ADDIS ABABA UNIVERSITY

SCHOOL OF EARTH SCIENCES

EVALUATION OF GROUNDWATER QUALITY IN WESTERN PART OF UPPER AWASH BASIN

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfilment of the requirements for the Degree Master of Science in Hydrogeology

By

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This is to certify that the thesis prepared by Workitu Wogi, entitled: Evaluation of Groundwater Quality in Western Part of Upper Awash Basin, submitted in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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By my signature below, I declare and confirm that this thesis is my own work. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly article that is included in the thesis has been given acknowledgment through reference.

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List of Acronyms

DEM	Digital Elevation Model
DW	Deep Well
EC	Electrical Conductivity
ESA	Ethiopian Standards Agency
FAO	Food and Agriculture Organization
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
HCA	Hierarchical Cluster Analysis
HD	Hand Dug well
LULC	Land use/land cover
m.a.s.l	meters above sea level
meq/l	mili-equvalent per litre
mg/l	milligram per litre
R	River
S	Spring
SAR	Sodium Absorption Ratio
SH	Shallow well
SON	Standard organization of Nigeria
SWL	Static Water Level
TDS	Total dissolved Solids
WHO	World Health Organization
WWDSE	Water Works Design Supervision Enterprise
UTM	Universal Transverse Mercator

Abstract

The quality of water is a serious issue for developing countries. Hence, evaluation of water quality in terms of physiochemical parameter is a crucial point to determine water quality for various purposes. This research was conducted on the western part of Upper Awash River basin, Central Ethiopia to examine the quality of water. Thus, the hydrochemistry of water by using Aquachem software and Hierarchical Cluster Analysis (HCA) was analyzed from the perspective of physiochemical parameters. For the analysis, twenty-six water samples were collected and additionally more secondary data from previous work were used to categorize water types into clusters. Furthermore, an assessment of water quality for various purposes was also carried out.

As the hydrochemical analysis indicates, the sodium and bicarbonate are the study area's dominant cations and anions, respectively. The concentration of sodium varies from 9.58mg/l to 255.1mg/l, whereas the concentration of bicarbonate ranges from 44.8 mg/l to 866 mg/l. The lowest value of Electrical Conductivity (EC) and Total Dissolved Solids (TDS) was measured in the spring water sample (S_3) which indicate that groundwater less mineralized in the area. In the area, water types were also identified by using piper diagram. The identified types are NaCaHCO3, CaNaHCO3, CaMgNaHCO3, CaHCO3 and NaHCO3. On the other hand, a hierarchical cluster analysis method was used to group water into four water groups and six sub-groups. Group one and group three are mainly distributed in the plateau area, whereas group two was identified in the area covered by tertiary acidic volcanic rocks. An attempt has been made to identify the quality of water for domestic, irrigation, and industrial purposes. As indicated by the plots of Wilcox Diagram, all water samples except few samples can be said to be suitable for irrigation purposes. Moreover, groundwater in the study area is suitable for domestic uses. However, there are exceptions that the discharges of domestic and industrial wastes lead to deterioration of water that needs proper follow up.

Key Words: Water quality, Western part of Upper Awash basin, physiochemical parameters, water type, HCA, and piper diagram.

Chapter One

Introduction

1.1. Background

The geological units of Ethiopian categorize in to Precambrian basement, late Paleozoic to Early Tertiary sedimentary rocks and Cenozoic volcanic. (Mengesha Tefera et al., 1996). Volcanic rocks that include lavas and ashes of tertiary and younger age dominantly cover the highlands lying the Rift Valley and the Rift Valley itself. Over and above, “two third of Ethiopia is covered by volcanic rocks” (Seifu Kebede, 2013:7). These rocks are associated with the evolution of the Rift system.

The present study area is located in the Upper Awash basin. The Upper Awash basin is situated at the western margin of the Main Rift Valley system. In Existing 1:2,000,000 geological maps (Kazmin, 1972; Merla et al., 1973, and Mengesha Tefera et al., 1996) the Precambrian basement rocks, the Mesozoic Sedimentary rocks, the Tertiary and Quaternary volcanic rocks of acidic to basic composition and Quaternary lacustine and alluvial deposits are described.

The main rock units in the study area are Ignimbrites, Tarmaber basalt, Rhyolites, Trachytes and Alluvial deposit. These rocks are widely covering the target area of the study and have variable hydrogeological characteristics. Since they differ in their texture, structure, and mineralogy, their water potential varies accordingly (Tenalem Ayenew and Tamiru Alemayehu, 2001). Groundwater potential depends on many factors such as geology, geomorphology, structure (particularly fracture patterns), and past climates (Cobbing and Davis, 2008). Hence, the groundwater potential of these rocks differs significantly, reflecting the complexity of geology (Seifu Kebede, 2013).

Although, evaluating of groundwater quality is a complicated one, determination of its quality is very important. Fundamental data used in the determination of water quality are obtained by the chemical analysis of water samples in the laboratory or in situ test of chemical properties in the field. Interpretation of the physico-chemical parameters of groundwater helps us to understand the hydrogeological conditions and quality of water in a particular study area. On the other hand, managing quality of groundwater is a key to manage the quality of surface water and vice versa (Tamiru Alemayehu, 2008). Therefore, controlling the quality of both groundwater and surface water is vital to reduce the impact of one another on each other and to maintain quality water supply for various purposes.

The quality of groundwater and/or surface water are/is described in terms of chemical compositions (Major ions, Minor ions and Trace constituents), physical characteristics (Turbidity, Color, Odor, Taste and etc), biological constituents (Bacteria, Virus, Fungui and Protozoa) and radiological (Boyd, 2015).

