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GROUND WATER QUALITY PROBLEMS IN SUMMIT-BOLE AND YAKE-KOTEBE AREA OF ADDIS ABABA

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

By

Shilima Abebe Demie

July 2011

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Declaration

I hereby declare that I am the sole author of this thesis and have not been presented for any degree in any university and all the resource of material used for the thesis have been duly acknowledged.

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ABRREVATIONS

AAWSA	Addis Ababa Water and Sewerage Authority
a.m.s.l	above mean see level
BOD	Biochemical Oxygen Demand
CSA	Central Statistical Authority
DO	Dissolved Oxygen
DRASTIC	Depth, Recharge, Aquifer, Soil, Topography, Impact, Conductivity
EC	Electrical conductivity
EPA	Environmental Protection Authority
KN	Kjeldelal Nitrogen
SBPDA	Sanitation Beatification and Parks Development Agency
TAR	Tinshu Akaki River
TDS	Total Dissolved Solids
WHO	World Health Organization

ABSTRACT

Pollution of ground water either from geogenic or anthropogenic sources has become a thing of health concern in the city of Addis Ababa. This study assesses the quality hazards of ground water resource by sampling some boreholes from Yaka-Kotebe and Summit-Bole area of the Addis Ababa. Collected samples were analyzed for water quality parameters using standard procedures. The parameters determined were Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe), chloride (Cl^-), floride (F^-), nitrate (NO_3^-) and sulphate (SO_4^{-2}).

Results were subjected to evaluations using Arcgis, Aquachem and SPSS for descriptive and analysis of the results. $Ca\text{-}Na\text{-}HCO_3$ and $Na\ \text{-}Ca\text{-}HCO_3$ were the dominate water type in the study area. The mean value of iron (0.55 mg/l) and floride (3.2 mg/l) were above World Health Organization standards for drinking water in Yaka-Kotebe area. Similarly, the mean value of TDS (862 mg/l) and EC (1356 mg/l) for water samples from Summit-Bole were greater than maximum permissible standards for drinking water Guide Line of World Health Organization. It was also observed from EPA secondary data upstream to downstream along Akaki rivers increase in the concentrations of heavy metals, TDS, EC, pH, and temperature and associated with the generally declining DO level.

Generally, in the study area from water sample analysed about 50% of water samples were greater than World Health Organization maximum permissible standards for drinking water for water quality parameters such as Fe, F^-, NO_3^-, EC, and TDS. Therefore, elevated values of these parameters are of great concern to public health when the water from these boreholes is consumed by people without treatment.

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

The natural physicochemical properties of water render its vital importance to sustain the living planet Earth and every form of life on its face, including human beings. Its vital role in many human activities including agriculture, industry, domestic, electric power generation, transport and recreation shows that to what extent water is an integral part of human's life. The normal functioning of a natural system such as a human body depends entirely on the availability of adequate quantity and quality of water.

Owing to the natural interaction among the earth's subsystems, pure water does not exist by default and its quality can be affected by some dissolved and or suspended substances of natural or anthropogenic origin, and consequently gets polluted. Water pollution is the state of alteration in the natural, physical, chemical, biological, bacteriological and radiological properties of water that causes in an impairment of its inherent and or designated uses (Susan and Joy 1998). This also disturbs the biophysical entities of a water body and negatively affects the socioeconomic values of water.

This day's water pollution resulted from industrialization, urbanization and population explosion has become a global problem. Our country, Ethiopia is also facing the problem of water quality degradation. However, the extent and degree of severity of water pollution is more pronounced in major cities, like Addis Ababa where the problem is at its peak currently (Tamiru Alemayehu, 2003).

The impact of human population on surface and groundwater is increasing with the development of industry and population size in the city of Addis Ababa (Tamiru Alemayehu, 2003). The introduction of undesirable materials into soil, water and air can occur not only as a consequence of man's activities but also through the natural processes. As a result, there is a change in the characteristics of soil, water and air, which may have effect on the health of people.

1.2. OBJECTIVES

General objective

The main objective of the study was to analysis and interprets ground water quality problem for selected boreholes and springs in Yeka-Kotebe and Summit-Bole area of Addis Ababa.

Specific objectives:-

- ✓ To trace sources/reasons of ground water quality problems.
- ✓ To assess the degree and intensity of ground water quality problems.
- ✓ Study groundwater flow of an area.
- ✓ To determine physicochemical analysis for selected boreholes and springs in an area.
- ✓ Finally, to give recommendation so that ground water quality can be maintained for longer period of time.

1.3. METHODOLOGY

In order to achieve the objectives of the research project, the followings methods and materials were used:-

- Collecting and review of existing geological, hydrological, hydrogeological and water quality data and reports covering the study area.
- Generation of primary and organization of secocondary water quality data which include major ion chemistry of water samples from boreholes and springs were made the data base of the research work.
- Interpretation laboratory results and secocondary data based on maximum permissible standards for drinking water Guide Line of World Health Organization and Ethopian water quality standard.
- Software, such as, Aquachem4, Arcgis9.2, SPSS16, Sulfer8 and Microsoft excel were used to interpret and analysis data in the area under study.

Generally, from numerous data existing in the study area 30 water samples were collected for hydrochemical analysis from selected existing water sources in Yeka-Kotebe and Summit-Bole area of Addis Ababa to come up with the aerial classification of the water in terms of usability and suitability of the water for the intended purpose.

After a representative sample was collected, then analyzed for the component of interest, and for all other components of the system that may affect the behavior of that component
Parameters that analyzed were TDS, EC, pH, HCO_3^-, SO_4^{-2}, NO_3^-, Cl^-, F^-, Ca^{2+}, Mg^{2+}, Na^+, $K^+$and Fe using titration, electrical phenomena measurement and quantitative spectrophotometry techniques are the methods of chemical water quality inspection.

1.4 PREVIOUS WORKS

In Addis Ababa and its surrounding areas, both surface and groundwater resources have been investigated in terms of potential, flow models, water quality assessment and vulnerability by different investigators.

The main groundwater movement is from North to South in the central and Northern part of the catchments and towards the South-East direction in the lower part of the catchments (AAWSA *et al.*, 2000). The increase in the concentrations of potentially harmful substances such as heavy metals (Fe, Mn and Cr), ammonia, hydrogen sulphide, sulphates and phosphates is found to be associated with the generally declining DO level in the down stream direction (Abdishikur Mohammed, 2007).

Demlie *et al.* (2006) study soil and groundwater pollution of an urban catchment's by trace metals and indicates that a relatively high content of the analyzed trace metals in the soil attributed to anthropogenic and geogenic sources. The same work was done by Tamiru Alemayehu (2006) accordingly heavy metal analyses of rocks, soils, streams, springs and boreholes have been carried out to identify the presence of potentially harmful solutes. He was reported that rock and soil outcrops of Addis Ababa are anomalously rich in heavy metals derived from hydrothermal activity and he was concluded that heavy metal concentrations in the surrounding rocks and soils are related to geogenic sources whereas anthropogenic contribution as a cause of these concentrations is minor.

Akaki river catchment's vulnerability of groundwater increases from the central part to the peripheral areas and the recharge areas are more vulnerable to groundwater pollution as compared to other areas in the catchment's (Dereje Nigusse, 2003). Ebasa Oljira (2006) also counducted numerical groundwater flow simulation of Akaki River catchment, as numerical groundwater flow models represent the simplification of complex natural systems, different parameters was assembled into conceptual model to represent the complex natural system in a simplified form. The most of the industries in Addis Ababa are concentrated in the Southern and Western parts. Among the Industries located in the city 90% of them discharge their wastes without any treatment into the adjoining water coarse and open spaces (EPA, 2001 and 2002). The main threat to the surface water quality in Addis Ababa is environmental pollution derived from domestic and industrial activities as a result uncontrolled (improper) waste disposal has deteriorated the quality of surface water (streams, rivers, reservoirs) by changing the chemical, physical and organoleptic properties of water (Tamiru Alemayehu, 2001).

Tamiru Alemayehu *et al.* (2003) study ground water vulnerability mapping of the Addis Ababa water supply aquifers and they have been conducting the risk for groundwater pollution through DRASTIC mapping of water supply aquifers, and finally, they reported that main sources of pollutants that deteriorate the quality of water in the project area are wastes generated from industries, domestic activities, garages, health centers and fuel stations.

According to Solomon Waltenigus (2007), it was possible to extract information on the contribution of rainfall to the spring discharge, storage conditions of the spring reservoir, the recharge conditions (rate of recharge) and the current reserve for sustainable flow.

Tenelam Ayenew (1998, 2001) describes the hydrochemical and signatures of different water types of Addis Ababa. Accordingly a very dilute Ca-HCO_3, Ca-Na-HCO_3 type water in (the North Intoto range) draining the Intoto silicics, Ca-Mg-HCO_3, Mg-Ca-HCO_3 type water drains the Addis Ababa basalt in the central of the Addis Ababa and the Bishoftu basalt aquifers in the South and Na-HCO_3 type water of the 'Filwuha' thermal system, which have rock dominated hydrochemistry. While a Ca-NO_3 and Ca-Cl type water circulating in the Central part of the Addis Ababa is a result of anthropogenic influences, Similarly Tamiru Alemayehu (2004) identified four kinds of water in Addis Ababa: Na-HCO_3, Na-Ca-HCO_3, Ca-Mg-HCO_3 and Ca-Mg-Cl., Most of the river water belongs to Na-HCO_3 and Na-Ca-HCO_3 types. The chemistry of spring water becomes a Ca-Mg-Cl and Ca-Mg-HCO_3 type. A shift of the water chemistry towards SO_4+ Cl is mostly related to the infiltration of contaminants into the subsurface rather than natural dissolution processes.

All above listed studies, although they vary in scope and degree of geological and geochemical information, they have stressed that the quality of surface water is often affected by uncontrolled waste disposal of domestic and municipal wastes and industrial effluents. They further indicated that these would have potential impact on the quality of groundwater of the region.

Geology of Addis Ababa city classified into volcanic rocks of Intoto trachyte, Intoto mixed rocks, Foota basalt, Cheleka basalt, Repi basalt (trachy basalt and basalt), lower ignimbrite, Wechecha-Furi-Year trachyt and trachy basalt, Wechecha-Furi-Yere ignimbrite, Quaternary olivine basalt, Quaternary Scoria, Tertiary sediment and Lake sediment (Assiged Getahun, 2007). And they are correlated with the volcanic rocks of central Ethiopia. And the sedimentary rocks are Tertiary intravolcanic lake sediment.

Kebede Tsehayu and Taddessse Miriam (1990) were studied for engineering geology mapping of Addis Ababa area. According to this work the units mapped in the area are the trachyte and rhyolite, ignimbrite tuff, trachy basalt and basalt of different ages. Moreover, a number of faults most of which have subprarallel trend with the main Ethiopian rift fault are identified in the area. Tsegaye Abebe *et al.* (1995) have studied the Yerer –Tulu Wellel extensional structure. This study was mainly for the understanding of the structure and volcanic associated centers.

CHAPTER TWO

OVERVIEW OF THE STUDY AREA

2.1. LOCATION

The Addis Ababa city was founded in 1871 at the Western shoulder of the Main Ethiopian Rift. The city has been widening from time to time to attain the current aerial extent of about 1,500 Km^2, that is geographically bounded by UTM coordinates of about 978000N, 1005500N and 456000E, 495000E (Figure 1).

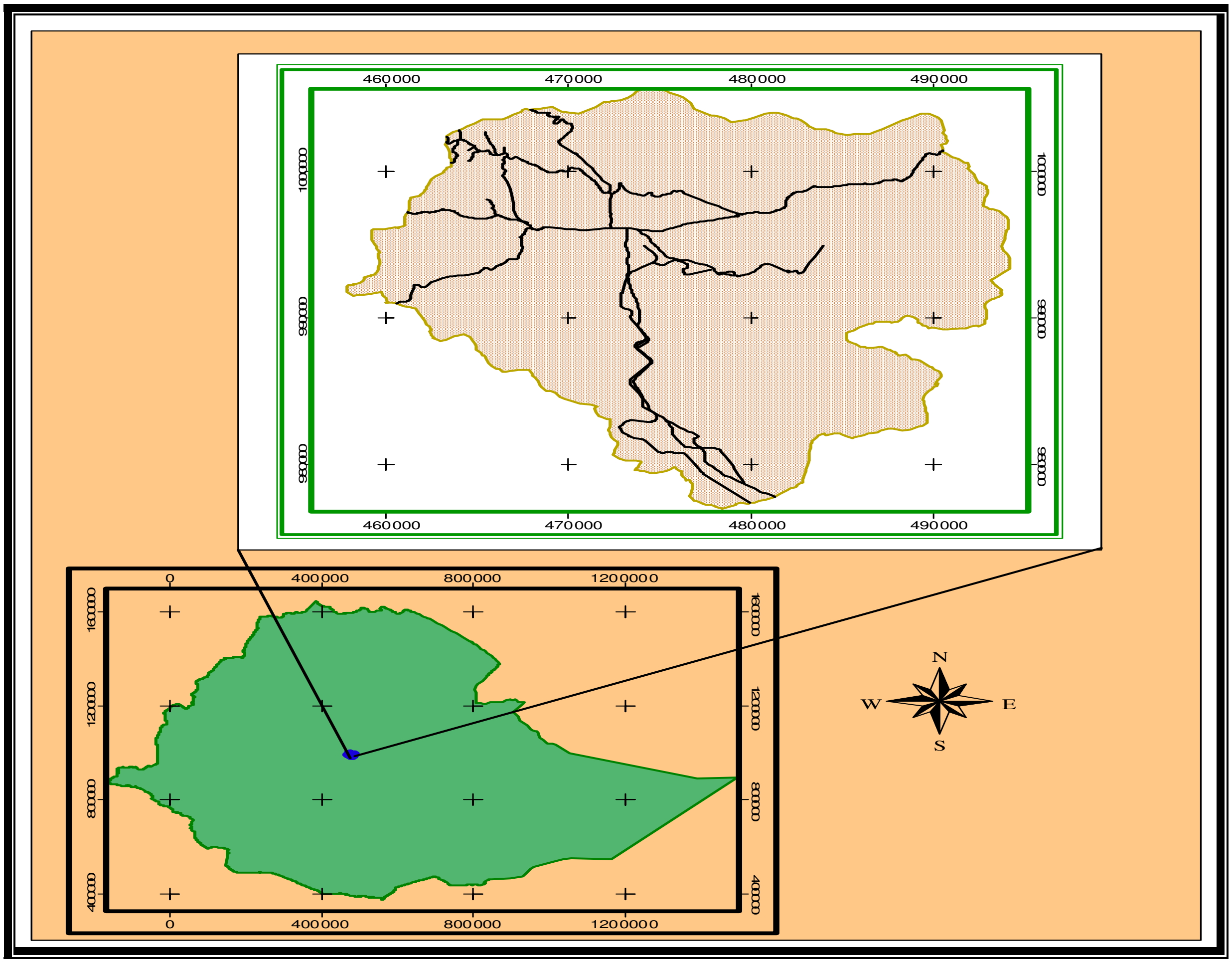


Figure 1 Location map of Addis Ababa

2.2. PHYSIOGRAPHY

In Addis Ababa, elevation ranges generally between 1780 m and 3380 m a.m.s.l. However, the portion of the area with elevation greater than 3200 m a.m.s.l is negligibly small. A considerable portion of the Northern part is within the elevation range of 2670 m and 3000 m a.m.s.l. This area is very sloppy, however, both elevation and slope decreases progressively towards the South. A large portion of the central part of the project area falls in a narrow elevation range of 2313 and 2491 m a.m.s.l. Proceeding further South wards, the topography becomes very gentle and a very wide area falls under a smaller elevation range of 1958 m and 2135 m a.m.s.l. The lowest elevation is found at the Southern border of the study area which is about 1780 m a.m.s.l.

Apart from the Intoto Mountain range that marks the Northern border of the city, other Mountainous volcanic centers also occur in the Western, South-Western and South-Eastern borders. These Mountains are Wechecha (3,391 m a.m.s.l), Furi (2484 m a.m.s.l) and Yerer (3,100 m a.m.s.l). Generally, undulating to flat topography is dominant within the city boundary.

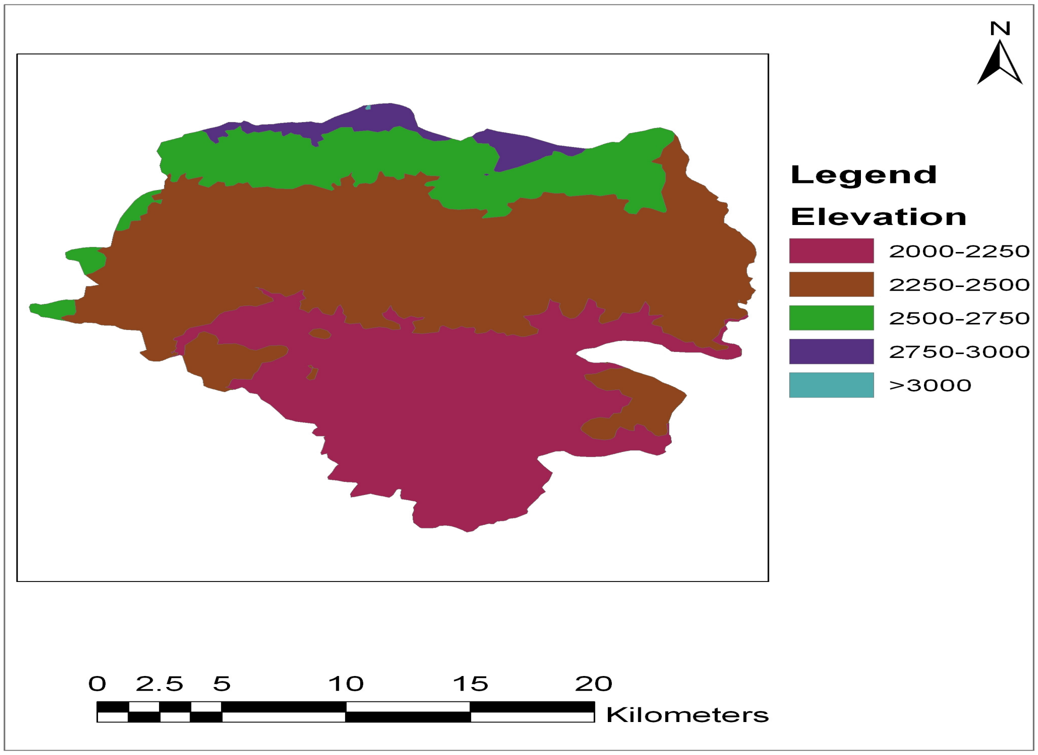


Figure 2 Physiographies of the study area

2.3. DRAINAGE

The Addis Ababa area located in Akaki catchment's which consists of Akaki River catchments and numerous small rivers. The dominant ones are the Big Akaki, which drains the Eastern part of the catchment's area, and the Little Akaki that drains the Western part of the catchments and their respective tributaries. The two rivers form one of the biggest tributaries of the Awash River called Akaki River that enters Abba Samuel Lake, leaves the lake and passes through a gorge up to 100 m deep which extends for about 8 km before it joins the Awash River. Almost all the streams in the catchments originate from the Northern part of the catchments.

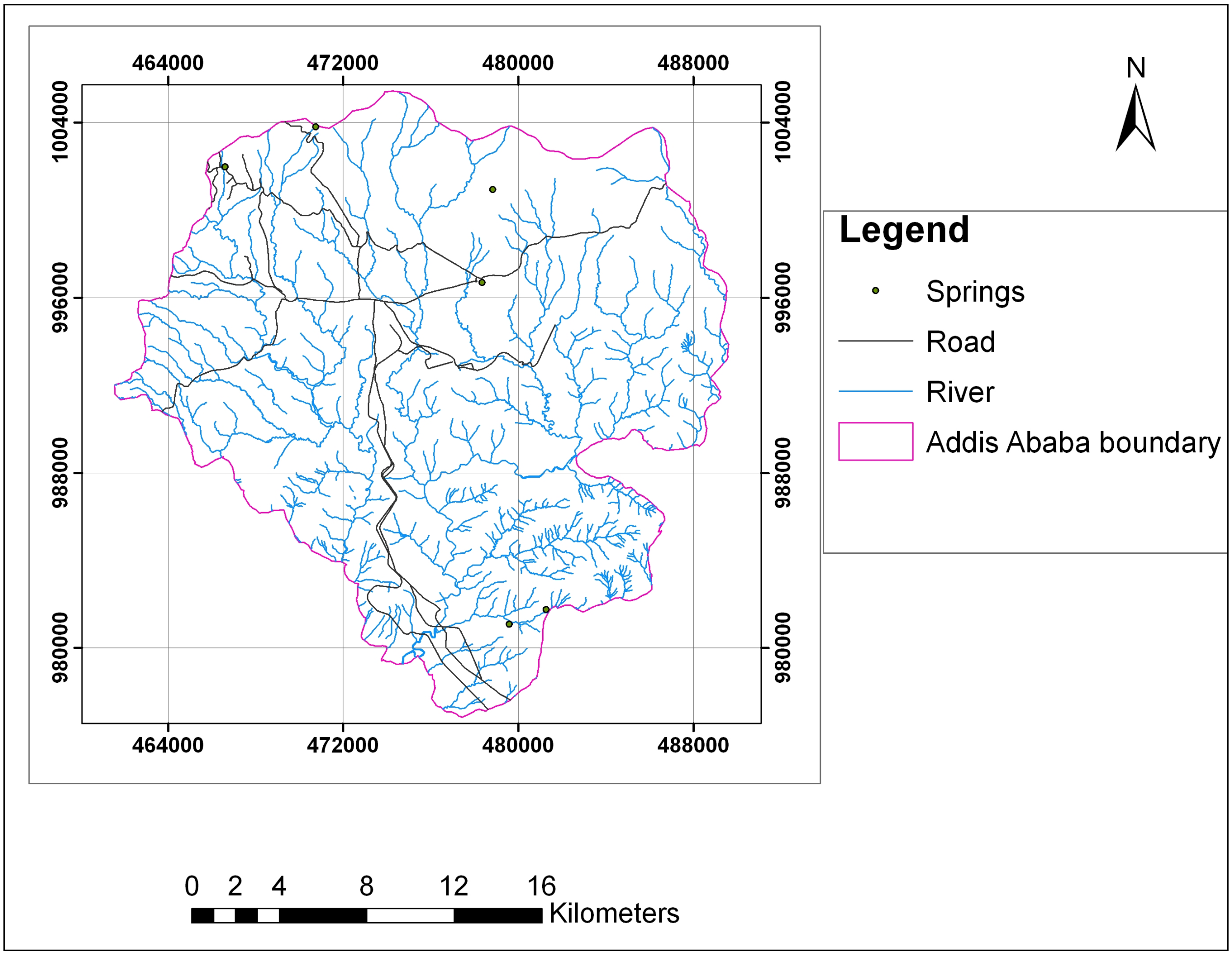


Figure 3 Drainage of the study area

2.4 HYDROMETEOROLOGY OF THE AREA

2.4.1 CLIMATE

National Atlas of Ethiopia (1981) defined five climatic zones: "Kur" (Alpine), 3000m and above mean sea level; "Dega" (temperate), 2300m to about 3000m; "Weina Dega" (Sub tropical), 1500 to about 2300m; "Kolla" (Tropical), 800m to about 1500m and "Bereha" (Desert), less than 800m. Having a maximum and minimum elevation range a little above 3000m and a little below 1500m respectively, most part of Addis Ababa falls under the Weina Dega (Sub tropical) category. Accordingly the climate of Addis Ababa area is typically characterized by two distinct seasonal weather patterns: the wet season which extends from June to September, contributing about 70% of the annual rainfall, and the dry season which covers the period from October to May with a minor rainy season in March and April well known for its frequent failure. Such climates which are characterized by alternating wet and dry seasons may favor weathering

2.4.2 PRECIPITATION

According to Daniel (1977) classification of Ethiopia's rainfall regions, Addis Ababa is located in the region where the rainy months are contiguously distributed (Regime IE). In this region there are seven rainy months from March to September and the small rains occur from March to May. The big rains are from June to September. High concentration of rainfall occurs in July and very high concentration in August.

