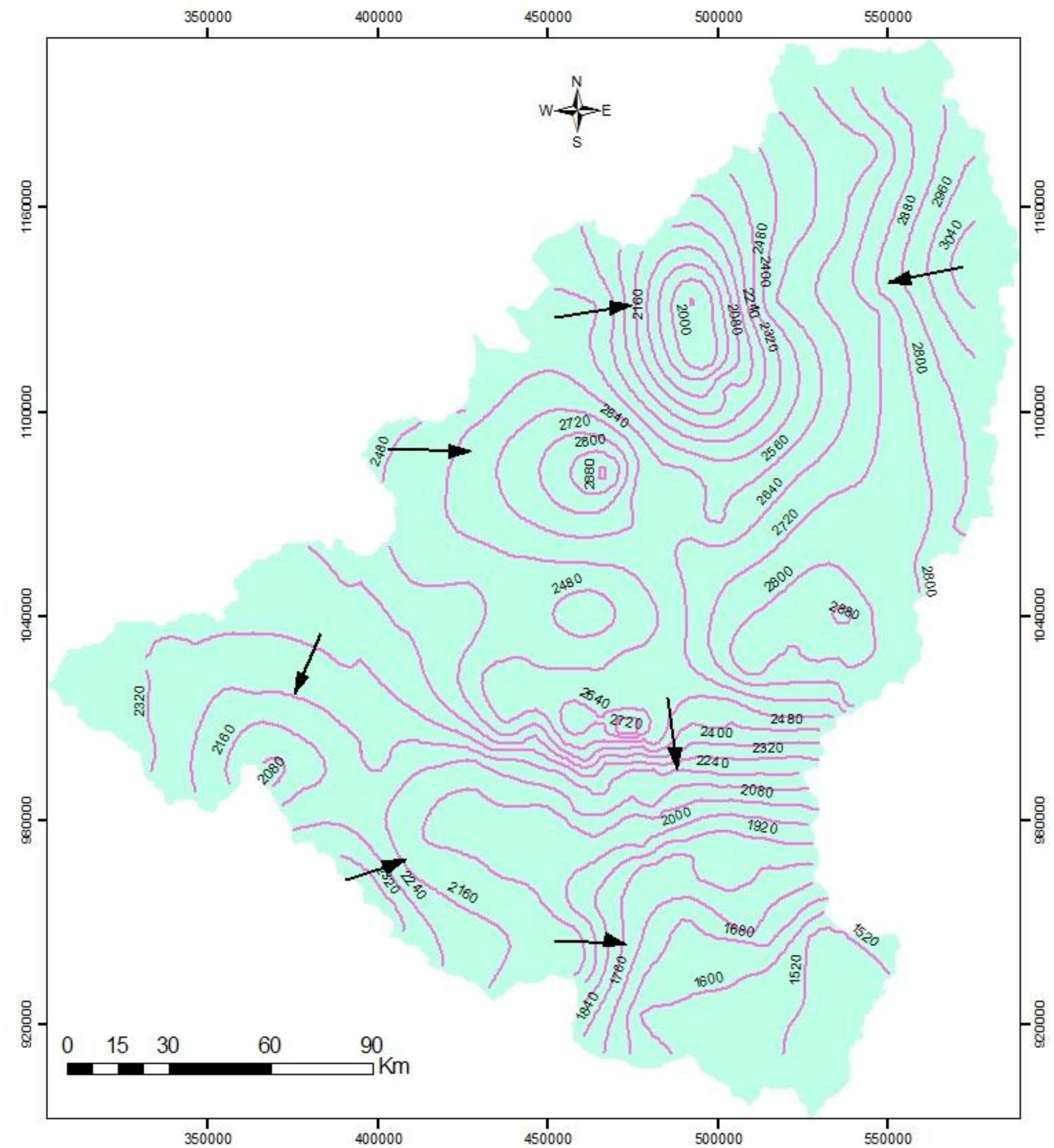

Figure 11: Ground level contour lines and the general ground water flow

CHAPTER 5

HYDROCHEMISTRY

5.1. General

The objectives of chemical hydro geological investigations are to determine the sources, concentration and fat of dissolved constituents within the physical frame work of flow and transport. The term “water chemistry” (or water quality) refers to the quantities of these various substances (commonly called solutes) that are present in a particular water sample, making up its chemical composition water acquires very small quantities of some solutes from dust and gases when it falls through the atmosphere as precipitation, but it typically acquires the majority of its solvents once it reaches the land surface. Solutes that were already present in the water increases in concentration because of the processes of evaporation and transpiration, for the most part, remove water while leaving the solutes behind.

The main environmental factors that control the amount of solutes present in the natural water climate, structure and position of the rock strata and biochemical effects associated with life cycle of plants and animals are considered by(Hem: 1971). So those, accurse of basic and acidic volcanic rocks, major tectonic discontinuity and topography are the major water quality controlling factors. Urbanization and associated development features for more than a century in in Addis Ababa city significantly change the chemical and biological constituents of surface and ground water. Standardization of water quality based on world health organizations can also be generated on the basis of hydro chemical data.

5.2. Groundwater Sampling

In this chapter an attempt is made to provide the hydro geochemical characteristics of the area from the point of view of the spatial natural compositional variation and water quality for domsic t uses. As an objective of this section, the physiochemical analysis, which is considered as hydro chemical data is resulted from different water sources like boreholes, hand dug wells, spring and surface water. These determine of ground water flow along the river basin. In its approach as ground water moves from place to place, the chemistry of water changes due to, displacement and replacement reaction between ions, duration and interaction between rock and water. The groundwater quality analysis was conducted on the different geological formation of the study area. The analysis is crucial for the recommendation of water quality of the study area for human consumption comparing to WHO standard. A total of four hundred five (405) water samples data from boreholes, dug wells, springs and surface water (river) were collected. Most of the sample used in this study collected from WWDSE, Geological survey and AAWA laboratory service. For fulfill the gap where there were data scarcity, water samples are taken from seven bore holes of which sex deep wells and one hand dug well and three springs samples were collected from the two basin. Measure of Electrical Conductivity (EC) and PH were made during the field.

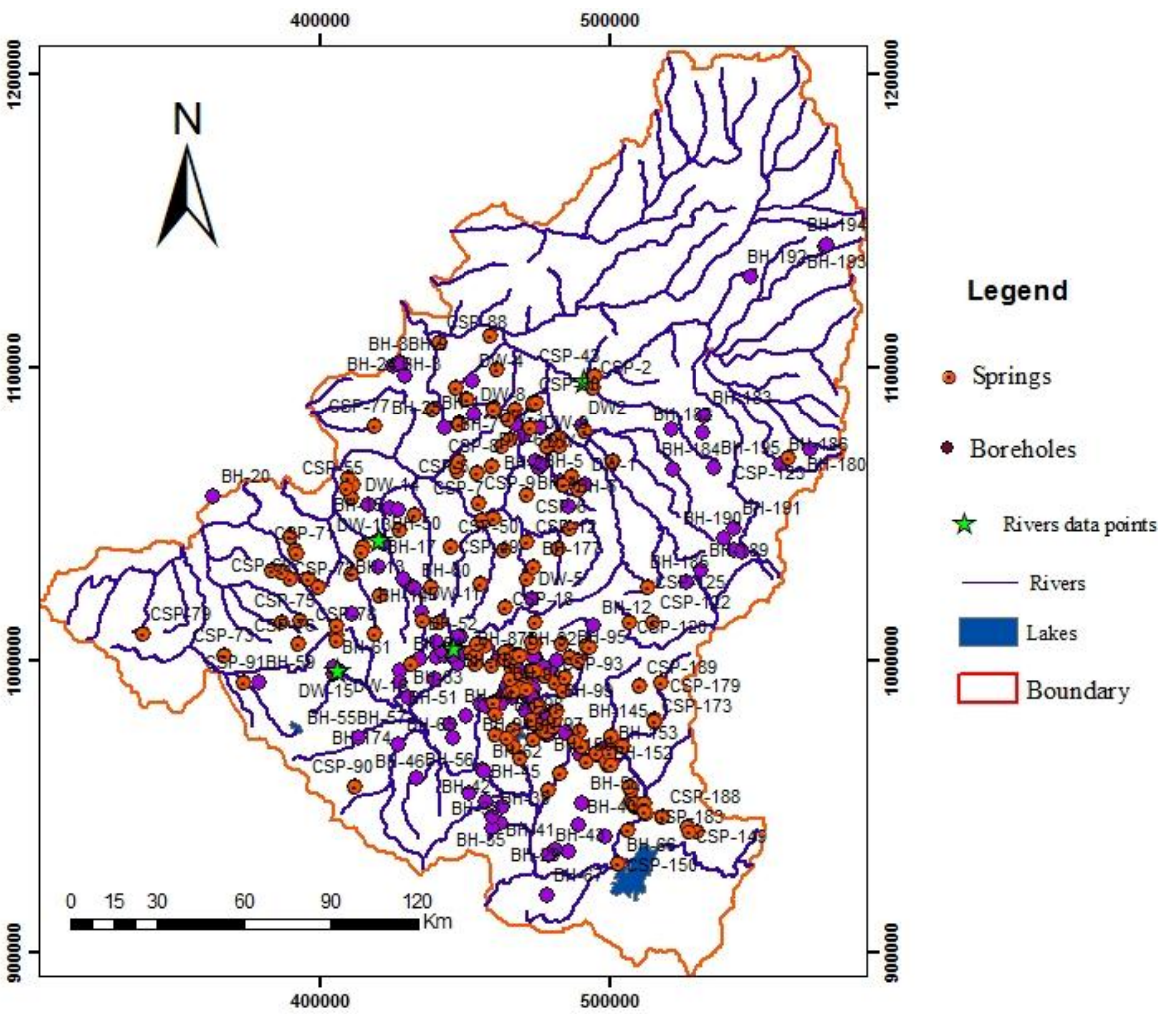

Figure 12: Location of water sample points

The main hydrochemistry of natural water characteristics of the study area can be expressed by some physical parameter like PH, TDS, conductivity and major constituents, (HCO3, SO4, Cl, Na, Ca and Mg) and secondary constituents (K, F, NO3, and CO3) have been used.

5.3. Physical Parameters

5.3.1. Hydrogen-Ion Activity (PH)

PH is a measure of water's acidity or alkalinity PH scale ranges from 0 (high concentration of positive hydrogen ions, strongly acidic) to 14 (high concentration of negative hydroxide ions, strongly basic). In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and pH measures exactly 7.
For most natural waters, the range of PH is between 6 and 8.5. The field measured PH is also 6.7 to a maximum of 7.9 and many of the study area water samples lies within this range. Most water samples from boreholes ranging from 6 to 9.1and water samples from springs ranging from 5.9 to 8.8. In WHO standard less than 6.5 is acidic, 6.5-8.5 is normal and greater than 8.5 is basic water. In study area, 405 water points have been taken for pH sampling, as it shown on figure-11. PH value below 6.5 counted 25 water points, from 6.5-8.5 PH value counted 363 water samples and greater than 8.6- 9.1 PH value counted 17 water points. These shows that the natural water in the area have a good quality in terms of PH value for the sampled water points. However there are also some exceptions.

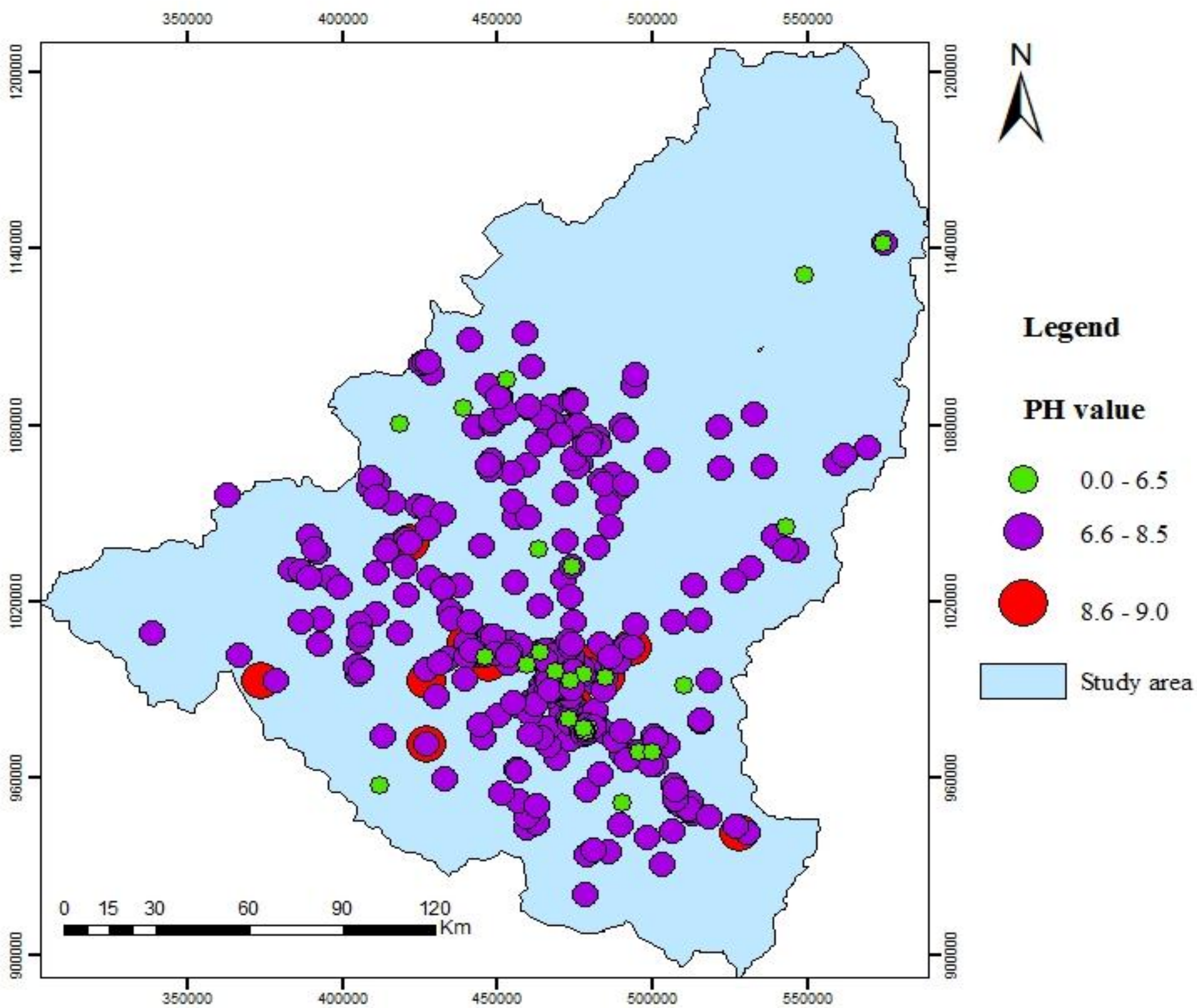

Figure13: Map showing distribution PH of area

5.3.2. Electrical conductance (EC)

Electrical conductance or conductivity is the ability of the substance to conduct an electric current. It is measured in micro Siemens per centimeter (μS/cm) at a specified temperature, usually 25 degrees Celsius. Pure water is a poor conductor of electricity, but minerals dissolve in water, and the resulting ions conduct electricity. In the highlands the EC of groundwater is usually less than 449 uS/cm. The EC varies and highest considerably in the central Addis Ababa. This may be due to the hot springs in Filwoha faults.

In general the larger the value of specific conductance, the greater the concentration of dissolved solids in the water sample and the poorer the water quality. The chemical analysis shows very high electric conductivity (EC) and TDS on the BH-26 and csp 141 borehole which are 3380 us/cm and 2240 mg/l for the first and 3350 us/cm and 3527.7 mg/l for the latter and they have also high temperature, up to 78 ^{0}C, this could be related thermal aquifer source of the water. The general formula that can relate the specific conductance of natural water and dissolved solids is expressed as

KA=S, S= stands for dissolved solids in mg/l

K = conductance in micromhos

A= Conversion factor and for most groundwater the specific conductance multiplied by a factor of 0.55 to 0.75 gives reasonable estimate of the dissolved solids (Tenalem Ayenew, and Tamiru Alemayehu, 2001).

There is a straight line regression (R^2=0.9721) relationship between TDS values and conductivity measured in the field and laboratory with very low deviation (Figure 12). The EC is directly proportional to TDS. The relation is used to convert the conductivity value measured in the field to total dissolved solids to fill the data gap of laboratory analysis results.

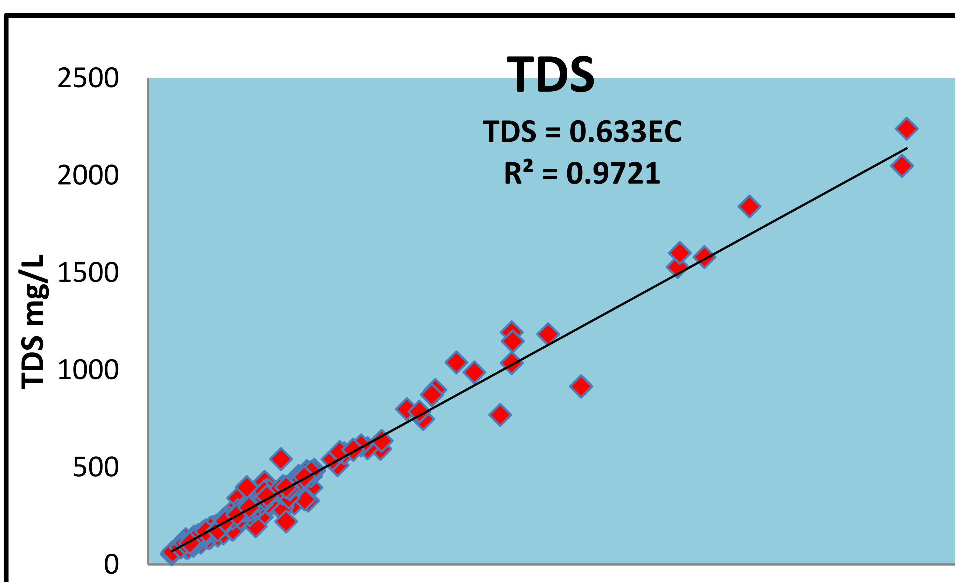

Figure 14: *Relation between TDS and EC of natural water samples.*

5.3.3. Alkalinity and Acidity

The properties of alkalinity and acidity are important characteristics' of natural and polluted waters and are almost always included in the chemical determinations. However, these properties differ in important ways from most of the other determination reported in the analysis. It is controlled by pH and the concentrations of strong bases such as carbonate and silicate ions. Strong acids are not common in natural ground water. Their occurrence represents contamination from human activity.

The solution of silicate and carbonate minerals does provide strong bases in solution in natural situations. Consequently, as ground water flows through an aquifer, it dissolves more carbonate and silicate minerals there by increasing the alkalinity and the pH. Generally springs alkalinity is less than that of borehole alkalinity. Because springs are young fresh water that does not make long time interaction with rock in order that the alkalinity is raised. Residual Alkalinity (RA=Con (HCO_3)-(Con (Ca +Mg) meq/l) which increases with the increasing of TDS helps to identify recharge area and inflow of meteoric waters in to the aquifer system (Fig13)

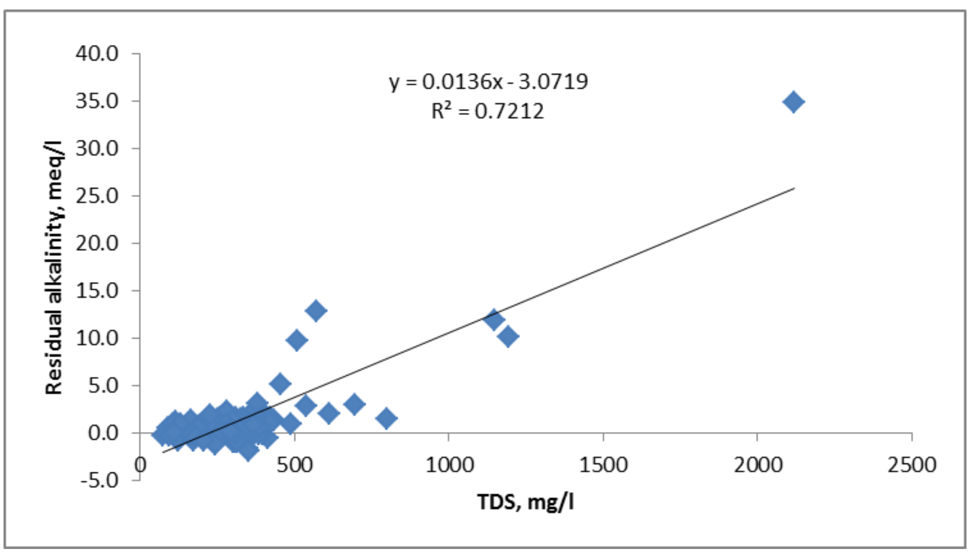

Figure 15 : TDS vs. RA plot

5.3.4. Hardness

Hardness is the chemical property of water suggesting the presence of Ca^{+2} and Mg^{+2} which principally cause the water to be hard. Hard water contains cations with a charge of +2, especially Ca^{2+} and Mg^{2+}. Calcium and magnesium enter the water via the action of carbonic acid. As water and carbon dioxide react, carbonic acid is produced and dissolves calcium and magnesium from carbonate rocks (e.g. Limestone, Dolomite),What constitutes "hard water" has been variously described. A generally accepted classification for hardness as mg/l of CaCO3 according to Dufer and Becker (1964) cited in Tamiru and Tenalem (2001) hardness range in milligram per liter (mg/l) is given by:

0 to 60 = Soft

61 to 120 = moderately hard.

121 to 180 = Hard

>181 = Very Hard.

Hardness levels above 500mg/l are not desirable for domestic use. Samples of the study area have more Ca^{++}, thus hardness of water is one factor of water quality. In general, it is relatively high for borehole and small for spring water. Those water samples rich in calcium are categorized as hard water calcium is imparted by leaching of calcium rich rocks (basic rocks), acidic rocks dominated by Na characterized by water low hardness.

The surface water of the area can be considered as very soft water which require only simple disinfection or infiltration and hardening for potable supply. But rivers in Addis Ababa city are highly polluted and affected by undesirable substances due to the impact of urban activates.

Description	**% of Sample**
Soft	20.6
Moderately Hard	27.7
Hard	24.6
Very Hard	26.2

Table 3: Classification of the water sample of the area by hardness

5.3.5. Total Dissolved Solids

TDS: Total Dissolved Solids include all the solid substance in solution. The amount of dissolved solids can be determined from the weight of the dry residue remaining after evaporation of the volatile portion of the water sample (usually at 180 ^{o}C) or may be calculated if the concentration of major ions is known (Hem, 1992).TDS can have important effects on the taste of drinking water. The field measured value ranges from 191.25 to 801 in mg/l. The total dissolved solid (TDS) of different samples from different geological unit ranges from 34 to 3527.7 mg/l which shows a big variation indicating the impact of different rock types to water chemistry. The lowest TDS value is observed in springs at the Entoto ridge (csp-16, csp- 17, csp-20 and csp-21), Annex 6. Since the Entoto ridge is a recharge area, very shallow groundwater circulation and short period of settlement time leads to poor rock-water interaction. The highest TDS value is associated to the faulting zones and where there is high tendency of dissolution in sedimentary rocks, especially in limestone. A fault that trends NE-SW pass through Addis Ababa city is responsible for the appearance of hot springs at 'Felwuha' with very high TDS (BH-26 and CSP141).

In general, the concentration of alkaline earth metals, Ca and Mg gradually decreases when the ground water becomes rich in TDS. In the contrary, the concentration of the alkaline metals, Na and K increases with the increase of TDS.Very low value of the Ca/Na ratio is the characteristics of the thermal aquifers and those aquifers with considerable amount of clay and paleosole intercalations in the weathered and fractured scoraceous basalt aquifers. A higher ratio, in the contrary, is attributed to the groundwater from basaltic or if acidic, they are located on the fault line that could serve as a conduit for the water to come from the deep lower basaltic aquifer that underlay the penetrated acidic unit.