The quality of groundwater or surface water can be affected by various human activities. For instance, human being introduces contaminants into the environment and natural processes, which result in elevated concentrations of certain constituents that are naturally percolated into groundwater from minerals existing in rocks (Neven, 2009). These may include surface water pollution by effluents of industries to rivers or streams and in turn pollution of groundwater by these factors and other related factors.

Additionally, improperly constructed wells can result in poor water quality and quantity. Such kinds of wells construction may result in aquifer contamination by establishing a pathway for pollutants to enter a well from drainage of the surface. Such activities may also provide the opportunity for waste disposal to enter in to well and water quality deterioration in terms of Turbidity, Red water (Iron encrustation), Odor and Taste changes (Wilcox, 1955).

As already mentioned, groundwater quality management is a basic thing for reduction of contamination of water. Therefore, local water authorities have a responsibility to aware the community about proper water use, and every user should use water properly. Besides, waste disposal from various industries should be managed carefully. So, if such activities can be taken conjointly with all concerned bodies, the problem of water quality may be easily solved in every corner of our country.

Nowadays, distribution of water is rapidly increasing due to increasing number of population, small-scale irrigation, flower farming, expansion of industry and urbanization to mention a few. Hence, the level of dependence on groundwater is elevated from time to time specifically for smaller sized towns (Seifu Kebede, 2013). These holds true for both urban and rural of the study areas. By preluding the issue this much, let us now look at statements of the problem to the present study area.

1.2. Statement of the Problem

The research site, Western part of Upper Awash basin, which is mainly developing to an industrialized zone. For instance, Alemgena, Sebeta, Tefki Addis Alem, Teji, Asgori towns, and their surroundings are targeting for industrial and agricultural development investments. Most of the activities carried out in these areas are a threat to the groundwater as well as surface water since the industries release wastes into rivers or streams.

In addition to the above facts, both traditional and contemporary agricultural activities such as flower farming, uses fertilizers and pesticides now a day. Consequently, fertilizers and pesticides may cause both groundwater and surface water pollution. Therefore, the quality of water at different water points such as river, spring, borehole, and hand dug water of the study area, both at urban and rural, needs attention. Hence, these water points fulfill most of the requirements of domestic water supply, irrigation or agriculture, industry etc. of the community in the area. Therefore, this research will target to evaluate and distinguish water quality of the already mentioned study area by assessing the levels of some physico-chemical parameters.

1.3. Objective

1.3.1. General Objective

The basic objective of this thesis is to assess the quality of groundwater in Western part of Upper Awash basin in terms of its physico-chemical laboratory analysis with reference to WHO and Ethiopia drinking water quality guidelines.

1.3.2. Specific Objectives

Based on the general objectives of the study, specific objectives are:

- ✓ To present some information on hydrogeology of the area.
- ✓ To categorize water-chemistry by using statistical techniques.
- ✓ To identify water types in the study area.
- ✓ To evaluate water quality criteria for different purposes.

1.4. Significance of the study

This study aimed to assess the quality of groundwater in Western part of Upper Awash. Accordingly, the study would have the following significances among many others:

- ✓ It is used as a standard to fulfill the requirements of MSc accomplishment.
- ✓ It may service as a reference material for students and researchers of Geology and other neighboring disciplines, such as Hydraulics and Chemistry.
- ✓ The result can induce other researchers to make further timely investigation in a very large scale of the catchment.
- ✓ It may contribute to Consultants, Clients, and Contractors involved in the water supply industry in the study area.

- ✓ It helps to schematize and characterize the geochemical processes and water quality distribution of the area.
- ✓ Based on the overall outcome of the study, recommendation would be given about the quality of groundwater in the area, which may help the stakeholders.

1.5. Methodology and Materials

The study was conducted through several basic steps to achieve the final goals. These include Methods and Materials.

The study was started with review of previous works, which includes geological and hydrogeological studies, consultancy reports, published and unpublished academic thesis conducted in the study area, journals, case studies, and different accessible books. Collecting of topographic map from Ethiopian mapping agency, Geological maps and hydrogeological maps, well completion reports that includes physico-chemical analysis were collected from different organization. Moreover land use/land cover maps were modified from land use /land cover maps of Ethiopia (FAO, 1984). Also the physiographic map of study area is produced from DEM using tools in global mapper and surfer. Hydrogeological map with groundwater contours, water points, groundwater flow direction and geological map were produced using tools in ArcGIS 10.3.

During field work, well inventory of site features, taking readings of borehole locations and elevation, take photo, asking local people about area and take note were done. On the other hand sampling of water from different water point such as springs, hand dug wells, shallow wells, deepwell and river is done for laboratory analysis.

Accordingly twenty-six (26) water samples were collected from different water points of the study area using Containers such as plastic bottles for collecting representative water samples. Spring samples were collected from the emanation point. Along with the sampling in situ test was made for parameters like EC, PH and Temperature. EC meter (for measurement of temperature and electrical conductivity) and PH meter for measurement of PH were used during in situ test.

The other Parameters of water samples collected were analyzed in the laboratory. The Locations of sampling sites are shown in Fig 5.1 and the results of the analyses are presented in appendix 2 and 3. Moreover available chemical data have been taken from drilling companies and previous studies (Tilahun Azagegn, 2014). These secondary data are presented in Appendix 4.

Both primary and secondary data of Hydrochemical results have been interpreted using Aquachem version 4.0 to calculate charge balance error and to identify water types. Different tools in ArcMap10 have been used for analysis spatial distribution of TDS. A Microsoft EXCEL add-in module XLSTAT2018 was used to conduct the HCA. HCA is a statistical technique used to classify water samples in to groups or subgroup. Also using this statistical technique dendogram was generated.