The monthly mean rainfall records for the four station (Appdixs1) showed that the mean annual rainfall at Intoto station (at an elevation of 2900 m a.s.l), Addis Ababa Observatory (at an elevation of 2408 m a.s.l.) Bole (at an elevation of 2324 m a.s.l.), and Akaki Mission (at an elevation of 2170 m a.s.l.) are 1088.5 mm, 1251.5 mm 1164 mm and 1087.01 mm respectively. Thus, the city receives annual average rainfall of about 1123 mm and the long term mean annual rainfall observed at Addis Ababa Observatory is about 1256 mm.

Moreover, in all stations the heaviest amounts of rainfall occur in the months of August, while the minimum amount of rainfall occurs in November at Addis Ababa Observatory and in December at all other stations.

2.5 GEOLOGICAL SETTINGS

2.5.1 REGIONAL GEOLOGY

Mohr (1963) attempted to divide the Cenozoic rocks of Ethiopia in to the Trap and Aden Series. The term Trap Series is still widely used to represent the whole pile of Tertiary flood basalt sequences, which form the North-Western and South-Eastern plateau and attain a thickness of up to 3km (Tefera Mengesha *et al.,* 1996). The term Aden series was used for post-rift (middle Miocene- Quaternary) volcanic rocks of the Main Ethiopian Rift, Afar depression, and some parts of the Ethiopian plateau.

According to the general geological description of the Awash River basin (Tenalem Ayenew *et al*., 2007) most of the highlands are covered with early Cenozoic Trap Series volcanics (dominantly basalt, rhyolite and ignimbrite).

All the rocks are faulted in the rift and adjacent rift escarpments. The rift is distinctly separated from the plateau by a series of step-faults. A major fault running East-West via Kesem River, Addis Ababa-Ambo cuts across the Western rift escarpment and uplifted its Northern block (Zanittin *et al*., 1978) about 8 million years ago. This fault marks the outer boundary of the Western Ethiopia rift margin immediately North of Addis Ababa - Ambo (Zanittin *et al*., 1974).

2.5.2 LOCAL GEOLOGY

The area that covers the city of Addis Ababa and/or the Akaki River catchment consists of various volcanic rock units of different composition and age. Following a traverse from North (Intoto Mountain) to South (Kaliti-Akaki area), the geological formations change from the oldest volcanic sequences to the youngest. Haileselassie Girmay and Getaneh Assefa (1989) proposed the stratigraphy of the area starting from Sululta to Nazareth. Accordingly, the suggested Miocene-Pleistocene volcanic succession in the Addis Ababa area from bottom to top are Alaji rhyolites and basalts, Intoto silicics, Addis Ababa basalts, Nazareth group, and Bofa basalts.

Alaji series covers the Intoto Mountain and extends to the North beyond the study area. It comprises of basalts associated with rhyolites, trachytes, ignimbrites, tuffs and agglomerates.

Intoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian (Haileselassie Girmay and Getaneh Assefa, 1989). The rhyolitic lava flow outcrop on the top and the foothills of the Intoto ridge, predominantly in the Western side

Addis Ababa basalts overlie Intoto silicics and outcrops mainly occur in the Intoto Mountain, central Addis Ababa, along Akaki River course (South) in the vicinity of Lega – Dadi dam to the north of Lake Gefersa and Southern part of the city.

Younger volcanic can broadly be classified into Nazareth Group and Bofa Basalts. According to Hailesellasie Girmay and Getaneh Assefa (1989) the Nazareth Group rocks out crop dominantly to the South of Filwuha Fault and extend towards Nazareth, Aphanitic basalt, welded tuffs, ignimbrites, trachytes and rhyolites make up this group.

Bofa basalts are found South ward from Akaki River, South-Eastern part of Addis Ababa and it comprises of olivine porphyritic basalt, scoria, vesicular & scoriaceous basalt, and trachy - basalt lava flows.

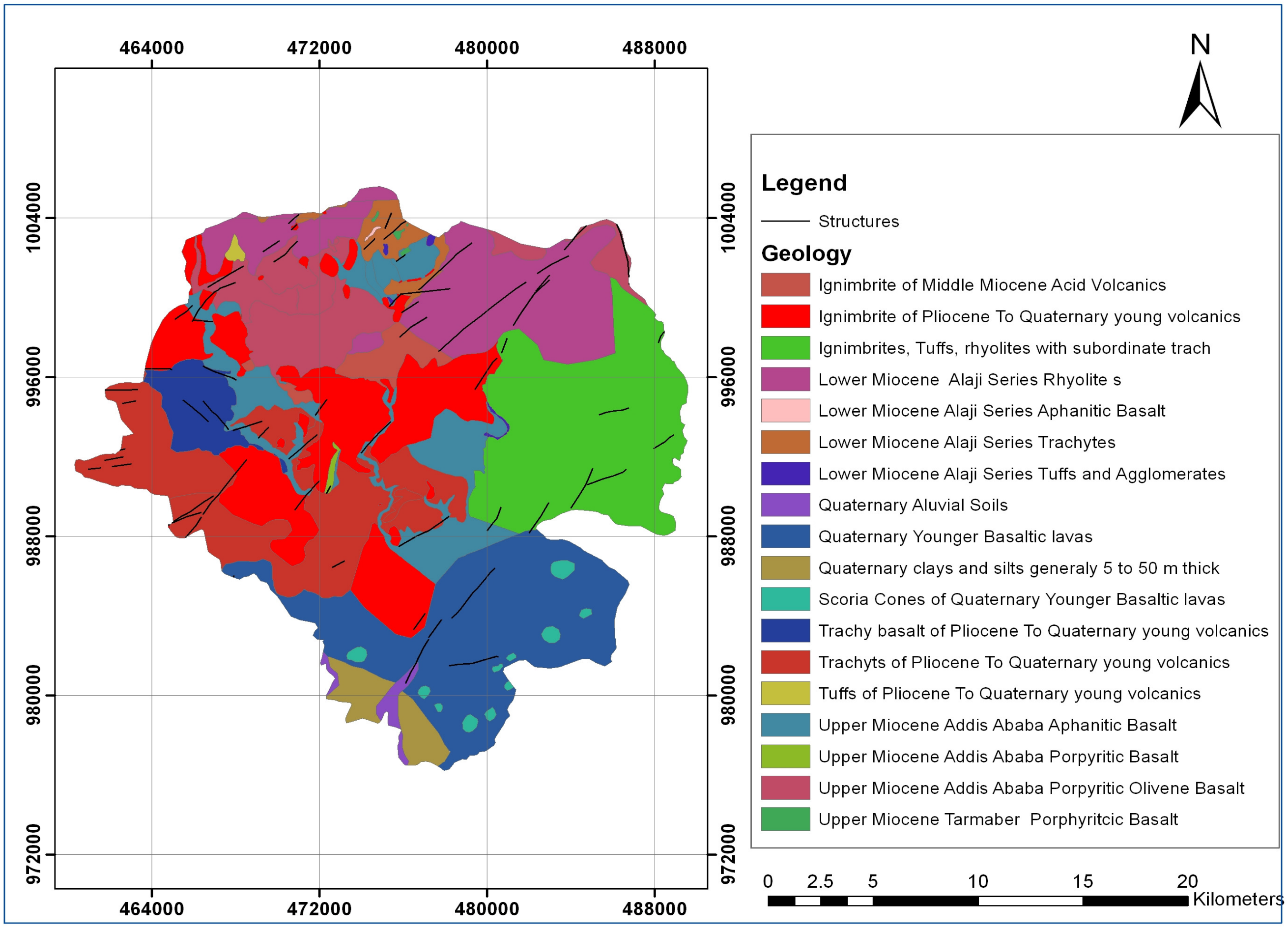


Figure 4 Geological map of study area (modified from AAWSA, 2010)

Lacustrine deposits, Alluvial and Residual deposits are Quaternary to recent deposits. Lacustrine soils occur around Bole, Ledeta, Mekanisa, between Abba Samuel Lake and Small Akaki River. The thickness of this deposit varies between 5 m to 50 m. Alluvial deposits are found in some places along Small and Big Akaki Rivers, especially South and South-West of the capital city. Thick alluvial deposit occurs in the area between Akaki Town and Abba Samuel Lake. Some deposits occur along the Kebena River, North-West of Bole area. Soils, which are developed in-situ by the decomposition of rocks, are located in the Central, Southeast, Northeast, Gullele and Kolfe area.

2.5. 3 GEOLOGICAL STRUCTURES

The area is highly tectonized and is complex in structure because its vicinity to the Main Ethiopian Rift or its margin. The main diastrophic structures encountered are lineaments and faults whereas the non diastrophic structures are bedding and volcanic layering. .

Different geomorphic features align mostly to the North East-South West direction which is parallel to the structure of the rift or rift margin.

Most of the faults mainly observed in the South-East part of the study area and cut the entire unit. They have a structure trending in NE-SW direction. These faults are mainly normal faults.

Joints and fracture are openings in a rock along which there is no observable movement. The lengths of the structures vary between few centimeters to several meters. In some places they are oriented normal to the flow banding and are parallel to each other (Assiged Getahun, 2007).

2.6 HYDROGEOLOGY

The origin, flow and chemical constitution of groundwater is controlled by the type of lithology, distribution, thickness and structure of hydrogeological units through which it moves (UNESCO, 1972). Moreover, the stresses due to tectonic and weathering conditions govern the hydrogeochemical characteristics of earth materials. Therefore, acquiring knowledge about the existing aquifer materials, their spatial distribution and their hydraulic properties is a necessity.

The whole terrain on which the study area falls are volcanic rocks mainly basalts, rhyolites, trachytes, scoria, trachy-basalts, and ignimbrites, welded and unwelded tuffs. Yet, groundwater circulation and storage in volcanic rocks depend on the type of porosity and permeability formed during and after the rock formation. The primary and/or secondary porosity developed in the different rock formations is different according to their genesis, the weathering and tectonic conditions they were subjected to. Rocks possessing a primary porosity may not necessarily give rise to primary permeability unless the primary porosities are interconnected. Later connection of primary porosities by means of weathering or fracturing may result in secondary permeability.

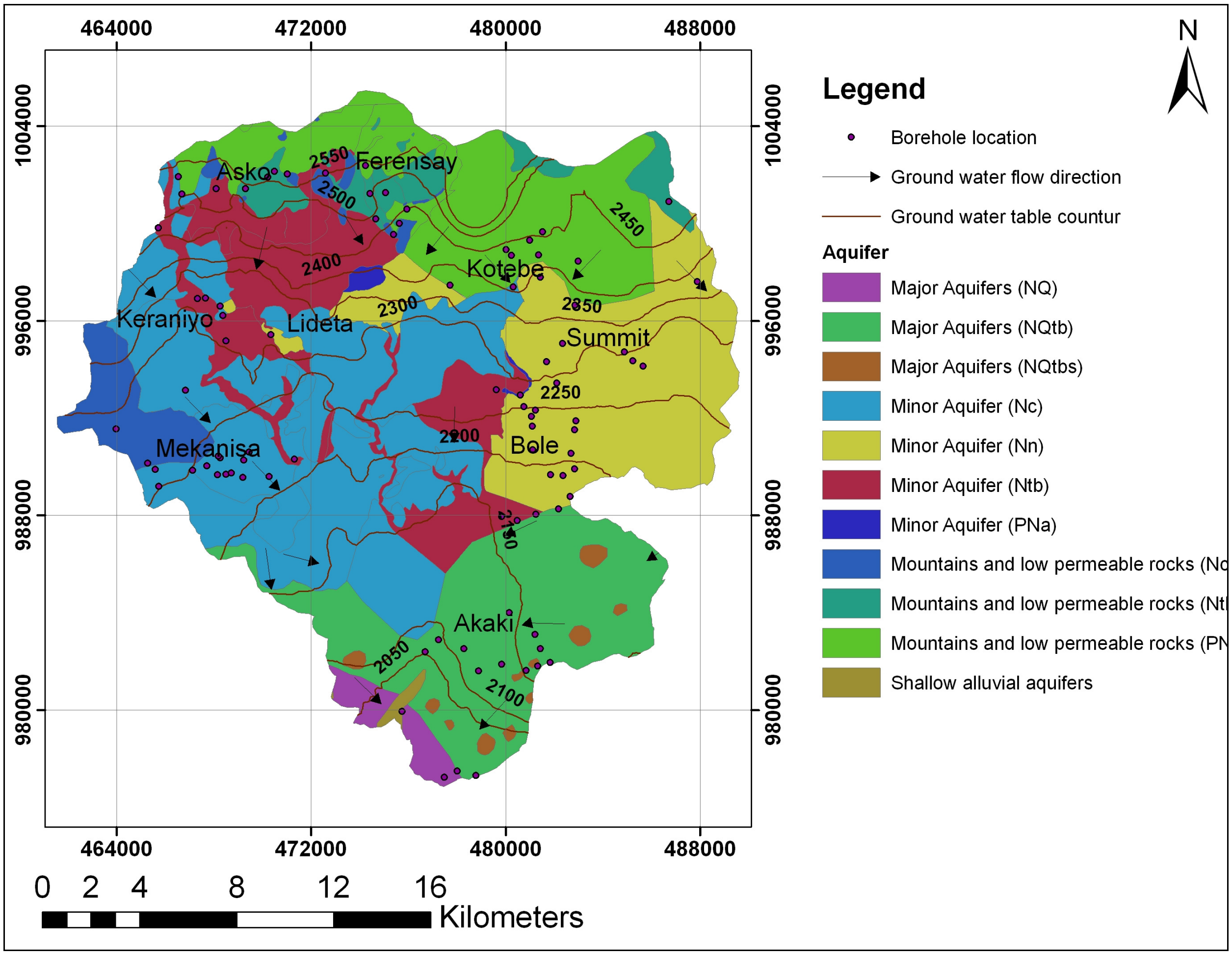


Figure 5 Simplifed hydrogeological map of study area (modified from AAWSA, 2010)

Although primary porosities are common features in volcanic rocks, they only play a minor role in the permeability of a given formation. This is due to the fact that primary porosities are expected to alter with time when volcanic rocks are exposed to various geological processes, such as weathering and tectonic processes. This is explained by Custodio (2004) as the ‘aging effect’, which describes the importance of secondary properties regarding the hydraulic behavior of volcanic formations through internal adjustment and rock alteration. The presence of secondary porosities could enhance the permeability of volcanic rocks by increasing the interconnectivity of isolated primary porosities that were randomly distributed in the host rock. Secondary porosities that permit flow and storage of groundwater are created mainly by weathering and fracturing processes.

2.7 HYDROCHEMISTRY

The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, solution or precipitation reactions occurring below the surface, and cultural effects resulting from human activities (Hem, 1992). The chemistry of groundwater in the saturated zone is controlled by chemical reaction rate, residence time within the saturated zone, and mineralogy of the rock matrix, where residence time and flow path are determined by factors such as aquifer thickness, permeability and amount of recharge (Griffioen, 2004). These factors combine to different degrees to create diverse water types with compositions that vary with space and time. The objectives of the hydrochemical investigations are to determine the sources, concentration, and fate of dissolved constituents within the physical framework of flow and transport (Griffien, 2004).

Hydrochemical investigations are conducted to understand the functioning of the hydrogeological system by relating the quality of the groundwater to different processes in the aquifer system. Water chemistry data can be used to infer groundwater flow directions, identify sources and amounts of recharge, estimate groundwater flow rates, and define local, intermediate, and regional flow systems (Anderson and Woessner, 1992). Underlying this hydrochemical approach are a number of assumptions including (1) natural water chemistry is a result of rock-water reaction such as dissolution/precipitation, reactions on aquifer surfaces and biological reactions, (2) distinctive chemical signatures are related to specific sets of reactions, (3) dissolved concentration generally increase along the surface flow path until a maximum value dictated by mineral equilibrium, and (4) hydrochemical facies are directly related to the dominant processes (Thyne *et al.,* 2004).

In order to investigate the water chemistry of the area representative samples were collected from areas where the borehole is polluted and measurements for 30 water samples (2 springs, 28 boreholes) were analyzed in laboratory of Addis Ababa Water and Sewerage Authorty (AAWSA) in Water Quality Laboratory (results of the laboratory analysis is shown in Table 1 and 2). Additionally, secondary data from different sources (boreholes, springs and rivers) were collected from different organizations (AAWSA, 2010, EPA 2005/6, 2007/8).

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 PHYSICOCHEMICAL ANALYSIS

Analysis was carried out for various water quality parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{2+}) magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), nitrate (NO_3^{-}), sulphate (SO_4^{-2}), iron (Fe), floride (F^{-}) using standard method and the results of the physicochemical parameters for water samples are presented in Table (1 and 2).

3.1.1 pH, EC and TDS

pH

The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. It is a measure of the acidity of groundwater: the lower the pH, the more acidic is the water. Natural rainwater is slightly acidic (Krauskopf, 1994) because it combines with carbon dioxide (CO_2) in the atmosphere, forming carbonic acid (H_2CO_3) according to reaction (1).

1. $H_2O + CO_2 \rightarrow H_2CO_3$

Some of the carbonic acid in the rainwater disassociates or breaks down according to reaction (2), producing bicarbonate (HCO_3^{-}) and H^{+}.

2. $H_2CO_3 \rightarrow HCO_3^{-} + H^{+}$

The hydrogen ion produced by reaction (2) lowers the pH of rainwater. Howfar it lowers from the neutral value of 7 depends on how much carbonic acid is in the water, which in turn depends on how much carbon dioxide is in the atmosphere. The more CO_2 present, the more acidic is the water, consequently the greater the hydrogen ion availability the lower the pH, the higher the TDS in the water. A guideline value pH range of 6.5–8.5 was established for drinking water (WHO International Standards for Drinking-water, 1984).

Most ground waters found in the study area have pH values ranging from about 6 .5 to 8.6 i.e, between the range of WHO recommended unit.

1. Yaka- Kotebe Escarpment

Table 1 Result of Physicochemical Analysis of Samples from Yaka_ Kotebe area

No.	Well name	X	Y	Z	pH	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	F^-	Cl^-	HCO_3^-	SO_4^{-2}	NO_3^-	Fe-total
						µs/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Yeka michaeal	477715	997474	2388	7.31	284	182	29.5	6.4	26.4	4.32	1.31	9.93	169.1	8.25	2.3	0.21
2	Ankorcha-1	480239	998671	2451	8.44	754	361	30.5	3.2	53.76	4	2.48	8	258.6	6.38	0.01	0.338
3	Salayish	480999	999648	0	7.38	464	308	62	5	33.6	8.16	1.72	21.9	274.5	23.5	NILL	0.2
4	Salayish School	482682	994124	2293	7.38	464	308	62	5	33.6	10.2	2.6	7.94	254.7	19.57	0.31	0.83
5	Around CMC	481365	998698	2293	6.99	381	250	68	7	15.12	4.08	5.8	10.9	209.8	14.09	0.24	0.61
6	Wondirad BH Kotebe	481365	998698	2453	7.3	411	197	55	4.6	76	26	1.51	11	190	23.9	0.01	0.374
7	SELAM BH (Kotebe)	484190	998500	2475	7.11	539	258	40	5	130	52	2.95	NB	216	46.1	0.03	1.09
8	Kara	484190	998500	2480	7.2	265	247	55	2.2	33.6	6.3	0.89	1.1	125	2.9	1.33	1.09
9	Kotebe	481650	998950	2460	6.8	408	260	24	4	50.4	10.2	2.6	7.94	254.7	19.57	0.32	0.83
10	Kotebe, Selam techinical college	481650	998950	2460	7.39	442	282	55	4.6	35.28	8.16	1.62	10.9	263.5	11.3	8.5	0.29
11	WNDV-3 Around new kara road	481434	987787	2399	6.75	445	292	42	5.9	50.4	7.14	2.2	14.89	239.12	23.1	0.3	0.27
12	EUKA	998429	482994	2437	6.87	213	142	9.8	3.4	27.7	4.59	1.67	8.94	109.8	10.8	1	0.555
13	Kara area - Luke Stearm	468100	1001625	2585	7.34	218	104	9.8	3.4	40	10	3.48	5.5	90	0.099	0.01	0.145
14	AYAT 1	489127	999697	280	7.89	524	344	77	22	16.63	3.24	1.72	42	225.46	29.73	TRACE	0.772
15	Kotebe - Ankorcha-spring	481462	998906	2478	7.24	414	272	30.5	3.2	53.76	10.71	2.48	7.94	258.6	6.38	0.16	0.28

Table 2 Result of Physicochemical Anlyis of Samples from Summit – Bole area and Centeral part of Addis Ababa

No	Well name	X	Y	Z	pH	EC	TDS	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	F$^-$	Cl$^-$	HCO$_3^-$	SO$_4^{-2}$	NO$_3^-$	Fe-tot
						µs/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	B/Med. BH	476691	994535	2337	6.9	280	290	14.4	4.1	31.1	6.7	0	2.6	179	1.7	3	<0.01
2	East bole (EBV 03)	480604	992935	2266	7.78	2270	1132	380	35.5	17.64	8.94	2.5	23.8	1176.08	40.84	0.24	0.19
3	Bole lemi (SMV-21)	482790	989806	2236	7.6	731	472	122	13.9	38.64	8.67	0.9	12.91	470.92	4	0.68	0.2
4	East bole (EBV 22)	481101	991646	2250	7.1	498	316	80	7.4	33.6	5.61	0.87	8.94	314.76	0.76	1.7	0.22
5	East bole (EBV23)	481061	992052	2252	8.64	2318	1132	73	7.3	31.92	7.14	0.97	6.95	314.76	6.47	2.62	0.16
6	East Bole (EBV 24)	480760	992453	2261	8.55	1980	1246	128	12.1	31.08	7.65	3.05	11.92	492.88	14.09	4.1	0.18
7	Summit (SMV-6)	481681	994296	2290	6.96	1908	782	465	22	20	6.12	3.05	23.83	1307	30.1	0.01	0.076
8	Summit (SMV10)	482109	993423	2278	6.81	993	480	123	12.9	38.64	6.63	0.67	11.9	980	133.5	ND	0.548
9	Summit (SMV-13)	484883	994701	2320	6.5	1904	1394	495	24.5	25.2	5.61	6.4	47.66	1434	0.39	0.3	0.19
10	Summit (SMV-14)	485228	994341	2312	6.75	2500	1620	580	31	26.04	5.61	3.05	44.69	1512.8	99.5	12.6	0.18
11	Summit (SMV-15)	485664	994125	2295	6.6	1654	1136	440	23	21	8.16	1.32	33.76	1078	60.8	11.2	0.11
12	B/College well	470227	996307	-	8.1	405	362	25	2.1	35	12.5	-	23.6	168	7.3	40.5	<0.005
13	Lidata Spring	479600	981100	-	8.5	346	410	64	4	46.4	7.81	-	1.5	290	0.1	5.7	0.22
14	T/ Mare. BH	470950	995225	2300	7.2	714	344	41.9	2.9	65.6	29.8	0.44	69	231.8	13	54.93	<0.03
15	Coca Cola Factory-2	470000	996400	-	7.7	1154	652	18.7	2.3	68.9	48.9	0.4	35.4	616.0	-	50.7	

Electrical conductivity (EC)

Conductivity, or Specific conductance, is a measure of the ability of water to conduct an electric current. It is sensitive to variations in dissolved solids mostly mineral salts. The degrees to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. Conductivity is expressed as micro siemens per centimeter (µS/ cm) and, for a given water body, is related to the concentrations of total dissolved solids and major ions.