In addition, the TDS concentration of the area shows high dependency on the altitude. TDS of Water samples increase from the plateau area towards the river gorges and relatively low lands. Generally topographically high areas with high rainfall show low TDS than low topographic area with low rain fall. Because high attitude is recharge area.

WATER TYPE	TDS IN PPM	TDS IN MG/L
Fresh water	0-1000	0-1
Brackish water	1,000-10,000	1-10
Salty water	10,000-100000	10-100
Brines	More than 100,000	More than 100

Table 4: Water classification based on TDS (Freeze & Cherry *(*1979)

Almost all samples have TDS value under the limits of highest desirable and permissible. Out of 405 water points that are sampled from, BH-26, sp-141, csp-142, csp-144, Csp-13, BH-168, BH-169, BH-170, BH-137, BH-27 and BH-60 (Annex, 6 & 7) exhibits very high TDS and exceeds the limit of water level standards. The TDS of groundwater shows big variation. The highest TDS values are observed to those places associated with fault lines (BH-26=3527.7 mg/l), and the lowest are observed at elevated recharge areas (csp-20=34.13 mg/l).

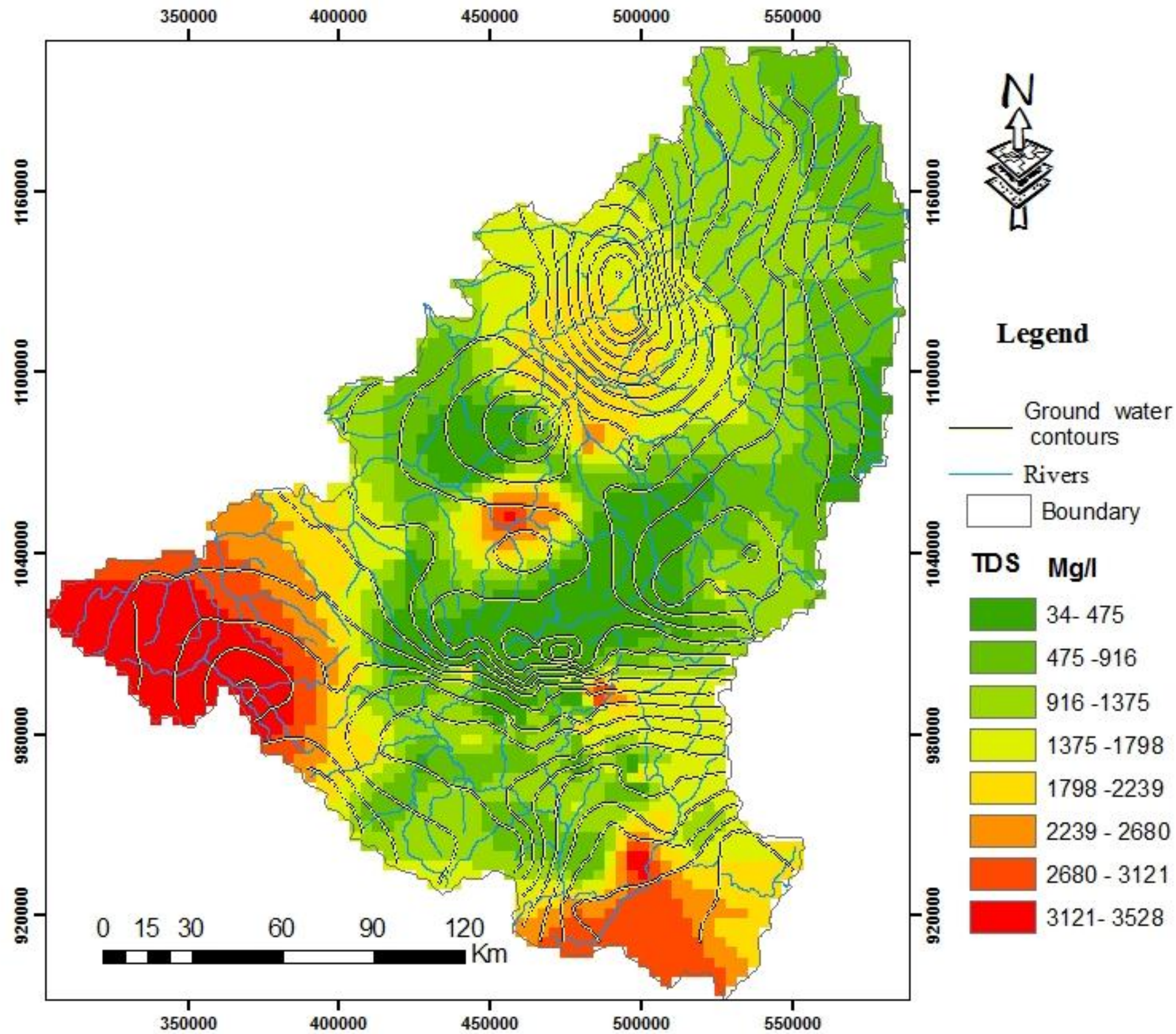

Figure 16: Map showing TDS distribution of the area area

Number of samples						
Parameter	Unit	Min	Max	Average	St.Dev	Sample number
EC	Us/cm	39	3380	480.2	218.7	352
TDS	Mg/l	34.1	3352.7	304.2	129.1	352
PH		7.56	5.89	9.1	0.48	389
Ca	Mg/l	2	140	41.5	24.69	405
Mg	Mg/l	0.54	66	11.86	8.35	405
Na	Mg/l	0.01	0.01	930	110	405
K	Mg/l	0.08	31.5	5.1	6.43	405
HCO3	Mg/l	7	2213	270.51	272.59	405
Cl	Mg/l	0.1	82.5	11.12	11.07	405
SO4	Mg/l	0.1	202	9.86	30.01	405
NO3	Mg/l	0.02	78	7.92	9.5	405
F	Mg/l	0	28.6	1.37	7.12	405
CO3	Mg/l	0	100.8	1.24	7.44	405

Table 5: statistics valve of 405 water point's chemistry in the study area.

5.4. Cations and Anions

5.4.1. Sodium Ion (Na)

Sodium is one of the major cations characterized ion exchange chemical reaction during evolution process by Ca and Mg. 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).The generalized reactions are as follow (Hem, 1985)

$Na_2X + Ca^{2+} = Ca\,X + 2Na^{+}$

$Na_2 X + Mg^{2+} = Mg X + 2Na^+$, Where X = aquifer solid

The WHO guideline value for sodium in drinking water is 200 mg/l. Many surface waters have below 50 mg/l. However, ground water concentrations frequently exceed 50 mg/l; Sodium is commonly measured where the water is to be used for drinking or agricultural purposes, particularly for irrigation.

The sodium concentration in almost all water samples in the study area is below the maximum desirable and permissible level of the standards with the exception of (BH-26 csp-141, and csp-142). The high concentration of sodium of these boreholes and springs are associated with the NE-SW running fault. The surface water in the study area shows normal concentration of sodium ion (23 Awash mg/l to 9 mg/l Holeta and Lega Robi).

5.4.2. Calcium Ions

Calcium is an essential constitute of many igneous rock minerals, especially of the chain silicates pyroxene and amphibole and feldspars. The plagioclase feldspar group of minerals represents mixture in various proportions of the end members' albite $NaAlSi_3O_8$. The concentration generally is low, however mainly because the rate of decomposition of most igneous minerals is low. It is represented

$$CaAl_2Si_2O_8 + H_2O + 2H^+ = Al_2Si_2O_8(OH)_4\ Ca^{2+}$$

In the study area the calcium concentration varies 140 mg/l Menilik School (BH-86) to the concentration of Holota-town new (BH-51). Surface waters have Concentration ranging from 48 awash to 10mg/l lega Robi.

5.4.3. Magnesium Ion (Mg^2)

In igneous rocks, the magnesium is typically a major constitute of the dark colored ferromagnesian minerals. Specially, these include olivine, the pyroxenes, the amphiboles and the dark-colored micas, along with various less common species. The magnesium ion Mg^{2+} will normally be the predominant form of magnesium in solution in natural water. The ion pair MgSO4 (aq) has about the same stability as the species CaSO4 (aq), and magnesium complex with carbonate or bicarbonate have approximately the same stability as the similar species of calcium. In the 400 sampled boreholes Holeta/ welmera, 66 mg/l $Mg^{2+}$is the maximum concentration and the minimum concentration was found Filwuha/ Addis Ababa and Red Fox Flowers, koka area is (0.5mg/l). In sampled springs, magnesium concentration varies from 39 mg/l Gonji, (Csp9) to 0.5 mg/l AA-Water lll Testwell-B9 (csp106). The surface water concentration of Mg^{2+} fluctuates from 66 mg/l Holet River to 11 Awash River.

5.4.4. Potassium Ion ($K^{+)}$

The principal potassium minerals of silicate rocks are the feldspars orthoclase and microcline (KAlSiO8), the micas and the feldspathoid leucite (KAlSi2O6). The potassium feldspar is resistant to attack by water. In dilute natural water in which the sum of sodium and potassium is less than 10 mg/l, it is not unusual for the potassium concentration to equal or even exceed the sodium concentration. In the study area 382 sodium and potassium samples from water supply wells, springs and surface water shows that the concentration of Na^+ (mg/l) is greater than concentration of K^+ (mg/l) in all sampled data.

5.4.5. Bicarbonate ions ($HCO_3{}^{2-}$)

The presence of carbonates and bicarbonate influences the hardness and alkalinity of water. The weathering of rocks contributes carbonate and bicarbonate salts. The relative amounts of carbonates, bicarbonate and carbonic acid in pure water are related to the PH. As result of the weathering process, combined with PH range of surface waters, bicarbonate is the dominant anion in most surface waters. In study area, the maximum bicarbonate ion concentration is 2213 mg/l in Filwuha; Addis Ababa concentration (HBH-26). Springs have bicarbonate concentration of 2198 mg/l D/Z-Health College (Csp-142). In the surface water; bicarbonate ion concentration varies between 262 mg/l in Awash River to 157 mg/l in Holeta River.

5.4.6. Sulfate ion ($SO4^{2-}$)

Sulfate concentrations are associated with type of Lithology and pollution from surface water. There are high concentrations of sulfate at springs and wells which emerged at the contact between limestone, shale and gypsum intercalation. This is due to the high sulfate dissolving from gypsum. In the study area, wells have the highest sulfate ion concentration is 129.9mg/l AA-Water lll Testwell-B9 (BH-99). In springs, the maximum concentration of sulfate is 202 mg/l merhabit (Csp43) and surface water bodies ranges from 64 mg/l Jema to 2 mg/l Lega Robi rives.

5.4.7. Chloride (Cl^-)

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 .The high chloride concentration is associated with type of Lithology and pollution from surface water. The concentration of chloride is relatively high in densely populated areas of Addis Ababa area. High chloride concentrations in groundwater show contamination from pit Latrines, waste disposals. In the investigated area, the chloride concentration for almost all samples taken from groundwater is under range of the limit of the standard, chloride ion ranging from 82.5 to 0.1 mg/l in wells, 64.7 to 0.1 mg/l in sprigs and 441 to 1in Rivers.

5.4.8. Fluoride Ion (F^-)

The fluoride concentration of natural water in the study area shows almost uniform with small variations. In some parts especially in the rift zone and samples from some boreholes which are associated with fault Zones show higher fluoride concentration than the normal drinking water standard. The higher concentration of fluoride in the study area is associated with recent acidic volcanic (Berhanu Gizaw 1996). High Fluoride concentration, up to 28.6mg/l in central and rift zones associated with thermal waters. Very low fluoride concentration is observed in plateau zone waters. In the study area, the maximum concentration of fluoride ion is 28.6 mg/l Filwuha/ Addis Ababa (BH-26), and 27.6mg/l Alem Gena-Dika (Sp141) in springs. The concentration of these ions is in significant in surface water.

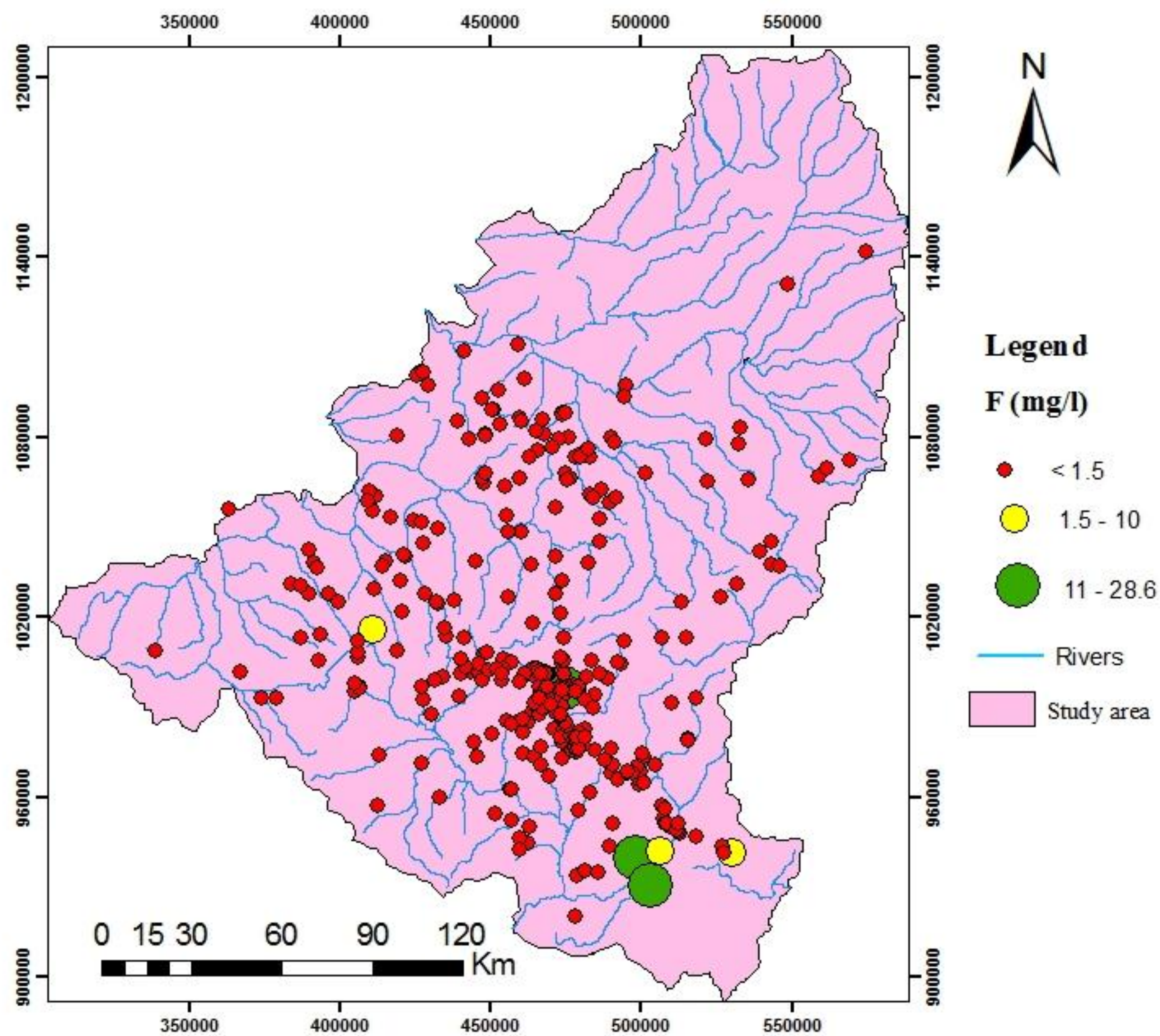

Figure 17: Fluoride distributions of natural waters.

5.4.9. Nitrate (NO3)

Nitrate is commonly used a quality indicator of potential contamination of groundwater. Like chloride the concentration of nitrate is relatively high in densely populated areas of Addis Ababa. High nitrate concentration levels indicate contamination from municipal wastes. The Nitrate level in surface water is (excess 4 mg/l $NO3^-$). This usually indicates pollution by human and animal waste or fertilizer run off. As the WHO recommended, maximum limit for drinking water is 10mg/l $NO3^-$ Water with higher concentration of represents a significant health risk.

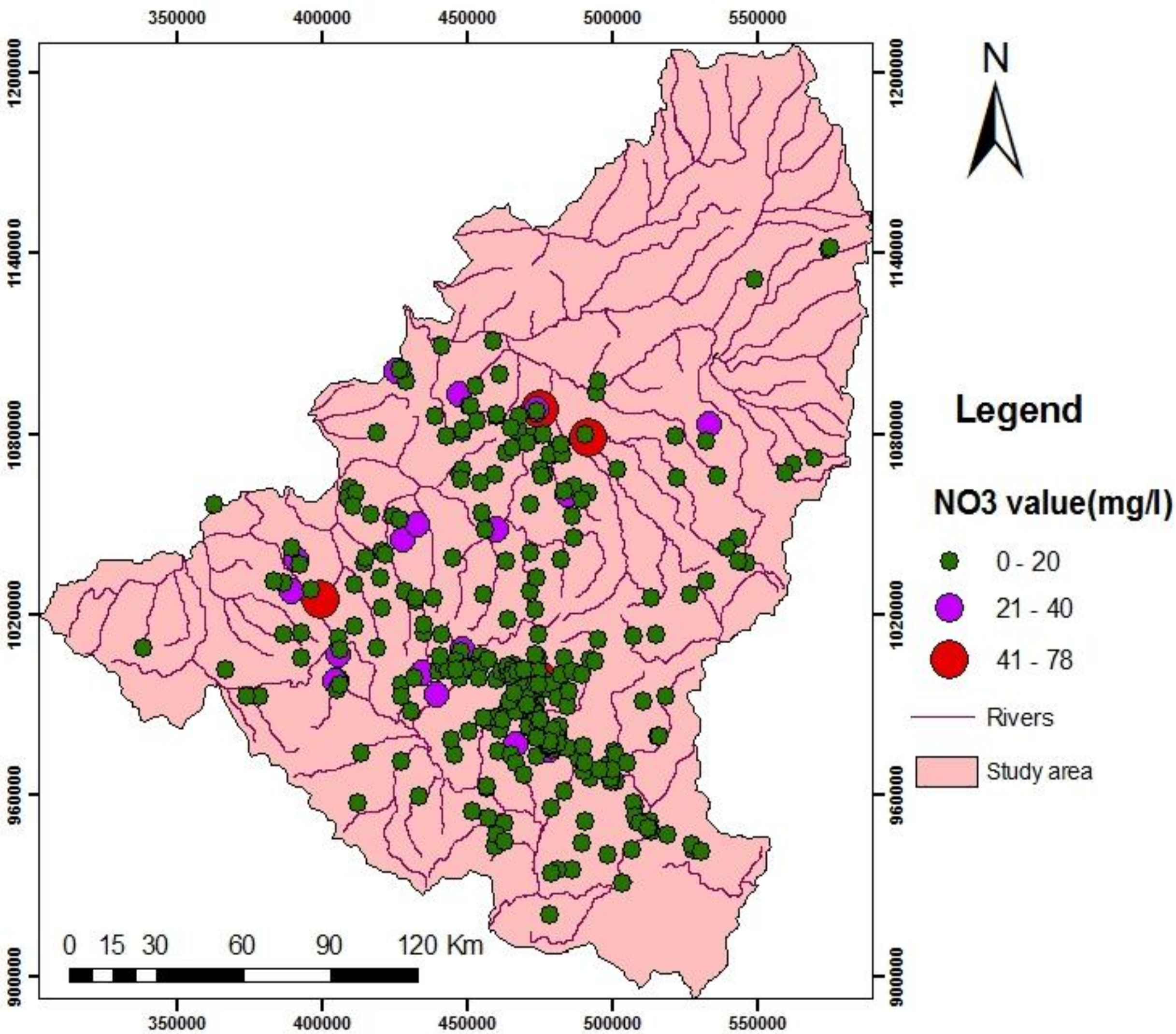

Figure 18: Map showing Nitrate distribution of the study area

5.5. Classification of Natural Waters

Classification of natural water is used to express the groundwater chemistry on the Hydro chemical map. Hydro chemical types are classified based on Aquachem Software

5.4.1. Classification Based on Aquachem Software

The ion concentration in most of the water samples is dependent on elevation, litho logy, structures and climatic conditions. The high concentration of chloride and sulfate is observed in river gorges and in association with faults. In addition to these, litho logy of the area has a significant effect on the concentration of chloride, sulfate and sodium. The presence of high Concentration of chloride, sulfate and sodium shows a complex process of rock-water interaction and ion exchange. The predominant water types in Ethiopia based on the dominant anions which are bicarbonate, sulfate, and chloride types (Tesfaye, 1993). In general, the classification of water samples of the area based on the Aquachem software analysis is made as follows based on the Aquachem software analysis.

Bicarbonate Water (HCO3)

The analysis shows that the dominant water type of the study area is bicarbonate type. The Presence of this water type shows fast hydro geological regime and lithologically homogeneous Aquifers with a relatively high amount of rain fall. The cat ion groups associated with bicarbonate are Ca, Ca-Mg, Ca-Mg-Na, Ca-Na-Mg, Ca-Na, Mg-Ca, Na-Ca and Na-Ca- Mg.

Bicarbonate Sulfate Water (HCO3-SO4)

This water type is dominated in river gorges of Jema and Muger where there is gypsum intercalation in sedimentary succession. The high sulfate concentration results from the dissolution of gypsum through water circulation. There is also a high concentration of sulfate in water samples drilled along fault lines such as HBH-26 and BH-99. Springs that emerge from rhyolite and trachyte rocks of Entoto ridge have a relatively high sulfate. Water samples from springs Csp-53 and Csp-104 exhibit such kind of water type. In addition, the high concentrations of toxic and pollutant minerals such as nitrate are observed from few groundwater samples. The occurrence nitrate bicarbonate water is limited in the study area. Out of 405 water samples three samples, three samples (csp- 21, Csp-62, Csp-72) shows bicarbonate nitrate type and only one sample (Csp-65) has nitrate type. The springs are found on Entoto ridge at Gutoweserbi locality near Eleas Church, the highlands of Jeldu and near Chilimo Mountain. Since they are found on recharge zone and the aquifers are highly weathered basalt and lateritic soil, the probable source of nitrate would be waste from the villagers or may be from the fertilizer.

Water type	No of Water type for Wells	Water type for springs	Total case
Ca-Na-HCO3	55	32	87
Ca-HCO3	47	16	63
Ca-Mg-HCO3	45	77	122
Ca-Na-Mg-HCO3	8	10	16
MgCaNaHCO3-SO4	1	1	2
Ca-Mg-Na-HCO3	18	12	30
Na-Ca-HCO3	14	12	26
Ca-HCO3-SO4	2	1	1
Ca-Mg-HCO3-NO3			2
Mg-Ca-HCO3	1		
Na-HCO3	15	16	31
Na-Ca-Mg-HCO3	2	2	4
NaMgCaHCO3	4	1	5
CaMgHCO3SO4		1	1
CaNaHCO3SO4		1	1
Ca-Mg-NO3-HCO3-Cl		1	1
Ca-Na-Mg-HCO3-NO3		1	1

Table 6: the hydrochemical type in the study area.

Water groups represented by Ca-Mg-HCO3 (Table 6), are associated with the shallow systems (springs, Rivers and wells of depth less than 150m) in all the three physiographic regions of the study area. Waters in this group are characterized by dilute chemistry (TDS<340mg/l) and known to circulate in the upper basaltic aquifer.

Samples having chemical facies of type Ca-Na-HCO3 (Table 6) are associated with moderately mineralized waters (TDS< 500mg/l) and are mainly distributed to the central and rift part of the study area. This part of the area is characterized by intercalations of acidic volcanics (rhyolites, ignimbrites, tuff, trachytes and Pyroclastics), where water systems are tapping the weathered and fractured rocks rich in Ca- and Na- plagioclases which could be responsible to have such water chemistry.