Piper plots, hydrochemical map, Semilog-box plot, are used to present the different water types and hydrochemical distribution. Wilcox Diagram also was used for interpretation of water quality for irrigation purpose.

1.6. Limitation of study

The collected data from stakeholder institutions were not sufficient as per the researcher needs. In addition, the data gathered from different organization have not full complete analysis. Some physiochemical parameters were missed for instance calcium. Hence, secondary data were not used as much as the researcher need. On the other hand the overall quality of water in this research depends on physical characteristics and chemical compositions. However biological constituents are not included. Moreover, the taken water samples are limited in number due to the cost of water quality analysis laboratory is very increasing.

1.7. Previous works (Related works)

Upper Awash basin was thoroughly investigated in terms of geological, hydrogeological and hydrochemical. However, the assessment of water quality in the western part of the basin is not investigated specifically. Even though this is the fact, different authors and/or researchers produced scientific research on Upper Awash basin in general in different time frames. The following are among the others.

Andarge Yitbarek (2009) carried out detail investigation on hydrogeological and hydrochemical framework of complex volcanic system in the Upper Awash River basin, Central Ethiopia. The result showed that the waters type in Upper Awash is classified into five major groups of chemical facies depend on dominant cations and anions. These classifications are Ca-Mg-HCO3, Ca–Na–HCO3, Na-Ca-Mg- HCO3, Na-HCO3 and Ca–HCO3. Tilahun Azagegn (2008) addresses schematic conceptual models for spatial geochemical variations, evolution and recharge area zonation for shallow, and deep aquifer systems separately along four groundwater flow paths in the three major geomorphologic zones by the help of geochemical data. These zones are plateau, transition and rift. According to Tenalem Ayenew et al. (2008) on the other hand, three distinct regions with varying ground-water circulation and evolution history are identified in the Awash River basin. They are shallow fresh waters, intermediate and deep groundwater, and deep fractionated thermal waters with very high salinity and TDS.

Tilahun Azagegn (2014) carried out detail investigation on Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia. He discusses the hydrogeological, hydrochemical, isotope hydrology, groundwater flow model and Estimation of recharge of the Guder Jema, Muger and Upper Awash sub basin. As stated in Alemu Mesele (2017) on the other hand, the groundwater level and TDS contour map indicate the local groundwater flow direction in Becho area tends to the main Awash River. According to his water chemistry analysis, the dominant water type in Becho area is Ca-HCO3. Reys Asfaw (2016) carried out a research on Ground Water Potential Evaluation and Use Trends in Upper Awash Basin. As he discussed, Groundwater is playing an important role in Koka and Becho area for irrigation purpose due to various reasons. Among these reasons technology access, water shortage in Awash and Modjo rivers, market demand for agricultural products and government extension program and increased private investments are mentioned.

There are three MSc. theses that mainly aimed at water pollution. The first work is the work of Amare Mezgebu (2017), which assesses water quality by using benthic macroinvertebrates in streams and rivers around Sebeta town. The second work is the work of Shaka Nugusu (2015) that assesses surface water quality in Upper Awash river basin. The third work is the assessment of groundwater vulnerability to contamination on Atebela river catchment by Solomon Kenea (2007). All the three researchers address the high concentration and variation of pollutants along the Awash River tributaries due to the rapid urbanization and industrialization.

Lastly, there are two reports compiled by different organizations. The first is a report done by WWDSE (2009), which discusses the hydrogeological conditions of Ada'a and Becho plains based on geophysical investigation and drilling pilot wells. The second is a report of GSE (2011) that discusses the hydrogeology, hydrochemistry, and geomorphology of Akaki-Beseka area. It is important to notice that a number of scientific research have been conducted and published on Upper Awash basin (Behailu Berehanu et al., 2017; Andareg Yitbarek et al., 2012 to mention a few).

Chapter Two

General overview of the study area

2.1. Location and Accessibility of Study Area

The western part of Upper Awash basin, which is the study area, is located in the central part of Oromia regional state. Its absolute geographical location is between 9°15'N-8°30'N latitude and 38°00'E-38°45'E longitude with an area and a perimeter of 4,574.24 square kilometers and 392.68 kilometers, respectively. The map of the study area bases the two known hydrogeological maps of Upper Awash basin. These hydrogeological maps are Akaki-Beseka sheet (NC 37-14) and Addis Ababa Sheet (NC 37-10).

The accessibility of study area is an asphalt road stretching from Addis Ababa-Holeta and Addis Ababa-Alem Gena to small towns of the area. The asphalt road through Addis Ababa-Holeta has two main asphalt roads that are important to access some study areas: Holeta-Enchini-Mugher and Holeta-Addis Alem-Ginchi asphalt roads. On the other hand, Addis Ababa-Alem Gena asphalt road holds Alem Gena-Boneya-Leman and Alem Gena-Sebeta-Tulu Bolo main asphalt roads. There are also some all weather gravel road from different small towns to small towns and/or rural villages such as Lemen to Geto, Asgori to Bantu and Tulu Bolo to Busa to mention a few (Figure 2.1). Additionally, dry weathered soil roads are access to small villages in the study area.