The conductivity of most freshwaters ranges from 10 to 1,000 µS /cm but may exceed 1,000 µS /cm especially in polluted waters, or those receiving large quantities of land run-off.

In the research area, water samples near recharge zones (Yaka-Kotebe) have low conductivity of 213 µS/cm and the EC value increases to water samples near discharge zones (Summit-Bole) that may attain values greater than 2500 µS/cm.

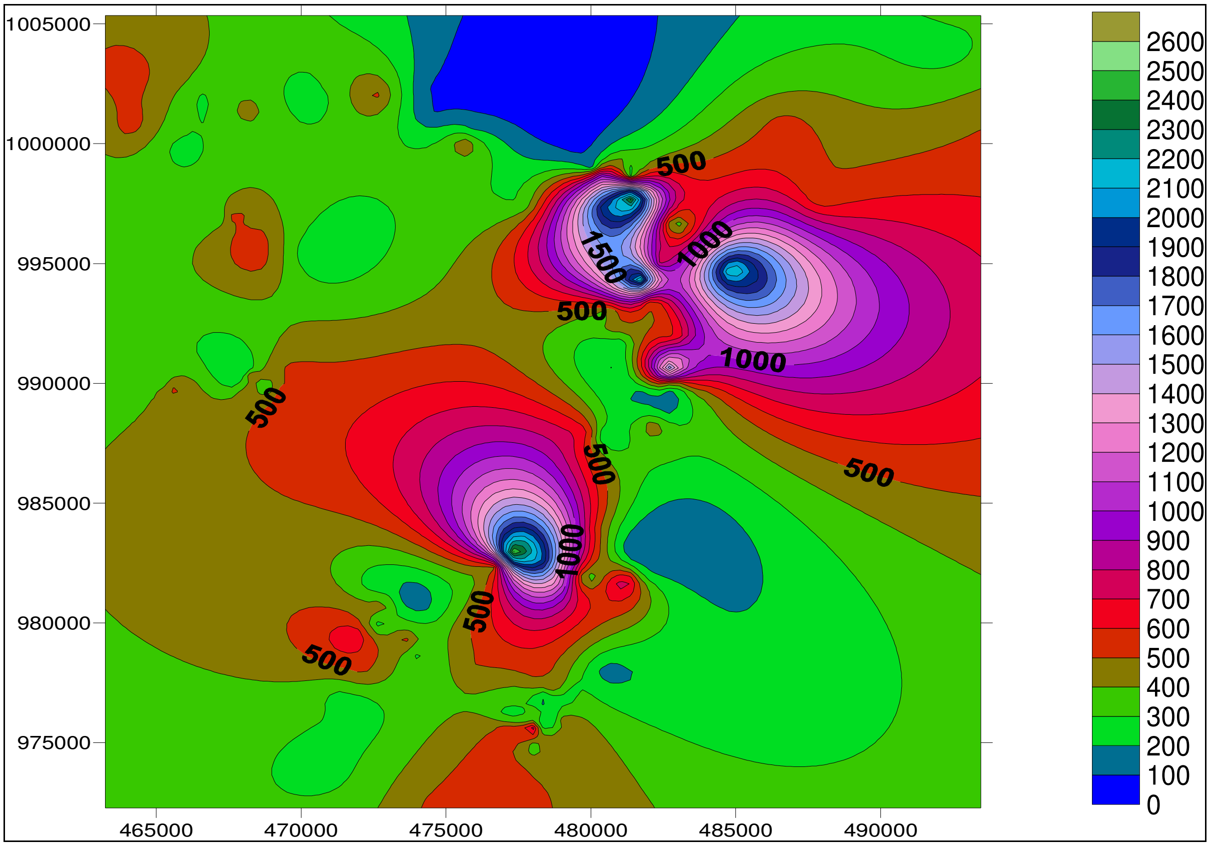


Figure 6 EC map of the Summit-Bole area

Total Dissolved Solids (TDS)

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions.

Groundwater tastes different in different places or at different times of the year for several reasons. What gives groundwater its taste is the amount and type of dissolved minerals within it, pure water, i.e., having no dissolved minerals, doesn’t occur naturally, and if it did, it would have no taste. So, it is not pure water people want, it is water that tastes good and is safe to drink (Dennis Nelson, 2002). The amount and type of dissolved minerals in water is what gives waters their individual taste.

Factors that control the dissolved minerals in groundwater include [1] the types of minerals that make up the aquifer, [2] residence time of the groundwater in the aquifer, the longer the groundwater is in contact with the minerals, the greater the extent of its reaction with those minerals and the higher will be the content of dissolved minerals, and [3] the chemical state of the groundwater (Dennis Nelson, 2002).

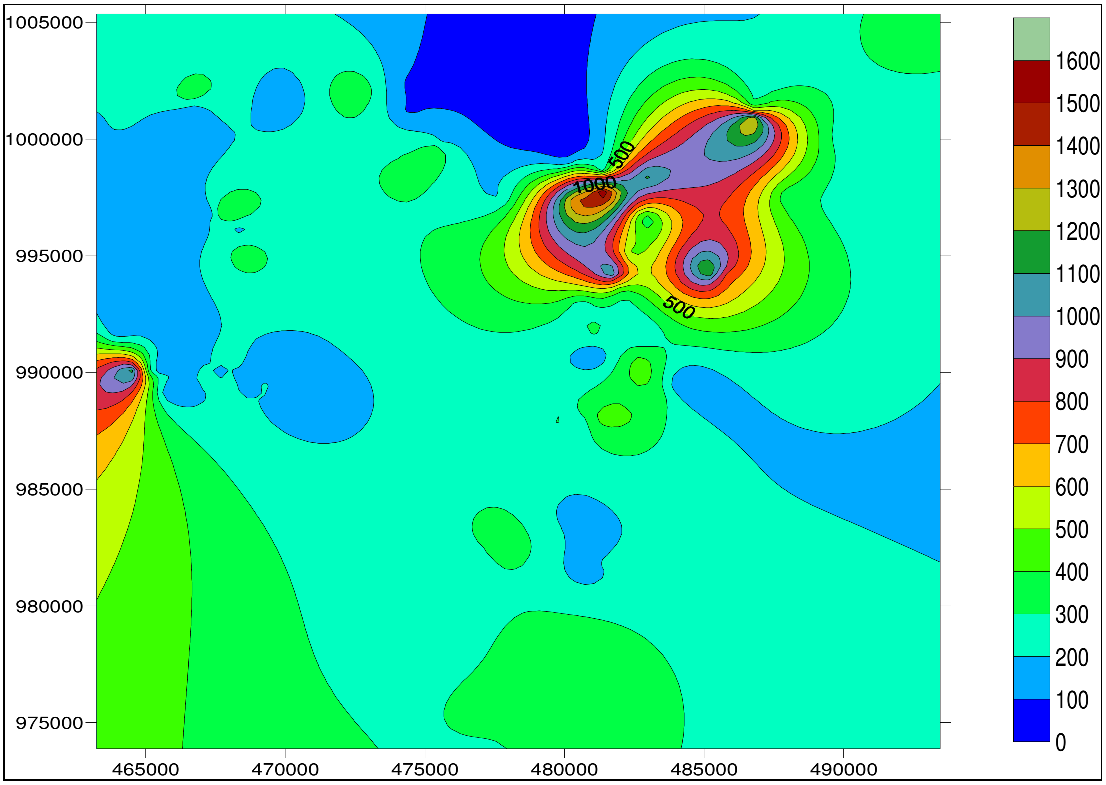


Figure 7 TDS map from Summit-Bole area

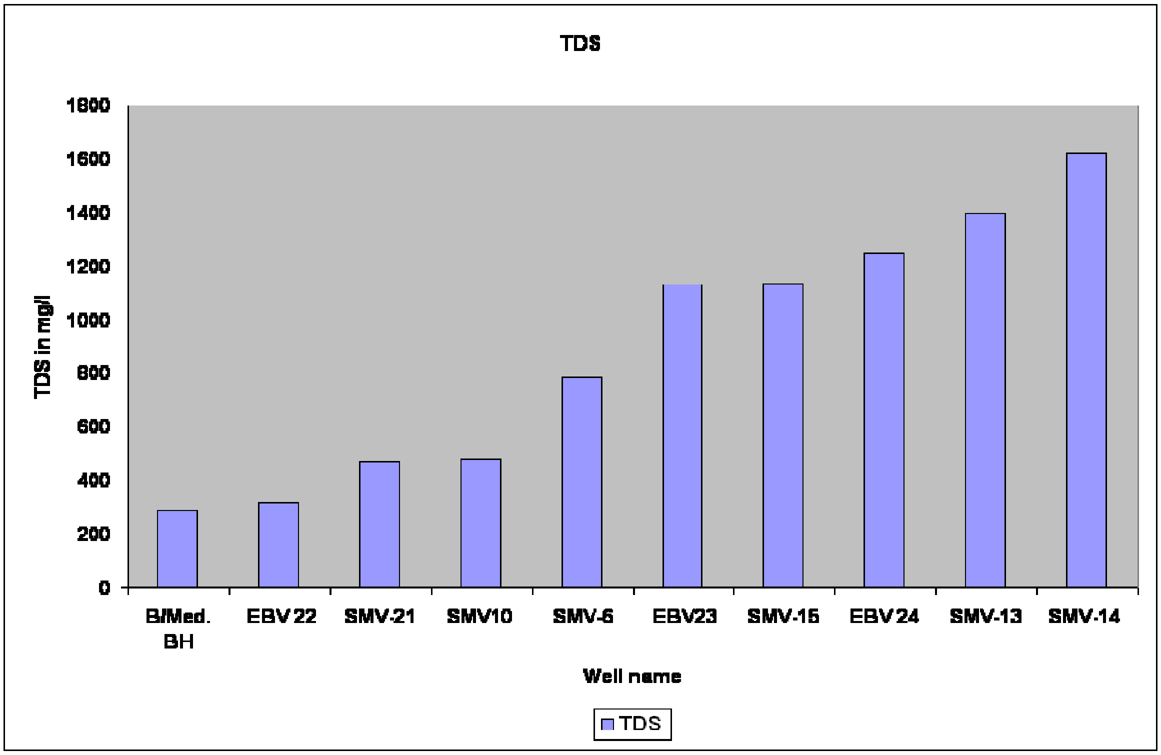


Figure 8 Variation of TDS in water samples in the study area (from fresh to slightly sline water)

The result of laboratory analysis indicate that TDS was lower for Boreholes in the part of the Yaka-Kotebe area and the value increases towards boreholes to Summit-Bole, maximum value of 1620 mg/l and majority of samples exceed the guideline value for WHO (1000mg/l) from water sample of Summit-Bole area.

The wide variations of the value in the study area are mainly due to two major reasons According to (Dennis Nelson, 2002).

- Residence time of the groundwater in the aquifer, the value of TDS in the study area increases from Yaka-Kotebe to Summit-Bole. This indicates that contact time of groundwater with rocks is longer and the interaction with different earth materials increases.
- The types of minerals that make up the aquifer, in Summit-Bole area, most of the area covered with acidic rock, such as ignimbrite, tuff, which causes reaction with aquifer and countribute high TDS to ground water.

Depending on international water quality guide line (WHO) and Ethopian Water quality standard the water of the study area categorized as fresh in most part of the study area except in Summit-Bole area which was characterized by Slightly Saline water.

3.1.2 Graphical Presentation, Classification and Interpretation of Analytical Results of Laboratory Measured Parameters

As described in the geology of the area, the whole terrain on which the study area falls were volcanic rocks mainly basalts, rhyolites, trachytes, scoria, trachy-basalts, and ignimbrites, welded and unwelded tuffs. The composition of the majority of the highland volcanic plateau was silicate minerals of mostly plagioclase feldspars of the albite and anorthite group and pyroxene composition. These minerals were rich in Ca, Mg and Na. Hydrolysis, decomposition and/or leaching of these silicate minerals enriches the water in the highlands by Ca, Mg, and Na cations. These rocks are dominantly affected by fracturing and weathering. In the study area most water types obtained from laboratory analysis at/or near recharge area have low TDS and most of them were Ca-Na-HCO_3 type (Yaka-Kotebe area) evolving down the flow path to dominantly Na-Ca-HCO_3 water (Summit-Bole area).

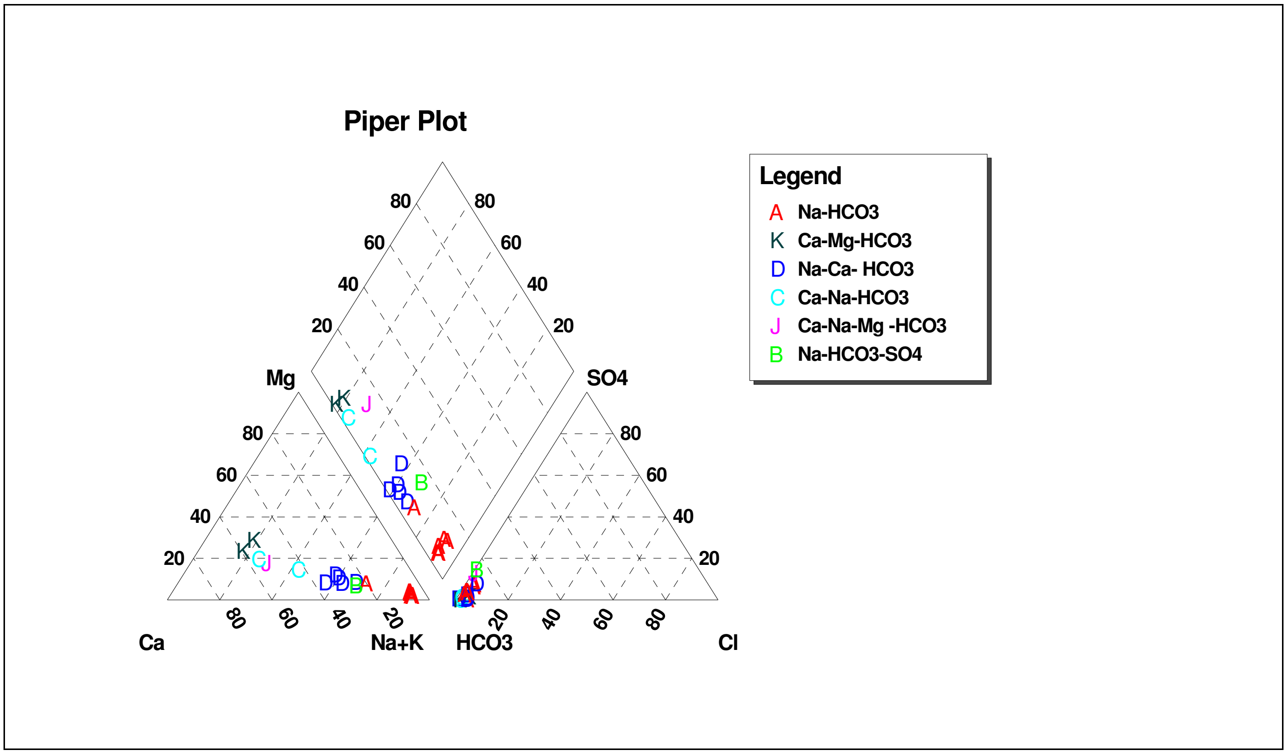
Piper Trillinear Diagram

A Piper diagram is a form of the trilinear diagram that provides a visual representation of the concentrations of major ions in water (Hem, 1992). This diagram can be useful for looking at similarities and differences among water samples. The Piper diagram plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto an adjacent grid. This plot reveals useful properties and relationships for large sample groups. The main purpose of the Piper diagram is to show clustering of data points to indicate samples that have similar compositions.

From the diagram below (Figure 9) the following water types were identified:

- Ca-HCO3 type water
- Ca-Mg-HCO3 type water
- Ca-Na-HCO3 type water
- Na-Ca-HCO3 type water

Generally, the piper plot shows that most of water samples were of Calcium-Sodium-Bicarbonate type for water sample for Yaka-Kotebe area and Sodium-Calcium- Bicarbonate type for Summit-Bole area.



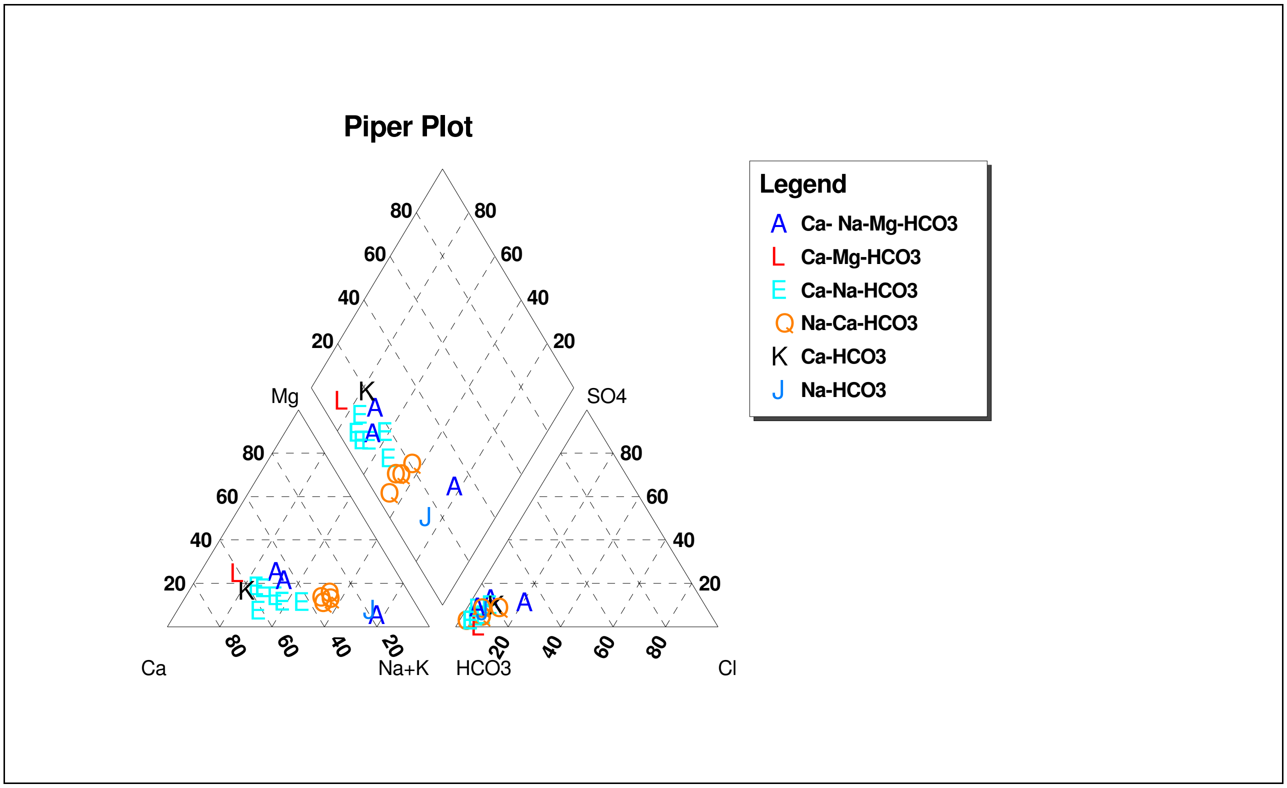


Figure 9 Piper plot Bole-Summit (top) and Yaka-Kotebe (bottom) area.

3.1.3 Major Ion Evolutions and Their Controlling Factors

The composition of groundwater along the flow path is primarily dependant up on chemistry (chemical composition) of the starting water (precipitation), climate, types and relative solubility of the minerals available in the rock, topography/physiography and physical aspects of the hydrogeologic system. These factors together combine to create diversified water types that change in compositional character spatially and temporally as precipitation infiltrates the soil zone, moves down a topographically-defined flow path and interacts with the minerals derived primarily from the underlying bed rock.

3.1.3.1 Ca^{2+}, Mg^{2+} and Na^{+}

The cationic composition of groundwater is related to the type of volcanic rock. In ground water, only seven solutes make up nearly 95 percent of all water solutes (Runnells, 1993). These solutes are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{-2}), and bicarbonate (HCO_3^{-}). Although many sources and reactions influence the concentrations of these solutes, the predominant sources of these solutes to ground water in the the study area was derived from the hydrolysis, dissolution of silicate minerals, such as plagioclase feldspars and pyroxene group, and ion exchange reactions where by sodium is released to the water in exchange for calcium or magnesium.

Calcium value was higher in most wells and the value ranges from 25.4 mg/l (Yaka michel) to 130 mg/l (Selam BH) (Yaka-Kotebe) and 17.4 mg/l (EBV 03) to 92 mg/l (SMV-19) (Summit-Bole) area (Table 1 and 2) and the value decreases from Yaka-Kotebe to Summit-Bole mainly due to releasing of CO_3^{-2} to the water during rock water interactions. The most probable source of Ca in samples in the area is weathering of rock forming minerals of volcanic rocks like plagioclase feldspar.

Sodium concentration was varies from 9.8 mg/l (Luke Stearm) to 62 mg/l (Salayish School) (Yaka-Kotebe) and 14 .4 mg/l (B/Med. BH) to 580 mg/l (SMV-14) (Summit-Bole) area. The WHO guideline limit for sodium in drinking water is 200 mg /l.