The other facies groups are the Na-Ca-HCO3 type waters and are mainly encountered in two different physiographic regions, the plateau and the rift part of the study area (Table 6). In the plateau part of the study area these waters are associated with deep wells having a diluted chemistry (TDS<235mg/l). In many groundwater circulation systems strata of high permeability may be separated by clay or shale layer of much less permeable rocks. These layers can act as semi permeable membranes and thus give rise to anomalous effects on the concentration of dissolved ions. Sodium is retained by adsorption on mineral surface, especially by minerals having high cation-exchange capacities such as clays. Cation exchange process in fresh water systems tend to extract divalent ions such as Ca^{2+} from solution and to replace them with monovalent ions such as Na^{+} (Hem, 1992). The Na^{+} dominance in some of the borehole samples, therefore, might indicate the exchange of Ca by Na^{+}, the presence of thin layer of clay/paleaosols in some of the borehole logs of the plateau area supports this idea. In the rift part of the area this type facies is associated with wells having a moderate mineralization (TDS<600mg/l). The reason for this could be groundwater evolution along its flow path.

Na- HCO3 type waters are found to be associated to three different regions (Table 6). Some diluted chemistry deep wells in the plateau area have this type of water in which a similar reason could be adopted as those plateau wells having Na-Ca-HCO3 discussed earlier in this section, likely with intensive ion exchange that replaces the whole calcium in the water. Some wells in the southern part (rift) of the study area, also found to have this facies which could be an outcome of groundwater evolution along the regional flow path.

The other systems with this facies are the highly mineralized (TDS>1600mg/l) thermal wells which are located along the Filwuha fault belt of central Addis Ababa (BH 26, CS 141). From their association to acidic volcanics in place, these waters might have evolved from Ca-Na-HCO3 and Ca-HCO3 type water-silicic rock interaction at elevated temperatures where Ca is lost through CaCO3 precipitation. The other process could be deep circulation and longer residence time which leads to further hydrolysis of silicate minerals in the Ca-Mg-HCO3 type waters whereby the concentration of Na, K and HCO3 increase. Similar conclusions were made by previous researchers (Kebede et al. 2005 and Demlie et al 2008)

Ca-HCO3 type waters are also encountered in the study area (Table 6). Based on the Groundwater chemical evolution models, this group represent ground waters that are recently recharged and/or contain waters at the early stages of geochemical evolution which have not undergone significant water–rock interactions (Bartolino et al., 2003). This is further evidenced by the association of these water types to the shallow systems of the plateau area. The recharge zones in the plateau have a relatively dilute hydrochemistry which gradually evolves to a relatively concentrated hydro chemical composition as groundwater moves to the transition and rift zones of the study area along the flow path, which assumes a north-south general direction

5.4.2. Graphical presentation of hydro geochemical Facies

The diagnostic chemical properties of water are presented by graphical methods. The most common of which are the hydro chemical facies, e.g. the Piper (1944) tri linear diagram. This diagram is useful in screening and sorting large numbers of chemical data, which makes interpretation easier. Furthermore, a Piper diagram can define the patterns of spatial change in the water chemistry among geological units, along a line of section or along a flow path (Raji &Alagbe, 1997). In this study, the results of the chemical analyses of all the original and complementary secondary different data points are plotted on Piper diagrams. In addition to displaying all water sources together, piper diagram is also important to display each water source of more than one sample. In the figure below, five piper plots are observed which are representing springs, shallow boreholes, deep boreholes and hand dug well and surface water.

In the majority of waters from dug wells (Figure21); Calcium dominates their cations species followed by magnesium and bicarbonate dominate their anions. Thus, the water samples from HDW fall in the Ca-Mg-HCO3, Ca-HCO3, and Ca-Na-Mg-HCO3 and Ca-Na-HCO3 type in the Piper plot.

In deep bore holes water samples (Figure 22); the dominant cations are Ca and then Na and Mg. The dominant anion is HCO3. The dominant Water types of samples from deep bore holes are $CaNaHCO_3$ and $NaCaHCO_3$ types.

In the piper plot of shallow bore holes (Figure 23), the dominant cat ion is calcium followed by magnesium and sodium. The dominant anion is bicarbonate and minor sulfates. The dominant water types are Ca-HCO3, Ca-Mg-Na-HCO3 and Ca-Mg-HCO3 types.

Spring Samples position on the piper plot (Figure 24) represent fresh waters. The dominant cations in these spring waters are calcium followed by magnesium and sodium and the dominant anion is bicarbonates and minor sulfates, Nitrates and chlorine. The domiant water types from springs are Ca-Mg-HCO3 and Ca-Na-HCO3 type in the Piper plot.

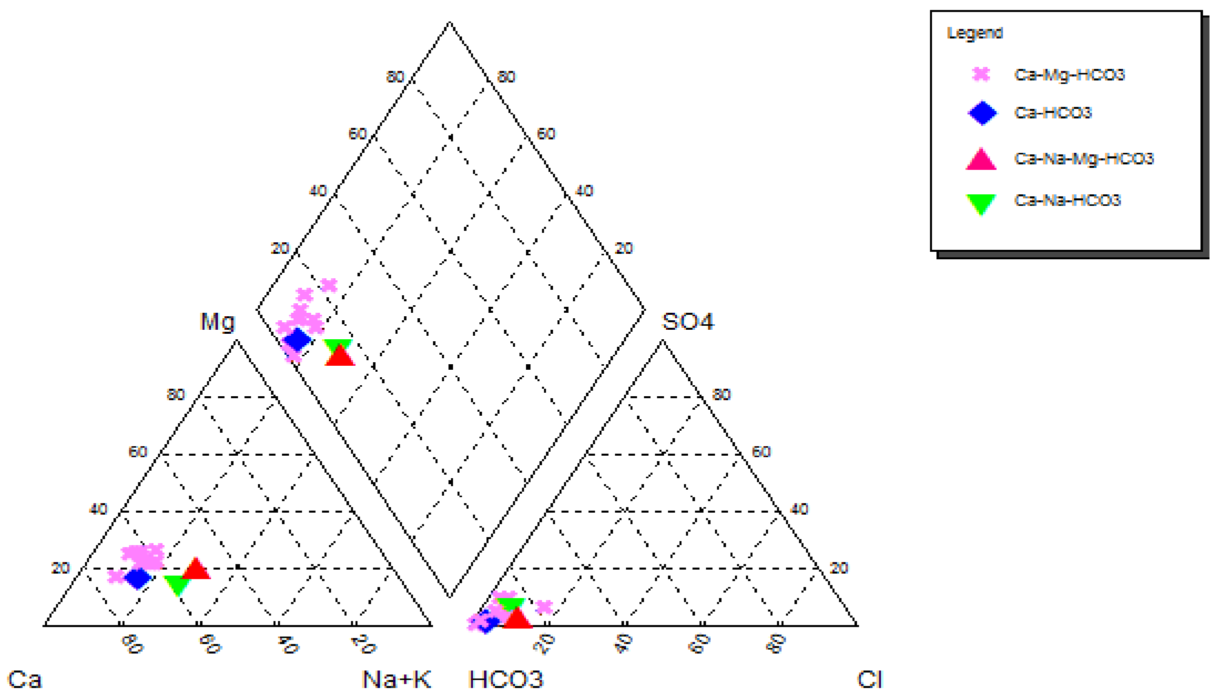

Figure 19: Piper plot of Hand dug wells

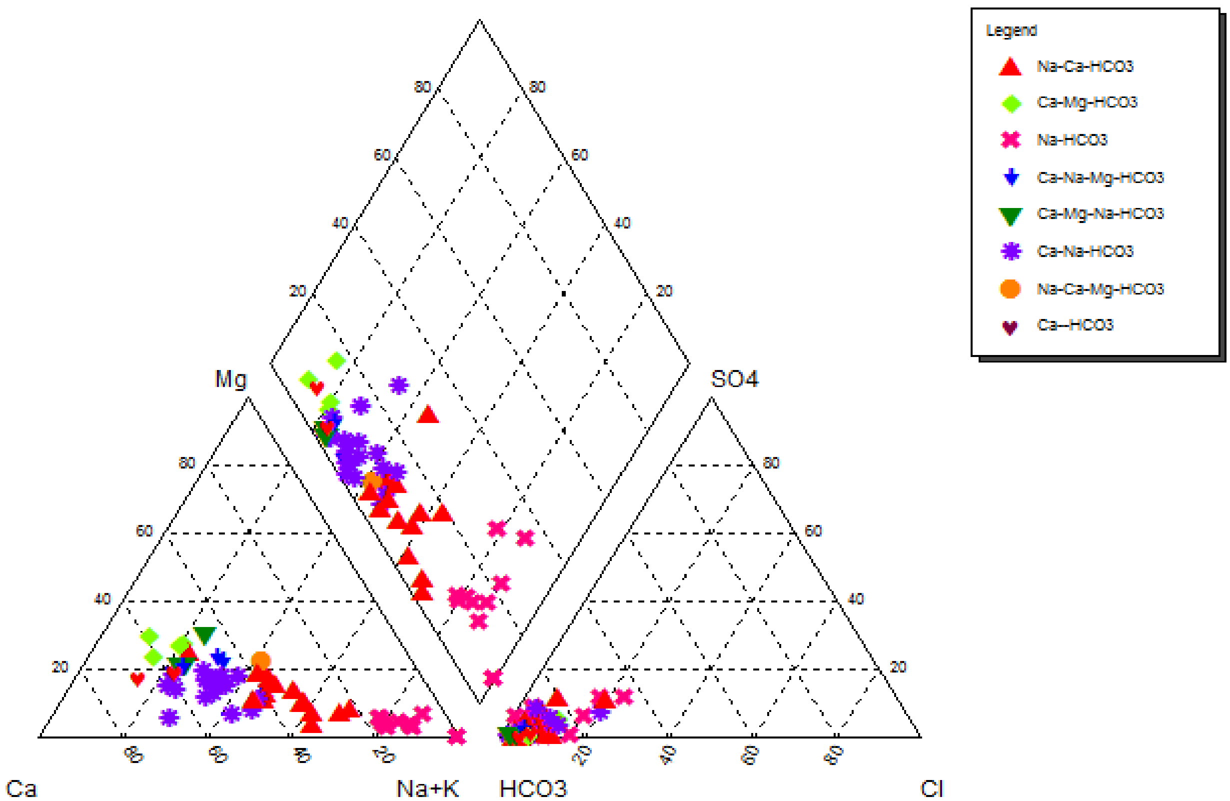

Figure 20: Piper plots of deep wells

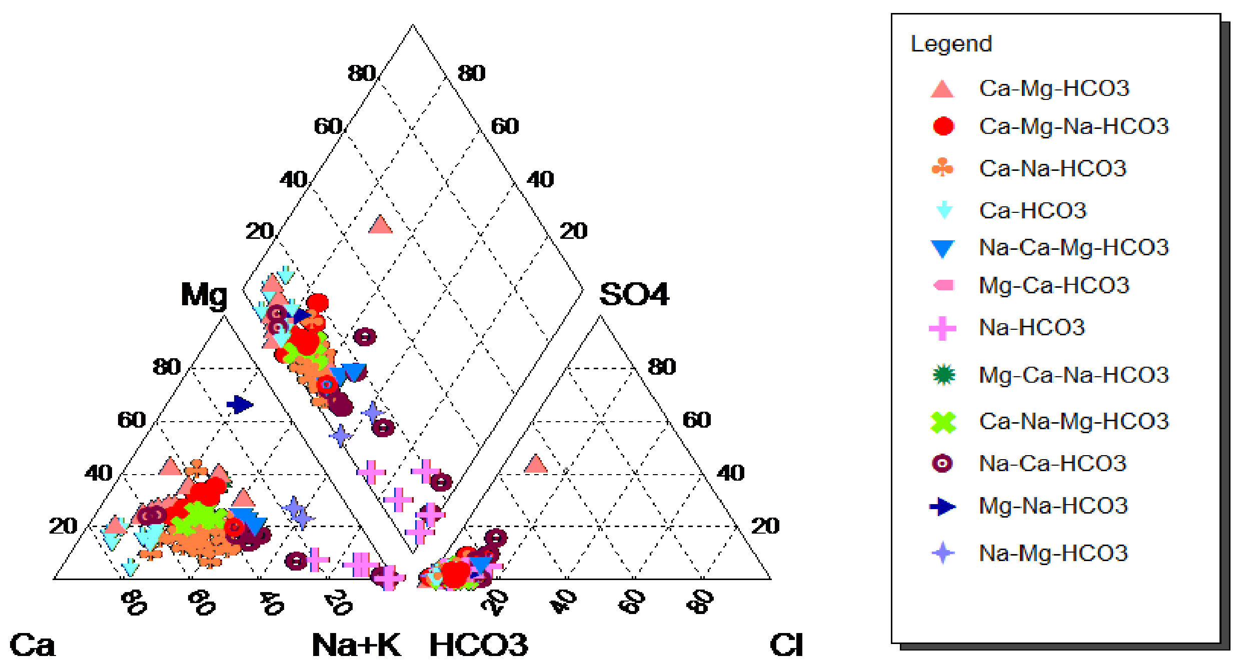

Figure 21: Piper plots of shallow wells

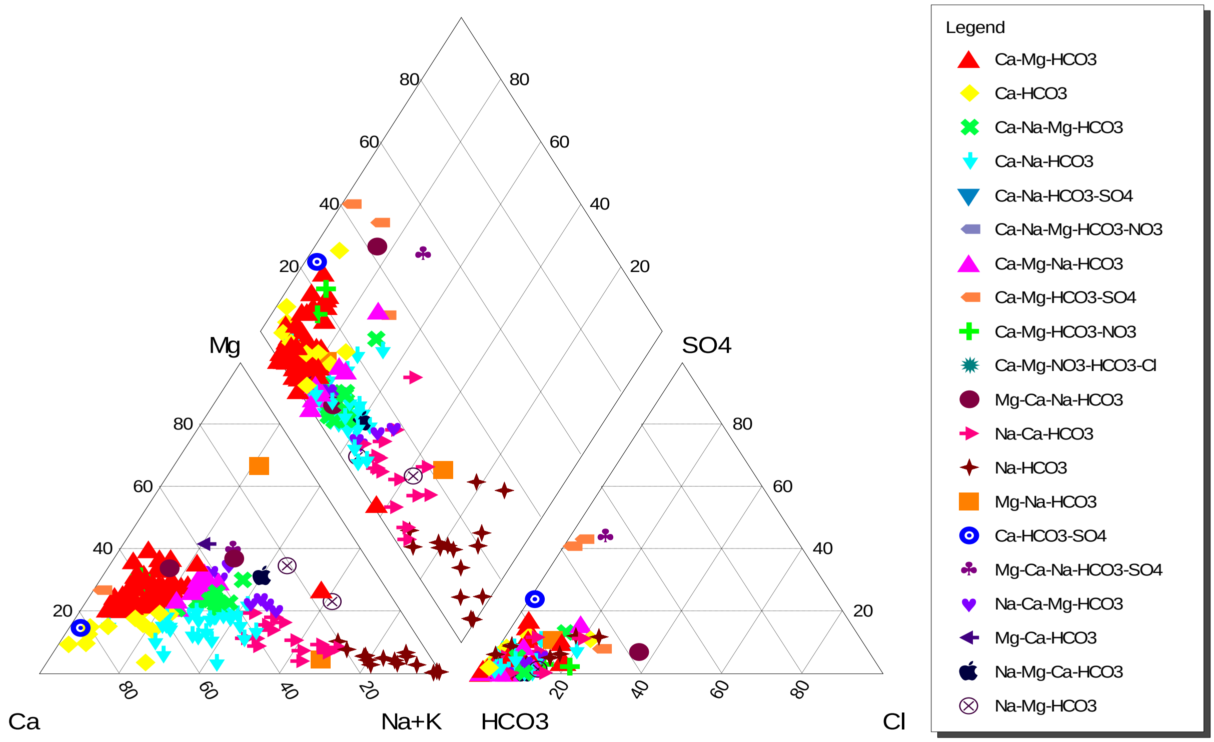

Figure 22: Piper plots of springs

5.6. Hydrochemistry of Surface Water

The hydrochemistry of surface water is represented by foure samples, which are taken from Jema, Holeta, LegeRobi and Awash Rivers. Surface water samples from Awash and Leg Robi Ca-HCO3 Water type, the water sample taken from Holeta river shows Mg-HCO3 water type. The surface water of Addis Ababa city shows very high concentration of Sodium, Nitrate, chloride and biological indicators of pollution such as algae and bacteria resulted from domestic and industrial activities, Tamiru (2008). Also in surface water bodies, the water sample from Jema River (RW-1) on the way Lemi to Alemketema near the bridge exhibits a high chloride concentration. This sample has a relatively higher TDS about (746 mg/l) which is unusual for river water chemistry under normal condition. The laboratory analysis result shows a relatively a high chloride (411 mg/l) and a high sulfate (64 mg/l) concentrations. It is impossible to say that the source of high concentration of chloride at the place could be from the lithology or groundwater, because the area is sedimentary terrain. So, the probable source could be an artificial source that is human or animal activity. In general the surface water in the study area is dominantly Ca-HCO3 type and the same with ground water chemistry where they are recharged by the rivers.

ID	River name	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	water type
Rw-1	Jema	491700	1095608	429	746	7.2	22	5	35	15	411	<0.04	0.5	188	0	64	Cl-HCO3
Rw-2	Holeta	446268	1004251	248		7.7	9	2	24	66	1	2.2	0.2	157	0	4	MgCaHCO3
RW-3	LegRobi	420767	1041048	276		7.6	9	2	31	10	2	4	0.3	171	0	2	Ca-Mg-HCO3
RW-4	Awash	406400	996465	444	800	7.1	23	5	48	11	8	4	0.3	262	0	12	Ca-Na-HCO3

Table 7: Chemical data of rivers

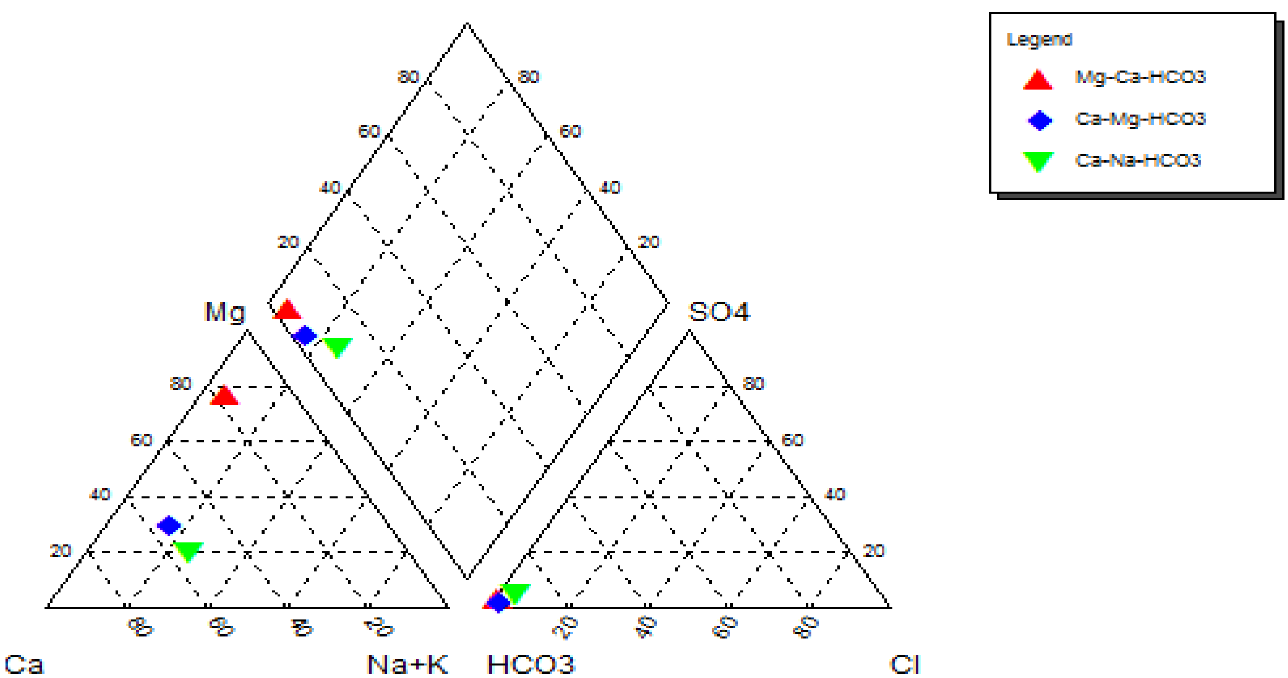

Figure 23: Piper plot diagram of surface water.

5.7. Aquifer Systems and Hydrochemistry of ground water

5.7.1. Hydrochemistry of Groundwater in Volcanic Aquifers problem

The groundwater in the volcanic aquifers receives its recharge from adjacent mountains and Ridges and also from direct precipitation. The recharge from those sources infiltrates and then percolates through the fracture, joints and weathered surfaces by dissolving different minerals and substances. Along its flow, the groundwater will be enriched by different chemical compounds.

The volcanic aquifers of the study area are comprised by different mafic to felsic rocks of basalt, trachy basalt, trachyte, rhyolite, ignimbrite, ash and tuff. Accordingly the ground water chemistry shows some variation throughout these aquifers. The ground water chemistry of these aquifers is represented by 336 water samples. The dominant water type is bicarbonate type, but in some places there are minor anomalies of nitrate. In some places especially, in urban centers groundwater chemistry shows Ca-NO3 and Ca-Cl type. These anomalies may be related to seepage from contaminated river water and surface run off.
The TDS of volcanic aquifers shows a big variation and range from 34 mg/l to 3527.7 mg/l with an average of 302 mg/l.

The lowest TDS is observed in cold springs (Csp-20), which is found on recharge areas of highly elevated mountains and ridges such as Entoto area, where there is active circulation of ground water. The highest TDS in BH-26 (3527.7 mg/l) area associated the NE-SW Felwuha and N-S Entoto faults. A relatively higher TDS is also observed in BH-19 (658.31 mg/l) , BH-79 (696 mg/l), BH-27(1193 mg/l), BH-57 (798 mg/l), BH-59 (1148 mg/l), BH-169(1580 mg/l), BH-170(1530 mg/l) which are related to the deep groundwater circulation and long settling time of groundwater.

In addition, high TDS values are seen in Dahana, DebreLibanos, and Lelisa, areas on Csp-6 (707.39 mg/l), Csp-27 (742.27 mg/l) and Csp-39.This may be attributed to mixing of groundwater with other sources due to human or animal activities. The ground water in volcanic aquifers of Addis Ababa city is highly susceptible to pollution problem, since wastes from domestic and industrial activities are increasing day to day. Relatively high concentrations of sulfate are observed from the chemical analysis. This could be attributed to the highly polluted water sources of rivers and surface water, which can serve as a local recharge to the groundwater directly or indirectly to the area.