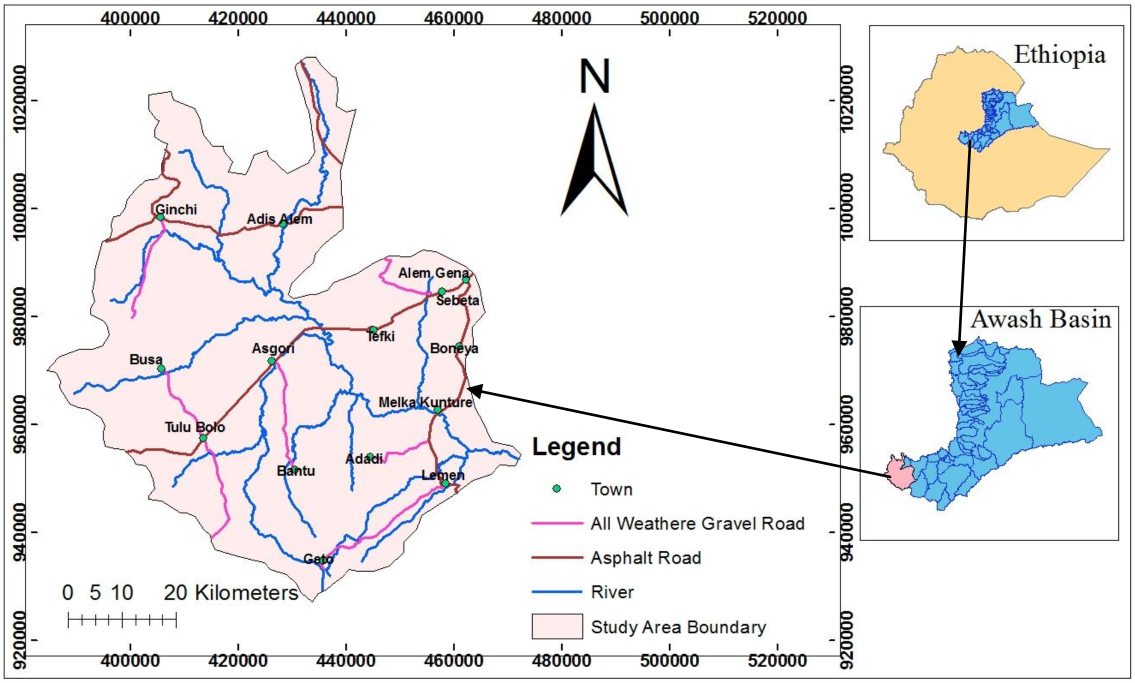

Figure 2.1 Location Map of Study Area

2.2. Climate Condition

The climate of the study area is humid and hot humid during summer season and sunny during winter season. In plateau area such as Holeta to Enchini, misty and cloudy climatic condition is usual in summer season. As described by Behailu Berehanu et al. (2017), the characteristics of climate are decided mostly by movements of the currents flowing across the country, specifically by westerly winds from the Atlantic and eastern and southern currents coming from the Indian Ocean. The moist wind come from Indian and Atlantic Ocean brings the rainfall in the study area and all over the country. Accordingly, the heavy rainfall occurs during summer season starting from June to September. The area also gets small amount of spring rain, which fallout from February to April. From beginning of October to end of December, the weather of study area is very cold in the morning and very hot at mid of the day. The elements of climate that are temperature, relative humidity, wind speed, and sunshine hour are varying from season to season in the study area.

Ethiopia has five climate divisions depend on altitude (Daniel Gemechu, 1977). These divisions are desert that measures less than 800m.a.s.l, tropical that measures between 1500-1800m.a.s.l, subtropical that measures between 1800-2400m.a.s.l, the temperate that measures between 2440-3500m.a.s.l, and the alpine that measures over 3500m.a.s.l. Of these climatic divisions, the study area has subtropical, temperate, and alpine with dominance of subtropical division. The total annual rainfall in the area is 1168.3mm on average and the mean annual temperature is 18 ^{0}c.

2.3. Physiography and Vegetation

2.3.1. Physiography

The study area is located in central Ethiopian plateau on Ethiopian Rift Escarpment. The plain land features with gentle slopes in the central part, small ridges such as Debel around Tefki area and Tulu Korma around Addis Alem to Kimoye main roads, mountains such as part of Furi and part of Wechecha, and highlands such as Weliso and Gurage highlands characterize the morphology of the study area (Figure 2.2). Tectonic activity, erosion processes, and volcanic eruption form the physiography of the study area.

2.3.2. Vegetation

Before some decade years ago, the study area was tickly vegetated. However, nowadays, it is slightly vegetated due to deforestation mainly for the sake of farmland and coal. The types of vegetation in the study area are woodland, shrub, tree, bush, and other indistinguishable plants. Dense vegetation covers mountains in the study area. There is also a protected forest, which is called suba forest in the study area.