Generally, in research area concentration of Ca decrease and concentration of Na increases from sampling of near recharge area (Yaka-Kotebe) to sample of near discharge area (Summit -Bole) (Figure 10).

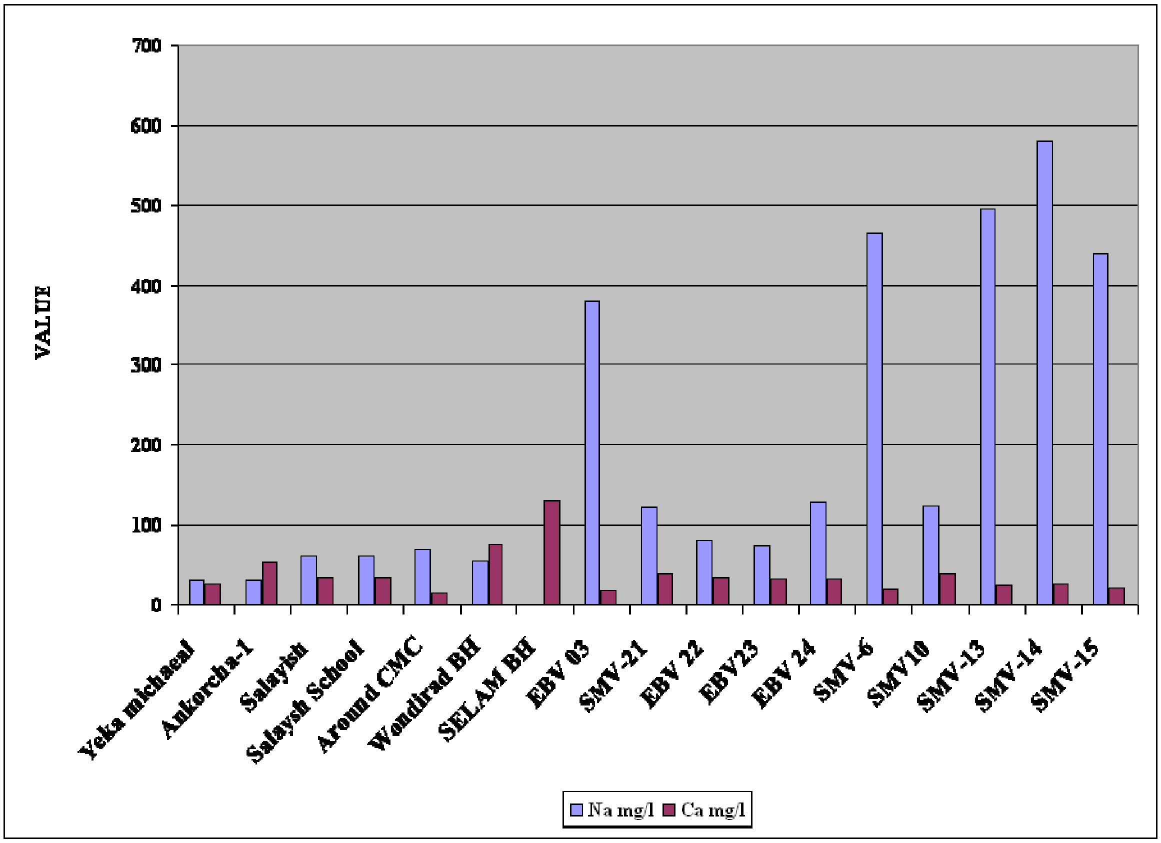


Figure 10 Sodium and Calcium ploted versus Samples from Yaka-Kotebe (leftmost samples) to Summit-Bole (right most samples)

Weathering reactions: Dissolution and precipitation of mineral phases determine the contribution to and removal of ionic species in solution. In these cases primary minerals become dissolved or altered and secondary minerals may be produced.

In the volcanic aquifer system of the study area patterns in the water chemistry of ground water have helped refine important concepts about the ground-water flow system, including sources of water, directions of flow, and travel times.

i) Hydrolysis of silicate minerals: One of the factors that control the evolution of ions is consequently depletion of calcium ion, and enrichment by sodium ion as the hydrolysis process procceeds along the ground water flow path. Among the rock-forming minerals involved in hydrolysis, plagioclase was perhaps the most common and important. Plagioclase comprises a solid-solution between Na and Ca end-members.

The Ca end-members are preferentially weathered relative to Na and therefore the Na/Ca ratio in plagioclase increases as the reaction proceeds. Dissolution of the two end-members, anorthite and albite, which produces kaolinite plus cations, can be written separately as follows:

Anorthite to Kaolinite: $CaAl_2Si_2O_8 + 2CO_2 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Ca^{+2} + 2HCO_3^-$

Albite to Kaolinite: $2NaAlSi_3O_8 + 2CO_2 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4SiO_4$

In the study area in terms of anion, the dominant was HCO_3^-, and it shows an increasing trend from sample near recharge area (Yaka-Kotebe) to sample near discharge area (Summit-Bole) with similar trend of Ca^{2+} and Na^+ ions. And HCO_3^- concentration of the samples in the area was also attributed to hydrolysis of these silicate minerals and as a result of dissolved CO_2 in the soil zone from atmosphere and unsaturated zone.

HCO_3^- concentration of the samples in the area as a result of dissolved CO_2 in the soil zone from atmosphere and unsaturated zone can be expressed by the following reaction

(Freeze, 1979):

$$CO_2 + H_2O \rightleftharpoons H_2CO_3\ (aq)$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

ii) Cation Exchange: - It is a reaction which involves a replacement of one chemical for another at the solid surface. Cation exchange process plays an important role in controlling the chemical composition of groundwater. The relative abundance of Ca^{2+} and Na^+ cations in the ground water is due to cation exchange (Hem, 1985). The cation exchange capacity is determined by the clay content, type of clay minerals present, and the organic matter content.

For Cation evolution in ground water along the flow path, 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. The cation exchange reactions along the groundwater flow paths can be represented as:

$$M^{2+}(aq) + 2Na\text{-}X_2 \rightleftharpoons 2Na^+(aq) + M\text{-}X_2$$

Where, M^{2+} is a divalent cation such as Ca^{2+} ,Mg^{2+} and X is the exchange substrate, such as clay mineral or aquifer solid and substrate (aq) refers to cations in aqueous solution.

In the study area ground water near recharge area was represented by water dominant in Calcium-Sodium-Bicarbonate (Ca-Na-HCO_3) with lesser amounts of magnesium. Pure magnesium type water or calcium-magnesium water was rare probably due to absence of dark-colored ferromagnesian minerals such as olivine, pyroxenes, and amphiboles.

Groundwater in the study site generally begins as a Ca-HCO_3 type in the recharge areas and chemically evolves along the flow paths as a function of the lithologies encountered.

The chemical evolution path from recharge to discharge area is from Ca-rich rainwater in to Ca-Na-HCO_3 to Na-Ca-HCO_3-type waters. The water type differences are the result of the rocks contacted during ground water circulation.

Ca-Na-HCO3 and Na-Ca-HCO_3 were the dominant water type Yaka-Kotebe and Summit-Bole area, rescpectively. Water groups represented by Ca-Mg-HCO_3 and Ca-Mg-Na-HCO_3 are often weakly mineralized waters circulating with in the basaltic and scoraceous aquifers at a relatively shallower depth (Tenalem Ayanaw *et al.,* 2008). Those represented by Ca-Na-HCO_3, Na-Ca-HCO_3 and Ca-HCO_3 are draining the fractured acidic and intermediate volcanic rocks such as rhayolites, ignimbrites, tuff, trachyte and have a more dilute chemistry.

Generally, the water samples from the Yaka-Kotebe area were characterized by low TDS concentrations indicating the rock-water interaction (residence time) is short and the resistance of volcanic rocks to weathering but water sample from Summit–Bole area characterized by high TDS indicating residence time is long.

3.1.3.2 HCO_3^-, SO_4^{-2}, Cl^-, F^- and NO_3^-

In areas of non-carbonate rocks, HCO_3^- , originate entirely from the atmosphere and soil CO_2 and hydrolysis of silicate minerals. The whole study area was covered by volcanic rocks and due to absence of non-carbonate rocks, bicarbonate ion was the product of atmospheric and soil CO_2 and hydrolysis of silicate minerals. Therefore, bicarbonate water type was the predominant in the study area.

Bicarbonate value was higer in most samples from the research area (Yaka-kotebe and Summit-Bole) and this is may be due to bicarbonate dissolved in groundwaters is derived from two principal natural sources (Younger and Paul, L., 2007)

Biogenic: CO_2 is released into the soil atmosphere, and thus into waters draining through the soil, both directly from plant roots and (more importantly) by the microbial degradation of soil organic matter. At circum-neutral pH, CO_2 dissolves in water to form bicarbonate as follows:

$$CO_2\,(d) + OH^-(aq) \leftrightarrow HCO_3^-(aq)$$

Mineral: the dissolution of the same carbonate minerals which release Ca^{2+} and Mg^{2+} to solution also yield abundant dissolved HCO_3^-.

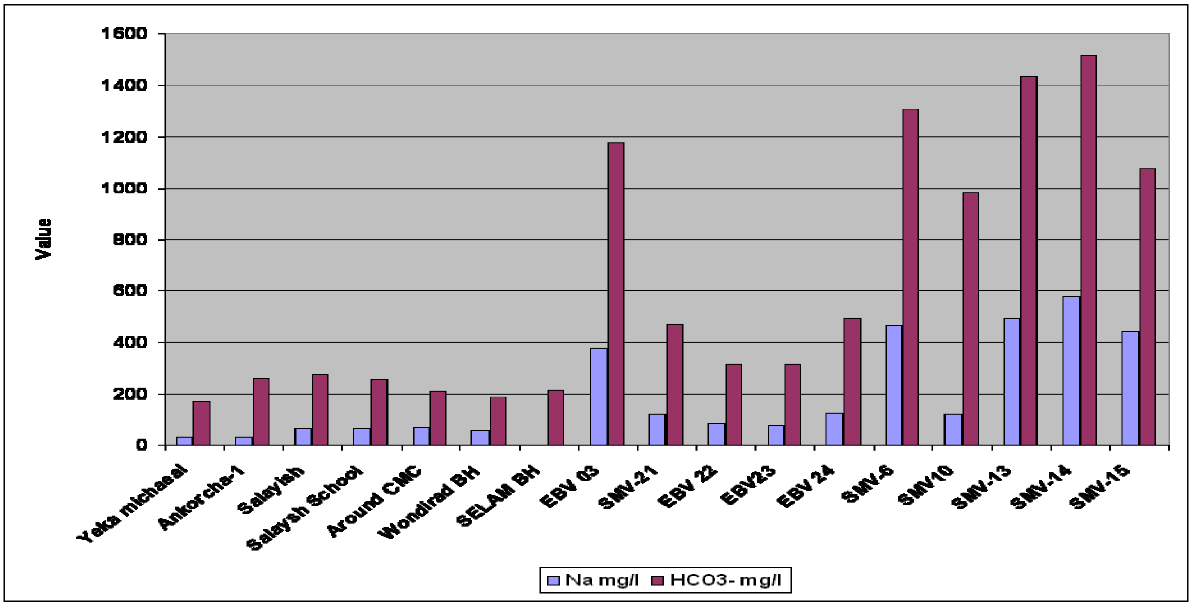


Figure 11 Increasing bicarbonate and Sodium from sample of Yaka-Kotebe to sample of Summit- Bole areas

Chloride is one of the least reactive solutes found in groundwater systems, and as such it has very few natural mineral sources. Given the sparsity of mineral sources for Cl^-, it can often be a very effective index of the degree of evaporation a given groundwater must have undergone after first arriving at the soil surface as rainwater.

In reseach area the value of chloride was below WHO recommende unit for most of the water sample from Yaka-Kotebe and Summit-Bole are, however, the value is highe for water sample from centeral part of the study area due to antropogenic impact. Similarly, nitrate concentration for most of the samples of the study area was below WHO recommende unit except for some borehole in the cenreral part of the city which shows high value of nitrate dueto antropogenic impact.

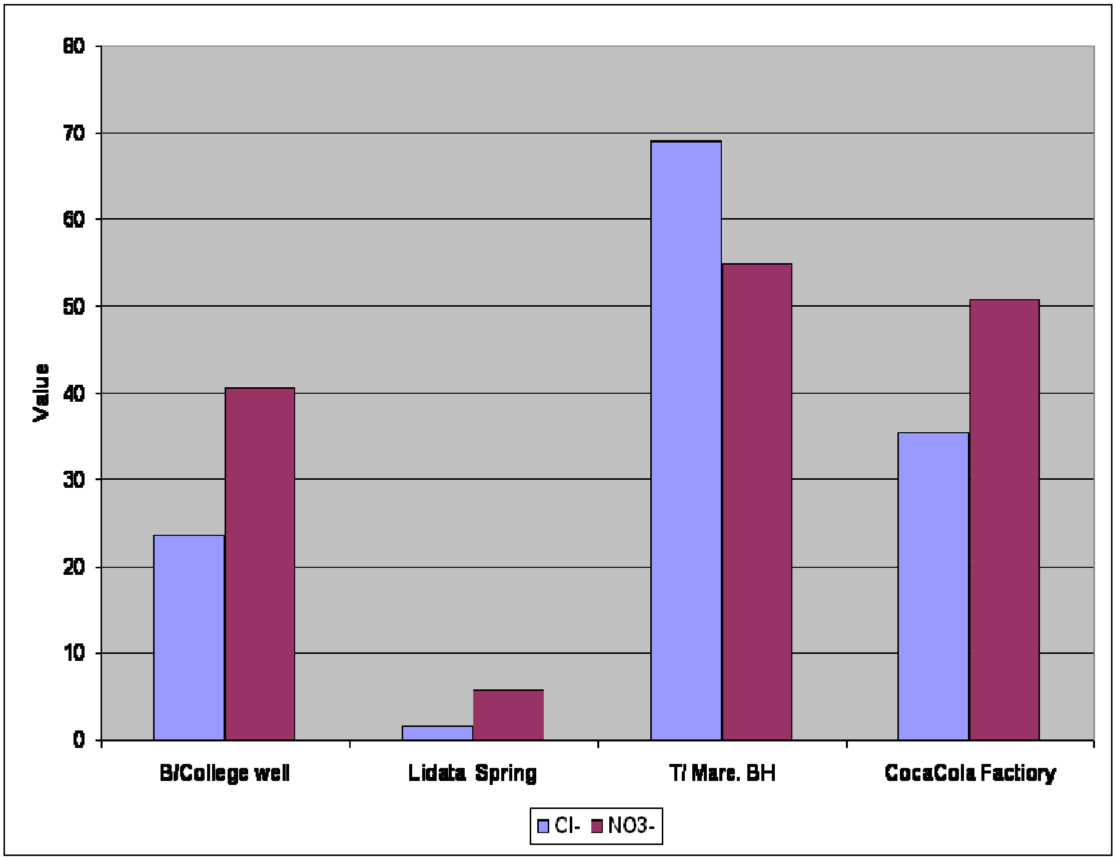


Figure 12 Chloride and Nitrate plotted versus Borehole from Central part of Addis Ababa

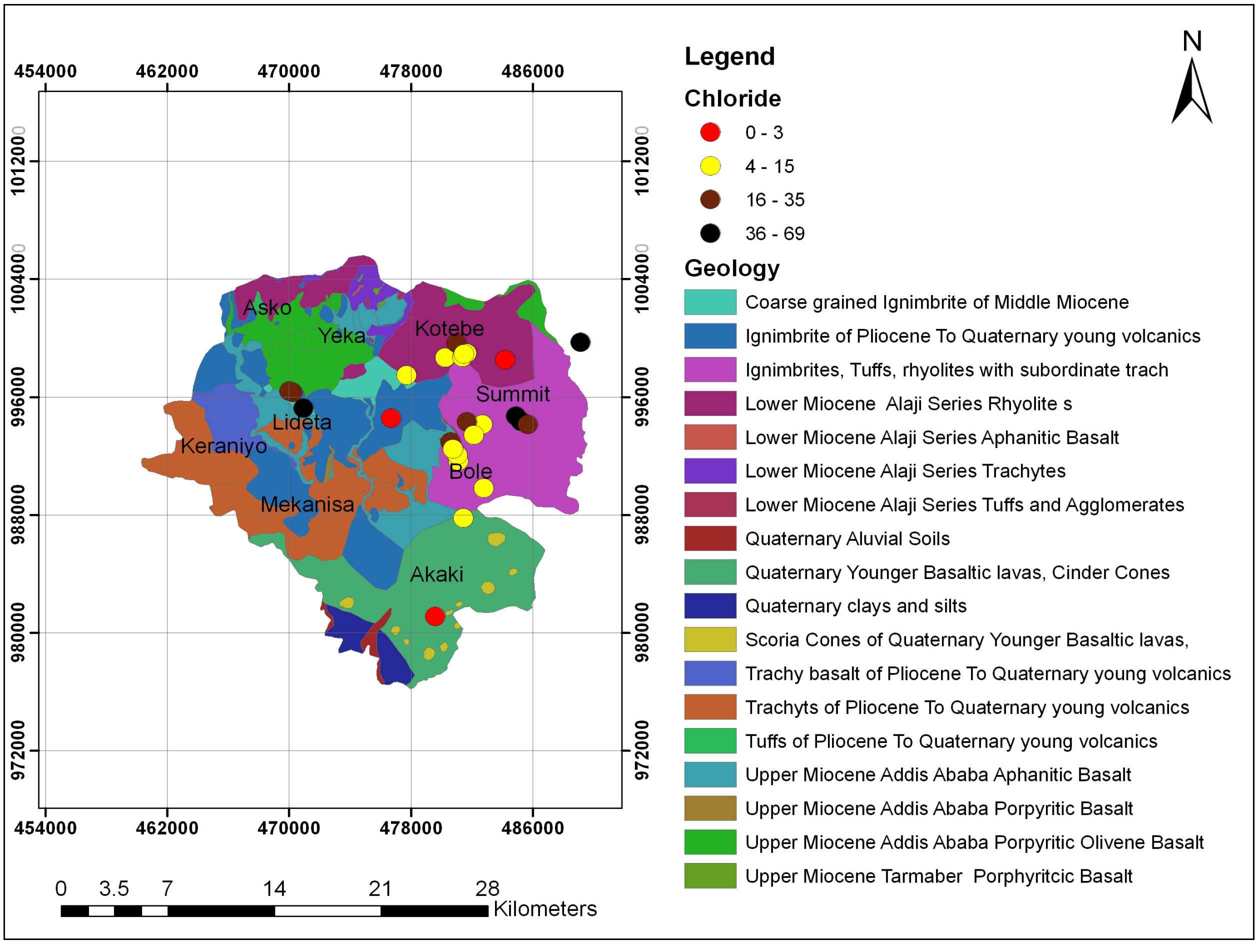


Figure 13 Distribution of chloride on the considered study area

Sulfate dissolved in groundwaters has two principal natural sources: Weathering of sulfide minerals, most commonly pyrite, weathering of gypsum and/or anhydrite in relation to Ca^{2+} release. Besides being a common source of dissolved SO_4^{2-}, gypsum also serves to impose an upper limit on sulfate concentrations in most groundwaters, due to its maximum solubility limit of around 2500 mg/l, which is frequently reached in waters which receive their SO_4^{2-} from pyrite Oxidation (Younger et al. 2002)

Its concentration in most samples considered is lower than WHO recommended value in most borehole of study areas and exceptional higher values in few boreholes that probably attributed to deep hydrothermal influences.

Fluoride

The dominant controls on fluoride build-up in water are geology, contact times with fluoride minerals, groundwater chemical composition and climate and leaching of F^- into surface, soil and ground waters is the most common cause of fluoride endemics worldwide. Fluoride in groundwater was found to be predominantly from a geological source, mainly fluorine-bearing silicate minerals such as biotite and hornblende. Specific hydrogeological conditions, mainly rock-water interactions and groundwater recharge and discharge patterns, were found to determine the vulnerability of groundwater to fluoride. The groundwater vulnerability was higher in areas where there is limited recharge that promotes longer residence times and greater rock-water interaction.

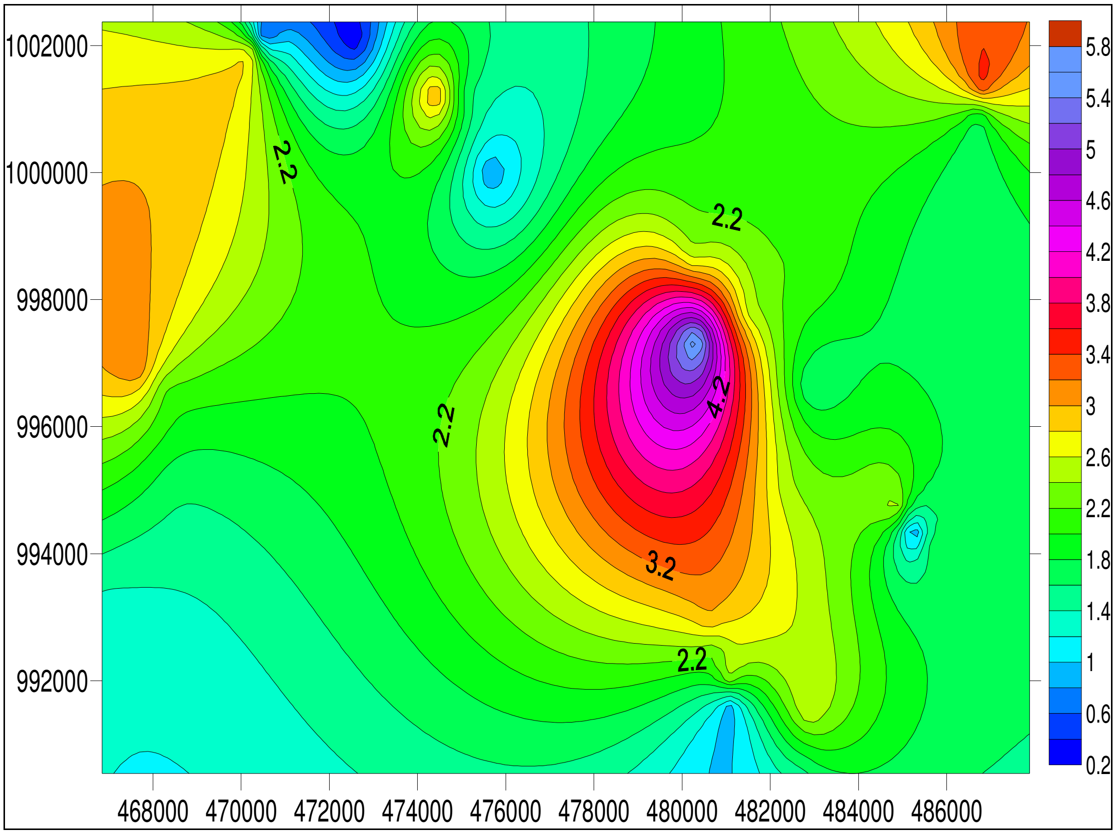


Figure 14 Floride map from Yeka-Kotebe area

Fluoride was above WHO recommended (>1.5 mg/l) in most water samples Yaka-Kotebe and Summit-Bole as well, this is mainly according to (Dennis Nelson, 2002).