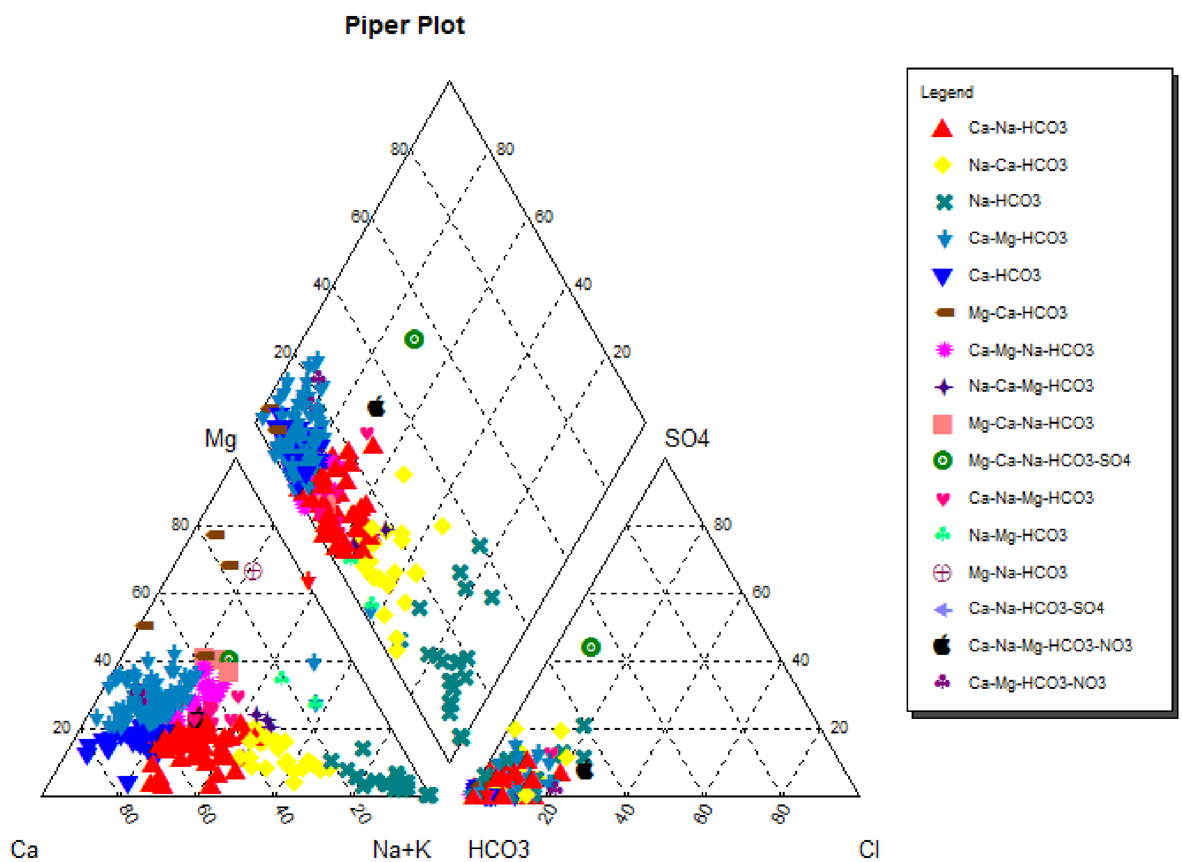

Figure 24: Piper plot diagram of natural water on volcanic aquifers

5.7.2. Hydrochemistry of Groundwater in Mesozoic and Quaternary Sediments

The ground water chemistry of Mesozoic sediment is a little bit different from those of volcanic. Around 34 samples were taken from Mesozoic sediments (Sandstone and Limestone). The common water types are Ca-HCO3. The TDS varies from 63.22-1045.83 mg/l with an Average of 563.88 mg/l. The lowest TDS is observed in Csp-78 (63.22 mg/l) on the lower Sandstone and the highest are in Csp-9 (1045.8 mg/l) on the limestone. There is a higher TDS Value in limestone than sandstone aquifers. This is due to the high solubility and dissolution Capability of limestone by water.

The chemical composition of water from this aquifer is under the permissible range with sulfate exceptions. There is a high concentration of sulfate in limestone as well as in some places of sandstone. This could be associated with the intercalation of gypsum. Such condition is clearly seen at Folfoy Merhabet; csp-43 (202 mg/l), QendiMetarobe; Csp-53 (177 mg/l) and ShontaJeldu; Csp-70 (80 mg/l).The bicarbonate concentration shows also higher value in Limestone terrain. Becuase of their outcrop availability in the deep canyons of the Blue Nile, Muger, Guder, Jema as well as their tributaries and due to the absence of big urban centers, the ground water quality in these areas is good with little risk of pollution.

In Quaternary sediments of the area, the groundwater chemistry is the same as their source rock with a slight difference. There are about 35 water samples taken from this aquifer. The water type is predominantly bicarbonate type. The TDS ranges from 57.23- 685.15 mg/l with an average of 367.3 mg/l. The groundwater in this aquifer is unconfined and phreatic and hence there could be a potential of ground water pollution directly from surface water by human or animal activities

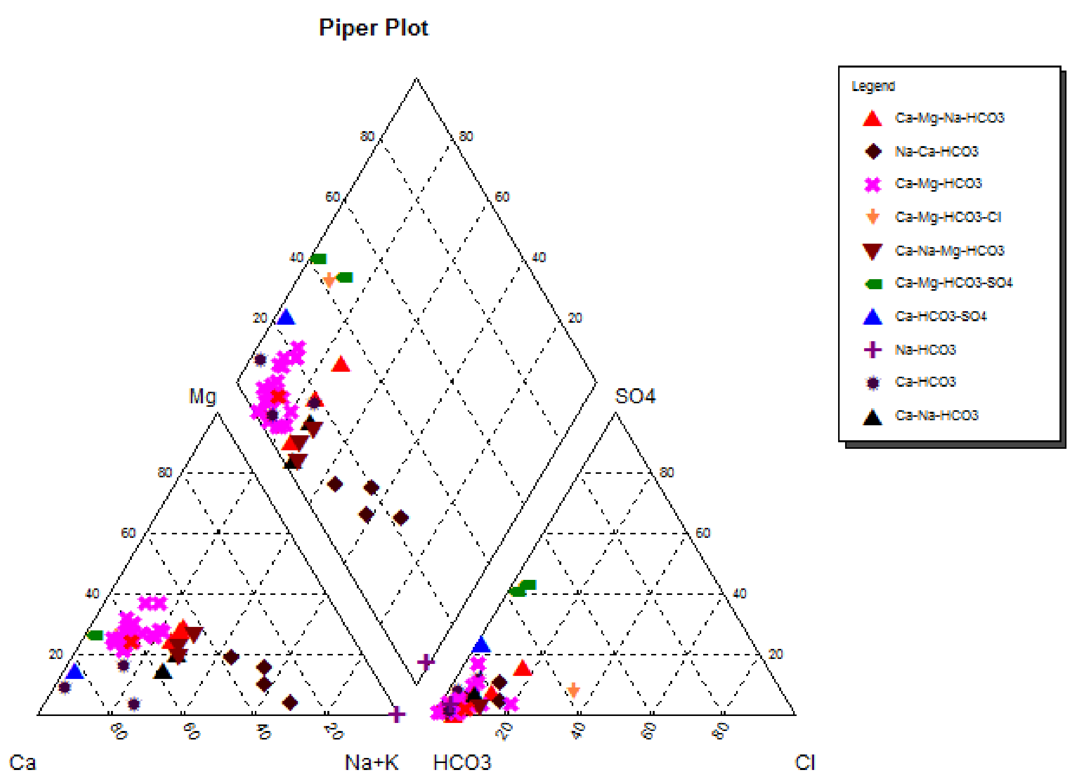

Figure 25: Piper plot diagram of natural water on Mesozoic sediments springs and Borehole

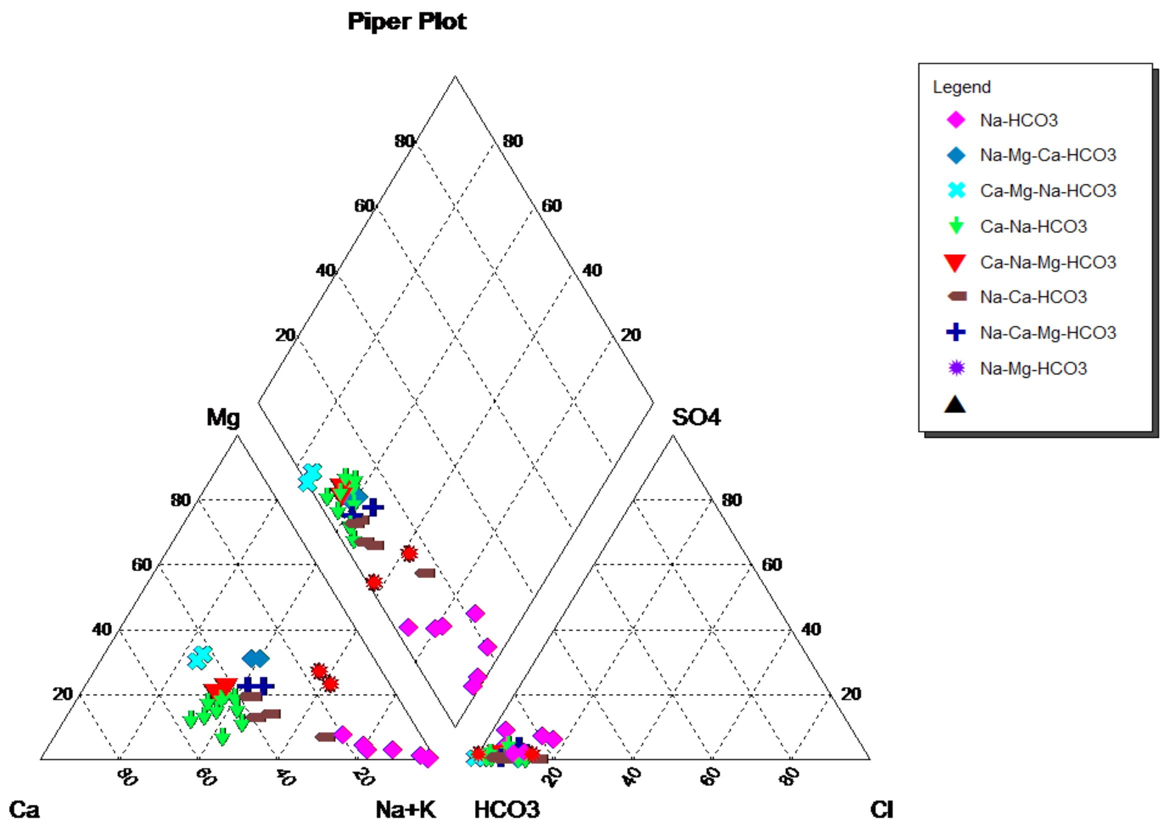

Figure 26: Piper plot diagram of natural water in quaternary sediments, alluvial and elluvial, (Boreholes, springs, and Dug wells).

5.8. Quality of water for public use

Water quality affects the daily lives of everyone and thus it is one of the most important topics addressed in water-supply studies. Concerns about the quality and safety of the Nation's water have led to the growth of a large industry devoted to filtering, treating, or bottling water for domestic use and human consumption. The variation of chemical properties of groundwater in the aquifer is due to many factors including where water enters, the distance it travels and the rock types it contacts within the aquifer, and human activity. The main objective of purification and water treatment is to get pure water from available sources and subject it to processing which will ensure water of good physical quality, free from unpleasant test or oder and containing nothing which might be determined to health.

Ethiopia has its own standard guideline values, but recognizes the WHO standards as a target for drinking water. The suitability of water of the study area for drinking purpose has been checked in reference to the standard for drinking water quality set by WHO (2008) and Ethiopian guideline values which are higher than the WHO maximum allowable concentration standards for drinking water quilt. In the study area, evaluation of water samples from bore holes, shallow wells, springs and surface water is analyzed and compered with the Ethiopian guideline value. These water values are analyzed with respect to sodium, fluoride and TDS.

Physico-Chemical parameters	**WHO Standard**	**Ethiopian standard**	**Water samples% above Ethiopian standard**
pH	6.5-8.5		
TDS(mg/l)	1000	1776	2.4
Na	200	358	3
F	1.5	3	4.2
NO3	45	50	0
Cl	250	533	0
SO4	400	483	0
Total Hardness.	500	392	0.25

Table 6: Summery of water quality parameters detected in groundwater sample (BCEOM-Seureca, 2000)

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Mesozoic sedimentary rocks dip away from Abay gorge which was formed on the zone of maximum crustal swell (uplift) along regional fracturing. Tertiary period volcanic rocks, which were formed due to outpouring of magma through fractures along maximum swell, are laid on the dipping Mesozoic sedimentary units. Late tertiary period faulting brought about rifting and associated volcanic activities. Recent volcanic rocks and lacustrine deposits were also formed during the Quaternary period. The area can be divided in to three geomorphologic features (zones): central gentle slopes and plateau, western, northwestern and northeastern deep gorges of Blue Nile, Guder, Muger and Jema rivers and low elevation area, and elevated picks of mountains and ridges.

Fissured aquifers hosted in Tertiary basalts are the main hydro stratigraphic unit where ground water is accumulated. Porous aquifers of sandstone, alluvium, fissured and karst aquifers of limestone have also good groundwater holding and bearing capacity. They are classified as high to moderately productive aquifers. Mesozoic sandstone possesses both primary and secondary permeability for groundwater movement and occurrence. The main water bearing horizon is constituted by interstitial spaces. In addition, the groundwater occurrence and movement is governed by secondary fractures and joints which enhanced the porosity and permeability. In this aquifer there are many springs following the NE-SW and N-S faults. In general, these rocks are classified as high productive aquifers. The productivity of Antalo limestone is highly dependent on secondary porosity (Fractures, joints and Karsts). Springs of high yield are concentrated on karst and fissured aquifers of limestone. This rock is found to be poor in groundwater occurrence where it is massive and fresh. But in most places, it is highly fractured and karstified having good groundwater occurrence, and it is classified as high productive aquifer. The porous aquifers of alluvium and upper sandstone bear groundwater by dug wells and springs respectively. Lower ignimbrite exposed in the southern part of the study area has a relatively moderate potential to groundwater due to its limited weathered and fractured surface. It is mapped as moderately productive aquifer. The Tertiary acidic volcanic rocks of trachyte and rhyolite have minor significance in occurrence of groundwater resource.

Aquifer characterization is the process of quantifying the physical and chemical features of an aquifer which control groundwater or contaminant movement in the subsurface. To characterize aquifer quantitatively the borehole density and spatial distribution are other required conditions. Groundwater flow direction in the study area is mainly controlled by structures and geomorphology. Rain water infiltrates in outcrops of volcanic rocks and flows within aquifers from recharge areas into discharge areas in shallow and deep circulation.

Data obtained from the analyses of groundwater of the study area from AAWSA, GSE and WWDSE are used in the characterization of aquifer in terms of chemical constituents of groundwater. Analyses of spring and borehole sample show considerable differences in the amounts and dominance of major ions. Chloride, Nitrate, Fluoride and total dissolved solids (TDS) are commonly used as groundwater quality indicators of potential contamination of groundwater. The concentration of nitrate and chloride are relatively high in densely populated areas. High nitrate concentration levels indicate contamination from municipal wastes, whereas high chloride concentrations in groundwater show contamination from pit Latrines, waste disposals and from city water supply.

Moderately high pH values that are commonly associated with water are high in bicarbonate.TDS and conductivity of the water samples show increase in concentration parallel to the general ground water flow direction. The highest TDS is about 3527.7 mg/l on the Felwuha fault while the lowest is 34 mg/l on the highly elevated Entoto Mountains.

In some parts especially in the rift zone and samples from some boreholes which are associated to fault Zones show fluoride concentration is higher than the normal drinking water standard. High Fluoride concentration, up to 28.6mg/l in central and rift zones associated with thermal waters due to the high temperature which helps the ion to precipitate freely in aqueous solution also the acidic rock has a big contribution. Calcium is the only dominant cations in a Sample collected from boreholes. Bicarbonate is by far the dominant anion water sample collected from boreholes with variation in composition of Ca, Na and Mg. The relative abundance of the cations indicates the dissolution of minerals that constitute either basic or acidic volcanic rocks.

The chemical analysis of major ions in spring water sample shows Sodium and Calcium as the dominant cations and they are more or less equally abundant. The classification of water has been based on dominant ions which are bicarbonate water ($HCO3$) and bicarbonate sulfate Water ($HCO3$-$SO4$). The cat ion groups associated with bicarbonate are Ca, Ca-Mg, Ca-Mg-Na, Ca-Na-Mg, Ca-Na, Mg-Ca, Na-Ca and Na-Ca- Mg. The water type in the study area is predominantly bicarbonate type (Mg-$HCO3$, Ca-$HCO3$, and Na-$HCO3$).

According to Ethiopian standard of water quality most of the water samples taken in this analysis have good qulity except some samples. Among the 405 all water sample analyzed TDS 2.2%, Na 3 %, F 5.2 % , $NO3$ 4.2 % of the total samples that analyzed are above the Ethiopian water standard guidline.

6.2. Recommendations

Detail hydrogeological and hydro chemical investigations are recommended in order to identify and delineate zones of economic and investment interest like thermal zones like along regional faults, gas rich water zones like areas surrounding acidic volcanics, Suspected zones that limit portability of water like high fluoride, high TDS and other parameters which determine the usefulness of water for a given purpose should be carefully investigated.

The study area, along the major regional faults like Ambo-Filwuha, Ambo-Butajira and Dukem-Abusera fault zones, where TDS and fluoride concentrations are expected to be high, chemical analysis of water samples should be conducted before well completion during drilling in order to save at least the cost of construction materials. Appropriate environmental protection measures should be done in areas with highly permeable geologic formations like in Adaa plains, Akaki well field and in areas surrounding Holota where active flashing of surface runoff is expected to pollute groundwater. Impact assessment should be done for the chemicals/fertilizers used by flower farms.

In urban center, cares should be taken to the ground water pollution. The surface water of Addis Ababa city is highly polluted and contaminated. This could directly or indirectly pollute the volcanic aquifer of Addis Ababa city. The chemical analysis of water samples from some shallow boreholes in Addis Ababa city show contamination from surface water. So the surface water of the city should be controlled and protected. In the study area, there are numerous numbers of flower farming. The risk for pollution of groundwater will be high due to the waste disposal from such kind of farming. It should be given a special attention for flower farming disposal.

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Annex-1: Selected Lithologic logs

Inchini mapping well

No	*Depth interval, m*	*Lithologic Description*
1	*0-12*	*Fractured basalt*
2	*12-24*	*Highly weathered and fractured basalt*
3	*24-50*	*Moderately weathered and fractured basalt*
4	*50-76*	*Slightly fractured basalt*
5	*76-92*	*Massive basalt*
6	*92-96*	*Highly weathered and fractured basalt*
9	*96-146*	*Massive basalt*

2. Holota mapping well

11	*114-122*	*Fractured & weathered basalt*
12	*122-126*	*Massive basalt*
13	*126-132*	*Highly weathered basalt*
14	*132-150*	*Massive basalt*
15	*150-156*	*Moderately weathered basalt*
16	*156-186*	*Massive basalt*
17	*186-214*	*Moderately weathered & fractured basalt*
18	*214-236*	*Massive basalt*
19	*236-300*	*Scoraceous basalt*

3. Holota Nano Galgala shallow well

No	*Depth, in m*	*Lithology*
1	*0-15*	*Alluvium*
2	*15-21*	*Basalt*
3	*21-24*	*Highly weathered basalt/clay*
4	*24-50*	*basalt*

4. Holota Marko flower farm well

No	*Depth, in m*	*Lithology*
1	*0-200*	*Fractured basalt*
2	*200-220*	*Scoraceous basalt*

5. Kimoye mapping well

No	*Depth, in m*	*Lithology*
1	*0-8*	*Top soil*
2	*8-36*	*Clay*
3	*36-46*	*Highly weathered*
4	*46-52*	*Coarse gravel*
5	*52-64*	*Highly weathered basalt*

5. Dimajalewa mapping wells

No	*Depth, m*	*Lithology*
1	*0-52*	*Tuff & Pumice*
2	*52-96*	*Moderately weathered basalt*
3	*96-110*	*Circulation loss*
4	*110-172*	*Fractured & weathered basalt*
5	*172-300*	*Tuff & Loose pyroclatic deposited*
6	*300-311*	*Scoraceous basalt*

6. Asgori mapping well

No	*Depth , m*	*Lithologic description*
1	*0-1*	*Black top soil*
2	*1-24*	*Moderately weathered tuff*
3	*24-76*	*Moderately weathered ignimbrite*

No	Depth , m	Lithologic description
4	76-96	Highly weathered ignimbrite
5	96-136	Ash
6	136-154	Moderately weathered basalt
7	154-164	Massive basalt

7. Tefki Harojila

No	Depth, m	Lithology
1	0-22	Weathered pyroclastic deposit
2	22-30	Massive trachyte
3	30-36	Weathered trachyte
5	36-80	Massive trachyte
6	80-122	Scoraceous basalt
7	122-132	Ignimbrite
8	132-170	Scoraceous basalt
9	170-280	Scoria

8. Bantu Jawarokora mapping well

No	Depth in, m	Lithology
1	0-16	Black top soil
2	16-32	Highly weathered Rhyolite (Clay)
3	32-74	Moderately weathered Rhyolite
4	74-80	Pumice
5	80-118	Slightly fractured Basalt
6	118-194	Weathered Trachyte

9. Melkakunture mapping well

No	Depth, m	Lithologic description
1	0-2	Black top soil

No	Depth, m	Lithologic description
2	2-20	Rhyolite
3	20-26	Tuff
4	26-34	Ignimbrite
5	34-54	Highly weathered & fractured basalt
6	54-90	Massive basalt
7	90-110	Fractured basalt
8	110-134	Rhyolite
9	134-188	Ignimbrite
10	188-192	Pumice
11	192-290	Scoraceous basalt

10. Abusera mapping well

No	Depth, m	Lithologic description
1	0-148	Tuff and weathered ignimbrite
2	148-192	Fractured basalt
3	192-330	Tuff and loose pyroclastic deposite

11. Adulala mapping well

No	Depth, m	Lithology
1	0-4	Top soil
2	4-8	Scoraceous basalt
3	8-12	Paleosole
4	12-16	Scoraceous basalt
5	16-22	Circulation loss
6	22-26	Clay
7	26-30	Circulation loss

No	Depth, m	Lithology
8	30-32	Scoria
9	32-50	Circulation loss
10	50-54	Scoria
11	54-60	Circulation loss
12	60-128	Tuff
13	128-212	Scoraceous basalt
14	212-225	Highly fractured basalt

12. Modjo mudasenkele mapping well

No	Depth ,m	Lithology
1	0-12	Top soil
2	12-24	Moderately weathered trachyte
3	24-102	Highly weathered tuff
4	102-146	Weathered and fractured trachyte
5	146-225	Highly weathered tuff
6	225-230	Circulation loss
7	230-320	Highly weathered tuff
8	320-330	Scoraceous basalt

12.Chancho mapping well

No	Depth, m	Lithologic description
1	0-38	Black top soil
2	38-44	Slightly weathered scoraceous basalt
3	44-146	Highly weathered scoria
4	146-164	Highly weathered basalt
5	164-176	Massive basalt

6	*176-186*	*Fractured basalt*
7	*186-188*	*Highly weathered scoria*
8	*188-210*	*Massive basalt*
9	*210-220*	*Highly weathered scoria*
10	*220-230*	*Highly weathered basalt*
11	*230-240*	*Moderately weathered scoria*
12	*240-264*	*Massive basalt*
13	*264-268*	*Highly weathered scoria*
14	*268-280*	*Massive basalt*
15	*280-290*	*Highly weathered scoraceous basalt*
16	*290-300*	*Scoraceous basalt*
17	*300-308*	*Fractured basalt*
18	*308-312*	*Massive basalt*
19	*312-320*	*Moderately weathered scoria*
20	*320-324*	*Massive basalt*

14 Segno Gebeya mapping well

No	*Depth in ,m*	*Lithology*
1	*0-6*	*Black top soil*
2	*6-28*	*Moderately weathered scoraceous basalt*

15. Legadadi mapping well

No	*Depth ,m*	*Lithology*
1	*0-8*	*Black top soil*

2	*8-70*	*Highly weathered rhyolite*
3	*70-86*	*Highly weathered tuff*
4	*86-116*	*Moderately weathered tuff*
5	*116-140*	*Moderately weathered basalt*
6	*140-170*	*Slightly fractured basalt*
7	*170-180*	*Highly weathered ignimbrite*
8	*180-282*	*Moderately weathered ignimbrite*
9	*282-354*	*Slightly weathered scoraceous basalt*

16. Sululta mapping well

No	*Depth, m*	*Lithology*
1	*0-8*	*Black top soil*
2	*8-56*	*Highly weathered rhyolite*
3	*56-84*	*Moderately weathered basalt*
4	*84-94*	*Fractured basalt*
5	*94-96*	*Highly weathered ignimbrite*
6	*96-110*	*Highly weathered rhyolite*
7	*110-120*	*Massive basalt*
8	*120-126*	*Fractured basalt*
9	*126-140*	*Highly weathered basalt*
10	*140-156*	*Fractured basalt*

17. CMC mapping well

No	*Depth, m*	*Lithology*
1	*0 - 48*	*Moderately weathered tuff*
2	*44 -100*	*Slightly weathered ignimbrite*
3	*100 -104*	*Clay*
4	*104 -134*	*Moderately weathered ignimbrite*
5	*134 -190*	*Pyroclastic deposit*

No	Depth, m	Lithology
6	190 - 208	Highly weathered ignimbrite
7	208 - 262	Massive basalt
8	262- 368	Moderately weathered ignimbrite
9	368-??	???