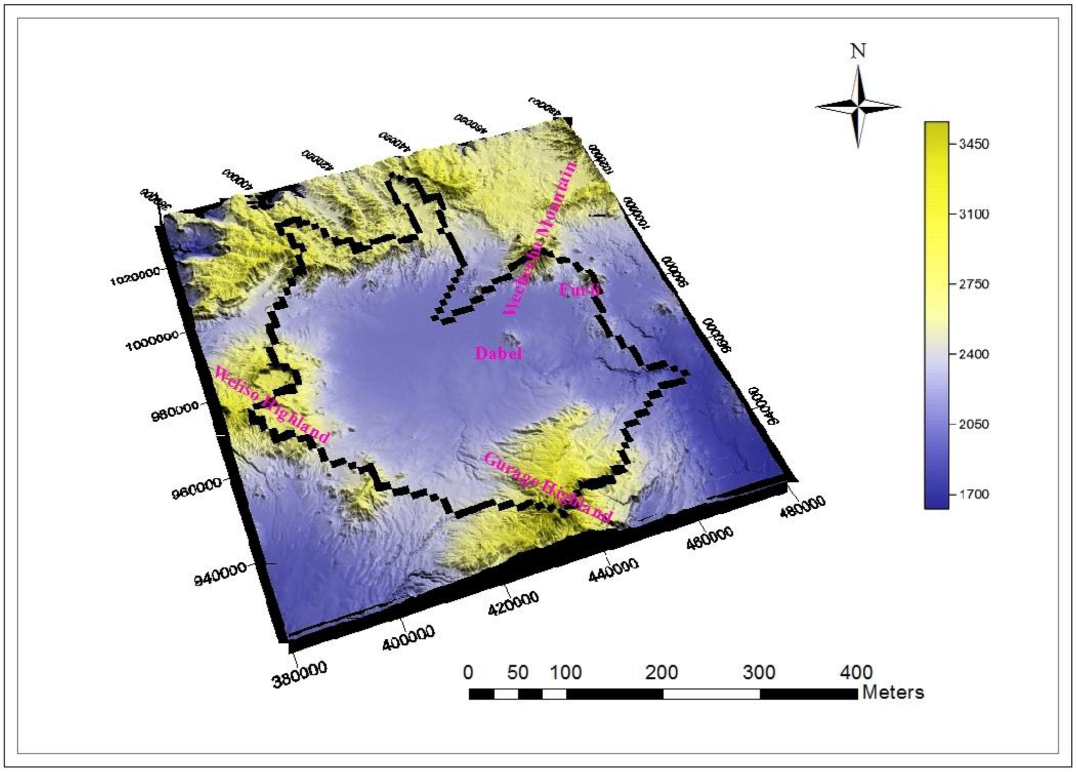

Figure. 2.2. Physiography of study area produced from DEM

2.4. Soil Type

The formation of soil in the study area is based on the effect of interactions between different soil forming factors such as parent material, topography, climate, organisms (fauna and flora) and time. Accordingly, heterogeneous soil types are formed and developed in the area. The soil types in the study area are Pelli Vertisols, Eutric Nitosols, Lithosols, Chromic Luvisols, Chromic Vertisols, Orthic Luvisols and Vertic Combisols. Among these types, the dominant soil type covers the target area is Pellic Vertisols soil. The Pellic Vertisols that dominantly comprised of the montmorillonite clay mineral.

2.5. Drainage

The Awash River begins from the Oromia region near Ginchi, flows southeast, and ends in the salty lake Abbe on the border with Djibouti. The main tributaries of this river in the study area are Berga, Kelina, Teji, Mamo, Jamjam, Bantu, Watira, Lemen and Atebela (Figure 2.3). They join the Awash river at different location and follow dendritic drainage pattern. These tributaries may potentially pollute the river. For instance, the Atebela River that originates from Sebeta area and joins Awash River at Melka Kunture site is a good example among others. Atebela River is mainly polluted by liquid and solid byproducts of industries and garbage dwellers from the Sebeta area (Solomon Kenea, 2007). Since the societies near polluted rivers tend to use these rivers for their daily life, they are directly or indirectly susceptible to health problems that in turn may have the potential to jeopardize their very existence. Consider the plate 2.1, which shows the people bathing Awash River at its junction with Atebela at Melka Kunture site.

Some parts of the study area, for instance Awash Belo, are exposed to flooding and drainage problem during the summer season. As discussed by WWDSE (2009), there are measures that would minimize drainage problems in this area. These are using efficient irrigation system particularly drip irrigation, providing sufficient drainage facilities, provision of interceptor drain that would intercept excess runoff water draining to the command area and discharging it to natural water ways or streams and training the irrigation users in effective water application. The below figure, figure 2.3, indicates the drainage of study area.