- Deeper (older) ground waters from tube wells are most likely to contain high concentrations of fluoride.
- Shallow aquifers situated in active volcanic areas affected by hydrothermal alteration like hydrothermally alteration of rhyolitic rocks of Intoto area.
- Reaction times with aquifer minerals high fluoride concentrations can be built up in ground waters which have long residence times in the host aquifers. Generally, there is no increase or decrese the value of floride from Yaka-Kotebe to Summit-Bole unlike other parameters such as Ca^{2+} decreasing, and Na^+ and HCO_3^- increases.

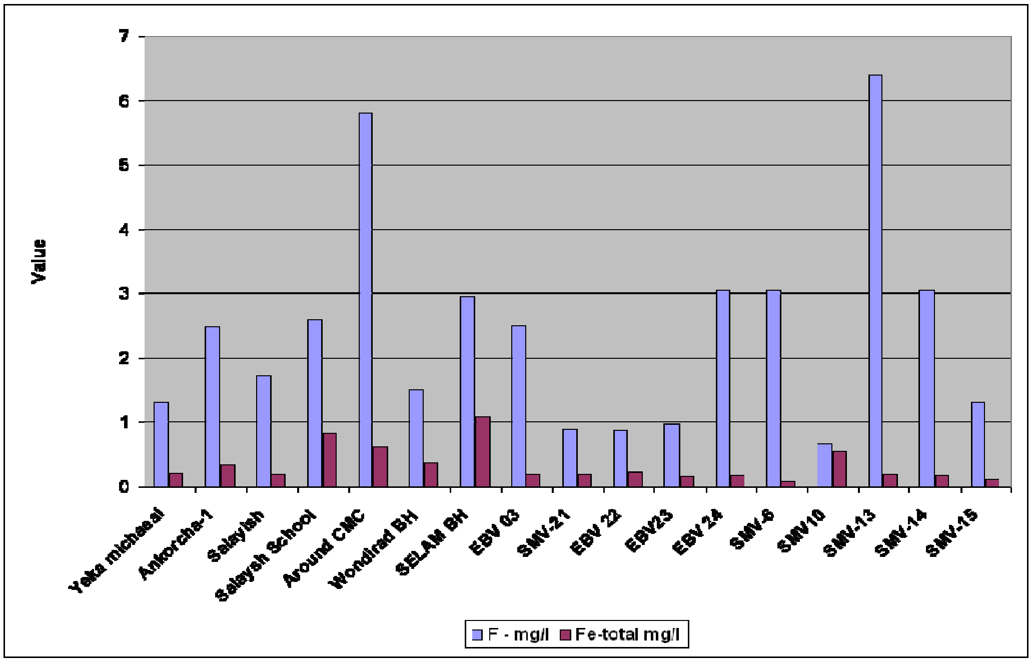


Figure 15 Floride and Total iron ploted versus sampling in the study area

Iron

The primary sources of iron in the hydrosphere are the iron minerals in igneous and metamorphic rocks. Among the silicates and aluminosilicates these include olivine, the pyroxene and amphibole mineral groups, and the mica biotite (Deer *et al.,* 1992). Pyrite (FeS_2) and magnetite (Fe_3O_4) are common minor minerals. Iron is largely mobilized and redistributed during the chemical weathering of igneous and metamorphic rocks. Mobilization is chiefly as dissolved Fe (II) under reducing conditions and as particulate Fe (III) oxyhydroxides in oxygenated environments.

The occurrence of iron in aqueous solution is dependent on environmental conditions, especially oxidation and reduction. Flowing surface water, that is fully aerated, should not contain more than a few micrograms perlitre of uncomplexes dissolved iron at equilibrium in the pH range 6.6 to 8.5. In groundwater, however, much higher levels can occur. In anoxic groundwater with a pH of 6 to 8, ferrous iron (Fe^{2+}) concentrations can be as high as 50 mg/l and concentrations of 1 to 10 mg/l are common. The iron originates by solution at sites of either reduction of ferric hydroxides or oxidation of ferrous sulphide (Hem, 1989) and the process is strongly influenced by microbiological activity.

The iron ion which is released by attack of mafic minerals by water is the most mobile in ground water. The solubility of iron is the function of oxidation and pH condition, iron is relatively soluble at a lower pH less than 5 under moderate oxidizing conditions, mostly the iron ion is re-precipitated (Hem.1992). A recommended upper limit for iron in public water supplies by World Health Organization (WHO) is 0.3 mg/l.

Iron concentration above WHO (0.3 mg/l) recommended unit in samples fromYaka- Kotebe areas such as Salayish School, Ankorcha-1, and Wondirad BH (Table1). This is mainly due to (Hem.1992):-

- The study area (Yaka- Kotebe) relatively receiving the highest rain falls. Therefore, effects of dilution and enrichment often occurs on the solutes leached from the acidic rocks (Intoto rhyolite) is high and as aresult contrubted the cause of high concentration of iron to ground water.
- Hydrothermally altered rhyolitic rocks of Intoto area, which might have experienced hydrothermal alterations, are expected to provide much iron to the groundwater whenever they are in contact than the basalts.
- Igneous rock minerals whose iron content is relatively high include the pyroxenes, the amphiboles, biotite, magnetite, and, especially olivine are attacked by water, the iron that may be released is generally precipitated as can be observed in some boreholes along the rhyolitic Intoto mountain range such as Yaka-Kotebe areas.

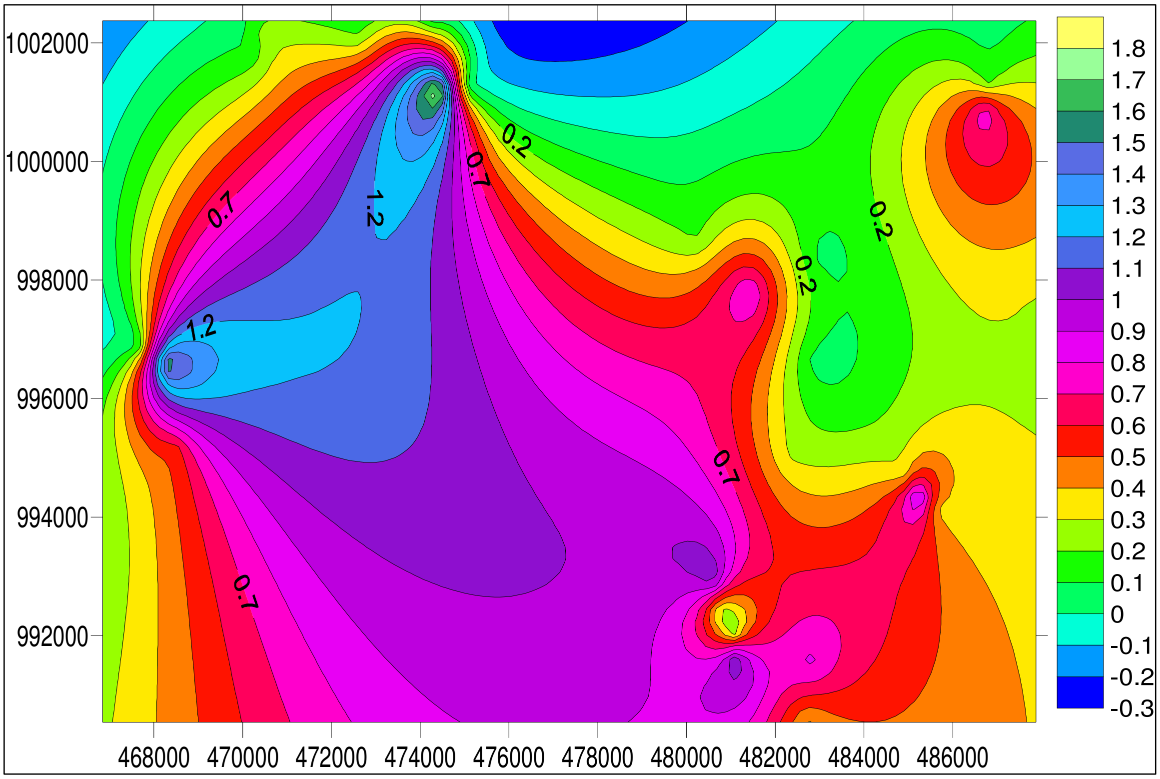


Figure 16 Iron map from Yeka-Kotebe area

3.2. WATER CHEMISTRY OF SPRING

Water Chemistry data has been collected from AAWSA (2010) and afew data from primary data (Table 3) for the purpose of analysis and interpretation based on major cations and anions.and the resulting piper plot is shown in Figure 17.

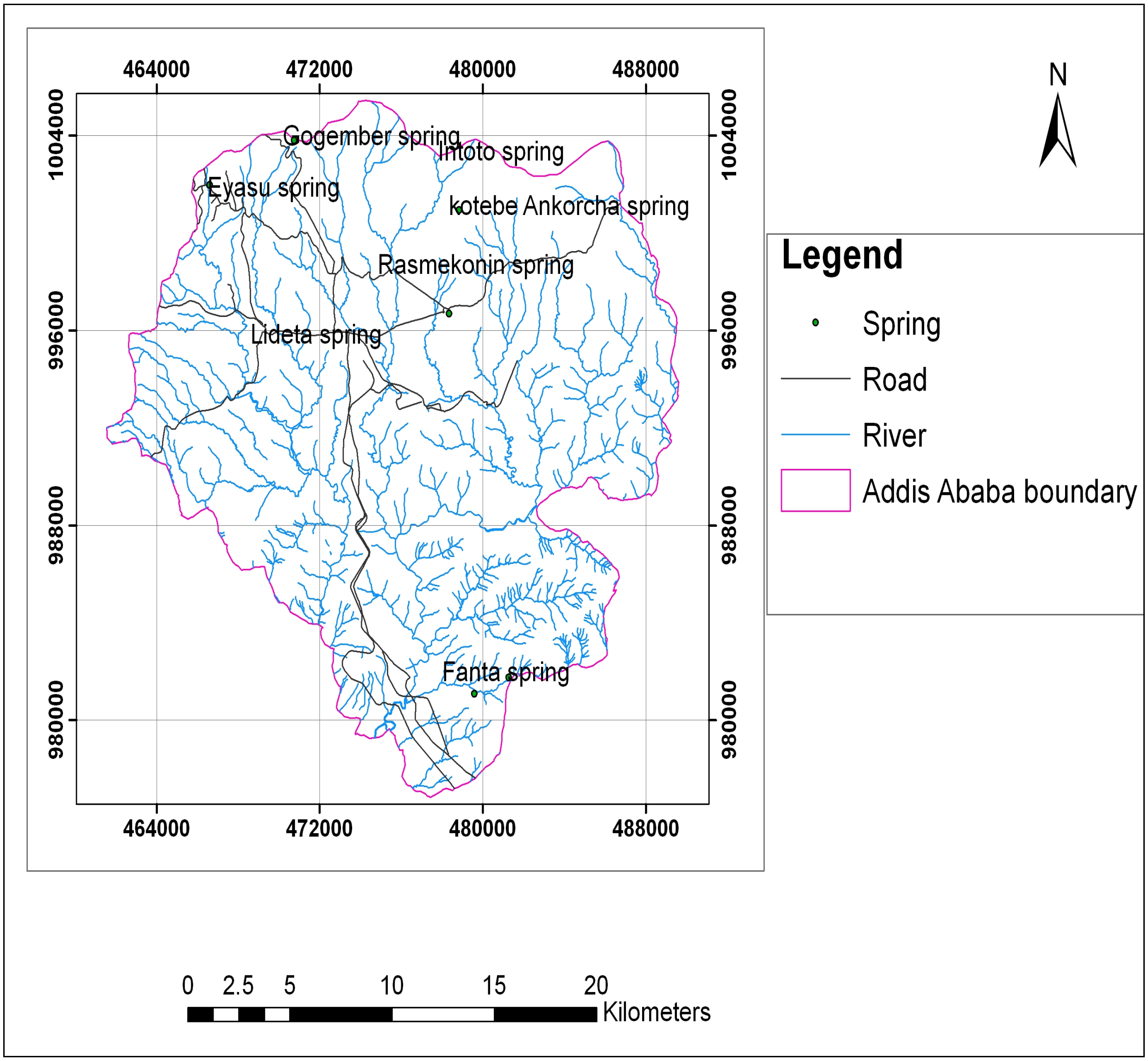


Figure 17 Location of spring

Table 3 Major ion concentrations of spring water samples

Item	Unit	Akako Spring (A)	Akako Spring (B)	Gojam Ber Spring	Ras Mekonnen Spring	Fanta Spring (A)	Fanta Spring (B)	Eyasu spring	Lideta sprig
Ca^{++}	Mg/l	3.24	2.56	7.56	100	55.6	40.8	10.18	46.4
Mg^{++}	Mg/l	0.68	0.63	2	60	24.1	23.9	2.5	7.81
Na^{+}	Mg/l	4.3	2.22	8.5	38	34.0	35	6.8	20.5
K^{+}	Mg/l	2.3	1.81	1.8	3	2.85	4.48	2.6	4
HCO_3^{-}	Mg/l	24	17	4.6	61.02	323.3	351	69	290
Cl^{-}	Mg/l	0.58	0.62	0.9	56.5	10.4	5.69	2.25	1.5
SO_4^{--}	Mg/l	0.41	0.43	0.72	19	19.9	13.14	2.24	0.1
NO_3^{-}	Mg/l	4.85	4.83	3.76	481.41	13.9	14.96	3.49	5.7
F^{-}	Mg/l	<0.1	<1	0.1	-	<0.1	0.4	nill	nill

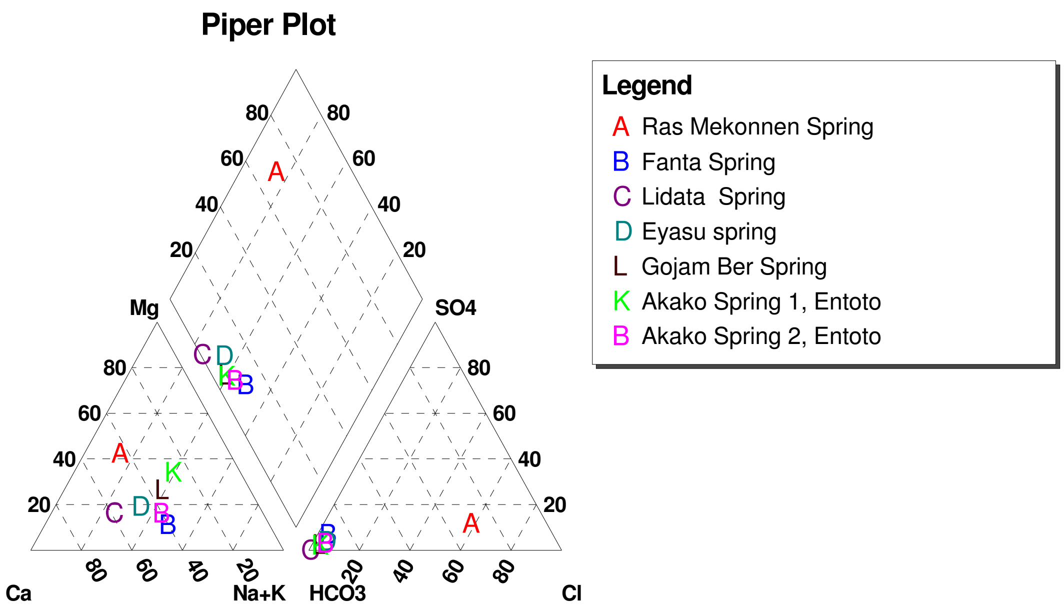


Figure 18 Piper diagram for springs

Accordingly, springs of northern Addis Ababa (Akako and Gojam-Ber) tend to have a relatively high concentration of Na than Ca and Mg (Na-Ca-HCO_3 water type) where as central and Southern area springs tend to be more concentrated in Ca and Mg than Na (Ca-Mg-HCO_3 water type). This might not be the result of groundwater evolution. However, the spring basins were considered as isolated patches created by structures that have to be characterized separately rather than as interconnected. The cations might have originated from the dissolution of the principal minerals that constitute the reservoirs. The carbonates, on the other hand, might have a different origin; they might come from the hydration of the atmospheric carbon dioxide gas and the oxidation of the organic substance that is found naturally in the soil.

Polluted waters tend to increase their Cl concentrations (Ca-Mg-Cl water type) as in the case of Ras Mekonnen spring (Arat Kilo area), the shift of Ca-Mg-HCO_3 to Ca-Mg- Cl mostly relate to the infiltration of contaminants into the subsurface rather than natural dissolution processes. Waters, which tend to be polluted, have higher Na for their K, HCO_3. Therefore, higher Na/K, Na/HCO_3, Cl/SO_4 and Cl/HCO_3 could be considered as an indication of pollution (Solomon Waltanigus, 2007). Polluted waters appear to have higher Cl for their Na, and hence lower Na/Cl these indicators have more or less happened to be observed in the mentioned spring than the others.

The plot of the concentrations of iron from Akako, Intoto, Gojem-ber, Ras mekonnen and Fanta springs for dry and wet seasons (Figure 19) showed that concentrations are generally greater for the rainy season than the dry season. This might be due to the relatively high rate of dissolution as a result of infiltrating low pH rain water. Yet, concentrations were not beyond the standard limit (<0.21 mg/l). Iron concentration for Ras Mekonnen spring was as high as those around Intoto Mountain indicating its recharge zone might extend northwards into the rhyolitic rocks. The structural map has also indicated a North-South trending fault line that extends from the mountain to the spring emerging point.

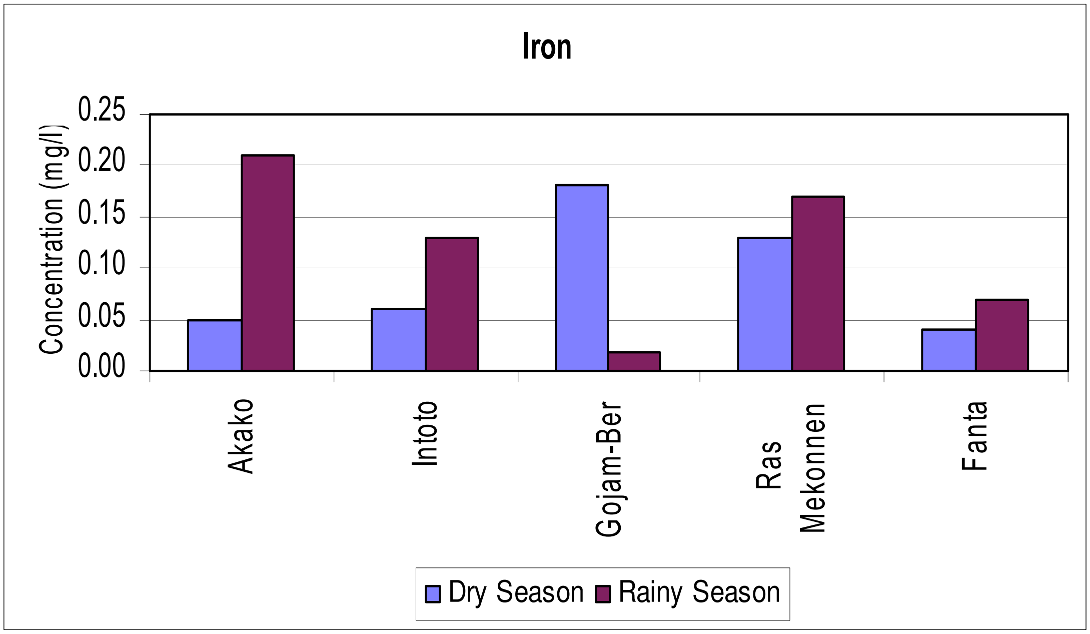


Figure 19 Spatial and Temporal variation of Iron Concentration in the springs

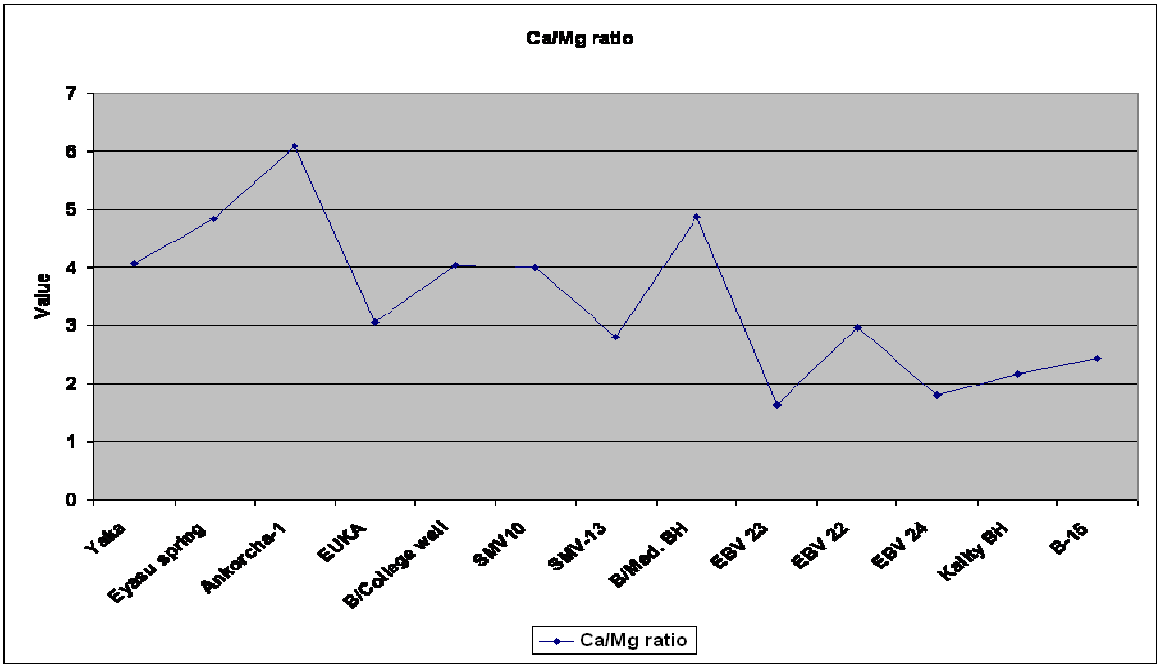
3.3 VARIATION OF IONIC CONCENTRATION ALONG THE GROUND WATER FLOW PATH

The main objective of considering groundwater chemistry in this study was to support the groundwater flow direction determined from water level data using groundwater chemistry. Concentrations of ions in water that determine the water types depend on the mineral composition of the porous media and the rate/time of interaction of water with the media. In places where inert tracer concentrations vary spatially along ground water flow path; the path followed by the tracer through the aquifer delineates flow direction. One of such tracers used most often is chloride because of its very conservative nature (Ebsa Oljira, 2006). In this study, chloride concentration shows small variation in borehole of the study (in Bole and Kotebe area) except centeral part of the study area high value recorded due to antropoigenic pollution and increase to south which can be due to additional chloride input along flow direction.