18. Yeka Michael well

No	Depth, m	Lithologic description
1	0-209	Trachyte, rhyolite
2	209-216	Trachy basalt

19. AYAT-II- New high yield artesian well

No	Depth, m	Lithologic description
1	0-197	Trachyte, rhyolite tuff
2	197-200	Fractured basalt

20. Akaki well field deep well

No	Depth ,m	Lithology
1	0-14	Clay
2	14-90	Scoraceous basalt
3	90-160	Vesicular basalt
4	160-250	?
5	250-270	Amygdaloidal filled basalt/weathered
6	270-300	?

21. Akaki well field collapsed

No	Depth, m	Lithologic description

No	Depth, m	Lithologic description
1	0-4	Black top soil
2	4-42	Moderately weathered & fractured basalt
3	42-80	Slightly fractured basalt
4	80-86	Slightly weathered vesicular basalt

22. Dukem mapping well

No	Depth ,m	Lithology
1	0-26	Weathered tuff and pyroclastic deposit
2	26-40	Moderately weathered trachyte
3	40-104	Highly weathered trachyte
5	104-132	Moderately weathered trachyte
6	132-178	Scoraceous basalt
7	178- 180	Paleosole
8	180-206	Scoraceous basalt
9	206-226	Weathered tuff
10	226-242	Weathered basalt
11	242-254	Massive basalt
12	254-264	Scoraceous basalt
13	264-282	Massive basalt

Annex 2: Location of boreholes and Depth of the wells.

Region	Zone	Woreda	Kebele	Local Name	UTME	UTM N	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Total Casing	Total Screen
Oromiya	North Shewa	Berhe		Tafo, Ropack International real estate	487800	1E+06	2488	80	25	5.6	23		
Oromiya	East Shewa	Adaa		D/Z-Veternary College BH2	500078	968505	1880	56	15	15	0.5		
Oromiya	North Shewa	Berhe		Legadadi-NAS Food Factory BH No	488150	1E+06	2489	175	26	1.6	69		
Oromiya	North Shewa	Berhe		Sendafa-Said Ali Paint Factory	488243	1E+06	2486	96	26	2	14		
Oromiya	North Shewa	Berhe		Sululta Depot	472975	1E+06	2650	114	12	2.2	11		
AA	AA	AA		AA-Bole Lem-2-99	482896	991871		205	14	13	1.2		
AA	AA	AA		AA-Bole Lemi-5-99	484152	989566		182	0	17	9.7		
AA	AA	AA		AA-Mekanisa-99	467135	989840		213	3	25	94		
AA	AA	AA		AA-Mekenisa Harbu-2-99	467723	990028		161	4	20	7.8		
AA	AA	AA		AA-Repi-Harbu-5-99	465591	989872		257	7.8	30	59		
AA	AA	AA		AA-Repi-1-99	465295	990132	2282	200	9.8	20	22		
AA	AA	AA		AA-Mekanissa-99	470070	991000		170	9.5	10	56		
AA	AA	AA		AA-Bole Lemi-99	482850	989900		168	0	20	0		
AA	AA	AA		AA-Repi-Dertu-99	466308	989421		185	4.2	15			
AA	AA	AA		AA-Repi-Alem Gena-99	466200	988800		100	0	5	38		
AA	AA	AA		AA-Burayu-99	464031	1E+06		200	0	18	6.9		
Oromiya	East	Adaa		D/Z-Oromiya	491980	96584	1958	250	140	11	0.1	250	

Region	Zone	Woreda	Kebele	Local Name	UTME	UTM N	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Total Casing	Total Screen
AA	AA	AA		AA-Sebeta	460295	98676	2222	158	31	17	50		
Oromiya	West Shewa	Wolmera	Wolmera	Holota-Marginpar Flower plc	447549	1E+06	2520	203	24			203	
Oromiya	South West Shewa	Melka Kunture	Awash	Melkakunture-Awash	456314	962592	2014	290	0	36	2.7	154	54
Oromiya	East Shewa	Adaa	Ziquala	Abusera	478990	955803	1830	330	38	2	42	204	0
Oromiya	North Shewa	Berehe	Chancho	Chancho	473911	1E+06	2543	324	1	6	158	324	84
Oromiya	North Shewa	Sendafa	Legadadi	Legadadi	493518	1E+06	2468	354	28	15	43	354	78
AA	AA	Akaki	Akaki	Akaki	476790	981229	2070	328	0			0	0
Oromiya	North Shewa	Wuchale	Woberi	Woberi	501332	1E+06	2654	209	71	16	0	209	42
Oromiya	East Shewa	Adaa	Dukem	Dukem Rural	477741	965964	1891	188	86			0	0
Oromiya	North Shewa	Sululta	Sululta	Sululta	474421	1E+06	2610	304	18	15	49	304	66
Oromiya	South West Shewa	Alem Gena	Tefki	Tefki-Harojila	450359	981037	2084	280	11	19	42	281	78
AA	AA	Bole Kifleketema	CMC-Meri	CMC	484821	994284	2320	368	42	5.8	59	225	0
Oromiya	East Shewa	Adaa	Modjo Ude	Modjo Ude	506765	957179	1836	278	19	17	17	278	66
Oromiya	East Shewa	Adaa	Borora	Borora	505014	970969	1879	126	21			0	0
Oromiya	North Shewa	Aleltu	Onodo	Onodo	513157	1E+06	2904	348	97	10	54	188	66
Oromiya	East Shewa	Adaa	Adulala	Adulala Roge	490513	951595	1770	178	101			0	0
Oromiya	East Shewa	Adulala	Adulala	Adulala Roge	490444	951336	1765	225	98	16	0.9	225	72
Oromiya	East	Lume	Muda	Modjo Muda	506464	94199	1697	268	73	10	23	268	60

Region	Zone	Woreda	Kebele	Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Total Casing	Total Screen
Addis Ababa	Nefas Si	Nefas Silk Laft		Lebu mekanisa	469191	989547			4.2	4.2	102	230	90
Oromiya				Legatefo	486738	1001391	2455		8.1	28		250	90
Addis Ababa	Ferensay			Ferensay,Ras Kasa	475165	1001449			106	18	1.2	260	96
Addis Ababa	Akaki	Akaki		Fanta valley III	481828	981943	2064		29	7	146	260	96
Oromiya	Bole	Bole		Bole Lemi,SMV 19	482757	990710	2227		0	32	33	280	96
Addis Ababa	Yeka	Yeka		Summit,Michael	481681	994296	2280		12	13	145	250	84
Addis Ababa				Alem Bank, Kidane Mihiret	466430	994219	2367		250	2	147	250	80
Oromiya	West Shewa	Meta Robi	Lega Robi	Inchini-Lega Robi	421795	1E+06	2457	146	20	16	9.9	135	42
Oromiya	North Shewa	Bekie	Bekie	Bekie	507086	1E+06	2578	300	26	6.1	163	300	60
Oromiya	East Shewa	Adaa	Dukem	Dukem Town	490336	970789	1924	282	91			282	90
Oromiya	South West Shewa	Tole	Jawaro Kora	Jawaro Kora	433200	959670	2111	194	0	19	17	194	42
Oromiya	West Shewa	Ejere	Holota	Holota	440274	1E+06	2525	300	12	36	25	289	66
Oromiya	South West Shewa	Becho	Teji Dima Jalewa	Dima Jalewa	413137	973900	2090	311	8.5	17	35	311	84
Oromiya	West Shewa	Ejere	Koradima	Kimoye Koradima	427395	992768	2109	243	6	18	36	243	72
Oromiya	South West Shewa	Becho	Asgori	Asgori	427126	971361	2075	308	4.2	36	3.7	302	90
Oromiya	South West Shewa	Melka Kunture	Awash	Melkakunture-Awash	456314	962592	2014	290	0	36	2.7	154	54
Oromiya	North Shewa	Mulo	Segno Gebeya	Segno Gebeya	455620	1E+06	2610	273	70	2.1	100	273	66

Annex 3: Location of springs and discharge

ID	UTME	UTMN	Local name	Lithology (Aquifer) SP	Discharge
Sp1	494137	1093448	Beleblity salayishN.shewa,Amhara	Fractured lime stone(karast)	15
SP2	465505	1075390	Wisi Briqe,Gerar,N.shewa	Fractured basalt	3
SP3	459615	1066487	Burqa Geberu, Nonof Chemeri / Yaya Gulelle / N.shewa,orma	Fractured basalt	7
SP4	454500	1063823	Haye, Deleti / Yaya Gulelle / N.Shewa / oromia	Vesiculated & Fractured baslt	0.5
Sp5	464186	1065719	Lemi,Lemi /yaya Gulelle /N. Shewa /Oromia	Fractured and weatherd basalt	5
Sp6	471680	1056576	Chefie fadu, Akako/ Wechale/ N. Shewa/oromia	Fractured basalt	0.5
sp7	446945	1066467	Qundi Agemso, Qundi Agemso/Degem/ N.shewa, Oroma	Fractured basalt	6
sp8	455086	1053735	Gonji, Buyema quat/ Yaya Gulelle/ N.Shewa	sand stone	2
sp9	458961	1110844	Goho, Abado/Herbo Abote/ N.Shewa/Oromia	Karstified lime stone	40
sp10	486264	1045358	Duber,01/ Sululta/N.Shewa/Oromia	Fractured & highly weatherd basalt	10
sp11	471668	1040491	Boku Abo, Boku ureta/Sululta/ N.Shewa/Oroma	Fractured basalt	0.5
sp12	459951	1048382	Leguda,Ada gimbichu/Sululta/N.Shewa/Oroma	Fractured basalt	0.5
sp13	451196	1027438	Babolle,Mullo Quersa/Mullo/N.shewa, Oroma	Fractured basalt	0.03
sp14	483313	1005608	Quersa, Quersa/Sendafa/N.Shewa/Oromia	Rhyolite,trachyte and tuff intercalate	0.6
sp15	474208	1005540	Entotomariam, Kebele 20/Addis Ababa	Highly waetherd tuff	0.2
sp16	457146	1004953	Billbile, wata bicha	Laterait soile	1.2

ID	UTME	UTMN	Local name	Lithology (Aquifer) SP	Discharge
sp17	492039	1005044	Yeneguswehа,Guto	Highly weatherd trachyte	0.5
sp18	463999	1018139	Burka Gibsa, Hawaso/Sululta/N.shewa/	Boulder type basalt	1
Sp19	463263	1037563	Seyo, lillo chebeka/Sululta/N.Shewa/Oromia	Fractured basalt	0.5
Sp20	473059	1006482	Chefie entoto, Guasa/Sululta/N.shewa	Highly weathered trachyte	0.25
Sp21	453492	1002295	Menagesha, Kebele 01/Welmera/W. Shewa	weathered basalt	2
Sp22	453776	998997	Ashenda, Menagesha gedam/Welmera/	weathered basalt	0.8
Sp23	466264	996974	Mesk woha, Gerar	sand stone	1.6
Sp24	0502003	1069113	Bri / Mukturi /,N. Shewa , Oromia	Fractured columnar basalt	1.4
Sp25	500465	1073976	Kecha , Ilu Eteya / Wuchale , North shewa Oromia	Fractured basalt	0.5
Sp26	491280	1078405	Wedenki,Dembi Gerage / Ensaro , N.shewa Amhara	Fractured columnar basalt	2.0
Sp27	475032	1087994	Mesk woha, Gerar Jarso, N.Shoa	Sand stone	1.6
Sp28	501798	978894	Godino	Basalt	10.0
Sp29	454124	1002590	Gefersa Ethio-Cup	Basalt	2.0
Sp30	454124	1002590	Menagesha Town WS	Basalt	10.0
Sp31	417869	1105911	Gohasion	Basalt	1.0
Sp32	575952	1120671	Molale	Ignimbrite	1.5
Sp33	569556	1116964	Menasaria	Basalt	2
Sp34	560815	1108338	Kolo Margafea	Basalt	0.035
Sp35	569894	1110557	Astoye	Basalt	0.05
Sp36	582994	1125394	Melaya	Ignimbrite	0.01

Annex 4: Pumping test data result

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
AA-Burayu Spring Water Bh1/Aqua Addis	462743	1002521	2620	250	35	3	154.8	0.02	2.01
AA-Anwar Mosque	471300	998200	2445	87.5	16.5	0.5	43	0.01	1.21
AA-Anwar Mosque	471300	998200	2445	87.5	16.5	0.5	43	0.01	1.21
AA-Armay hospital	469800	996300	2350	51.9	16.5	4.2	36.7	0.11	11.87
AA-Awash Winery	469900	996000	2335	67.1	13.7	4.2	36.7	0.11	11.87
AA-Civil Aviation	469800	996200	2342	60	7	0.25	13	0.02	1.99
AA-Ethio-Plastic factory	478450	995600	2353	171	86.65	1.5	57.11	0.03	2.72
AA-Armay hospital	469800	996300	2350	51.9	16.5	4.2	36.7	0.11	11.87
AA-Awash Winery	469900	996000	2335	67.1	13.7	4.2	36.7	0.11	11.87
AA-Civil Aviation	469800	996200	2342	60	7	0.25	13	0.02	1.99
AA-Ethio-Plastic factory	478450	995600	2353	171	86.65	1.5	57.11	0.03	2.72
AAWSA Ras Kassa Sefer/Ferensay	475000	1001300	2542	168	73.54	18	4.92	3.66	379.32
AA-Anwar Mosque	471300	998200	2445	87.5	16.5	0.5	43	0.01	1.21
AA-Armay hospital	469800	996300	2350	51.9	16.5	4.2	36.7	0.11	11.87
AA-Awash Winery	469900	996000	2335	67.1	13.7	4.2	36.7	0.11	11.87
AA-Civil Aviation	469800	996200	2342	60	7	0.25	13	0.02	1.99
AA-Ethio-Plastic factory	478450	995600	2353	171	86.65	1.5	57.11	0.03	2.72
AA-Anbessa/Walya Transport(Diabaco)	471200	993700	2300	85	23.3	5	18.7	0.27	27.72
AA-Abay Mesk Soft Drinks-1(pepce)	473000	992700	2292	121.2	110.6	4.17	1	4.17	432.35
Misrak flour & oil mills-2	472900	992500	2280	156.2	89.6	2	51	0.04	4.07
United Oil mills-1	473200	992400	2287	68.5	29	2.55	19.8	0.13	13.35
AA-Adey Abeba Cotton Mill-2	473848	990072	2247	100	39.3	0.4	46.3	0.01	0.9
National Road Transport Corp	475000	987800	2180	172	27.8	4	119.2	0.03	3.48
Meher Fiber Factory-2	475335	980717	2075	179.4	17.1	2.6	109.9	0.02	2.45
Akaki Indo-Europian Textiles-1	476500	981300	2055	53.3	3.7	1.38	10.6	0.13	13.5
Akaki Indo-Europian textiles-2	476600	981500	2070	126.2	3.5	4.17	70	0.06	6.18
Akaki Mesfin Zelwlew Dairy Farm	481507	976220	2100	132	120	5	1	5	518.4
AA-Ethio-Metal Meal-2	476400	980700	2058	126	53.4	3.5	16.7	0.21	21.73
Akaki Ethio-Fiber-1	477400	979500	2080	96	27.4	2.5	44.7	0.06	5.8
Akaki Telecommunications	476600	978200	2065	79.2	46.4	2.12	2.4	0.88	91.58

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
AA-Kality Military Camp-1	475300	983800	2105	93	0	6.2	20.9	0.3	30.76
AA-American Embassy(Marine old)-1	473900	1001050	2564	200	14.55	2	128.45	0.02	1.61
AA-Kality Military Camp-2	475300	984000	2100	128.5	0	5.75	51.9	0.11	11.49
AA-Glass and Bottle Factory	467200	1001017	2517	150	35.3	4.54	64.7	0.07	7.28
AA-Anbessa Transport Garage	468400	1001016	2580	192	3	1.5	47.2	0.03	3.29
Alem Gena-Gen.Gebre Kebede	463600	988200	2280	64	27.5	3	6.1	0.49	50.99
Mercato privavte well	470600	998100	2450	38					11.87
AA-Coca Cola Factory-1	470000	996400	2335	38		6.67	12	0.56	57.63
AA-Coca Cola factory-2	470000	996400	2338	44	14	6.67	12	0.56	57.63
National Palace-2	473400	996300	2352	249	0	5	51.6	0.1	10.05
AA-Ghion Hotel-1	473300	996100	2342	77.7	0	4.16	47	0.09	9.18
AA-Ghion Hotel -2	473300	996200	2344	56.4	7.6	4.16	47	0.09	9.18
AA-Brewey-1	471600	995800	2345	34	19	1	12.8	0.08	8.1
AA-Brewery-2	471500	995900	2345	34	17	2.7	4.5	0.6	62.21
AA-Brewery-3	471400	995800	2345	64	12	0.8	39.5	0.02	2.1
AA-brewery-4	471400	996000	2345	32.4	23	2.5	1.6	1.56	162
AA-Brewery-7	471500	995800	2345	52	16	5	29.8	0.17	17.4
AA-Brewery-8	471300	995800	2345	85	7.6	7.7	2.7	2.85	295.68
AA-Hana Mariam-2	471700	986600	2220	81	26.1	0.6	51.2	0.01	1.22
Stars Business Group,Tana Transport	481205	976968	2155	184	121	7	1	7	725.76
AA-Anbessa Transport (ledeta)	471200	995700	2343	192	3	1	47.2	0.02	2.2
AA-Alert-3 Well	468100	993200	2300	83	45	1.55	15	0.1	10.71
Sheraton Hotel BH-1	473334	997204	2360	355	4.2	1	140	0.01	0.74
AA-Cement Factory-1	473100	991800	2280	93.9	56.4	1.45	7.6	0.19	19.78
AA-Cement Factory-2	473100	991900	2270	153.9	112.7	2.5	9	0.28	28.8
AA-Addis Tyre factory-1	473900	989000	2224	201.5	45.4	3.67	55.3	0.07	6.84
AA-Hilton Hotell	474050	996650	2373	400	9.8	2.2	44.2	0.05	5.16
Aa-Ethio-Spice extraction	473300	987700	2161	103	44.7	0.91	35.3	0.03	2.67
AA-WWDA Ware House	473300	987300	2163	120	35.39	0.5	74.13	0.01	0.7
AAWSA Kality Well	475000	985800	2112	120	0	25	109.5	0.23	23.67
Meher Fiber Factory-1	475662	980783	2055	51.8	27.4	1.5	10.3	0.15	15.1

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
Akaki Indo-Europian Textiles-3	476369	981717	2062	63.7	7	3.33	22.7	0.15	15.21
AA-Ethio-Metal meal-1	476400	980600	2056	120	16.9	5.6	37	0.15	15.69
AA-Kality Airforce-1	476400	984800	2125	90	12	3.45	34.22	0.1	10.45
Galetti Project	474800	984700	2140	71.3	0.5	6.7	1.65	4.06	421
AAWSA Asko Borehole	465507	1002282	2555	178	1.95	6	73.79	0.08	8.43
Kotebe metal Tools Factory	480629	998771	2471	96	13.6	6.3	8.5	0.74	76.85
AAWSA-2 Near Defence Industry	470900	995075	2295	121.5		19	8.1	2.35	243.2
Old Airport-2	470500	994500	2320	170	41.7	2.7	3.4	0.79	82.33
AA-Gulele Glass-Factory-3	466900	1001005	2517	150	20.4	2.5	105.9	0.02	2.45
AA-brewery-9	471400	995900	2345	88	16.8	6.3	0.1	63	6531.84
NMWC Pump Factory	477608	978689	2090	116	57.7	2.96	11.5	0.26	26.69
AA-Kality Metal products Factory	474225	982650	2150	177.8	30.78	2.63	11.5	0.26	26.69
Prefabrication Factory	474429	986829	2177	187	40.5	1.5	53	0.03	2.93
AA-Artificial Insemination	475300	983800	2120	140	0	5	15.5	0.32	33.45
Akaki Textile Mill	476350	981300	2060	65	7.4	2.5	5.8	0.43	44.69
AA-EELPA,Kotebe	480431	998457	2452	181	15.4	12	9.2	1.3	135.23
Meta Abo Brewery	455000	985200	2200	126	50.86	3.5	33.84	0.1	10.72
AA-Darge-Suq,WSSA	464300	990600	2290	52	14.4	4.4	31.1	0.14	14.67
AA-Abay Mesk Soft Drinks-3/pepci cola Factory	473000	992700	2292	90	23.67	2	9.48	0.21	21.87
AA-American Embassy-3 Near Garage	474050	1000875	2550	156	14.6	2	128.4	0.02	1.61
Aa-Ethio-Meat Concentrete Factory	473326	986813	2180	86.7	25.2	1.99	34.9	0.06	5.91
AA-Ethiopian iron and Steel faoundry BH-1	476426	980749	2060	43.7	4	3	9.4	0.32	33.09
AA-Ethiopian Iron And Steel Faoundary BH-2	476430	980669	2060	62	6.5	6	8.9	0.67	69.9
Sunshine Terminal PLC(Dalota)	483093	976323	2159	207	137.6	3.5	22	0.16	16.49
Tatek Tor Sefer-3	459800	998250	2580	68.5		5	23	0.22	22.54
Taker Tor Sefer-4	459600	997500	2581	120					0
Tatek Tor Sefer-5	459700	998075	2580	67	10.2	5	19.8	0.25	26.18
AA-Abay Mesk Soft Drinks-4	473000	992700	2290	187		0.4	124.7	0	0.33
AA-Water lll Testwell-B3	463700	988500	2280	130	19	4	5.5	0.73	75.4