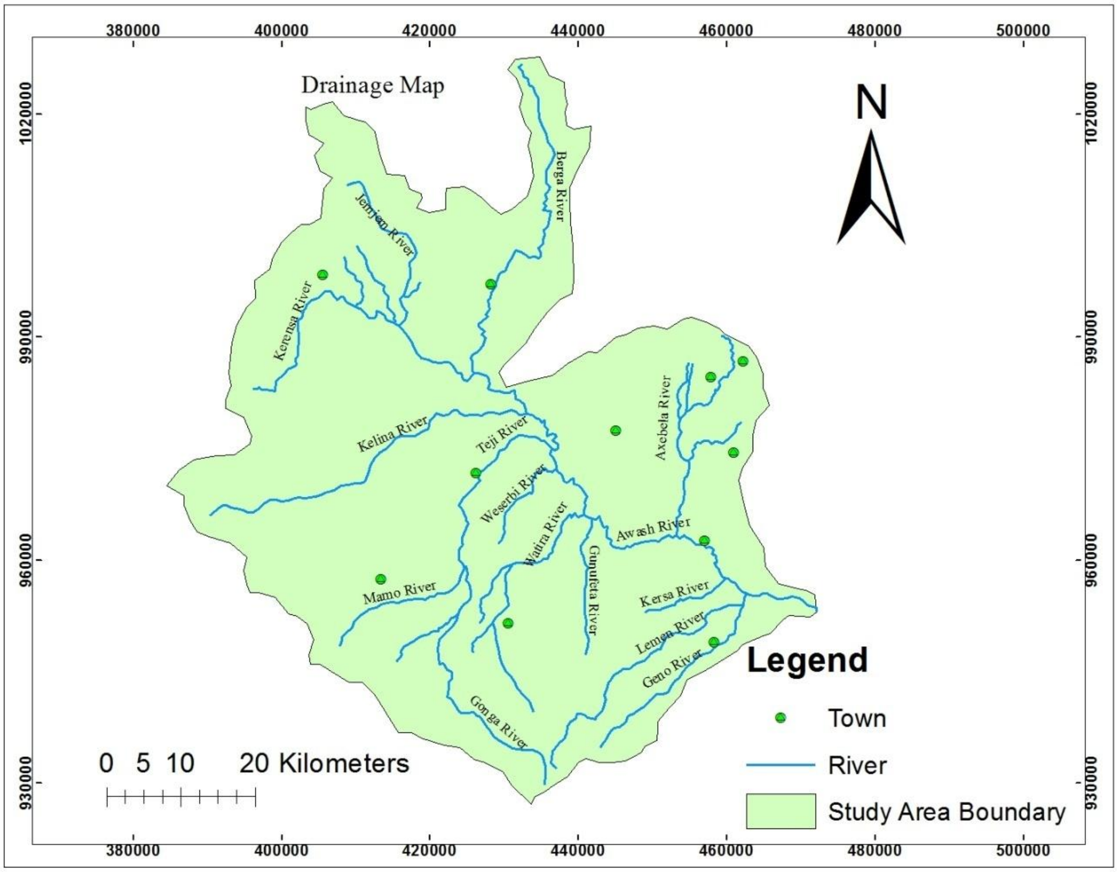

Figure 2.3. Drainage map of the study area

Plate.2.1. Photo of polluted Atebela and Awash rivers at their junction: Melka Kunture

2.6. Land use/cover

The major land use/cover (LULC) of the study area consist the cultivated agricultural land, grass Land, wetland, and shrub land. The main crops grown in this area are teff, wheat, barely, oil seeds, peas, and bean. They are cultivated by waiting the rain season and bean is cultivated at the end of rainy season. Some vegetation such as Onion, Cabbage, Tomato and Potato are also cultivated in the major farmer's compound during summer season. Additionally, small-scale irrigations are practiced in some part of study area by using rivers and shallow groundwater during dry season. In addition, there is numerous flower farming in the study area. As already mentioned above, mountains are covered by forest and hills are covered by grassland even though they are few in the area. The other part of study area is urban, which includes residential areas, gardens, markets, different factories, petrol stations, garages, and sporting grounds. The major factories are tanning, food and beverages, soup, hatchery and textiles. The following figure 2.4 indicates the land use/cover map of the study area.

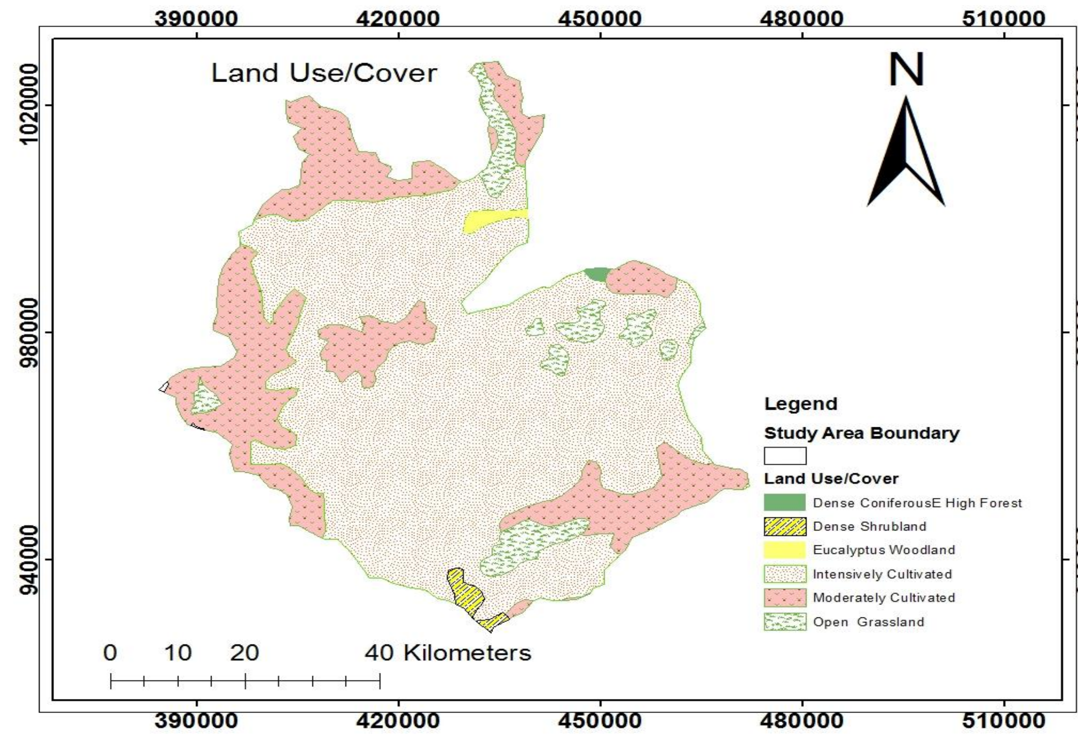

Figure 2.4. Land Use /Cover map (Modified from FAO, 1984)

As shown in figure 2.4, the dominant LULC is cultivated agricultural land that approximately covers the area greater than 90%. Other parts of the area are covered by grassland, shrubland and woodland. Plate 2.2 indicates the grassland of the study area.

Hydrochemistry can be affected by land use land cover. In the study area, Koftu (the place located near Asiko around Holeta-Inchini road) is covered by grassland (Plate 2.2). The society in the area used this grassland for rearing of animals. Livestock produce manure that is directly deposited to the land by animals during grazing and this manure deposition near to stream causes water pollution. The increase in Chloride, Nitrate, bacteria, and Sulfates result from sewage effluent and sludge, and animal slurry (Kevin M. Hiscock, 2005).