In addition, different ions ratios of representative water samples were employed to infer groundwater flow directions. The major indicators used were Ca/Mg ratio, Na/∑cations ratio, HCO_3 /∑anions, Ca+Mg / Na+K and Na/HCO_3 ratios.

Table 4 Ions ratios in representative samples used for flow direction inference

Well name	Ca/Mg	Na/ HCO_3	Na / ∑cations	Ca+Mg/ Na+K	HCO_3 /∑anions
Yaka	4.07	0.1	0.31	1.35	0.89
Eyasu spring	4.83	0.09	0.28	1.76	0.97
Ankorcha-1	6.1	0.17	0.4	0.86	0.891
Kotebe	3	0.3	0.59	0.41	0.93
EUKA	3.05	0.2	0.62	0.57	0.97
B/College well	4.03	0.18	0.39	1.08	0.88
SMV10	4	0.23	0.44	0.96	0.91
SMV-13	2.8	0.15	0.34	1.75	0.7
SMV-14	4.64	0.08	0.26	2.04	0.96
B/Med. BH	4.88	0.17	0.32	1.71	0.87
EBV 23	1.63	0.21	0.46	1.03	0.92
EBV 22	2.96	0.17	0.33	1.28	0.9
EBV 24	1.8	0.19	0.4	1.29	0.93
Kality BH	2.17	0.2	0.41	1.19	0.91
B-15	2.43	0.23	0.46	1.03	0.84



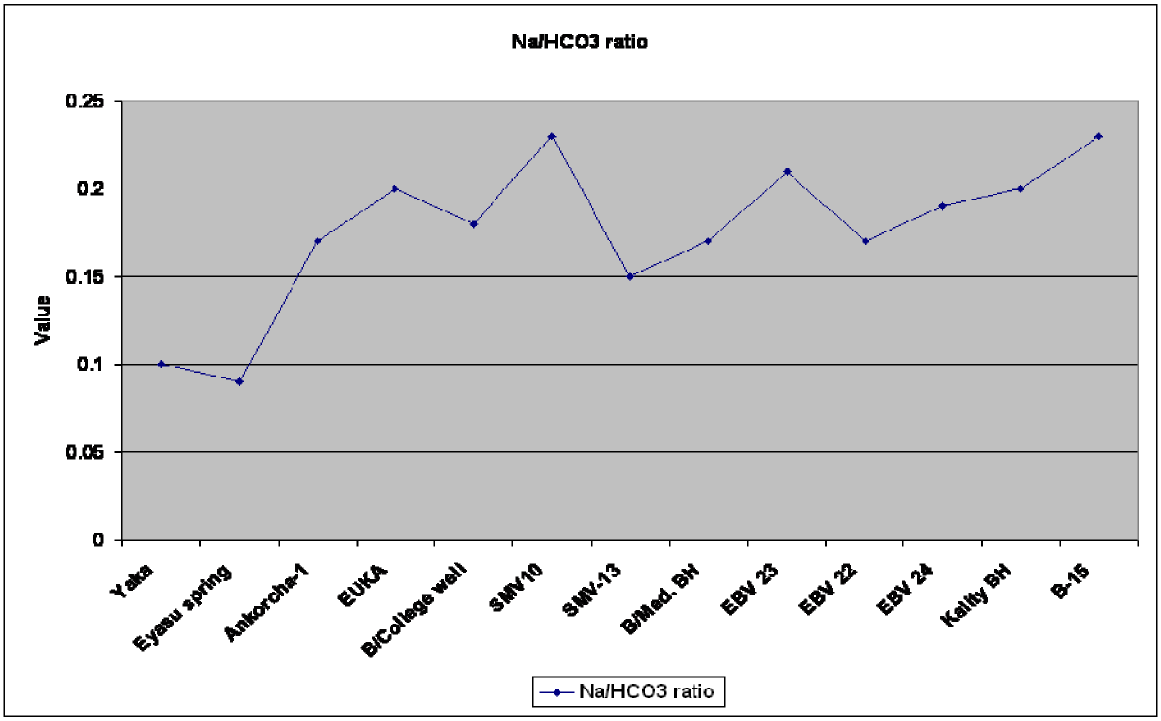
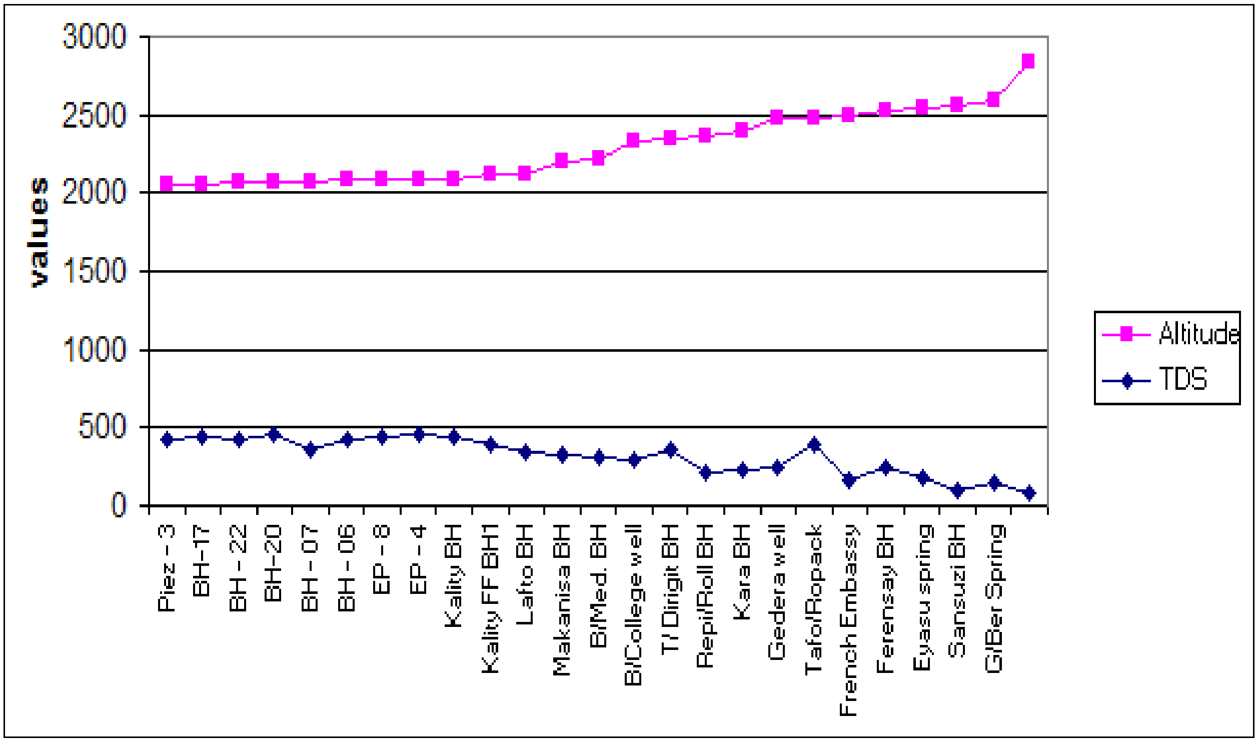


Figure 20 Ratio of Ca/Mg (top) and Ratio of Na/HCO_3 (bottom) ploted against samples. The samples arrangement from left to right shows samples from Yaka-Kotebe to Summit-Bole respectively.

The above plots and tables show that groundwater samples from northern part of the catchment's have different chemical compositions compared to samples in the central and southern parts. Based on this, the general groundwater flow direction was inferred.

Groundwater samples from northern part (most left samples on the above plots) of the catchment's have higher Ca/Mg ratio, lower Na/HCO_3 ratio, and higher Ca + Mg / Na + K ratio and lower Na/∑cations ratio. In addition, these samples have lower TDS/EC, and pH values. On the other hand, samples from southern part of the catchments have lower Ca/Mg ratio, higher Na/HCO_3 ratio, lower Ca+Mg/ Na+K ratio, higher Na/∑cations ratio and higher TDS/EC and pH values. An increase in chemical parameters or ions ratios to the south indicated increased groundwater-rock interaction along flow path and longer residence time of water in the ground. And a decrease of Ca/Mg and Ca+Mg /Na+K ratios to the south was due to removal of calcium with bicarbonates along flow paths. These variations in ions ratios and parameters following a general trend were used to define recharge areas and infer flow directions. Accordingly, the Northern part of the catchment's was defined as a recharge zone and groundwater flows from this area to the South, based on which the general groundwater flow pattern in the catchment's was inferred to be from North to South. This trend was in a close agreement with the general groundwater flow direction defined from water level data.

In addition, plots of TDS versus altitude and TDS versus well depth were used as indicators to infer the general groundwater flow direction. The samples were arranged from left (South) to right (North).



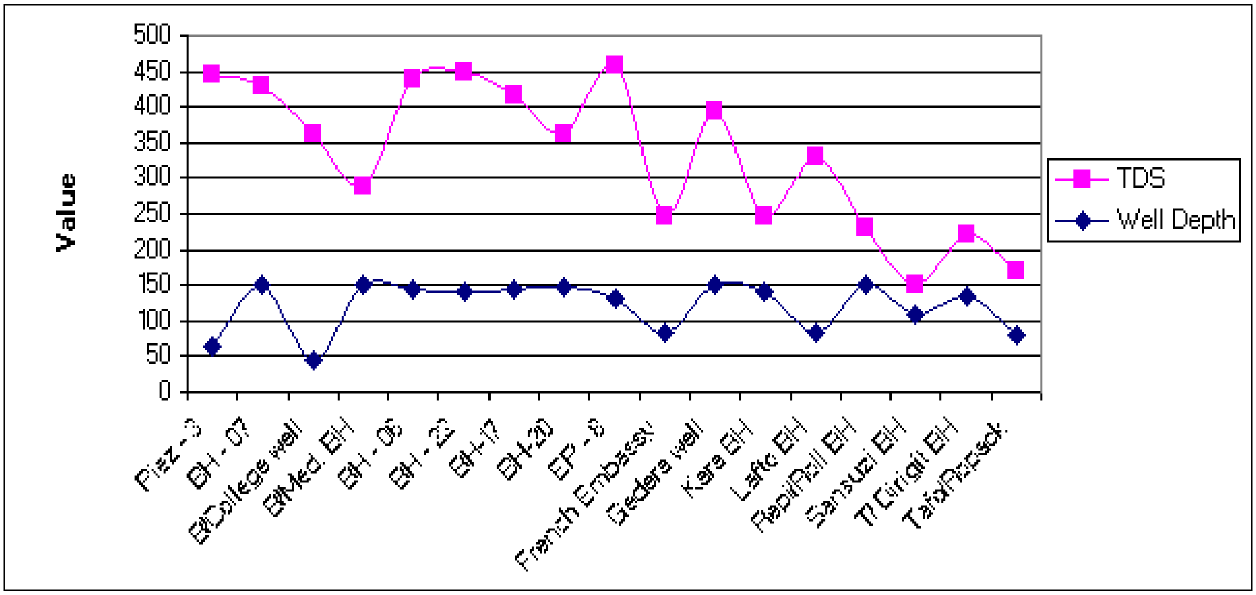


Figure 21 Plots of TDS vs. altitude (top) and TDS vs. well depth (bottom) against samples

TDS vs. altitude plot indicated an inverse relationship. Samples from Northern part of the catchments were located at higher altitude and have lower TDS, and those at lower elevations have higher TDS values. As groundwater table is a subdued replica of surface topography, samples to the North were expected to have shallow water table compared to the South ones. As groundwater flows from an area of shallow water table to an area of deeper water table, this was used to infer that groundwater flows from North to South in the catchment's following the surface morphology.

The plot of TDS vs. well depth showed that as well depth increased, the TDS value also increased in the catchments. This is very rough conclusion because most shallow wells were highly polluted and have higher TDS values. In general, a well depth increase from north to south in the catchment's so does the TDS. This relation may be used in combination with other data to infer flow direction.

3.4 SURFACE WATER POLLUTION

The first step in the water quality analysis of a ground and surface water system is the identification and characterization of wastes emanating from various pollution sources. Both natural and anthropogenic activities can contribute to the pollution of a given water body.

However, in a catchments system that drains an industrial, highly populated and socio-economically vibrant urban centers like Addis Ababa, the relative effects of anthropogenic activities in deteriorating the quality of the water exceed by far the natural causes (Tamiru Alemayehu, 2003).

The main sources of pollutants that deteriorate the quality of water in the project area are wastes generated from industries, domestic activities, garages, health centers and fuel stations (Tamiru Alemayehu, 2003). The pollutants identified in surface and ground water bodies include organic wastes, nutrients, inorganic constituents and microorganisms. Moreover, river water in Addis Ababa is characterized by objectionable physical properties offensive odor, and colored water. There was seasonal variation in EC, TDS and pH more rapidly in surface waters (rivers and streams) attributed to the type of wastes and industrial effluents (Abdurkarim Mohammed, 2007). It was worthwhile to note the high EC values as compared with groundwater.

For this portion of the research study monitored secondary data along Akaki River (Big and Tinishu Akaki*)* of four years (2005-2008) collected from Addis Ababa Environmental Protection Agency and the depletion of Dissolved Oxygen and factors causes of depletion are analyised.

Dissolved Oxygen depletion along Akaki Rivers (Big and Tinishu Akaki)

Dissolved oxygen is important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The DO values indicate the degree of pollution in water bodies. It is really a physical distribution of oxygen molecules in water. There are two main sources of DO in water: atmosphere and photosynthesis. The amount of DO that can be held by water depends on 3 factors: water temperature, salinity, and atmospheric pressure. Amount of DO increases with decreasing temperature (colder water holds more oxygen) and increases with decreasing salinity (freshwater holds more oxygen than saltwater does) and amount of DO decreases with decreasing atmospheric pressure (amount of DO absorbed in water decreases as altitude increases).

Low DO concentration and the presence of oxygen depleting substances (organic and inorganic pollutants) appears to occur along the course of the impaired of Akaki rivers (Big and Tinishu), where most the industry found in Addis Ababa located along it.

The fall in DO level towards the down stream of TAR is observed to be accompanied with an increase in the production, mobility and toxicity of potentially harmful substances such as ammonia, heavy metals (Cr, Mn, and Fe etc), sulphates, hydrogen sulfide, methane and phosphates, Moreover, the increase in chloride and heavy metals inhibit further depletion of dissolved oxygen towards the end of the river.

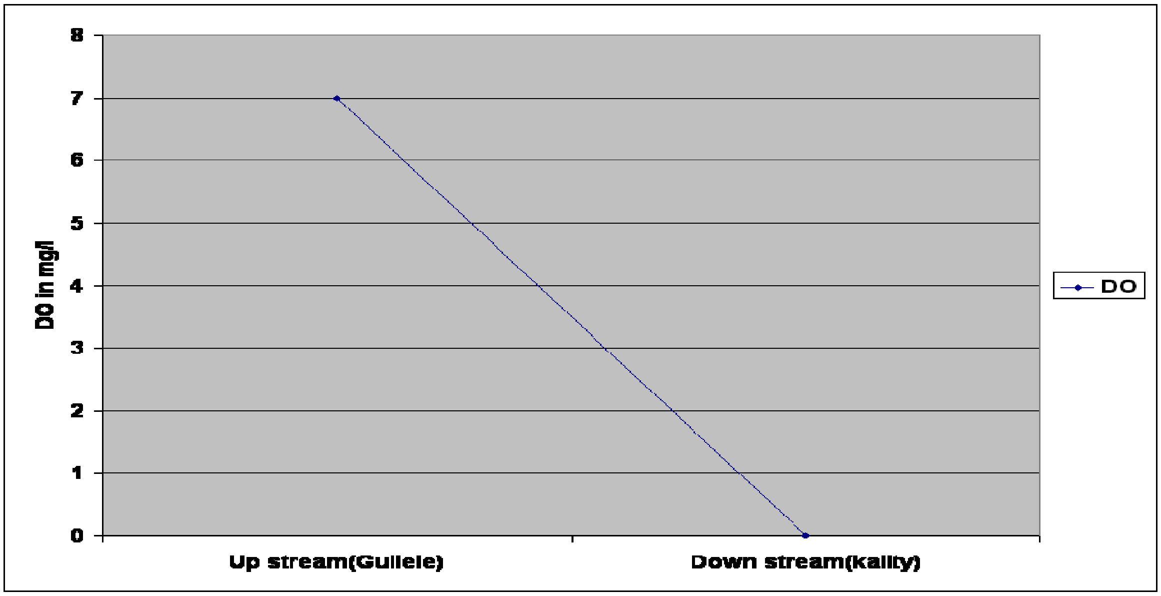


Figure 22 Dissolved Oxygen Pattern along Tinshu Akaki River

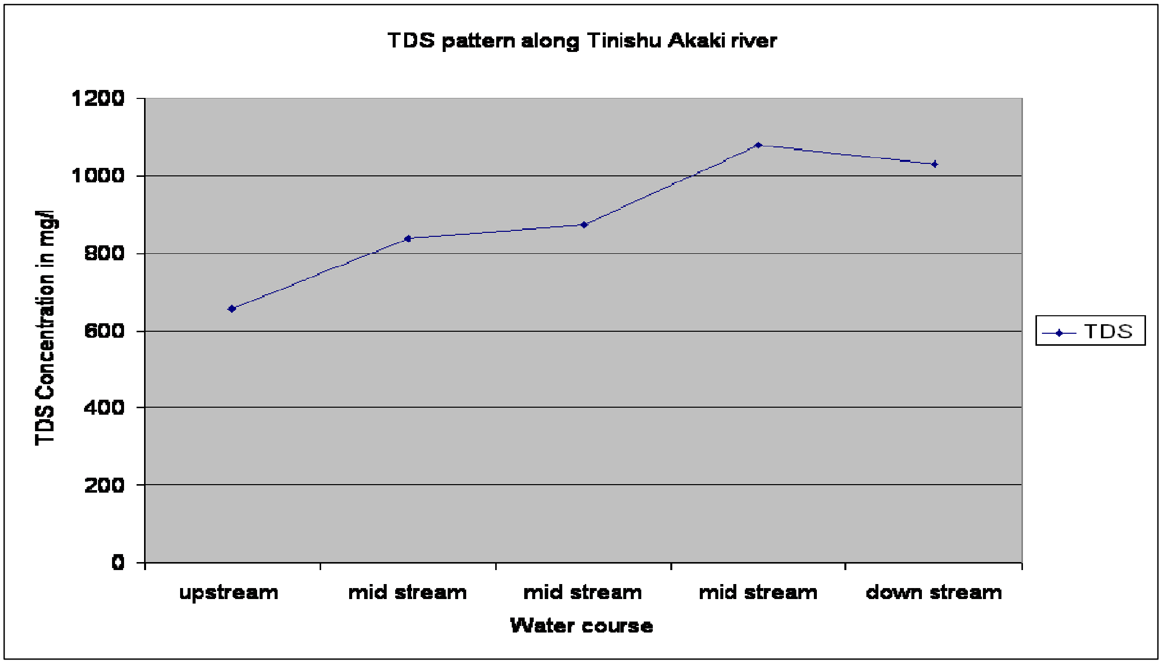


Figure 23 TDS pattern along TAR

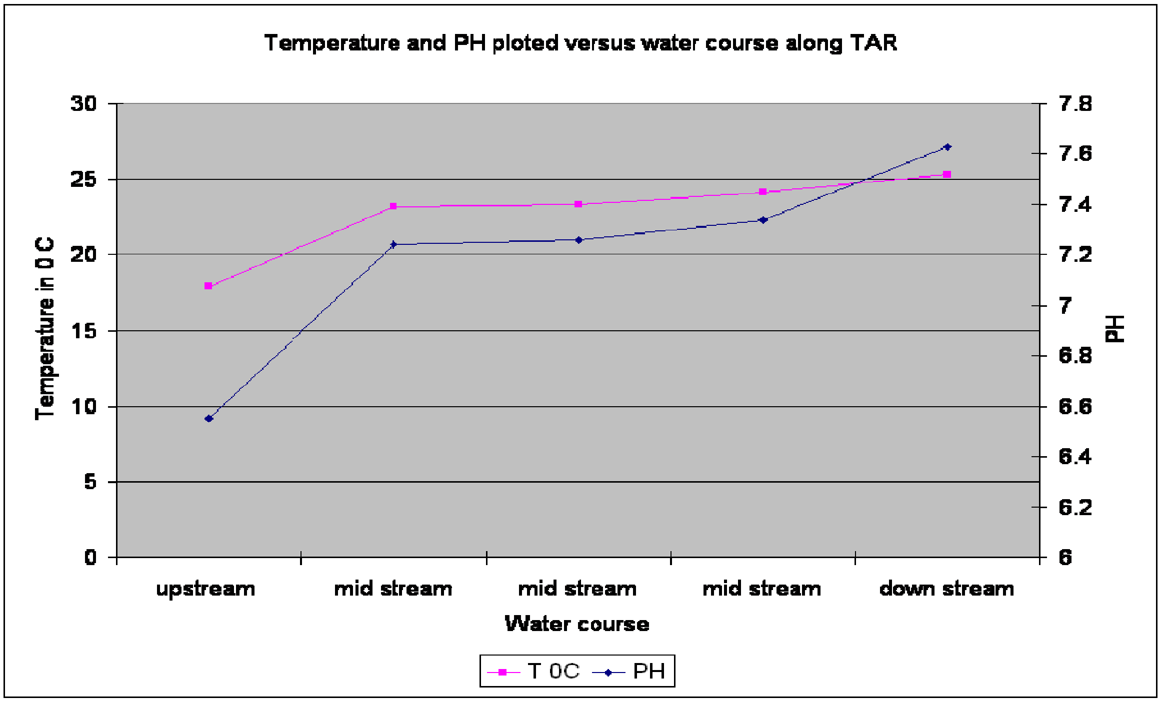


Figure 24 Temperature and PH pattern along TAR

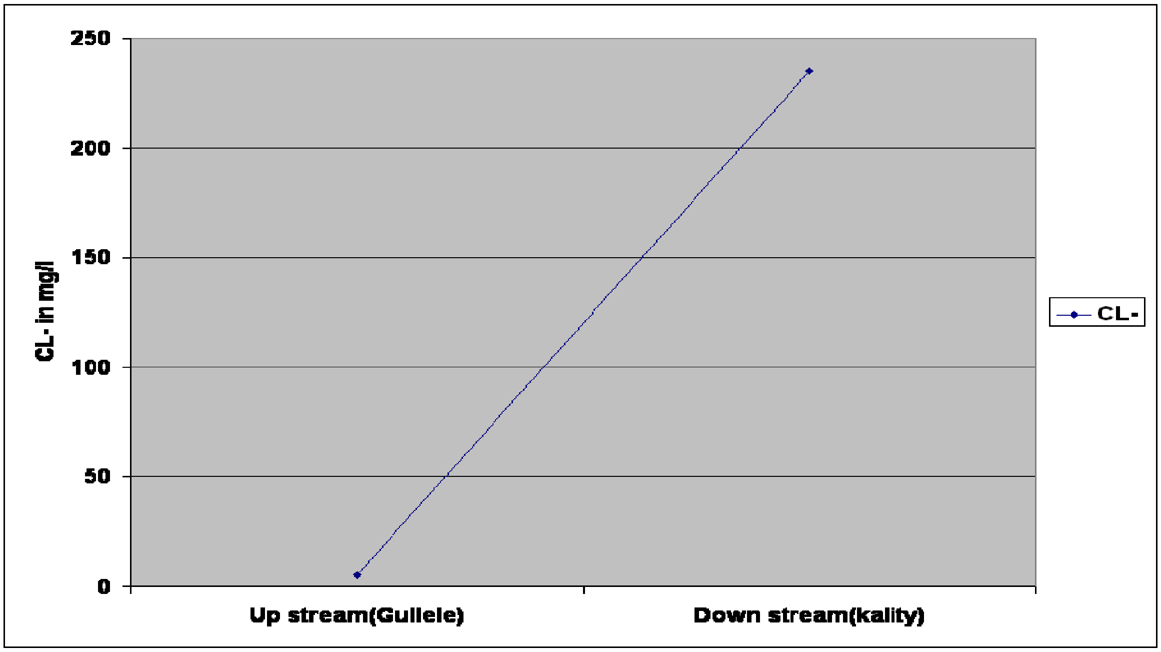


Figure 25 Chloride pattern along TAR

3.5 Water Quality Criteria

Water quality is relative and is defined as the characteristic of water that influences its suitability for aspecific use. Quality is defined in terms of physical, chemical and biological characteristics. The purpose of the water quality study is therefore to identify the areal distribution of concentrated waters in the study areas and assess their suitability for various purposes. Apressing need has emerged for comprehensive and accurate assessments of trends in water quality, in order to raise awareness of the urgent need to address the consequences of present and future threats of contamination and to provide a basis for action at all levels. With the advent of industrialization and increasing populations, the range of requirements for water has increased together with greater demands for higher quality water. Therefore, the study of water quality has great significance as it plays an important role in assuring a good quality of water for different purposes such as for domestic, livestock supply, irrigation and industry, etc.