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
AA-Water lll Testwell-B4	486200	1001042	2450	100	10	1.5	7.8	0.19	19.94
AA-Water lll Testwell-B5	481200	980000	2150	150	11	3	18.2	0.16	17.09
AA-Water lll Testwell-B6	470800	982900	2110	114	0	3	18.6	0.16	16.72
AA-Water lll testwell-B7	473566	978610	2070	122	23.5	4	3.4	1.18	121.98
AA-Water lll Testwell-B9	481600	982900	2205	120	35.1	3	1.6	1.88	194.4
AA-Water lll Testwell-B10	461500	1001023	2630	110	82	1	7.1	0.14	14.6
AA-Water lll Testwell-B11	466200	988800	2246	100	0	4	20.2	0.2	20.53
AA-Water lll Testwell-B12	466400	987600	2252	125	18.3	2.5	3	0.83	86.4
AA-Water lll Testwell-T1	481200	980000	2150.8	173	8.9	1.5	25.3	0.06	6.15
AA-Water lll Testwell-T5	481600	982900	2205	120	37.33	3	11.07	0.27	28.1
AA-Water lll Testwell-B13	479400	981400	2133.4	100	2.7	4	0.5	8	824.44
AA-Water lll Testwekk-B14	480900	978800	2126.4	160	86	2.5	1.9	1.32	136.42
AA-Water lll Testwekk-T2	479400	981400	2133.5	74	2.8	11.7	1.5	7.8	808.7
Akaki Water Supply Test Well EP-1	479340	981400	2131.33	108.7	0.73	26.5	12.78	2.07	214.99
Akaki Water Supply Test Well EP-2	481600	982850	2203.98	136	33.48	11.1	5.52	2.01	208.49
Akaki Water Supply Test well Ep-3	479740	981400	2133.88	126	3.38	9.5	41.42	0.23	23.78
AA-water lll Testwell-B15	473069	979881	2057.4	116	5.8	2.5	14.02	0.18	18.49
AA-Watet lll Testwell-T4	473108	979851	2058.34	103	7.07	0.5	8.34	0.06	6.22
AA-Water lll Borehole BH01	477972	974859	2078.5	133	59	87.58	4.98	17.59	18
AA-Water lll Borehole BH02	478399	975589	2072.5	122	53	87.58	0.53	165.25	
AA-Water lll Borehole BH3b	478713	974977	2083	130	64	87.58	2.59	33.81	
AA-Water lll Borehole BH05b	476574	975607	2070.3	142	51.4	87.54	1.5	58.36	
AA-Water lll Borehole BH16	478347	976752	2067.5	148	47.5	87.58	6.96	14.69	
AA-Water lll Borehole BH19	478019	977985	2070.2	150	51.5	87.58	1.78	49.2	
AA-Water lll Borehole BH20	477945	976985	2068.3	148	49.9	87.58	3.37	25.99	
AA-Watter lll Borehole BH22	477651	975923	2066.8	142	47.9	71.93	2.07	34.75	
AA-Water lll Borehole BH23	477477	977216	2064.3	145	44	87.58	1.25	70.06	
AA-Water lll Borehole BH24	477330	976793	2061.6	130	42.9	87.58	5.23	16.75	
Meta Abo Brewery BH5	455300	985250	2218	101	37.5	4.45	17.8	0.25	25.92
Meta abo brewery BH9	455550	983750	2138	181	46.8	4	24.93	0.16	16.64
Tefki-Golden Rose#1	444000	977700	2055	100	17.12	0.4	96.7	0.004	0.43

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
Sebeta Agro No.1, Alemgena	460850	985850	2260	106	43	6.5	2.8	2.32	240.69
Sebeta Agro No.2,Alemgena	460500	986500	2285	100	27.12	9.1	16.88	0.54	55.89
AA-Bingham Acadamy, kolfe	468650	999800	2460	172	68.5	0.5	93.4	0.01	0.56
Netherlands Embassy,Keranio area	468800	996600	2360	124	50.35	2	41.45	0.05	5
AA-Dire Tannery BH1, Gulele	468200	1001600	2578	150	45.9	3.8	54.75	0.07	7.2
Korea Embassy, Ketena Hulet area	468425	996350	2320	68	19.6	9	16.37	0.55	57
AA-Hagbes PLC., Bisrate Gabriel area	468875	993750	2298	130	11.16	4.97	38.47	0.13	13.39
AA-Vatican Indonesian embassy	470950	993300	2290	120	18.93	4	19.4	0.21	21.38
AA-Hillton Hotel	474175	996550	2365	120	40.25	4.8	200.4	0.02	2.48
Nigeria Embassy, Afinchober	472700	999800	2485	120	11.7	1.5	82.3	0.02	1.89
Tafo, Ropack International real estate	487800	1002200	2488	80	24.8	5.6	22.63	0.25	25.66
AA-Gulele Misionery of Charity No.1	465651	1001575	2540	76	7.3	6.7	10.21	0.66	68.04
AA-Gulele Misionery of Charity No.2	465600	1001855	2545	104	13.2	8	5.52	1.45	150.26
AA-Kera	472150	993300	2270	150	50.5	6.2	22.75	0.27	28.26
TW2 Test well No.2	473576	972821	2081	150	74	8.5	11	0.77	80.12
TW4 Test well No.4	489950	976019	2067	220	91	18.2	8	2.28	235.87
TW5 Test well No.5	485798	968308	1905	217	69.4	19	17.2	1.1	114.53
AA-Tadele Gelecha Plastic Bags factory, Burayu	465243	1003930	2615	115	26.17	3.2	17.61	0.18	18.84
AA-Zak Ethiopia	474957	982383	2140	135	24	6	20	0.3	31.1
AA-Jehova Witness Kotebe Well No.1	483350	999064	2487	116	59	6	0.43	13.95	446.7
AA-Tikur Abbay Shoe Factory(Asko Well No.2)	466350	1001000	2550	153	15.65	4	33.93	0.12	12.22
AA-Algeria embassy (Bisrate Gabriel)	469727	993542	2324	120	22.24	3.2	66.61	0.05	4.98
Alem Gena-Balz af Ethio-Liquor Factory	460121	985966	2239	120	39.7	6.67	3.98	1.68	173.76
AAWSA Mekanissa No.3	470316	991064	2222	170	9.5	10	55.6	0.18	18.65
AAWSA Keraniyo No.1	467000	996300	2340	132	51.75	6	29.39	0.2	21.17
AAWSA Keraniyo No.2	463908	995127	2450	147	40	3	29	0.1	10.73
AA-Ato Tahas Burayo	465410	1002944	2560	124	11.22	3	50.67	0.06	6.14
AA-Woreda 17 Kebele 23	476963	994106	2349	132	72.5	3	33.81	0.09	9.2
AA-Burayu Simachew mekonen Borehole	465161	1003103	2610	66.7	18.24	6.4	5.04	1.27	131.66

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
AA-National Bank Compund	472541	996743	2378	90	51.75	3	2.09	1.44	148.82
AA-Repi Enyi General Business Group	464538	991302	2300	94	5.33	4.7	9.39	0.5	51.9
AA-Samson PLC near Bisrate gabriel Church	469804	993691	2330	170	26.62	7	11.86	0.59	61.19
AA-Worwdw 17 kebele 17	476235	995275	2357	151	84	1	41.7	0.02	2.49
AA-Motor Engineering Company (MOENCO)	477463	994346	2335	170	91.86	2	16.54	0.12	12.54
D/Z-Airforce No.2	499500	964500	1890	72	30.5	4.5	0.75	6	622.08
D/Z-Sahilu	494829	967088	1917	80	64.1	3.37	0.3	11.23	164.67
D/Z-Girma Gebre Kidan	495561	968574	1906	60	49.9	2.43	0.22	11.05	145.19
D/Z-Almaz Ayele poultry Farm	499320	970175	1890	68	18.9	6	0.39	15.38	8
D/Z-Blue Nile Plastics	495765	966397	1910	94	46.6	4.5	0.33	13.64	141.82
D/Z-Hora Tannery	498633	970028	1890	74	34.1	10	2.5	4	414.72
D/Z-Veternary College BH2	500078	968505	1880	56	14.5	15.4	0.5	30.8	3193.34
Kotebe Selam vocational Trainning No.3	481878	1000148	2546	140	75.95	5.3	19.9	0.27	27.61
AA-American Embassy-4 New Marine	474000	1001000	2562	201	39.7	2.35	154	0.02	1.58
Legadadi-NAS Food Factory BH No.2 Legetafo	488150	1002300	2489	175	26	1.6	69	0.02	2.4
Sebeta-Dragados	457030	984617	2200	140	88.52	5	18.5	0.27	28.02
Akaki Beverly Internation	480895	977403	2120	104	84.8	4.41	0.07	63	6531.84
AA-Kality-Get-as	474788	982924	2150	124	23.54	5	19.24	0.26	26.94
AA-Batu Tannery	473466	987247	2165	65	9.25	11.5	39.51	0.29	30.18
AA-Kality-NET-SA Plc	474928	982697	2145	104		6.5	8.09	0.8	83.3
Sendafa-Said Ali Paint Factory	488243	1002102	2486	96	25.93	2	14.4	0.14	14.4
AA-Mekanisa-Santa Clara Monastry	470983	992553	2235	96	32.58	2	48.1	0.04	4.31
Legadadi-Dini Heriakos	486000	1000707	2485	54	12	1.2	36.44	0.03	3.41
Akaki BABRGUBA General Treading BH	474645	985501	2130	68	92.3	18	0.69	26.09	2704.7
AA-kality Elsa Flour	474641	985622	2155	68	8.2	4.4	36.3	0.12	12.57
Sululta Depot	472975	1011144	2650	114	11.7	2.2	10.7	0.21	21.32
AA-ZAF Pharmacutical Akaki	480965	977576	2139	131.5	98.87	6.5	2.05	3.17	328.74
AA-Tibebu Hospital	471799	999371	2484	114	8.45	27.5	37.45	0.73	76.13
AAWSA F7 at Koye	481337	982304	2190	135	23.35	40.88	9	4.54	470.94

Local Name	UTME	UTMN	Elv	Well depth, m	SWL, m	Discharge :	Draw Down	Specific yield (Capacity)	Transmissivity
AAWSA F1 at Fanta	479000	981400	2120	120	10	40	6	6.67	691.2
Military Food Service Kitchen	473900	985100	2165	72	8	1.8	28.03	0.06	6.66
Melkakunture-Awash	456314	962592	2014	290	0	35.5	2.65	13.4	1470
Legadadi	493518	1004421	2468	354	27.75	15.2	42.68	0.36	172
Sululta	474421	1013070	2610	304	18.2	15.2	48.91	0.31	31
Tefki-Harojila	450359	981037	2084	280	11.05	19	41.95	0.453	79.8
Modjo Ude	506765	957179	1836	278	19	16.7	17.15	97	174
Borora	504878	970766	1879	300	20.45	35.5	10.24	3.48	343
Onodo	513157	1025381	2904	348	96.61	10	54	0.065	4.42
Adulala Roge	490444	951336	1765	225	98.35	16	0.92	17.39	8710
Modjo Muda	506464	941989	1697	268	73	10	22.5	0.44	40.8
Inchini-Lega Robi	421795	1040108	2457	146	20.45	16	9.85	1.62	100
Dukem Town	490336	970789	1924	282	90.87				21.3
Jawaro Kora	433200	959670	2111	194	0	19.2	16.86	1.14	134
Holota	440274	1006055	2525	300	12.33	35.5	25.17	1.41	33.2
Dima Jalewa	413137	973900	2090	311	8.5	16.74	35.38	0.47	57.4
Kimoye Koradima	427395	992768	2109	243	6	17.74	36.35	0.502	51.7
Asgori	427126	971361	2075	308	4.2	35.5	3.66	9.7	669
Melkakunture-Awash	456314	962592	2014	290	0	35.5	2.65	13.4	1470
Garba Sirea, Wara Jarso	426539	1101549		211	64.11	2.5	66.46	0.0376	2.65
Bedhada-1, Wara Jarso	427542	1101581		138	6.54	4.29	19.24	0.223	33.7
Bedhada-2, Wara Jarso	427820	1101526		138	6.54	10.6	19.24	0.552	129
Selle, D/Libanos	483172	1061127		180	28.15	7.3	89.85	0.0912	196
Abyssinia Flower Farm Plc./Dire Secoro	494578	1011816				15.3	2.42	6.322	524.16
Addis Ababa.	473376	996607		300		14.6	15.5	0.942	0.023

Annex 5: Chemical data of Hand Dug Wells

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
DW-1	Ejera qersa,Lega Chefei/Muketuri,N.Shewa/Ormia	491481	1060076	395	250	7.4	8	1.4	51	12	8	19	0.2	203	0.00	18	Ca-HCO3
DW2	Dembi, Dembi gerarga/ Ensarro, N.shewa Amhara	490228	1079847	458	290	7.5	27	2	52	8	13	9.3	2	246	0.00	15	Ca-Mg-HCO3
DW-3	Danisa,Gerare geber/Gerar Jarso,N.shewa,Ormia	470484	1076732	308	195	7.1	10	1.2	41	6	4	0.9	0.2	192	0.00	2	Ca-HCO3
DW-4	Irraya,Yaya mariam/Hidehi Abote,N.shewa,Ormia	452799	1095655	193	122	6	11	0.6	17	4	6	5.8	0.2	78	0.00	2	Ca-Na-Mg-HCO3
DW-5	Burqa funi,Werirso malima/Sululta,N.shewa,Ormia	473336	1021305	384	697	7.7	10	0.5	44	11	6	7.5	0.2	228	0.00	10	Ca-Mg-HCO3
DW-6	Fitche, Gerar Jarso,N.shewa,Ormia	467782	1080827	319	202	7.7	10	0.9	40		5	16	0.4	185	0.00	1	Ca-HCO3
DW-7	Chafe, Gerar Jarso, N.shewa,Ormia	475954	1079777	476	301	8	10	1.1	52	13	13	5	0.4	232	0.00	6	Ca-HCO3
DW-8	Genda Shano, Degem, N.shewa,Ormia	453166	1084209	193	122	7.1	6	1.2	42	6	1.5	1	0.2	118	0.00	2	Ca-HCO3
DW-9	Chagale, Gerar Jarso,N.shewa,Ormia	480142	1074817	652	413	7.2	20	4.4	88	18	41	15	0.3	336	0.00	23	Ca-HCO3
DW-10	Tuti, Debre Libanos,N.shewa,Ormia	476651	1066670	320	203	7.7	11	1.3	38	8	7	19	0.3	144	0.00	8	Ca-HCO3
DW-11	Shero(ChanchoBiret) Adaa Berga Weread,west shewa,Ormia	434724	1016447	183	116	7.5	6	3	22	5	2	0.4	0.1	104	0.00	9	Ca-HCO3
DW-12	Tuli Dese(Somonegna)/Adaa Berga Wereda,west shewa, Orm	426782	10504222	416	263	8	11	3	55	13	12	8	0.6	244	0.00	5	Ca-HCO3
DW-13	Mendi Ella(Ella)/Meta Robe Werada west shewa, Ormia	426789	1051662	338	698	7.8	10	2	42	9	2	3	0.6	214	0.00	2	Ca-HCO3
DW-14	Degoye(Seko)/Dandi Wereda west shewa, Ormia	416460	1053271	160	101	7.5	5	1.5	19		2	8	0.3	90	0.00	1	Ca-HCO3
DW-15	Kerbo(Damitu)/Ejeri Wreda west shewa, Ormia	404837	995159	552	349	7.9	22	4	74	16	3	4	0.6	361	0.00	1	Ca-HCO3
DW-16	Kimoye/Ejeri Wereda west shewa, Ormia	427222	996598	772	489	7.8	29	2	95	26	11	19	0.4	497	0.00	1	Ca-Mg-HCO3

Annex 6: Chemical data of boreholes

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
BH-1	Ali-doro, Degem/North shewa	448254	1081234	199	139	7.4	9	2	26	6	2	6	0.1	121	0	1	CaMgHC03
BH-2	Chagale/Wortu/North shewa	479695	1073212	494	346	7	13	2.2	57	16	14	18	0.3	215	0	11	CaMgHC03
BH-3	Walechelelo, Gerar Jarso/North shewa	425376	1100923	412	288	7.8	22	1.7	40	12	18	21	0.6	201	0	14	CaMg NaHCO3
BH-4	Tere, D/Libanos/North shewa	475621	1065990	263	184	7.7	8	0.5	32	8	2	7	0.2	160	0	3	CaMgHC03
BH-5	Kuma, D/Libanos/North shewa	474590	1068254	305	214	7.7	10	0.1	48	8	11	12	0.7	167	0	1	CaHCO3
BH-6	Jemma Cement Factory/North shewa	485982	1052616	287	201	8	15	0.1	30	8	1.5	3	0.7	177	0	1	CaMgNaHCO3
BH-7	Hambiso, Degem/North shewa	459862	1086322	171	120	6.9	12	2.6	19	4.6	3	3.7	0.2	110	0	0	CaNaHCO3
BH-8	Garba Sirea, Wara Jarso/North shewa	426539	1101549	402	281	7.6	47	5.4	35		15	0.4	0.9	211	0	33	CaHCO3
BH-9	Bedhada-1, Wara Jarso/North shewa	427542	1101581	333	233	7.2	28	5	40	7	5.8	1.6	1	199	0	5.6	CaNaHCO3
BH-10	Bedhada-2, Wara Jarso/North shewa	427820	1101526	439	307	7.4	20	5.3	53	17	7.7	20	0.4	234	0	10	CaMgHC03
BH-11	Selle, D/Libanos/North shewa	483172	1061127	377	264	7.5	13	3.7	52	12	16	11	0.7	203	0	10	CaMgHC03
BH-12	Abyssinia Flower Farm Plc./Dire Secoro/North shewa	494578	1011816	269	188	7.7	15	3.1	26	6	2	1.8	0.7	154	0	4	CaNaHCO3
BH-13	Chebot/Maru chebot/Adda berga/ west shewa	432108	1025367	456	319	8.1	25	1	56	14	1	4	0.5	305	0	1	CaMgNaHCO3
BH-14	Homicho/Maru	428348	1027771	322	225	7.8	12	1	35	9	5	12	0.3	184	0	1	CaMgHC03

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-15	Boski_II/Harobor/ Adda berga/west shewa	424260	1052339	374	262	7.9	7	1	45	12	2	15	0.8	222	0	1	CaMgHC03
BH17	Shino/Meta Robi/west	420104	1032025	312	218	7.9	7	2	33	12	2	15	0.2	182	0	1	CaMgHC03
BH-18	Genchi 01/Dandi/west shewa	406144	996681	513	359	8	52	2	39	12	11	8	0.6	296	0	12	NaCaHCO3
BH19	Genchi 02/Dandi/west shewa	404749	997941	690	658	8	21	2	85	20	18	33	0.3	373	0	6	CaMgHC03
BH20	Kerosole/Gendeb eret/west shewa	362897	1056227	264	167	7.5	9	1	28	7	7	13	0.2	143	0	1	CaMgHC03
BH-21	Addis Alem/Ejere/west shewa	434248	1000353	483	306	7.7	22	2	50	16	11	22	0.2	275	0	1	CaMgHC03
BH-22	EthioDream plc 2/K.Gelgele/Wel mera/west shewa	440140	1000993	316	200	7.7	10	2	30	14	2	10	0.2	195	0	1	CaMgHC03
BH-23	Garad flower plc/welmera/west shewa	443048	1001649	197	696	7.8	94	9	48	9	18	2	4	390	0	26	NaCaHCO3
BH-24	Tulu miliki/Kersa/Not h shewa	428930	1097274	222	141	8	29	6	15	5	12	2	0.3	107	0	5	NaCaHCO3
BH-25	Ullamo/Ilile/Deg em/west shewa	442661	1079441	397	251	7.8	10	2	50	13	3	3	0.6	250	0	1	CaMgHC03
HBH-26	Filwuha/ Addis ababa	996607	996607	3350	3527 .7	7.7	919	15	4	0.5	42	0.4	29	2213	0	65	NaHCO3
	Jewi Bone/Bone/Jeldu, West shewa/Ormia	410971	1015748			8.1		6.8	8	3	23	5	5	7	0	106	NaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-27	Red Fox Flowers,koka area	498233	939885	1621	119 3	7.1	276	11	3.5	0.5	38	0.1	27	657	0	9.4	NaHCO3
BH-28	Woliso Negash, spring	445643	973409	333	219	7.5	17	4.2	50	8.3	2.9	7.5	0.8	236	0	22	CaHCO3
BH-29	Alem Gena-Debel yohanes	485970	935007	453	253	8	42	12	32	14	9.6	10	0	271	0	0.5	CaHCO3
BH-30	Galiyee, Adulala area	445773	1001323	168	130	6.3	9.5	1.8	32	19	11	15	1	196	0	3	CaHCO3
BH-31	Holota-Agri Research	448532	1008047	258	174	7.2	6	1.4	45	4.9	7.8	25	0	118	0	0	CaHCO3
BH-32	Holota-Wolmera Choke	451590	954524	430	280	7.1	20	11	51	15	7.7	12	1.6	274	0	6	CaHCO3
BH-33	Muti Dayu	441584	1003445	263	170	7.1	6.6	1.5	46	7.6	1	7	0	179	0	0.6	CaHCO3
BH-34	Nano Galgala	439632	993521	447	300	7.6	9.6	1.8	78	12	5.8	23	0	256	0	0.5	CaHCO3
BH-35	Wajitu Harbu#4	462554	944481	400	280	7.8	27	8.2	53	9.4	3.8	3	1.8	277	0	7.4	CaNaHCO3
BH-36	Gere Gertesa, Leman area	462875	950361	383	250	6.9	28	9.9	42	9	5.8	5	1.4	239	0	0.3	CaNaHCO3
BH-37	Kusaye Tiro, Leman area	456988	952135	368	246	7.4	22	7.2	46	15	4.8	4.8	1.2	241	0	0.3	CaNaHCO3
BH-38	Leman	459470	942670	440	278	8.5	27	8.8	53	12	5.6	5	0.5	279	0	0.5	CaNaHCO3
BH-39	Tere Jebdu. Leman are	459658	946538	378	258	7.5	32	9.5	45	7.2	2.9	3.2	1.1	218	24	0.3	CaNaHCO3
BH-40	Tere Shino, Adulala area	489485	943724	486	310	7.4	49	7.6	55	4.3	6.7	7.5	2.2	297	0	0.8	CaNaHCO3
BH-41	Tulu Bolo town spring	481162	935226	354	232	7.3	30	6.7	38	7.2	3.8	7	1	226	0	0.8	CaNaHCO3
BH-42	Ziquala-Adulala	456314	962592	536	360	7.7	41	11	65	12	8.6	2.4	1.4	312	0	4	CaNaHCO3
BH-43	Ziquala-Annate	478740	933707	400	260	7.6	40	10	33	6.4	6.7	7	1.6	239	0	0.3	CaNaHCO3
BH-44	Melkakunture	450359	981037	487	312	7.4	49	5.4	55	4.3	13	5.3	1.1	256	0	14	NaCaHCO3
BH-45	Mukiye, Ziquala area	456314	962592	497	326	8.4	52	11	56	8.7	7.9	1.4	1.3	320	0	0.8	NaHCO3
BH-46	Tefki-Harojila	427126	971361	229	142	8.1	27	2.1	19	5.6	4.8	0.4	0.3	117	7	7.5	NaCaHCO3
BH-47	Melkakunture TWS	447549	1007893	164	110	7.9	18	1.7	16	1.6	2.9	2.9	0.6	98.2	0	3.8	CaHCO3
BH-48	Asgori during	447200	998889	225	146	8.6	25	2	25	3.8	5.8	10	0	138	0	5.8	CaNaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-49	Holota-Marginpar Flower	445987	1001623	252	158	7.7	35	1.3	19	4.9	5.8	0.7	0.4	143	5	2.3	CaNaHCO3
BH-5050	Holota-Tsedey farm	421795	1040108	252	158	8.8	31	3	19	5.9	5.8	0.1	0.7	146	0	1.3	NaCaHCO3
BH-51	Holota-town new	427395	992768	430	282	8.8	102	1.3	3.4	1	35	5.8	1	159	14	1.5	NaCaHCO3
BH-52	Inchini-mapping well	440274	1006055	260	164	8.3	54	0.9	5.3	1.1	13	0.2	0.5	113	12	0.8	NaCaHCO3
BH-53	Kimoye Koradima	449177	1002158	146	88	7	19	1.4	12	1.6	1	0.8	0	79.3	2	16	NaHCO3
BH-54	Holota Mapping well	431584	998853	415	269	7.6	9.6	1.7	63	20	1.9	8	0	287	0	0.6	NaHCO3
BH-55	Mark Flowers Holota area	413137	973900	822	540	7.3	69	14	94	21	4.1	7.1	2.4	589	0	1.8	CaHCO3
BH-56	Badeg Adisalem spring	433200	959670	603	404	7.5	52	8	77	14	7.9	4.4	1.1	439	0	1.6	CaNaHCO3
BH-57	Dimajalewamapin g during drilling	413137	973900	1153	798	8	152	16	11 8	30	61	0.6	1	630	0	1.7	CaNaHCO3
BH-58	Jawaro Kora Mapping well	490444	951336	599	364	6.5	64	9.5	55	16	12	2	1.8	395	0	1.5	NaCaHCO3
BH-59	Dimajalewa shallow well	378552	992800	1625	114 8	7.5	262	28	72	21	33	0.1	1.4	1090	0	10 6	NaCaHCO3
BH-60	Adulala Roge mapping well	432432	1024464	303	190	7.7	25	1.6	84	2.6	11	9.9	0.8	322	0	0.9	NaHCO3
BH-61	Ambo Ethiopia Hotel spring	404656	997733	475	312	7.2	12	2.3	11 4	15	16	25	0	384	0	1.4	NaHCO3
BH-62	Woliso Prison well	456740	962388	663	434	7.4	42	9.8	63	9.4	6.7	7.5	1.3	333	0	0.3	CaHCO3
BH-63	Adabega Sur Camp well	430267	987498	510	350	7.4	42	3.6	83	14	19	7	1.7	350	0	0	CaNaHCO3
BH-64	Awash Melka, Bechomeda	444624	978143	630	380	7.3	116	6.6	36	6.1	57	4.8	3.6	346	0	2.6	CaNaHCO3
BH-65	Addis Alem-Amaro shallow well	427126	971361	726	455	8.6	160	23	9.7	2.7	63	0.1	2.2	366	0	22	NaCaHCO3
BH-66	Tefki town well	503210	930527	874	572	8.3	442	7.4	7.4	0	63	0	19	830	0	16	NaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-67	Asgori mapping during test	478200	920000	845	510	7.9	288	14	8.9	1.6	63	7.5	3.3	651	2	44	NaHCO3
BH-68	AA-French Embassay	474300	1001005	310	189	7.4	27	5.5	28	6.9	11	2.1	0.1	158	0	6.8	CaNaHC03
BH-69	AA-Glass and Bottle Factory	467200	1001017	188	115	8.6	43	3	16	3.9	7.1	0.1	2	146	0	18	NaCaHCO3
BH-70	AA-Anbessa Transport Garage	468400	1001016	176	107	7.8	38		8	2	14	0.3	0.6	98	0	14	NaHCO3
BH-71	AA-General Winget School	468300	1001003	0	164	7.9	0.6		26	12	0.1	3.1	0.1	126	0	0	CaMgHC03
BH-72	Aa-Ethio-Marble Industry-2	468900	1001007	0	132	7.2	23	5.6	10	2.9	2.5	4	0.3	110	0	0	CaHCO3
BH-73	Shola Dairy	479400	996800	0	74	7.9	27		14	3.4	0	2.2	0.7	50	0	0	CaMgHC03
BH-74	Ministry of Public Works	474500	996200	0	249	7.1	31	5	37	14	11	24	0.2	146	0	0	CaMgHC03
BH-75	Ras Biru Sefer	473900	995500	0	529	7.3	23		50	7.2	4	5.7	0	162	0	12	CaHCO3
BH-76	Total Ras Hotel	472700	996300	0	348	8.1	17		84	11	13	13	0.5	224	0	31	CaHCO3
BH-77	Ras Hotel	472500	996300	0	516	7.7	19	13	106	10	33	25	0.8	300	0	45	CaHCO3
BH-78	Repi Soap factory	466250	993050	0	180	7.2			35	10	2	7.9	0.2	140	0	0	CaMgHCO3
BH-79	Misrak Flour and Oil Mills-1	473500	992900	0	245	0			58	15	19	13	0.9	182	0	17	CaMgHCO3
BH-80	mekane Iyesus Compound	470400	991300	0	207	7.2			58	8.6	17	3.3	0.7	182	0	14	CaHCO3
BH-81	AA-ETHARSO-1	470250	991500	0	94	7.1			18	4.8	4	3.1	0.5	70	0	0	CaMgHCO3
BH-82	AA-Ethiopia Thread Factory	473800	990200	0	315	6.8			72	9.5	8.5	6.2	0.5	258	0	4	CaHCO3
BH-83	Aa-Ethio-Spice extraction	473300	987700	0		7.1			58	20	13	5.6	0.4	322	0	0	CaMgHCO3
BH-84	AA-Ethio-Metal meal-1	476400	980600	0	395	7.7			71	25	25	2.7	0.6	320	0	20	CaMgHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
BH-85	Galetti Project	474800	984700	0	354	7.8	36		33	12	11	5.4	0.6	299	0	0	CaNa MgHC03
BH-86	Menilik School	474100	998500	0	614	7.2			140	33	83	42	0.4	310	0	37	CaNaMg-HCO3
BH-87	AA-Gulele Glass-Factory-3	466900	1001005	0	0	7.9	15	1.3	21	6.8	7.1	5.9	0	122	0	0	CaNaMgHCO4
BH-88	AA-Beverage CorpGasv& Crate factory	478462	977721	470	287	8.2	30	2.5	37	9	13		0.5	259	0	0	CaNaHCO3
BH-89	NMWC Pump Factory	477608	978689	0	0	8	4	0	32	12	14	5.3	0.5	171	0	22	CaMgHCO3
BH-90	AA-Kality Metal products Factory	474225	982650	470	356	7.5	54	12	35	16	28	0.7	1.1	317	0	0	NaCaMgHCO3
BH-91	AA-Artificial Insemination	475300	983800	0	391	7.7	48	8.1	40	13	21	0.1	0.6	293	0	0	NaCaHCO3
BH-92	AA-American Embassy-3 Near Garage	474050	1000875	0	270	7.2	0	3	43	8	13	2	0.3	171	0	0	CaMgHCO3
BH-93	NMWC Spare Parts 7 Hand Tools Factory-2	478462	977506	372	227	8.5	29	3	43	8	13	2	0.3	171	0	0	CaNaHCO3
BH-94	AA-Water lll Testwell-B3	463700	988500	0	336	7.5	20	4.9	60	16	11	6.5	1	256	18	0	CaMgHCO3
BH-95	AA-Water lll Testwell-B4	486200	1001042	0	369	8	66	2.7	37	15	26		0.7	293	0	15	NaCaMgHCO3
BH-96	AA-Water lll Testwell-B5	481200	980000	440	396	8.4	41	13	47	31	14	19	0	378	0	0	MgCaNaHCO3
BH-97	AA-Water lll Testwell-B6	470800	982900	500	332	7.7	24	5.5	54	16	11	2.5	1.2	259	17	0	CaMgHCO3
BH-98	AA-Water lll testwell-B7	473566	978610	0	424	7.5	34	5.1	60	20	27	0	0.7	317	0	4.7	CaMgNaHCO3
BH-99	AA-Water lll Testwell-B9	481600	982900	520	424	7.3	40	4	41	31	20	9.3	1	177	0	130	MgCaNaHCO3SO4
BH-100	AA-Water lll Testwell-B10	461500	1001023	0	111	7.5	4.1	1.3	14	4	7.1	3	0.3	61	0	0	CaMgHCO3
BH-101	AA-Water lll 101	466200	988800	0	279	7.9	16	6.9	26	6.3	7.1		0.7	153	0	0	CaNaHCO3