Plate 2.2 Photo of grassland at Holeta to Inchini road: Koftu

2.7. Occurrence of Water Point in the Study Area

Different water points are distributed in the study area. These are deep well, hand dug well, shallow well, spring, and river (plate 2.3 for their samples). The major water supply of towns in the study area is deep well. However, there are a number of hand pump wells in the area in general and in Becho plain and Holeta-Enchini sites in particular. Accordingly, they are dominantly used in both Becho plain and Holeta-Enchini town areas. The rural communities of the study area on the other hand, mainly use hand dug wells, and shallow wells for drinking purpose. Furthermore, some rural communities are using deep wells', springs', and rivers' water for drinking purpose. Note that the user of river water for this purpose is insignificant as it is used for small-scale irrigations, rearing animals, and washing purposes. Still in some rural parts of the study area, small lakes that stored water during summer season and give services during dry season are used.

Plate 2.3. Photo of sample water points distributed in the study area

Chapter Three
Geological Setting

3.1. Regional geology

The geological setup is associated with the results of volcano-tectonic activities of trap serious volcanic of Ethiopian plateau and the development of the Ethiopian Rift System. The study area lies within the central part of the Ethiopian Volcanic Province and its regional geologic setting is situated to different rock units having different ages of formations. The following regional geologic description is adapted from the explanation of the Geological map of Ethiopia done by Mengesha Tefera et al. in 1996.

3.1.1. Tertiary Volcanic Rocks

Mohr (1964) divided the Cenozoic volcanic rocks of Ethiopia into the Trap Series and Aden Series. The term Trap Series widely used to refer to the whole Pile of the Tertiary flood basalt sequence with intercalation of felsic lava and pyroclastic Rocks (commonly on the upper part), which form the northwestern and southeastern Plateaus. The name Aden Series is used for post-rift (Middle Miocene to Quaternary) volcanic rocks of the Main Ethiopian Rift, Afar Depression and some parts of the Ethiopian plateaus.

Tertiary volcanic rocks are found in a wide variety from liquid basalt rocks to highly viscose acidic rhyolite representing a fissured and central type of volcanism. Various volcanic episodes and lava flows were followed by short or longer periods of river, lake sediment and soil development that can be found within volcanic sequences.

3.1.1.1. Ashangi Formation

The Ashangi formation represents the earliest fissural flood basalt volcanism on the northwestern plateau. The basalt flows several hundreds of meters to kilometers thick of strongly weathered, crushed, tilted basalts that lie below the major Pre-Oligocene unconformity (Zanettin et al., 1980).

3.1.1.2. Jima Volcanic

Merla et al. (1973) gave the name Jima volcanic to trachybasalts and rhyolites, which cover most parts of southwestern Ethiopia. The Jima volcanic which are considered analogous with the Main Volcanic Sequence of thick succession of basalts and felsic rocks with basalts dominating the lower part of most sections (Davidson, 1983).

3.1.1.3. Aiba Basalts

The Aiba Basalts represent the second major pulse of fissural basalt volcanism on the northwestern plateau. They are generally aphyric, compact rocks, in place showing stratification and contain rare interbedded basic tuffs (Mengesha Tefera et al., 1996).

3.1.1.4. Alajae Formation

The Alajae formation mainly consists of aphyric flood basalts associated with rhyolites (ignimbrites) and subordinate trachytes. This formation contains basalts transitional to tholeitic in nature and an increase in alkalinity that is observed in the younger members of the formation. Thus, the Miocene members of the Alajae formation are more alkaline and are associated with sub-alkaline acidic members (Mengesha Tefera et al., 1996).

3.1.1.5. Tarmaber Gussa and Tarmaber-Megezez Formations

Tarmaber formation represents Oligocene to Miocene basaltic shield volcanism on the northwestern and southeastern plateaus. The central type of Tarmaber formation basaltic volcanism was followed by fissural eruptions particularly along the escarpments of northwestern and southeastern plateaus.

3.1.1.6. Tulu Wollel Trachytes

These Trachytes were formed at the Tulu Wollel and Sayi areas in western Ethiopia during the Late Miocene with subordinate basalts. They overlie the Upper Aphyric Basalts of Seife Michael Berhe et al. (1987), which on this map are correlated with

Tarmaber-Megezez formation that form the base of the shield volcanoes (Mengesha Tefera et al., 1996).

3.1.1.7. Nazret Series

Nazret series were formed in Main Ethiopian Rift with 200-250m thickness during the Mio-Pliocene age. These series are known by possessing ignimbrite, tuffs, ash flows, and domes. AS stated by Mengesha Tefera et al. (1996), ignimbrites of the Nazret Series are considered to be products of eruptions mainly from marginal centers in the rift. They comprise sub-alkaline rhyolites and trachytes with rare peralkaline varieties as described by these scholars.

3.1.1.8. Chilalo Formation

The name Chilalo Formation represents a group of Early Pliocene shield volcanic complexes, which developed on both sides of the rift shoulders and margins of Main Ethiopian Rift (Kazmin and Seife Michael Berhe, 1981). There are many complex central volcanoes around Main Ethiopian Rift. Of these, the one near to present study is the western margin centers. These are Yerer, Wechecha, Furi, Gash Megel and their satellites centers that represent the late pulse of such felsic volcanism along the western escarpment of MER (Mengesha Tefera et al., 1996).

3.1.2. Quaternary volcanic rock

Initiation of subsidence of the Afar Depression and the MER subsequent volcanism was restricted at first to the evolving rifts and then to the axial zones which later became a focus of Quaternary and recent volcanic activity.

3.1.2.1 . Dino Formation

In the Awash Gorge an ignimbrite member of the Dino Formation was isotopically dated to be 1.5 Ma old (Kazmin and Seife Michael Berhe, 1978). The felsic lava of the Dino Formation is peralkaline in composition and Kazmin et al. (1980) have observed that the ignimbrite members are not confined only to the rift floor but are extensively developed on the escarpments.