Drinking water standards

The main water quality indicators are physical and chemical constituents of water. These constituents are highly influenced as a function of geological formation and human interferences. Quality of groundwater samples were evaluated using World Health Organization (WHO) guidelines. Elevated concentrations of a number of constituents beyond this guideline can cause problems for water use. According to these standards most analyzed water samples from the research area unfit for drinking in Yaka-Kotebe higher value of fluoride and iron content was measured which slightly more than the recommended value of WHO similarly in Summit-Bole high value of salinity (EC/TDS) as shown in Table 5.

Generally, except in few water samples most water samples unfit for drinking water in considerd study area.

Hardness

When water is referred to as ‘hard’ this simply means, that it contains more minerals than ordinary water. Hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts. The total content of these salts is known as general hardness, which can be further divided into carbonate hardness (determined by concentrations of calcium and magnesium hydro-carbonates), and non-carbonate hardness (determined by calcium and magnesium salts of strong acids). Hydro-carbonates are transformed during the boiling of water into carbonates, which usually precipitate. Therefore, carbonate hardness is also known as temporary or removed, whereas the hardness remaining in the water after boiling is called constant.

Hardness (H) is given by the formula:

$$\mathbf{H = 2.5Ca + 4.1Mg},\ \text{Where, Ca and Mg are given in mg/l.}$$

A guideline value of 500 mg/litre (as calcium carbonate) was established for hardness, based on taste and household use considerations by WHO. Accordingly, total hardness in most of water samples of the study area as of $CaCO_3$ was between 10 mg/l and 150 mg/l as anavarge and this value is below the WHO standard and the ground water of the study area considered as soft except in few water samples, such as (SMV-13), SMV-14, above WHO gudie line and slightly hard water.

3.5. 1 WATER QUALITY STANDARDS

Water quality standards are fundamental tools that help protect valuable surface and ground water resources and serve as the foundation for the water-quality based approach to pollution control and are a fundamental component of watershed management. Water quality standards should have objectives like restoring and maintaining chemical, physical, and biological integrity of waters providing, wherever attainable, water quality for public water supplies, recreation, agricultural and industrial purposes.

The analysis result of the water sample collected in the area have been compared with the Ethiopian standards (ESA, 1990) and with the standards established by World health Organization (WHO,1984) were given in Table 5 below.

Accordingly, it was observed that Ca^{2+} value below WHO guide line for all water sample and Na^{+} value also below except for few water sample from Summit-Bole which were above the mean value of iron (0.55 mg/l) and floride (3.2 mg/l) were above World Health Organization standards for drinking water in Yaka-Kotebe area. Similarly, the mean value of TDS (862 mg/l) and EC (1356 mg/l) for water samples from Summit-Bole were greater than maximum permissible standards for drinking water guide line of World Health Organization, chloride and sulfate were below WHO guide line for all water samples from both area but HCO_3^- above guide line for all water samples

Generally, in the study area from water sample analysed about 50% of water samples were greater than World Health Organization maximum permissible standards for drinking water for water quality parameters such as Fe, F^-, NO_3^-, EC, and TDS. Therefore, elevated values of these parameters are of great concern to public health when the water from these boreholes is consumed by people without treatment.

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Table 5 Compersion of Selected Water Quality results of laboratory analysis with International Water Quality Standard (WHO, 1984) and Ethopian Water Quality Standards (ESA, 1990)

Parameter (mg/l)	Sampling points													Water Quality standards	
	Yaka-Kotebe (Iron/Floride problems)							Summit-Bole (EC/TDS / Floride Problems)						WHO(1984	ETHIOPIAN (ESA, 1990)
	Ankorcha-1	Salayish	CMC	Selam	Kotebe	EUKA	AYAT 1	EBV 03	EBV 23	EBV 24	SMV 13	SMV 14	SMV 15		
Color(TCU)														15	50
Odor	-	-	-	-	-	-	-	-	-	-	-	-	-	Odorless	
Taste	-	-	-	-	-									Tasteless	
Turbidity(NTU) mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	5	25
pH	8.44	7.38	6.99	7.11	6.8	6.87	7.89	7.78	8.64	8.55	6.5	6.75	6.6	<8	7-8.2
Ca^{2+}	53.76	33.6	15.12	130	50.4	27.7	16.63	17.64	31.92	31.08	25.2	26.04	21	75	
Mg^{2+}	4	10.2	4.08	52	10.2	4.59	3.24	8.94	7.14	7.65	5.61	5.61	8.16	50	
Na^{+}	30.5	62	68	40	24	9.8	77	380	73	128	495	580	440	200	
K^{+}	3.2	5	7	5	4	3.4	22	35.5	7.3	12.1	24.5	31	23	-	
HCO_3^{-2}	258.6	274.5	209.8	216	254.7	109.8	225.46	1176.08	314.76	492.88	1434	1512.8	1078	150	
Cl^{-}	8	7.94	10.9	NB	7.94	8.94	42	23.8	6.95	11.92	47.66	44.69	33.76	250	600
SO_4^{-2}	6.38	19.57	14.09	46.1	19.57	10.8	29.73	40.84	6.47	14.09	0.39	99.5	60.8	250	400
F^{-}	2.48	2.6	5.8	2.95	2.6	1.67	1.72	2.5	0.97	3.05	6.4	3.05	1.32	1.5	1.5
Fe	0.338	0.83	0.61	1.09	0.83	0.555	0.772	0.19	0.16	0.18	0.19	0.18	0.11	0.3	1
NO_3^{-}	0.01	0.31	0.24	0.03	0.32	1	TRACE	0.24	2.62	4.1	0.3	12.6	11.2	50	50
EC	754	464	381	539	408	213	524	2270	2318	1980	1904	2500	1654	-	-
T D S	361	308	250	258	260	142	344	1132	1132	1246	1394	1620	1136	500	1500

CHAPTER FOUR

CONCLUSION AND RECOMENDATION

4.1 CONCLUSION

- Analysis of the hydrochemistry of different water sources show that generally four types of water were identified based on their major cation composition; Ca-HCO_3/ Ca-Mg-HCO_3, Ca-Na-HCO_3 and Na-Ca-HCO_3 water types. The dominant water types were Ca-Na-HCO_3 type (Yaka-Kotebe) and Na-Ca-HCO_3 (Summit-Bole).
- Different ions ratios of representative water samples were employed to infer groundwater flow directions. These variations in ions ratios and parameters following a general trend were used to define recharge areas and infer flow directions. Accordingly, the Northern part (Intoto-Yaka-Kotebe) of the area was defined as a recharge zone and groundwater flows from this area to the South (Summit-Bole), based on which the general groundwater flow pattern in the catchment's was inferred to be from Intoto-Yaka-Kotebe to Summit-Bole. This trend is in a close agreement with the general groundwater flow direction defined from water level data.
- The whole study area is covered by volcanic rocks and due to absence of non-carbonate rocks, bicarbonate ion is attributed to atmospheric and soil CO_2 and hydrolysis of silicate minerals. Thus, anion composition all water types were HCO_3^- type waters whereas the $Cl^-$and NO_3^- water type's werenot due to natural evolution but attributed to anthropogenic effect.
- Ground waters found in the study area have pH values ranging from about 6.5 to 8.6 and it was between the ranges of WHO standared for drinking water. .
- Generally, the water samples were characterized by low TDS concentration (Yaka-Kotebe) indicating the rock-water interaction (residence time) is short and the resistance of volcanic rocks to weathering and the amount for water samples in the Summit-Bole area was high and above WHO recommended unit for most of the ground water samples mainly due to the types of minerals that make up the aquifer and residence time. Generally, both TDS and EC increase proportionally increases from Yaka-Kotebe to Summit- Bole areas.

- High amount of iron from ground water samples of Yaka-Kotebe areas due to the fact that An area receiving the highest rain fall the effects of dilution and enrichment often occurs on the solutes leached from the Acidic Rocks (Intoto rhyolite).and hydrothermally altered rhyolitic rocks of Intoto area, which might have experienced hydrothermal alterations, are expected to provide much iron to the groundwater whenever they are in contact than the basalts.
- Fluoride was above WHO recommended (>1.5 mg/l) in most water samples Yaka-Kotebe and Summit-Bole aswell, this is mainly deeper (older) ground waters from tube wells are most likely to contain high concentrations of fluoride (Summit-Bole area), the fact that shallow aquifers situated in active volcanic areas affected by hydrothermal alteration, like hydrothermally alteration of rhyolitic rocks of Intoto area (Yaka-Kotebe) and reaction times with aquifer minerals built up ground waters which have long residence times in the host aquifers (in case of Summit-Bole areas).
- The concentrations of NO_3^- and Cl^- were lower for most of water samples in Yaka- Kotebe and Summit-Bole area and the concentrations is higher in Centeral part of the study area dueto antropogenic impact.
- For surface water in the area, Akaki river water is totally unfit for domestic use, because the EC, TDS, pH, Cl^- and tempracture increases going down Akaki River. As aresult, it was found that the water quality downstream was strongly degraded resulting in low Dissolved Oxygen.
- Concerning drinking water quality, most water samples unfit for drinking in Yaka- Kotebe relatively higher value of fluoride and iron content, and Summit–Bole due to higher salinity (TDS/EC) which slightly above the recommended value of WHO standared drinking water.

4.2 RECOMMENDATION

This research work was done to show the ground water pollution and water quality condition of Addis Ababa area and the effect of surface water pollution on the groundwater on that basis for further detail research work to be conducted with in the area the following recommendation were given:-

- ✓ As pollution is a major problem of Addis Ababa city, the factories in the city and its immediate surroundings should develop treatment plants with proper design and the majority of their industrial effluent should be free or in minimum concentration in terms of pollutants.
- ✓ Further investigation of trace element and bacteriological analysis with high precision instruments must be carried out in order to study the degree of industrial pollution and anthropogenic effect on surface and groundwater of the study area.
- ✓ Continous monitoring the log-term trends of ground and surface water quality in the area by upgrading groundwater data set (increasing sampling point, more borehole information and Geophysical investigation) should be done.
- ✓ Additional study of the flow path and age (residence time) of groundwater by using isotopic is needed.
- ✓ Further investigation of groundwater flow modeling for characterizing and prediction of pollutant transport must be carried out. .

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APPENDIXES

Appendix 1 Summary of meterological data for the study area (source, National Meterological Agency)

		Months												
Parameter	Station(periods)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Rainfall, mm	Intoto(1989-2008)	14.74	33.43	57.55	84.375	68.07	143.375	309.715	339.66	136.105	26.52	13.145	8.19	1234.77
	Akaki(1975-2009)	15.7	27.77	69.92	86.64	68.34	114.74	254.288	258.12	122.08	24.27	5.45	3.33	1050.67
	AABole(1980-2009)	13.88	31.47	66.33	93.14	77.49	125.7	246.225	256.01	136.476	32.23	5.01	4.896	1088.43
	AA Obs (1980-2009)	16.8	38.42	70.32	94.3724	89.31	137.63	277.62	293.53	177.81	38.38	8.055	11.94	807.36
Mean		**15.28**	**32.77**	**66.03**	**89.63**	**75.8**	**130.36**	**272**	**286.83**	**143.11**	**30.35**	**7.915**	**7.089**	**1157.23**
Temp.^{0}c	Entoto (1989-2006)	19.9	21.1	20.6	20.0	19.7	17.8	16.2	16.4	16.7	18.2	19.4	18.8	242.5
	AA Obs (1980-2009)	24.3	25.0	25.7	24.9	25.3	23.6	21.2	21.0	22.0	23.1	23.3	23.1	282.4
	AA Bole(1980-2008)	23.85	24.775	26	25.1	25.1	23.2	21.1	21	21.7	23.15	23	23	281.05
	Akaki (1997-2009)	26.5	27.6	28	27.8	28.2	25.9	24.2	24	25.15	26	25.8	25.9	314.65
Mean		**23.63**	**24.61**	**25**	**24.45**	**24.57**	**23.7**	**20.67**	**20.6**	**21.4**	**22.61**	**22.9**	**22.7**	**256.34**
Pan Evap. mm	AA Bole(1987-2004)	186.1	190	190.8	177.4	202	106.2	62.3	60.6	99.5	287	189	171	1921.8
	AA Obs (1992-2004)	131.7	141	145	117.6	138.3	84.2	52.7	50.2	73	121	137	127	1318.5
Mean		**158.9**	**165.5**	**167.9**	**147.5**	**170.15**	**95.2**	**57.5**	**55.4**	**86.25**	**204**	**163**	**149**	**1620.15**
Sunshine Hr	AA Obs (1964-1993)	8.6	8.1	7.2	6.5	6.8	5.1	3	3.5	5	8.1	9	9.1	80
Mean		**8.6**	**8.1**	**7.2**	**6.5**	**6.8**	**5.1**	**3**	**3.5**	**5**	**8.1**	**9**	**9.1**	**80**
Wind speed km/hr	AA Obs (1982-2005)	0.6	0.6	0.65	0.65	0.65	0.4	0.3	0.25	0.45	0.65	0.7	0.65	5.9
Mean		**0.6**	**0.6**	**0.65**	**0.65**	**0.65**	**0.4**	**0.3**	**0.25**	**0.45**	**0.65**	**0.7**	**0.65**	**5.9**
R. H in%	AA Obs (1979-2009)	49	45	46	47	47	58	70	72	64	48	43	45	634
	AA Bole(1964-2005)	49	41	47	54	59	65	79	77	72	52	50	48	693
Mean		**49**	**43**	**46.5**	**50.5**	**53**	**61.5**	**74.5**	**74.5**	**68**	**50**	**46.5**	**46.5**	**663.5**

Appendix 2 Great Akaki Moniotering Data (EPA, 2007)

Sampling station	PH	DO (mg/l)	EC µs/cm	Temp °C	BOD (mg/l)	COD (mg/l)	NH3 (mg/l)	NO3 (mg/l)	PO4 (mg/l)	Cr(mg/l)	Pb (mg/l)	Co (mg/l)	Cd (mg/)	MPN /100 Coliform
Ga1(Around Entoto Church)	7.5	4.2	122.5	20	6	17	0.01	0	0.49	0.03	0	0	0.01	$27*10^{4}$
Ga2(below Hamle 19 park)	7.8	4.4	655	20	10	14	0.02	2.7	0.09	0.01	0	0.07	0	$11*10^{5}$
Ga3(Below Menilik Hospital)	7.8	5	572	20	25	32	0.24	2.1	2.78	0	0	0.05	0	$16*10^{7}$
Ga4(Below Migbare senay clinic)	7.7	5.4	608	20	10	13	0.23	2.4	3.01	0	0	0	0	$17*10^{6}$
Ga5(Below Agoza Market)	7.8	6.7	105.5	14.7	20	39	2.75	3.2	3.13	<0.01	0.1	0.06	0	$16*10^{6}$
Ga6(below peacock park)	7.45	2.5	112	15.4	60	150	2.75	1.2	5.5	<0.01	0	0.04	0	$35*10^{6}$
Ga7(Below saint Joseph church)	8.02	1.4	146.4	20.4	130	240	2.75	23.2	5.5	<0.01	0	0.05	0.01	$24*10^{6}$
Ga8(Below Abo church)	8.1	6	151	17.2	90	126	2.75	1.1	5.5	<0.01	0	0.05	0.01	$9*10^{7}$
Ga9(below textile and paint factory)	7.7	5.4	110	18.8	20	45	2.75	2.1	20	<0.01	0	0.03	0	$17*10^{5}$

Appendix 3 Great Akaki Moniotering Data (EPA, 2008)

Sampling station	PH	DO (mg/l)	EC µs/cm	Temp °C	BOD (mg/l)	COD(mg/l)	NH3(m g/l)	NO3 (mg/l)	PO4 (mg/l)	Cr (mg/l)	Cd (mg/l)	MPN /100 Coli form
Ga1(Around Entoto Church)	7.2	2.1	33.8	12.8	4	17	0.01	0	0.49	0.03	0	$27*10^{4}$
Ga2(below Hamle 19 park)	7.5	3.1	135.2	15.9	5.6	14	0.02	2.7	0.09	0.01	0	$11*10^{5}$
Ga3(Below Menilik Hospital)	6.9	4.3	116.3	16.6	5.9	32	0.24	2.1	2.78	0	0	$16*10^{7}$
Ga4(Below Migbare senay clinic)	7.8	4.5	121	22.4	6.2	13	0.23	2.4	3.01	0	0	$17*10^{6}$
Ga5(Below Agoza Market)	7.5	3.7	111.6	22.7	4.7	39	2.75	3.2	3.13	<0.01	0.1	$16*10^{6}$
Ga6(below peacock park)	7.6	2.7	593	17.3	70	150	2.75	1.2	5.5	<0.01	0	$35*10^{6}$
Ga7(Below saint Joseph church)	7.9	4.4	759	20.5	80	240	2.75	23.2	5.5	<0.01	0	$24*10^{6}$
Ga8(Below Abo church)	8.3	5.2	761	15.5	80	126	2.75	1.1	5.5	<0.01	0	$9*10^{7}$
Ga9(below textile and paint factory)	7.9	4.5	523	19	40	45	2.75	2.1	20	<0.01	0	$17*10^{5}$

Appendix 4 spring data (AAWSA, 2010)

Name of spring	EC µs/cm	TDS (mg/l)	PH	Na (mg/l)	K (mg/l)	Ca (mg/)	Mg (mg/l)	F (mg/l)	CL (mg/l)	HCO3 (mg/l)	SO4 (mg/l)	Total Fe (mg/l)	NO3 (mg/l)
Eyasu spring	116	93.8	6.2	6.8	2.6	10.18	2.5		2.25	69	2.24	–	3.49
Meka Sprng	530.00	360.0	8.5					0.7	10.0		7.8		
Yaka spring	73.5	35	6.8					0.54	2.5			nill	
Burka Spring	460.00	320.0	8.1					1	10				
Akako Spring 1, Entoto	72	35	6.7	4.3	2.3	3.24	2.56	0.03	0.58		0.41	0.05	4.85
Akako Spring 2, Entoto	72	35		2.22	1.81	2.56	0.63		0.62	17	0.43		4.83
Gojam Ber Spring	76	36	6.9	8.5	1.8	7.56	4.5		0.9	4.6	0.72	0.06	3.76
Ras Mekonnen Spring	322	670		38	3	100	60	0.15	71.5	61.02	19	0.13	481.41
Fanta Spring akaki	573	274	7.74	34	2.85	55.6	7.81	0.48	10.4	323.3	19.9	0.04	13.9
Kotebe -Ankorcha- spring (S-8)	293	139	7.69	30.5	3.2	53.76	10.71	0.21	4	144	2.3	0.02	0.8
Lidata Spring	346	410	8.5	20.5	4	46.4	7.81		1.5	290	0.1	0.22	5.7

Appendix 5 Tinishu Akaki Data (EPA, 2007)

Sampling station	PH	DO (mg/l)	EC µs/cm	T(^{0}C)	BOD (mg/l)	COD (mg/l)	NH3 (mg/l)	NO3 (mg/l)	PO4 (mg/l)	Cr (mg/l)	Cd (mg/l)	MPN /100 Coliform
La1 (Below marble factory)	8.1	1.6	102.5	19.4	60	118	0	2.64	0	<0.01	0.01	$9*10^{6}$
La2(Below Merkato Market)	7.5	0.7	168	21.4	210	280	0	2.75	5.5	<0.01	0	$16*10^{6}$
La3(Below Coca Cola factory)	8.1	0.8	238	21.5	320	496	1.2	2.75	5.5	<0.01	0	$16*10^{6}$
La4(Below Awash wine factory)	7.7	0.6	216	21.5	380	820	0.5	2.75	5.5	<0.01	0	$16*10^{6}$
La5(solid wastes around the River)	7.4	1.3	178	16.6	310	1238	16.6	2.75	5.5	0	0	$16*10^{8}$
La6 (Below Kera Abattoir, meet fact)	7.7	0.9	1070	20	430	880	24.7	1.78	5.5	<0.01	0.01	$16*10^{10}$
La7(The major River from Kera side)	7.4	0.7	179	17.6	220	1025	20	2.75	5.5	<0.01	0	$16*10^{8}$
La8(Tributary Below National Alcohol factory)	7.1	5.8	1853	20.4	90	374	35	2.75	0.27	0.01	0	$28*10^{7}$
La9(Below a vegetable farm)	7.5	1.7	187.2	18	150	429	0	2.75	4.74	<0.01	0	$28*10^{6}$
La10 (Inside Biheretsige park)	7.5	1.3	188	20.1	140	472	0	2.75	4.34	0.01	0	$14*10^{6}$
La11 (Below Batu leather industry)	7.5	0.3	305	21.5	110	503	6.5	2.75	3.47	0.12	0.01	$5*10^{6}$
La12(At the waste water treatment plant)	7.8	5.1	138.7	19.3	90	294	1.2	2.75	5.5	<0.01	0	$8*10^{5}$
La13(Below the waste water treatment plant)	7.9	5.2	231	20.5	100	338	3.6	2.75	5.5	0.01	0	$16*10^{8}$
La14(vegetable farm)	7.7	2.1	292	20.1	100	385	0	2.75	5.5	0.03	0	$14*10^{7}$
La15(At lake Abasamuel)	7.4	2.4	163	19.5	70	279	35	2.75	1.88	0.02	0.01	$11*10^{7}$
La16(After AbaSamuel Dam)	7.71	4	166	20.5	100	264	7.6	0	5.5	0.03	0	$27*10^{7}$