ID	Location	UTME	UTMN	EC	TDS	P H	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-102	AA-Water lll Testwell-B12	466400	987600	0	351	7.6	20	4	56	9.7	7.1		0.7	268	0	0	CaHCO3
BH-103	AA-Water lll Testwell-T1	481200	980000	530	385	7.4	41	5.3	67	16	14	12	1	366	0	0	CaNaHCO3
BH-104	AA-Water lll Testwell-T5	481600	982900	540	380	7.8	44	4	56	20	14	9.6	0.7	342	0	15	CaNaMg-HCO4
BH-105	AA-Water lll Testwell-B13	479400	981400	500	390	8.4	37	4	91	2.9	20	0.1	0.7	366	0	0	CaNaHCO3
BH-106	AA-Water lll Testwekk-B14	480900	978800	500	330	7.4	79	3.4	9.6	8	28	2.7	0.6	159	9	42	NaHCO3
BH-107	AA-Water lll Testwekk-T2	479400	981400	430	362	7.5	44	4	91	2.9	20	0.1	0.7	366	0	0	CaNaHCO3
BH-108	AA-water lll Testwell-B15	473069	979881	0	346	7.6	41	0	0	0	5	9.7	0.6	0	0	28	NaSO4
BH-109	AA-Watet lll Testwell-T4	473108	979851	397	0	0	37	5.3	55	22	14	19	0.7	317	0	25	CaMgNaHCO 3
BH-110	AA-Water lll Borehole BH01	477972	974859	0	0	7.3	0	9.9	64	21	21	28	1.1	256	0	28	CaMgHCO3
BH-111	AA-Water lll Borehole BH3b	478713	974977	0	0	7.3	0	2	70	20	4.5	8.8	0.5	325	13	1	CaMgHCO3
BH-112	AA-Water lll Borehole Bh07	479405	976735	493	301	0	26	4.2	46	27	9	19	0.4	307	0	6.6	CaMgHCO3
BH-113	AA-Water lll Borehole BH08	479061	976370	464	283	7.3	27	4.2	44	28	8.5	14	0.3	313	0	7.6	CaMgHCO3
BH-114	AA-Water lll Borehole BH09	479246	977104	512	312	0	27	3.6	45	29	17	26	0.2	305	0	0	MgCaNaHCO 3
BH-115	AA-Water lll Borehole BH10	479058	976020	478	292	0	31	3.6	49	28	8.7	17	0.2	305	0	0	MgCaNaHCO 3
BH-116	AA-Water lll Borehole BH11	478780	977307	516	315	8.8	31	4	40	28	14	3.9	0.4	329	0	6.6	CaMgNaHCO 3
BH-117	AA-Water lll Borehole BH12	478808	976867	527	311	7.7	30	3	47	26	11	21	0.3	293	0	18	CaMgNaHCO 3
BH-118	AA-Water lll Borehole BH14	478580	976051	476	291	0	27	4.3	61	20	7.2	9.7	0.4	300	17	1	CaMgHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO 3	SO4	Water type
BH-119	AA-Water lll Borehole BH16	478347	976752	542	331	8	27	5.9	48	26	9.2		0.7	329	0	6.6	CaMgNaHCO 3
BH-120	AA-Water lll Borehole BH17	478199	976361	486	300	0	28	5.3	56	24	14	3.9	0.4	329	0	5.4	CaMgHCO3
BH-121	AA-Water lll Borehole Bh18	478154	975966	437	266	0	0	4.3	57	20	11	13	0.3	295	13	9.5	CaMgHCO3
BH-122	AA-Water lll Borehole BH19	478019	977985	602	367	7.5	31	0	46	27	0		0.3	307	0	0	CaMgNaHCO 3
BH-123	AA-Water lll Borehole BH20	477945	976985	532	294	0	24	3.3	55	25	14	13	0.3	317	0	10	CaMgHCO3
BH-124	AA-Watter lll Borehole BH22	477651	975923	494	301	8.1	27	3.5	78	11	3.6	6.6	0.6	317	7	0	CaNaHCO3
BH-125	AA-Water lll Borehole BH24	477330	976793	477	291	7.8	41	4.3	50	23	14	14	0.4	293	0	7	CaMgNaHCO 3
BH-126	AA-Water lll Borehole BH26	477181	975680	476	291	7.8	27	4.6	40	20	14	12	0.4	293	0	0	CaMgNaHCO 3
BH-127	Akaki Water Supply Well Ep-4	479942	977322	480	310	7.9	24	4	50	23	12	12	0.6	293	0	7.4	CaMgHCO3
BH-128	Akaki Water Supply Well EP-5	478450	979950	529	343	7.8	0	2.1	43	27	6.1	14	0.1	286	0	4.7	MgCaHCO3
BH-129	Akaki Water Supply Well EP-8	478998	977937	496	303	7.3	37	3.3	40	24	9.2	16	0.5	303	0	7.9	CaMgNaHCO 3
BH-130	Dukem-Arena	487900	972421	632	386	7.3	32	7	62	31	12	12	0.3	383	0	8	CaMgHCO3
BH-131	Meta Abo Brewery BH5	455300	985250		139	6.7	14	6.6	20	46	7.1	0.1	0.7	122	0	0	MgCaHCO3
BH-132	Sebeta Agro No.1, Alemgena	460850	985850	244	159	7.9	16	3.1	29	4.8	3.9	14	0	142	0	1.8	CaNaHCO3
BH-133	Netherlands Embassy,Keranio area	468800	996600	375	253	7.5	24	2.8	40	6.8	11	15	0.2	195	0	0	CaNaHC03
BH-134	AA-Dire Tannery BH1, Gulele	468200	1001600		107	7.3	24	3.3	29	1	11		0.3	146	0	0	CaNaHCO3
BH-135	Korea Embassy, Ketena Hulet	468425	996350	395	246	0	19	5	42	14	5	2.8	0.2	242	0	3	CaMgHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
BH-136	AA-Vatican Indonesian embassy	470950	993300	0	0	7.5	25	4	53	9	23	12	0.5	220	0	0	CaNaHCO3
BH-137	AA-Hillton Hotel	474175	996550	3359	2049	7.2	840	15	6	2	43		21	2198	0	55	NaHCO3
BH-138	AAWSA Ayer Tena near kidanemeheret	466050	993650	336	160	7.6			37	12	1.5	12	0.4	171	0	0	CaMgHCO3
BH-139	AAWSA mekanissa	470450	990125	374	179	8.3			39	10	1.5		0.9	202	0	3.7	CaMgHCO3
BH-140	AAWSA LAFTO Hana mariam	471400	988250	498	237	7.4			62	11	1.5	12	0.4	251	0	0	CaMgHCO3
BH-141	AA-Gulele Misionery of Charity No.1	465651	1001575	380	250	7.6	7.4	3.2	41	16	10		0.4	185	10	0.9	CaMgHCO3
BH-142	D/Z-Genesis Farm#1	495447	968068	469	286	7.8	23	6.2		24	8		0.6	306	0	0	MgNaHCO3
BH-143	TW2 Test well No.2	473576	972821	498	305	7.5	45	7.7	60	7.3	7.2	8.8	0.8	303	0	4.5	Ca-Na-HCO3
BH-144	TW3 test well No.3	484475	975622	672	408	8	40	3.5	97	18	7	9.7	0.3	444	0	0.5	CaNaHCO3
BH-145	TW4 Test well No.4	489950	976019	537	315	6.8	40	11	56	17	7	7.5	0.4	317	0	0.5	CaNaMgHCO5
BH-146	AA-Ato Tahas Burayo	465410	1002944	135	89	8.4	12	4.6	9.6	3.4	2	1.5	1.7	76.9	0	1.6	NaCaHCO3
BH-147	Dukem-Industrial Park Borehole	490000	968000	671	454	7.8	120	9	30	6.8	6.1	1.3	2.4	388	24	2	CaNaHCO3
BH-148	AA-Burayu Simachew mekonen Borehole	465161	1003103	201	130	7.4	18	4.9	22	4	5	0.5	0.9	137	0	3.2	CaNaHCO3
BH-149	AA-Repi Enyi General Business Group	464538	991302	248	168	7.8	14	4.3	30	6.3	4.4	0	0.5	154	0	1	CaNaHCO3
BH150	D/Z-Airforce No.2	499500	964500	0		7.2	65	12	45	29	28	8.9	0.8	403	0	0	NaMgCaHC03

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
BH-151	D/Z-Girma Gebre Kidan	495561	968574	464	303	0	25	7.3	43	20	28	8.4	0.7	320	0	0.5	CaMgNaHCO3
BH-152	D/Z-Hora Tannery	498633	970028	0		7.9	58	5.6	43	26	13	6.7	0.7	381	0	9	NaMgCaHC03
BH-153	D/Z-Veternary College BH2	500078	968505	1041	635		138	12	36	36	4	0.4	0.7	625	0	6	NaMgCaHC03
BH-154	Kotebe Selam vocational Trainning No.3	481878	1000148	320	195	8.8	17	3.8	3.6	8	7	0.5	2	165	7	0	NaMgCaHC03
BH-155	Sebeta-Dragados	457030	984617	979	597	7.5	16	3.4	36	9	5	8.7	0.5	178	0	2.6	CaMgNaHCO3
BH-156	Akaki Beverly Internation	480895	977403	489	298	7	23	3.4	39	26	9	0.3	0.3	315	9	0	MgCaHCO3
BH-157	AA-Batu Tannery	473466	987247	337	206	8.3	34	4.6	56	15	11	1.8	0.5	317	0	0	CaNaMg-HCO5
BH-158	AA-Burayu-1-99	463972	1000788	280	190	7.5	50	3.7	14	3.2	2.9	0.4	2.3	161	7	0	NaCaHCO3
BH-159	Alemgena-electrocomercial	462260	984901	467	272	7	46	5.2	12	12	3.8	1	0.4	295	0	2.7	NaMgCaHC03
BH-160	AA-Lafto-99	471500	990500	438	280	7.3	14	5.2	66	10	9.9	6.2	0.8	246	0	2.8	CaHCO3
BH-161	AA-Yekamichael-99	477515	997474	284	182	7.3	30	6.4	26	4.3	9.9	2.3	1.1	169	0	8.3	CaNaHCO3
BH-162	AA-Burayu-99	464031	1002909	273	172	8.64	32	5.4	26	3.2	6.7	0.1	2.1	154	0	2.9	NaHCO3
BH-163	AA-Asko-99	465578	999808	341	206	8.6	76	2.6	3.5	1.08	7.94	0.03	3.4	180.6	12	0	CaNaHCO3
BH-164	Inchini-Lega Robi	421795	1040108	224	150	7.3	27	2	18	5.6	3.8	0.3	0.6	103	14	5.3	CaNaHCO3
BH-165	Inchini-Lega Robi	421795	1040108	244	160	7.7	31	2.5	19	5.4	7.7	0.1	0.3	140	0	0.5	MgCaHCO3
BH-166	Inchini-Lega Robi	421795	1040108	252	158	7.6	31	3	19	5.9	5.8	0.1	0.7	146	0	0.8	CaMgNaHCO3
BH167	Tefki-Harojila	450359	981037	487	312	7.8	49	5.4	55	4.3	13	5.3	1.1	255	0	7.5	CaNaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
BH-168	CMC	484821	994284	2370	1601	6.5	505	32	29	20	33	0.5	1.4	1495	0	113	CaNaHCO3
BH-	CMC	484821	994284	2480	1580	6.5	545	27	23	13	36	0.2	2.5	1487	0	65	MgCaHCO3
BH-170	CMC	484821	994284	2360	1530	8.7	535	27	26	13	34	0.2	2.4	1496	0	61	CaNaHCO3
BH-171	Holota	440274	1006055	233	144	8.8	46	1.7	3.7	0.6	6.7	2.2	0	112	7	2.3	CaNaHCO3
BH-172	Holota	440274	1006055	260	164	9	54	0.9	5.3	1.1	12	0.2	0.5	113	12	0.6	CaNaHCO3
BH-173	Holota	440274	1006055	260	160	8.4	54	0.9	3.5	0.5	12	0.2	0.7	115	10	0.5	CaNaHCO3
BH-174	Asgori	427126	971361	229	142	8.2	27	2.1	19	5.6	4.8	0.4	0.3	117	7	5.8	NaCaHCO3
BH-175	Segno Gebeya	455620	1026514	237	152	7.8	34	1.5	16	1.1	6.7	2.5	0.3	119	5	13	NaHCO3
BH-176	Chancho	473911	1031930	162	102	7.6	32	0.5	5.3	1.6	2.9	1.7	0.4	66.4	12	0.8	CaMgHCO3
BH-177	Chancho	473911	1031930	166	108	7.4	30	0.7	5.3	0.5	1.9	0.8	0.2	90.3	0	7.2	CaMgHCO3
BH-178	Legadadi	493518	1004421	382	244	7.5	33	6.7	37	8.6	5.7	0.1	0.5	226	0	16	CaMgHCO3
BH-179	Legadadi	493518	1004421	380	242	7.3	32	6.7	36	8.6	5.8	0.1	0.5	221	0	16	CaMgHCO3

Annex 7: Chemical data of springs

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-1	Wisi Briqe, Gerar Geber / Gerar Jarso ,N.Shewa /Amhara	491280	1078405	456		6.76	28	2	49	10	16	44	1.41	233	0	24	CaNaHCO3
CSP-2	Wisi Briqe, Gerar Geber / Gerar Jarso ,N.Shewa /Amhara	494137	1093448	648		7.84	27	5	76	2.1	15	8.9	0.46	354	0	40	CaHCO3
CSP-3	Wisi Briqe, Gerar Geber / Gerar Jarso ,N.Shewa/Ormia	465505	1075390	365		7.6	12	0.6	48	12	4	15	0.36	212	0	2	CaMgHCO3
CSP-4	Burqa Geberu, Nonof Chemeri / Yaya Gulelle / N.Shewa/Ormia	459615	1066487	323		7.24	15	3	31	11	3	8.4	0.18	201	0	3	CaMgHCO3
CSP-5	Haye, Deleti / Yaya Gulelle / N.Shewa /	454500	1063823	449		7.19	11	2	38	11	3	4.5	0.45	210	0	2	CaMgHCO3
CSP-6	Chefie fadu, Akako/ Wechale/ N. Shewa/Ormia	471680	1056576	785	707	7.14	26	3	107	34	17	3.1	0.29	438	0	11	CaMgHCO3
CSP-7	Illu, Qundi Agemso/Degem/,N.Shewa, Oromia	447470	1064576	486		7.18	14	4	48	22	10	3.5	0.39	237	0	27	CaMgHCO3
CSP-8	Qundi Agemso, Qundi Agemso/Degem/ N.Shewa/Ormia	446945	1066467	505		7.01	9	2.1	62	18	8	16	0.3	251	0	12	Ca-MgHCO3
CSP-9	Gonji, Buyema quat/ Yaya Gulelle/ N.Shewa	455086	1053735	1273	1046	7.91	75	31	124	39	63	8	0.83	543	0	76	CaNaMgHCO3
CSP-10	Goho, Abado/Herbo Abote/ N.Shewa/Oromia	458961	1110844	894		7.85	13	2.4	134	23	14	4.4	0.5	464	0	67	CaMgHCO3
CSP-11	Duber,01/ Sululta/N.Shewa/Oromia	486264	1045358	233		7.79	17	2	22	5	2	6.7	0.3	134	0	2	CaNaHCO3
CSP-12	Boku Abo, Boku ureta/Sululta/ N.Sh	471668	1040491	327		7.46	4	0.6	40	15	3	9.8	0.31	190	0	8	CaMgHCO3
CSP-13	Babolle,Mullo Quersa/Mullo/N.shewa	459951	1048382	495		7.06	12	0.4	60	20	6	29	0.28	287	0	5	CaMgHCO3