Appendix 6 Tinishu Akaki 2008 Data (EPA, 2008)

Sampling station	PH	DO (mg/l)	EC µs/cm	T(^{0}C)	BOD (mg/l)	COD (mg/l)	NH3 (mg/l)	NO3 (mg/l)	PO4 (mg/l)	Cr (mg/l)	Cd (mg/l)	MPN /100 Coliform
La1 (Below marble factory)	8.1	1.6	102.5	19.4	60	118	0	2.64	0	<0.01	0.01	$9*10^6$
La2(Below Merkato Market)	7.5	0.7	168	21.4	210	280	0	2.75	5.5	<0.01	0	$16*10^6$
La3(Below Coca Cola factory)	8.1	0.8	238	21.5	320	496	1.2	2.75	5.5	<0.01	0	$16*10^6$
La4(Below Awash wine factory)	7.7	0.6	216	21.5	380	820	0.5	2.75	5.5	<0.01	0	$16*10^6$
La5(solid wastes around the River)	7.4	1.3	178	16.6	310	1238	16.6	2.75	5.5	0	0	$16*10^8$
La6 (Below Kera Abattoir, meet fact)	7.7	0.9	1070	20	430	880	24.7	1.78	5.5	<0.01	0.01	$16*10^{10}$
La7(The major River from Kera side)	7.4	0.7	179	17.6	220	1025	20	2.75	5.5	<0.01	0	$16*10^8$
La8(Tributary Below National Alcohol factory)	7.1	5.8	1853	20.4	90	374	35	2.75	0.27	0.01	0	$28*10^7$
La9(Below a vegetable farm)	7.5	1.7	187.2	18	150	429	0	2.75	4.74	<0.01	0	$28*10^6$
La10 (Inside Biheretsige park)	7.5	1.3	188	20.1	140	472	0	2.75	4.34	0.01	0	$14*10^6$
La11 (Below Batu leather industry)	7.5	0.3	305	21.5	110	503	6.5	2.75	3.47	0.12	0.01	$5*10^6$
La12(At the waste water treatment plant)	7.8	5.1	138.7	19.3	90	294	1.2	2.75	5.5	<0.01	0	$8*10^5$
La13(Below the waste water treatment plant)	7.9	5.2	231	20.5	100	338	3.6	2.75	5.5	0.01	0	$16*10^8$
La14(vegetable farm)	7.7	2.1	292	20.1	100	385	0	2.75	5.5	0.03	0	$14*10^7$
La15(At lake Abasamuel)	7.4	2.4	163	19.5	70	279	35	2.75	1.88	0.02	0.01	$11*10^7$
La16(After AbaSamuel Dam)	7.71	4	166	20.5	100	264	7.6	0	5.5	0.03	0	$27*10^7$

Appendix 7 Some of the Selected Borehole Physico-Chemical Characteristics (AAWSA, 2010)

Site name	PH	TDS	EC	TA	TH	Ca Hardness	Mg Hardness	NO3$^-$	SO_4	PO_4	F $^-$	Fe	Mn	SiO2	Cl-	HCO3⁻
ABO	8.08	127	268	114	48	40	8	0.01	12	0.162	1.16	0.045	0.062	33.8	8	114
AKAKI 1	8.16	351	731	304	10	10	0	0.01	21.8	0.732	2.05	0.028	0.017	25.9	40.5	304
AKAKI 2	8.44	361	754	318	10	6	4	1.1	16.4	0.515	2.04	0.022	NB	NB	NB	318
ANKORCHA-1	7.6	177	369	156	108	76	32	0.03	20.1	0.134	1.61	0.066	0.278	14.9	10	156
ANKORCHA-2	6.93	203	423	198	174	122	52	0.01	23	0.139	1.99	0.338	0.152	11.3	8	198
ASKO A.SEFER	7.49	145	304	120	70	44	26	0.8	2	0.496	1.54	0.005	0.002	25.1	14	120
ASKO M.SEFER	6.84	73	155	60	38	28	10	0.38	2.1	0.119	0.89	0.043	0.004	32.6	4	60
AUGUSTA	8.38	131	269	110	56	40	16	2.4	5.9	0.271	ND	0.047	0.002	9	12	110
AYAT 1	7.89	238	497	180	42	34	8	0.01	31.1	0.106	0.62	0.772	0.076	8.5	180	0
BH-1	7.85	207	446	226	188	98	90	3.1	13.9	0.365	1.35	0.025	0.011	19.1	12	226
BH-2	7.7	211	440	222	202	110	92	3.9	12.6	0.622	1.15	0.03	0.004	18.4	11	222
BH-4	7.71	205	475	222	198	110	88	3.5	12.9	0.24	1.22	0.02	0.003	19.3	11	222
BH-5	7.44	265	487	258	224	138	86	5	37.4	0.35	0.46	0.014	0.013	18.9	14	258
BH-7	7.62	234	458	220	206	106	100	3.9	7.5	0.187	0.43	ND	ND	27.8	7	220
BH-8	7.65	239	501	218	222	110	112	4.2	9.5	0.188	0.08	ND	ND	34.3	9	218
BH-9	7.7	235	495	226	216	110	106	3.4	9.6	0.17	ND	0.021	0.005	38.9	NB	226
BH-10	7.58	235	489	232	230	108	122	3.5	32.2	0.234	0.19	0.045	0.007	16.8	10	232
BH-14	8.19	227	473	218	206	110	96	3.5	9.1	0.267	0.3	ND	ND	27.6	10	218
BH-16	7.57	262	547	254	228	119	109	3.8	33.6	0.364	0.76	0.081	0.017	19.8	12	254
BH-17	7.6	257	535	252	232	122	110	4.6	36.2	0.333	0.94	0.014	0.006	23.8	14	252
BH-19	7.63	276	576	258	242	144	98	3.7	22.2	0.224	0.45	0.037	0.019	39.5	19	258
BH-20	7.66	265	554	256	204	118	86	3.8	18.3	0.295	0.5	0.014	0.006	38.5	16	256
BH-23	7.3	226	472	256	232	162	70	3.5	12.7	0.482	0.56	0.023	0.015	29.3	18	256
BH-24	7.42	274	576	276	244	134	110	4.2	14.8	0.692	0.63	0.018	0.011	20.2	17	276
BH-25	7.63	234	488	234	208	110	98	3.9	10.5	0.532	0.17	0.032	0.009	23.8	15	234
BH-26	7.68	231	484	248	238	134	104	4.2	12.9	0.559	0.44	0.032	0.016	21.7	19	248
DEREK DILDIY	7.97	155	330	122	50	42	8	0.01	14.4	0.124	1.3	0.021	0.023	22.3	23	122
EBV 03	7.78	1090	2270	1260	54	40	14	0.01	63	0.454	6.3	0.053	0.064	20.8	1.5	956
EBV 23	8.64	1132	2318	1310	32	22	10	0.01	64.7	0.681	2	0.571	0.115	28.4	NB	134
EBV24	8.55	976	1980	1020	62	44	18	0.01	67.3	0.557	3.05	0.076	0.349	26.7	2.5	780
EGZ.ABE	7.54	92	196	82	28	20	8	1	3.2	0.165	0.88	0.03	0.062	31.1	3	82

EP-1	7.58	268	558	274	238	158	80	3.5	21.3	0.755	0.45	0	0.01	16.2	13	274
EP-4	7.61	238	496	234	210	106	104	3.3	8.5	0.425	1.88	0.01	0.007	17.2	10	234
EP-6	7.93	252	526	244	228	90	138	3.1	7.6	0.521	0.39	0.031	0.009	23.9	9	244
EP-7	7.92	228	475	242	208	94	114	3.6	17.6	0.405	1.11	0.017	0.01	17.8	14	242
Euca(kotebe)	6.77	214	449	202	168	122	46	0.01	23	0.168	2.18	1.61	0.129	11.6	10	202
F-3	7.47	217	449	248	176	118	58	3	24	0.886	0.79	0.01	0.009	19.3	15	248
Gelan-150	7.67	250	525	244	194	122	72	3.7	12.9	0.32	0.17	0.005	0.009	21.3	10	244
Gelan-200	7.55	244	521	238	186	118	68	3.3	15.5	0.404	ND	0.034	0.01	23.6	15	238
Gurd shola	7.71	593	1204	670	40	28	12	0.13	40.2	0.347	0.67	0.989	0.04	29.2	15	670
Kara	7.11	258	539	216	182	130	52	0.03	46.1	0.179	1.5	0.344	0.196	22.3	NB	216
keranio-1	8.16	97	203	116	50	32	18	0.17	4.6	0.091	ND	0.018	0.014	15.6	NB	116
keranio-2(fuafuate)	8.58	109	237	100	30	22	8	0.17	3.7	0.086	0.82	0.047	0.006	12.7	5	100
keranio-03	8.29	103	214	90	46	34	12	2.1	16	0.122	ND	0.012	ND	6.2	NB	90
Mekanisa	7.92	146	306	146	116	76	40	1	2	0.119	0.5	0.049	0.004	39.4	2.5	146
Mikililand	7.46	93	195	84	60	42	18	0.17	2	0.18	0.81	0.052	0.406	18.3	8.5	84
S5(r.seyoum)	8.05	128	269	110	48	40	8	0.03	10.5	0.143	1	0.021	0.052	16.8	8	110
S8(ankorcha)	7.69	139	293	144	134	100	34	0.8	2.3	0.251	0.21	0.02	ND	16.2	4	144
Salayish	7.6	208	438	196	102	74	28	ND	31.7	0.192	1.77	0.374	0.091	12	14	196
Selam	7.3	197	411	190	102	76	26	0.01	23.9	0.194	1.51	0.266	0.043	13.2	11	190
Shegole (awelia)	7.34	104	219	90	50	40	10	0.01	1.7	0.099	3.48	0.145	0.05	15.6	5.5	90
Shegole addisu meskid	7.16	178	375	140	160	110	50	6.6	1.2	2.529	0.3	0.013	0.021	15	19	140
Site-1	7.41	152	320	152	130	94	36	1.365	1.3	0.64	0.41	0.056	0.017	24.1	8	152
Site1/96	7.44	159	334	162	116	84	32	0.48	0.9	0.703	ND	0.022	0.01	56.8	6	162
Site2/96	7.45	149	322	152	128	88	40	1.25	14.5		NO	0.034			7	152
Site-1/97	7.16	213	448	204	196	138	58	0.33	1.1	0.61	0.1	0.017	0.008	24	9	204
Site-5	7.52	273	570	262	122	98	24	0.03	22.7		0.01	0.424			21	262
Site 16	7.25	166	348	162	136	96	40	1.365	2		no	0.031			9	162
SMV-6	7.88	782	2035	980	40	20	20	ND	133.5	0.989	2.48	0.548	0.173	30.7	8	980
Site 1/97	7.2	188	395	182	118	90	28	0.32	9.9	0.415	ND	0.014	0.027	28.6	10	182
Site-5	7.52	273	570	262	122	98	24	0.03	22.7	0.347	0.01	0.424	0.083	31	21	262
SMV-10	6.81	480	993	494	72	46	26	0.44	34	0.398	ND	0.069	0.072	35.6	13	494
SMV-19	7.13	447	927	462	116	92	24	0.33	32.5	0.377	0.12	0.092	0.019	34.4	14	462
SMV-21	7.45	1210	2560	1340	80	70	10	0.03	62.4	0.483	0.76	1.067	0.006	27.4	4	1340
TSION-1	7.12	87	182	82	30	20	10	0.02	1.5	0.166	0.44	0.241	0.135	29.4	2	82
TSION-2	7.45	106	223	100	38	24	14	0.7	2.7	0.246	0.89	0.048	0.042	29.1	5.5	100

EBV24	8.55	976	1980	1020	62	44	18	0.01	67.3	0.557	3.05	0.076	0.349	26.7	2.5	780
EGZ.ABE	7.54	92	196	82	28	20	8	1	3.2	0.165	0.88	0.03	0.062	31.1	3	82
EP-1	7.58	268	558	274	238	158	80	3.5	21.3	0.755	0.45	0	0.01	16.2	13	274
EP-4	7.61	238	496	234	210	106	104	3.3	8.5	0.425	1.88	0.01	0.007	17.2	10	234
EP-6	7.93	252	526	244	228	90	138	3.1	7.6	0.521	0.39	0.031	0.009	23.9	9	244
EP-7	7.92	228	475	242	208	94	114	3.6	17.6	0.405	1.11	0.017	0.01	17.8	14	242
EUCA(KOTEBE)	6.77	214	449	202	168	122	46	0.01	23	0.168	2.18	1.61	0.129	11.6	10	202
F-3	7.47	217	449	248	176	118	58	3	24	0.886	0.79	0.01	0.009	19.3	15	248
Gelan-150	7.67	250	525	244	194	122	72	3.7	12.9	0.32	0.17	0.005	0.009	21.3	10	244
Gelan-200	7.55	244	521	238	186	118	68	3.3	15.5	0.404	ND	0.034	0.01	23.6	15	238
Gurd shola	7.71	593	1204	670	40	28	12	0.13	40.2	0.347	0.67	0.989	0.04	29.2	15	670
KARA	7.11	258	539	216	182	130	52	0.03	46.1	0.179	1.5	0.344	0.196	22.3	NB	216
KERANIO-1	8.16	97	203	116	50	32	18	0.17	4.6	0.091	ND	0.018	0.014	15.6	NB	116
KERANIO-2(FUAFUATE)	8.58	109	237	100	30	22	8	0.17	3.7	0.086	0.82	0.047	0.006	12.7	5	100
KERANIO-03	8.29	103	214	90	46	34	12	2.1	16	0.122	ND	0.012	ND	6.2	NB	90
MEKANISA	7.92	146	306	146	116	76	40	1	2	0.119	0.5	0.049	0.004	39.4	2.5	146
MIKILILAND	7.46	93	195	84	60	42	18	0.17	2	0.18	0.81	0.052	0.406	18.3	8.5	84
S5(R.SEYOUM)	8.05	128	269	110	48	40	8	0.03	10.5	0.143	1	0.021	0.052	16.8	8	110
S8(ANKORCHA)	7.69	139	293	144	134	100	34	0.8	2.3	0.251	0.21	0.02	ND	16.2	4	144
SALAYISH	7.6	208	438	196	102	74	28	ND	31.7	0.192	1.77	0.374	0.091	12	14	196
SELAM	7.3	197	411	190	102	76	26	0.01	23.9	0.194	1.51	0.266	0.043	13.2	11	190
Shegole (awelia)	7.34	104	219	90	50	40	10	0.01	1.7	0.099	3.48	0.145	0.05	15.6	5.5	90
Shegole addisu meskid	7.16	178	375	140	160	110	50	6.6	1.2	2.529	0.3	0.013	0.021	15	19	140
Site-1	7.41	152	320	152	130	94	36	1.365	1.3	0.64	0.41	0.056	0.017	24.1	8	152
Site1/96	7.44	159	334	162	116	84	32	0.48	0.9	0.703	ND	0.022	0.01	56.8	6	162
Site2/96	7.45	149	322	152	128	88	40	1.25	14.5		NO	0.034			7	152
Site-1/97	7.16	213	448	204	196	138	58	0.33	1.1	0.61	0.1	0.017	0.008	24	9	204
Site-5	7.52	273	570	262	122	98	24	0.03	22.7		0.01	0.424			21	262
Site 16	7.25	166	348	162	136	96	40	1.365	2		no	0.031			9	162
SMV-6	7.88	782	2035	980	40	20	20	ND	133.5	0.989	2.48	0.548	0.173	30.7	8	980
Site 1/97	7.2	188	395	182	118	90	28	0.32	9.9	0.415	ND	0.014	0.027	28.6	10	182
Site-5	7.52	273	570	262	122	98	24	0.03	22.7	0.347	0.01	0.424	0.083	31	21	262
SMV-10	6.81	480	993	494	72	46	26	0.44	34	0.398	ND	0.069	0.072	35.6	13	494
SMV-19	7.13	447	927	462	116	92	24	0.33	32.5	0.377	0.12	0.092	0.019	34.4	14	462
SMV-21	7.45	1210	256	1340	80	70	10	0.03	62.4	0.483	0.76	1.067	0.006	27.4	4	1340

TSION-1	7.12	87	182	82	30	20	10	0.02	1.5	0.166	0.44	0.241	0.135	29.4	2	82
TSION-2	7.45	106	223	100	38	24	14	0.7	2.7	0.246	0.89	0.048	0.042	29.1	5.5	100
Tsabay maramia	7.55	317	660	160	286	160	126	21.5	19.3	0.095	0.44	0.037	0.004	13.2	69	160
TSION-1	7.3	81	167	62	30	30	ND	0.8	0.5	0.183	0.48	0.056	0.006	NB	NB	62
TSION-2	7.14	126	264	118	112	76	36	0.9	1.9	0.396	0.3	0.033	ND	36.9	4	118
W 10	7.85	239	498	242	214	112	102	3.9	9	0.538	0.41	ND	ND	43.2	15	242
W 9	7.11	96	200	86	70	48	22	0.5	1.4	0.228	0.18	0.16	0.113	NB	NB	86
W-1(Tsebay maremia)	7.58	184	384	136	142	198	24	5.5	1.1	0.169	ND	0.267	0.028	NB	NB	136
W11	7.23	138	289	146	98	70	28	0.08	ND	0.157	0.36	0.018	0.004	45.7	2	146
W-12	7.06	229	481	208	202	152	50	2.3	7.7	0.313	0.43	0.026	0.007	21.7	19	208
w-13(makanisa old)	6.98	134	282	126	108	78	30	1	0.6	0.292	0.27	0.022	0.024	28.9	4	126
W-14 lafto old	7.45	266	546	272	228	162	66	0.32	28.5	0.222	0.59	0.098	0.023	48.6	18	272
W-21 HAMLE 19	6.86	133	279	120	110	74	36	0.48	10.3	0.043	0.89	1.05	0.608	15.8	10	120
W22 KECHEN meketiya	7.11	96	200	86	70	48	118	0.5	1.4		0.18	0.16				86
W23	7.58	184	384	136	142			5.5	1.1		nill	0.267				136
W-3(REPI)	7.48	149	314	170	114	82	32	0.22	1.5	0.22	0.09	0.019	0.003	46.4	NB	170
W-4	7.99	127	267	114	50	42	8	0.2	10.2	0.103	0.48	0.032	ND	22.6	NB	114
w-6 KALITY WELL	8	83	148	68	46	34	12	0.49	3.9	0.116	0.34	0.006	ND	19.3	NB	68
W-7	8.56	395	830	306	10	8	2	ND	21.7	0.422	4.5	0.258	0.08	505	15.8	286
YEKA MICHAEL	7.45	235	495	226	208	152	56	1.3	1	0.146	0.42	0.006	0.018	44.1	NB	226
Site2/96	7.45	149	332	152	128	88	40	1.25	14.5	0.607	ND	0.034	0.014	47.1	7	152
WSA1	7.41	145	295	132	100	76	24	0.11	2.7		0.23	NO			0	132
W-24(MEKANISA)	7.23	138	289	146	98			0.08	no		0.36	0.018			2	146
karaniyo 2	8.58	109	237	100	30			0.17	3.7		0.82	0.047			5	100
W-25(GOFA C0NDEMINUM)	7.06	229	481	208	202	152	22	2.5	7.7		0.43	0.026			19	208
WSA2	7.55	236	495	222	176	114	62	3.7	11.7		NO	0.075			NO	222
Ankorcha spring S-8	7.69	139	293	144	134	100	34	0.8	2.3		0.21	0.02			4	144
Site 19	7.41	150	315	142	122	104	18	1.115	1.3		NO	0.02			6	142
S-1 (GOJAM BER)	7.14	52	105	80	42	24	18	1.1	nill		0.07	0.065			2.5	80

S-2(KECHENE)	7.71	34	72.4	28	22	16	6	0.29	1.7		0.47	O.519			4	28
Site20	7.12	196	411	202	134	98	36	0.26	1.3		0.8	0.048			11	202
site 24	7.3	150	316	152	106	72	34	0.75	2.1		0.47	0.002			9	152
site 25	7.32	227	475	212	210	154	56	1.25	11		0.45	0.034			17	212
site 26	7.33	163	343	148	128	92	36	1.225	1.6		0.89	0.025			11	148
site 27	7.31	154	325	158	122	98	24	0.8	1.1		0.47	0.004			9	no
site 29	7.63	144	301	148	110	74	36	0.74	1.3		0.61	0.002			7	no
site 31	7.14	178	371	182	158	126	32	0.7	2.6		0.42	0.07			8	no
Goro well	7.39	166	348	172	132	86	46	0.03	2.6		0.18	0.013			10	172
sususzi	7.62	111	235	114	22	10	12	no	6.5		1.07	2.985			9	114
S-3 FANTA SPRING	7.74	274	573	254	252	144	108	3.6	25		NO	0.045			16	254
Farransy abo well	8.17	133	281	90	58	46	12	0.01	9.7		1.28	0.099			23	90
S-5 RAS SIYUM	8.12	70	147	54	60	38	22	0.36	35.9		1.23	0.048			21	114
Goro	7.63	128	269	116	88	54	34	1.44	2		0.27	0.004			9	116
Pepsi	208	588	1230	248	480	320	160	21	50		no	0.041			125	248
K-03 karaniyo-3	8.29	103	214	9	46	34	12	2.1	1.6		no	0.012				90
Asco-1	6.96	136	249	104	72	32		no	5.4		1.01	0.03			no	no
Asco-2	7.48	146	308	90	60	30		no	3.9		0.72	0.031			no	no

Note all units in mg/l

Appendix 8 Ethiopian Drinking Water Quality Standards

Parameter	Maximum permissible limit (mg/l unless otherwise stated
Turbidity (NTU)	25
Color Units	50
Odour and Taste	Unobjectionable
Flouride	1.5
Iron	1
Chloride	600
Magnesium	150
Nitrate	10
Cadmium	0.01
Lead	0.1
Calcium	200
Copper	1.5
Ammonia	0.10
Manganese	0.5
Iron	1
pH	6.5-9.2
Arsenic	0.05
Hexavalent Chromium	0.05
Selenium 0.01	0.01
Total Coliform MPN/100ml	10
Lead	0.1
Total mercury	0.001
E. Coli, MPN/100ml	Nil