CSP-14	Quersa, Quersa/Sendafa/N.Shewa/Oromia	483313	1005608	325		7.57	11	1.2	40	8	1	4	0.52	205	0	5	Ca-HCO3
CSP-15	Entotomariam, Kebele 20/Addis Ababa	474208	1005540	178		6.65	4	1.4	28	5	4	8.4	0.07	107	0	4	Ca-Mg-HCO3
CSP-16	Gebrechefie, Kebele 01/ Addis Ababa	473540	1004307	45.1		7	3	2.1	7	0.8	1	3.1	1	29	0	3	Ca-Mg-HCO3
CSP-17	Billbile, wata bicha minjarro/Welmera/W.shewa/Ormia	457146	1004953	74.8		7.35	3	0.8	10	2.3	1	3.5	0.17	44	0	2	Ca-Mg-HCO3
CSP-18	Burka Gibsa, Hawaso/Sululta/N.shewa/Ormia	463999	1018139	106		7.59	4	0.8	11	4	1	4.4	0.19	71	0	2	Ca-Mg-HCO3
CSP-19	Seyo, lillo chebeka/Sululta/N.Shewa/Oromia	463263	1037563	448		6.39	7	0.3	44	20	18	19	0.09	239	0	5	Ca-Mg-HCO3
CSP-20	Chefie entoto, Guasa/Sululta/N.shewa /ormia	473059	1006482	39	34.1	6.73	2	0.1	2	0.6	1	0.4	0.03	24	0	4	Ca-Na-HCO3-SO4
CSP-21	Yenegusweha,Guto Weserebi/Sululta/N.shewa/ormia	492039	1005044	83		7.69	4	1.3	7	2	5	19	0.06	22	0	2	Ca-Na-Mg-HCO3-NO3
CSP-22	Menagesha, Kebele 01/Welmera/W. Shewa/Ormia	453492	1002295	184		7.45	6	1	30	8	1	8.42	0.19	146	0	1	Ca-Mg-HCO3
CSP-23	Ashenda, Menagesha gedam/Welmera/W.Shewa/Oromia	453776	998997	135		7.59	9	0.8	20	3	1	0.44	0.08	95	0	6	Ca-Mg-HCO3
CSP-24	Mesk woha, Gerar/Jarso, N.Shoa	466264	996974	362		7.48	13	3	44	12	3	7.53	0.64	227	0	4	Ca-Mg-HCO3
CSP-25	Bedo, Gerar Jarso/N.shewa/Ormia	473890	1087756	614		7.36	24	0.5	83	25	2	8	0.5	400	0	6	Ca-Mg-HCO3
CSP-26	Marame Wonnz,cerar,Jarso, Ns	473823	1088329	1012		7.61	55	9.7	90	35	52	26	0.67	351	0	64	Ca-Mg-Na-HCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-27	Dahana, D/Libanoes	482195	1076192	686	742	7.72	48	1.2	75	18	3	0.2	0.28	449	0	6	Ca-Na-HCO3
CSP-28	Dalo Gerar Jarso/North shewa/Ormia	467421	1086066	340		8.02	17	0.2	42	12	4	8	0.28	207	0	3	Ca-Mg-HCO3
CSP-29	Burka Qure Gerar Jarso	472636	1079468	307		7.91	20	1.1	32	9	6	15	0.38	166	0	3	Ca-Na-Mg-HCO3
CSP-30	Laga Nora, Degem/N.shewa	450218	1089388	181		6.83	12	1.3	16	6	2	7	0.13	104	0	1	Ca-Na-Mg-HCO3
CSP-31	Ali doro, Degem/North shewa	448147	1080415	114		7.57	4.5	0.8	12	3	2	12	0.08	57	0	1	Ca-Mg-HCO3
CSP-32	Odo worke, Degem/N.shewa/Ormia	450771	1089316	188		7.44	12	1.3	16	6	2	5	0.15	113	0	1	Ca-Na-Mg-HCO3
CSP-33	Gabesa, D/libanose/N.S	486762	1062813	323		7.81	8	0.4	39	10	20	20	0.25	147	0	5	Ca-Mg-HCO3
CSP-34	Teltele D/libanos/N.shwa/Ormia	482967	106610	336		6.64	12	2.7	34	12	7	14	0.39	154	0	8	Ca-Mg-HCO3
CSP-35	Ano-kare D/Libnos/N.shoa/Ormia	459891	1085626	64		7.51	2.4	0.4	8	1.6	1.5	6	0.09	32	0	1	Ca-Mg-HCO3
CSP-36	Selle, D/Libanos/North shewa	484181	1059882	387		7.5	10	0.1	55	11	6	31	0.19	196	0	5	Ca-Mg-HCO3
CSP-37	D/libanos town/D/lianose, N.shewa	482754	1073368	347		7.59	60	3.1	22	2	16	0.22	0.75	67	0	18	Na-Ca-HCO3
CSP-38	Wortu, gera jarso/ N. shoa/Ormia	478357	1073318	360		7.54	12	0.3	43	12	2	2.2	0.33	229	0	1	Ca-Mg-HCO3
CSP-39	Lelisa, Degem, N.shewa/ Ormia	461054	1099514	648	594	7.17	17	0.8	67	29	4	11	0.34	341	0	11	Ca-Mg-HCO3
CSP-40	Serree morosea Hidabu abote/NS/Amahara	447123	1093293	266		7.23	6	0.1	28	9	10	22	0.09	127	0	1	Ca-Mg-HCO3
CSP-41	Koke, Degem/ N. shoa/ N.shoa/Ormia	465013	1082202	150		7.29	7	0.1	16	4	1.5	0.22	0.15	90	0	1	Ca-Mg-Na-HCO3
CSP-42	Gordoma, Wuchale/N.S/ormia	494307	10972116	327		7.25	5	0.1	46	10	15	40	0.22	126	0	13	Ca-Mg-HCO3
CSP-43	Folofoy, merhabit	494708	1097216	871		7.44	23	3.5	115	25	14	5	0.54	318	0	202	Ca-Mg-HCO3
CSP-44	Gerbeside Logo, Engoye/Sululta/Oromia	435185	1013940	268		7.19	5	1	39	9	5	15	0.14	146	0	1	Ca-Mg-HCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-45	Reji Mokoda/Adaa berga/WS/Ormia	427734	1044649	432		7.37	10	0.8	48	14	25	25	0.24	172	0	6	Ca-Mg-HCO3
CSP-46	Arbu/Beyowegdi/Adaa Berga Wereda/WS/ormia	432678	1049554	386		7.41	9	0.4	57	12	8	24	0.26	176	0	18	Ca-Mg-HCO3
CSP-47	Burayu/Adaa Bega Wereda/ West Showa/Ormia	438064	1025445	124		7.89	4	1	17	4	1	5.8	0.16	78	0	1	Ca-Mg-HCO3
CSP-48	Teltele sululta wereda/WS/Ormia	455904	1048281	442		8.1	14	1	66	13	6	4.4	0.27	232	0	39	Ca-Mg-HCO3
CSP-49	Debersa/Aaa Berga Wereda/West shewa/Ormia	445052	1038814	321		8.25	9	0.3	47	11	1	2.7	0.1	214	0	1	Ca-Mg-HCO3
CSP-50	Makeffa/meta Robe wereda west shewa/Ormia	445052	1038814	362		7.85	10	0.7	50	14	5	6.6	0.19	234	0	2	Ca-Mg-HCO3
CSP-51	Gorol meta Robe wereda/WS/ormia	415052	1038814	221		7.83	7	0.3	32	7	4	12	0.47	124	0	1	Ca-Mg-HCO3
CSP-52	Sombo meta Robe wereda/WS/ormia	410751	1055690	198		7.36	8	0.1	21	6	2	0.4	0.16	120	0	1	Ca-Mg-HCO3
CSP-53	Bishar qiltu meta robi wereda	411562	1060348	775	52	7.43	3	1	102	23	7	13	0.28	317	0	177	Ca-Mg-HCO3-SO4
CSP-54	Ejersa (qunddegerssu) Meta robe wereda	409528	1062177	605		7.38	3	0.6	96	6	5	20	0.17	352	0	25	Ca-HCO3
CSP-55	Loya (goromako) meta Robe wereda/WS/Ormia	409018	1058908	258		7.43	10	1	32	7	6	20	0.15	132	0	2	Ca-Mg-HCO3
CSP-56	Keketo/meta robi wereda/ws/Ormia	414237	1037052	321		7.55	6	1	41	13	5	17	0.11	181	0	1	Ca-Mg-HCO3
CSP-57	Bichillu(meta Robe wereda/west shewa/Ormia	415194	103365	365		7.69	9	1	47	14	10	29	0.12	179	0	3	Ca-Mg-HCO3
CSP-58	Chefe Dubo/meta robi wereda/west shwea/ Oromia	410999	1029707	269		7.32	9	0.7	29	9	5	15	0.76	146	0	2	Ca-Mg-HCO3
CSP-59	Dada/metarobe/WS/Or	1E+06	10611349	596		7.54	8	0.4	98	9	8	29	0.27	342	0	4	Ca-HCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-60		420762	1022097	211		6.93	5	1	24	7	2	6.6	0.08	129	0	1	Ca-Mg-HCO3
CSP-61	Legeba tebo/galesa gofetu/Dandi/WS	405961	1008430	83		7.36	2	0.3	8	3	1	9.7	0.06	37	0	2	Ca-Mg-HCO3
CSP-62	Galesa/Qota Gesha/Dandi/WS/Ormia	405665	1006601	217		7.51	5	1	25	7	8	33	0.08	80	0	2	CaMgHCO3No3
CSP-63	Burga/Aba bule/WS/Ormia	405665	1012152	122		7.48	3	0.4	13	3	1	16	0.05	59	0	3	Ca-Mg-HCO3
CSP-64	Kurea/Jeldu woreda/WS/O	4E+06	1024045	169		7.08	5	2	17	5	3	12	0.1	89	0	2	Ca-Mg-HCO3
CSP-65	Dimo /chobe/Jeldu/WS/Ormia	389440	1027872	121		7.07	3	0.9	10	4	8	29	0.07	22	0	2	CaMgNO3HCO3 Cl
CSP-66	Amboy/Chobe/Jeldu	386831	1030394	65		7.11	2	0.1	22	1.5	3	13	0.06	16	0	2	Ca-HCO3
CSP-67	Tebella/Chobiol/WS/Ormia	383554	1030852	117		7.83	4	0.3	14	3	2	5.8	0.07	67	0	3	Ca-Mg-HCO3
CSP-68	Meska/Jeldu/WS	396016	1027976	284		7.44	6	0.7	37	10	5	11	0.1	159	0	2	Ca-Mg-HCO3
CSP-69	Dimo /like/Jeldu/WS/Ormia	391291	1037912	207		7.47	6	0.9	21	6	4	24	0.13	92	0	3	Ca-Mg-HCO3
CSP-70	Shonta/Tilke/Jeldu/WS //Ormia	389459	1042289	671		7.83	5	0.7	123	13	4	15	0.23	322	0	80	CaHCO3-SO4
CSP-92	AA-Asko-99	465578	999808	341	206	6.9	76	2.6	3.5	1.1	7.9	0	3.4	181	12	0	NaHCO3
CSP-93	AA-Ato Tahas Burayo	481230	992312	480	314	8.3	54.5	6.2	37.4	9.7	5.8	1.3	0.6	280	0	12.5	NaCaHCO3
CSP-94	AA-Bole Lemi-1(Hanku)-99	463972	1000788	280	190	7.3	50	3.7	14.1	3.2	2.9	0.4	2.3	161	7	0	NaCaHCO3
CSP-95	AA-Burayu-1-99	464031	1002909	273	172	7.5	32	5.4	25.5	3.2	6.7	0.1	2.1	154	0	2.9	CaNaHCO3
CSP-96	AA-Burayu-99	468200	1001600	167	107	7.1	23.8	3.3	28.8	1	11.3	0	0.3	146	0	0	CaNaHCO3
CSP-97	AA-Dire Tannery BH1, Gulele	466900	1001005			7.2	14.6	1.3	20.8	6.8	7.1	0	0	122	0	0	CaNaMgHCO3
CSP-98	AA-Glass and Bottle Factory	468875	993750	251	163	7.3	29	3	16	5	6	7.4	0.4	134	0	0	NaCaHCO3
CSP-99	AA-Gulele Glass-Factory-3	469458	990594	304	184	8.1	15	6.8	37.4	8.6	1.9	2.1	0.9	181	0	1	CaMgHCO3
CSP-100	AA-Hagbes PLC., Bisrate Gabri	470530	991988	412	270	7.2	31	8.1	51	6.5	29.8	1.1	2.1	187	0	14.2	CaNaHCO3
CSP10	AA-Jemo-1-99	470277	989578	369	265	7.4	48	10	39.6	6.5	18.4	0.4	1.1	234	0	1.7	NaCaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-102	AA-Mekanisa National Alchole	470070	991000	305	200	7	20	7.2	35.6	7	3.8	3.6	0.4	181	0	2.2	CaNaHCO3
CSP-103	AA-Mekanisa-1-99	465741	989188	265	174	7.5	10.4	4.5	36.1	9.2	2.9	2.7	1	161	0	0.9	CaMgHCO3
CSP-104	AA-Mekanissa-99	481600	982900	520	424	7.4	39.6	4	40.9	31.2	19.9	9.3	1	177	0	130	MgCaNaHCO3SO4
CSP-105	AA-Repi-99	466690	976790	588	376	7.6	67	9.5	41.8	13.8	20.2	32.5	0.8	266	0	17.3	CaNaHCO3
CSP-106	AA-Water lll Testwell-B9	473911	1031930	166	108	6.5	30	0.7	5.3	0.5	1.9	0.8	0.2	90.3	0	7.2	NaCaHCO3
CSP-107	AA-Yekamichael-99	471304	1027754	257	146	7.9	20.5	0.9	32.2	4.2	1.9	2.9	0	154	0	0.8	NaHCO3
CSP-108	Alem Gena-Ilamu	491980	965840	343	238	7	43.5	17.5	25.2	5.1	13.9	3.1	1.4	231	0	2.2	CaNaHCO3
CSP-109	Chancho mapping	482263	1038145	235	134	7	13.5	1.1	6.9	23	8.9	0	0.8	137	0	2.1	CaNaHCO3
CSP-110	Chancho town	452124	1002590	240	148	7.7	5.3	1.1	40.9	4.9	4.8	8.5	0	149	0	0.5	CaHCO3
CSP-111	D/Z-Oromiya well-99	453522	1001474	206	144	6.7	7.6	1.8	29.4	7	3.8	4.8	0	133	0	1.3	CaHCO3
CSP-112	Fiche-Gorfo	454124	1005990	272	172	8.2	6.1	1.6	43.6	9.2	0	10	0.2	172	0	0	CaMgHCO3
CSP-113	Gefersa Ethio-Cup	455620	1026514	237	152	8.3	34	1.5	16	1.1	6.7	2.5	0.3	119	5	13.2	CaMgHCO3
CSP-114	Holota-Jerico flowers	474421	1013070	289	192	6.9	55	0.8	5.9	3.1	25.8	0	0.9	69.8	24	25.6	NaCaHCO3
CSP-115	Menagesha Town	459689	998340	196	132	6.2	8.6	4.8	30.3	3.8	1	7.5	0.2	123	0	0.5	NaHCO3Cl
CSP-116	Segno Gebeya mapping	477940	995029	210	132	6.5	10.8	2.9	26.4	6.1	2.5	3	0.1	129	0	0.5	CaHCO3
CSP-117	Sululta mapping	477940	995029	275	178	7.5	14.6	3.6	39.6	5.9	5.7	3.8	0.8	160	0	1.1	CaMgNaHCO3
CSP-118	Tatek Military Camp	486200	1001042	573	369	7.5	65.5	2.7	36.9	14.6	25.5	0	0.7	293	0	15	CaNaHCO3
CSP-119	wwdse1	493518	1004421	380	242	8.8	32	6.7	35.6	8.6	5.8	0.1	0.5	221	0	16	NaCaMgHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-120	wwdse4	507086	1012954	412	235	7.4	80	19	8.8	2.2	28.8	7.6	1	137	19	19	CaNaHCO3
CSP-121	AA-Water lll Testwell-B4	489127	999697	524	344	8	77	22	16.6	3.2	32.8	0	1.7	226	0	29.7	NaHCO3
CSP-122	Legadadi, mapping well	514952	1013281	280	188	6.9	48	2	16.8	3.6	14.9	7.3	0.6	183	0	0	NaHCO3
CSP-123	Bekie mapping well	561897	1069503	187	110	7.3	6.7	2.4	26.1	3.7	5.8	5.4	0.2	94.6	0	1.1	NaCaHCO3
CSP-124	AA-Ayat-99	489336	1058283	305	176	8.3	5.6	1.3	48.7	8.5	8.6	14.3	0.5	157	0	2.5	CaHCO3
CSP-125	CGC Road Capm Aleltu	513157	1025381	258	170	7.6	29	1	24.5	3.8	16.9	1.3	0.6	104	10	12.9	CaMgHCO3
CSP-126	D/B-Dalocha DBH#4	501332	1068067	358	235	6.7	21	4.6	49.3	2.6	15.5	0	0.3	193	0	6.1	CaHCO3
CSP-127	Solo	484152	989566	363	240	7	20	4.8	46.3	10.3	5.8	1	0.5	223	0	4.2	CaNaHCO3
CSP-128	Onoda	471500	990500	438	280	7.1	13.8	5.2	65.6	10.3	9.9	6.2	0.8	246	0	2.8	CaNaMgHCO3
CSP-129	Woberi	467135	989840	344	226	7	17	6.8	46.6	9.2	6	4.6	0.6	235	0	0.1	CaHCO3
CSP-141	Alem Gena-Dika	473276	996535	3380	2240	7.5	930	16	2.8	1.1	7.7	1.9	27.6	1874	101	92	CaNaHCO3
CSP-142	D/Z-Health College	474175	996550	3359	205	7.5	840	15	6	2	43	0	21.1	2198	0	55	NaHCO3
CSP-143	Galetti Project	478990	955803	616	400	7.8	105	23.5	21.1	3.2	13.4	0.2	1.9	363	0	13.1	NaHCO3
CSP-146	Dukem Town mapping	506464	941989	854	578	7.7	170	15	16.8	3.1	52.6	0.7	7.5	424	0	25.9	NaHCO3
CSP-147	Dukem-Industrial Park Borehole	526928	943518			7.3	124	18	24	5	26	9	4	390	0	0	NaHCO3
CSP-148	Kusaye Adulala area	530429	941358			7.5	156	15.2	20.8	4.9	28.4	4.4	5.5	439	0	12.6	NAHCO3
CSP-149	Modjo Muda mapping	527667	941523	700	470	8.6	106	15	50.7	7	7.7	18.3	1.4	451	0	7.9	NaHCO3
CSP-150	Nazareth Metal Works	503210	930527	1930	915	7.1	442	7.4	7.4	0	62.5	0	18.7	830	0	9.4	NaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-151	Nazareth Trans Freight	466050	993650	459	280	8	36	4.9	45.7	20	14	0	0.5	317	0	0	NaHCO3
CSP-152	Nazareth-Yerer Flour Mill	489950	976019	537	315	7.7	40	11.4	56	16.5	7	7.5	0.4	317	0	0.5	CaMgNaHCO3
CSP-153	Red Fox Flowers	478580	976051	476	291	7.7	27.2	4.3	60.8	20.4	7.2	9.7	0.4	300	17	1	CaNaMgHCO3
CSP-154	AA-Military Food Kitchen	473566	978610	658	424	7.6	33.6	5.1	60.1	20	26.8	0	0.7	317	0	4.7	CaMgHCO3
CSP-155	AA-TW4	473108	979851	397	255	7.5	37.4	5.3	54.5	22.4	14.2	18.9	0.7	317	0	24.7	CaMgNaHCO3
CSP-156	AA-Water lll Borehole BH14	480895	977403	489	298	7.8	23	3.4	39	26	9	0.3	0.3	315	9	0	CaMgNaHCO3
CSP-157	AA-Water lll testwell-B7	464607	973547	507	312	7.2	20	6.1	68.7	17.5	3.8	8.5	1.2	316	0	0.6	MgCaHCO3
CSP-158	AA-Water lll Testwell-T4	495561	968574	464	303	7.6	25	7.3	43.2	19.8	0	0	0	320	0	0.5	CaMgHCO3
CSP-159	Akaki Beverly International	483243	961360	503	330	7.5	39	6.8	56.1	17.3	5.8	13.5	1.6	320	0	0.3	CaMgNaHCO3
CSP-160	Shoki Ziquala M. Mision Si	481200	980000	440	396	7.6	40.8	13.2	46.6	31.2	14.2	19	0	378	0	0	CaMgNaHCO3
CSP-161	AA-TW3	481200	980000	530	385	7.4	40.8	5.3	67.3	15.6	14.2	11.7	1	366	0	0	MgCaNaHCO3
CSP-162	AA-TW5	481600	982900	540	380	7.3	44.2	4	56.1	20.4	14.2	9.6	0.7	342	0	15	CaNaHCO3
CSP-163	AA-Water lll Testwell-B5	487900	972421	632	386	7.8	32	7	62	31	12	11.7	0.3	383	0	8	caNaMgHCO3
CSP-164	AA-Water lll Testwell-T1	499500	964500			7.7	64.6	11.9	44.9	29.2	28.4	8.9	0.8	403	0	0	CaMgHCO3
CSP-165	AA-Water lll Testwell-T5	507491	952694	950	612	7.2	57.8	10.3	65.7	17.8	28.4	2.7	1.5	415	0	0	NaMgCaHCO3
CSP-166	Dukem-Arena	507950	951364	741	482	7.4	70	17.5	73	20	18.2	10.5	1.9	469	0	9	CaNaHCO3
CSP-167	D/Z-Air force No.2	507950	951364	675	439	7.9	51.2	14.3	68.3	19.2	16.7	7.4	1.5	398	0	6.5	CaNaHCO3
CSP-168	Gafat#1	509385	950325	915	590	8	74.8	17.2	52.1	21.9	26.6	1.6	0.9	427	0	14	CaNaHCO3

ID	Location	UTME	UTMN	EC	TDS	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	CO3	SO4	Water type
CSP-169	Gafat#10	509020	950736	915	590	7.6	71.4	13.9	59.3	18.5	20.8	2.5	1.1	464	0	0	NaCaHCO3
CSP-170	Gafat#10-monitord	508684	951058	915	590	7.4	61.2	12.5	74.1	18.2	35.5	9.2	0.9	427	0	0	NaCaHCO3
CSP-171	Gafat#7	507714	955875	728	476	7.1	66	12.4	73.9	24.3	15.4	10	0.5	461	0	7.4	CaNaHCO3
CSP-172	Gafat#8	515693	979674	673	440	6.9	32	7.4	82.3	24.8	12.9	3.2	1.3	419	0	14.4	CaNaHCO3
CSP-173	Gafat#9	515449	979174	728	478	7.9	41	8.9	96.3	13.5	9.9	5.2	1.2	483	0	0	CaMgHCO3
CSP-174	Modjo-Biyo Beseka hand dug	506765	957179	664	414	7.9	54	13.1	80.6	12.2	15.9	3.5	0.6	404	0	2.3	CaNaHCO3
CSP-175	Tuludimtu#1	499131	965767	1209	786	7.9	181	22.1	42.5	38.2	64.7	7.8	0.7	691	1	7.7	CaNaHCO3
CSP-176	Tuludimtu#2	500078	968505	1041	635	8	138	12	36	36	0	0.4	0.7	625	0	6	NaHCO3
CSP-177	Modjo Ude mapping well	504878	970766	534	348	7.5	54	13.8	47	17.7	13.9	0	1.3	351	0	0.9	NaMgHCO3
CSP-178	D/zeit Air force ,main M	500909	964676	628	391	7.5	50	10.2	71.2	15.1	15.4	17.5	0.5	379	0	13.7	CaNaHCO3
CSP-179	D/Z-Veternary College BH2	518066	992824		484	7.6	23	5.5	10.7	10.7	6	2	0.6	266	0	1	CaNaHCO3
CSP-180	Borora mapping well	512282	951356			7.4	74.8	8.3	25.7	4	28.4	6	0.5	268	0	0	NaMgHCO3
CSP-181	D/Z-Air force	512957	947774	519	376	8.3	52	12.8	52.5	11.3	5.8	10.5	1.4	333	0	4	NaCaHCO3
CSP-182	Gimbichu Fentale spring	512011	949196	697	449	7.3	69.7	13.2	47	11	14.2	0.9	0.8	342	18	0	CaNaHCO3
CSP-183	Modjo Dairy Development	512408	948682	590	390	7.6	65	12	60.5	9.2	5.8	3.3	1.1	382	0	1.1	NaCaHCO3
CSP-184	Modjo Lume#3	500494	974376	519	338	8	28.4	6.7	67.2	17.7	8	6	0.7	332	0	3.5	CaNaHCO3
CSP-186	Modjo#3	500494	974376	530	350	8.3	31	6.8	78.3	11.9	5.8	13.5	0	348	0	2.1	CaNaHCO3
CSP187	Shimbira Meda BH#4-	500424	974376	615	397	7.5	33	9	48	15.3	17.7	1.9	0.5	256	18	0	CaNaHCO3