3.1.2.2 . Ghinir Formation

The Ghinir Formation was mapped on the southeastern plateau by Merla et al. (1973) to represent the Quaternary rhyolite volcanism in the Ghinir area (Bale Region). The Ghinir Formation is mainly made up of rhyolites with subordinate basalts.

3.1.2.3 . Rhyolitic Volcanic Complexes

The Quaternary central volcanic complexes, which are situated along the axial zone of the Main Ethiopian Rift (Wonji Fault Belt) and Afar have produced peralkaline lavas and pyroclastics (Mengesha Tefera et al., 1996). The products of the volcanoes range from trachytes to perakaline rhyolites (pantellerites and commendites). The oldest reported KI/Ar age from the central volcanoes of the Wonji Fault Belt are, from Bosete Volcano that is 1.6 Ma (Morbedelli et al., 1975).

3.1.2.4 . Quaternary Plateau Basalts

Quaternary alkaline basalts and trachytes were erupted along preexisting structures on the northwestern and southeastern plateau. The other younger analogous unit is the relatively fresh Tepi Basalts, produced by Central type eruption in southwestern Ethiopia with a Holocene age (Davidson, 1983) and is considered an analogous unit. These Quaternary basalt flows are characteristically alkaline and may represent the final pulse of basaltic volcanism on the Ethiopian plateau.

3.1.3. Quaternary Deposits

This unit comprises mainly the eluvial soil and very small position of alluvial soil. According to Mohr (1966) at the beginning of the Quaternary an ancestral lake that was almost certainly continuous from the Abaya–Chamo Lake to the south Awash basin to the north existed until it shrinked to smaller ones by late Pleistocene tectonic movements.

3.2. Geology of study area

Tertiary and Quaternary age group of acidic and basic volcanic rocks and Quaternary alluvial deposits composes the geologic formation of the study area. Tertiary Acidic Volcanic Rocks includes Addis Ababa ignimbrite, trachytes and Rhyolites. Tarmaber and Akaki basalts are Tertiary Basic Volcanic Rocks, whereas Weliso-Ambo basalt is Quaternary Basic Volcanic rock and alluvial is Quaternary Deposit. Details of rocks units in this study area are discussed as follows.

3.2.1. Addis Ababa Ignimbrite

The central of the study area covered with Addis Ababa Ignimbrite which is almost plain area. It is composed of welded tuff (ignimbrite) and non-welded pyroclastics fall (Ash and tuff). In the Becho area it occurs intercalating with the other; the comparatively thick deposit of unwelded tuffs and volcanic ash are most of the time blanketed by ignimbrite sheets of up to about 20m thick (WWDSE,2008). It is grayish to white color and when welded it exhibits fiamme textures, elongated rock fragments of various color. Around Melka Kunture area the thickness of this unit reaches up to 200m (exploration drill data) (WWDSE, 2008). In the Becho plain area, on the other hand it is covered by thin 5-7m thick residual soil developed from the same rock. The age of this unit is 5.11-3.26 Ma (Morton et al. 1979).

3.2.2. Trachytes

The Central Volcanoes units are mainly trachytic lavas exposed at Wechecha, Furi, Dendi and Gebiso area forming an elevated ridges or mountain picks. The south and southern western ridges are a watershed divide between the Omo-Gibe and Awash River basins. It is grayish color fine to medium grained trachyte with subordinate ash falls and ignimbrite (WWDSE, 2008). A petrographic study conducted by Tsegaye Abebe et al. (1999 cited in Abel Abebe, 2017) indicates that Trachytes of Wechecha and Furi are composed of plagioclase and sanadine phenocrysts predominating the trachyte, alkaline pyroxene and rare olivine. The groundmass varies from glassy to microcrystalline and is constituted mainly by alkali feldspar, pyroxene, and amphiboles and opaque.

3.2.3. Rhyolites

The rhyolites in the Becho plain forms isolated cones of Debel. Obsidian across is common at the picks of the cones. Data on the ages of the rhyolites are not available; however, from the crosscutting relationship they can be younger than the adjacent ignimbrite.

3.2.4. Tarmaber Basalt

The western and northwestern plateau area of Upper Awash, around the watershed that divide the Awash and Blue Nile river basins is mainly covered with Tarmaber Basalts (WWDSE, 2008). This Basalt covers the northern part of the study area. In the rift valley part of the study area, this unit is downthrown by the regional east-west trending Ambo Fault and overlain by thick (282m) younger ignimbrite as revealed from deep water well logs of Melka Kunture localities (WWDSE, 2008). It mainly consist scoraceous lava flows and at places where it is columnar olivine bearing basalt as pockets within the scoraceous components. This Basalt is highly weathered, fractured, and pinkish to grayish in color. The following plate 3 indicates example of Tarmaber Basalt in the study area.

Plate 3. Photo of Tarmaber Basalt at quarry site around Koftu area

3.2.5. Akaki Basalt

This unit is outcropped in Daleti area. It is coarse grained, porphyritic, and olivine basalt. It is also highly vesicular basalt and in places the vesicles are filled by carbonate minerals. Akaki basalt consists two types of volcanic products namely scoria and spatter cones with associated lava flows.

3.2.6. Weliso-Ambo Basalt

Quaternary Basic Volcanic rock contains Weliso-Ambo Basalt. This basalt is outcropped at the western parts of the mapped area. It is a lava flow composed of porphyritic basalt with large crystals of plagioclase, olivine and pyroxene, basalt breccias and minor tuff.

3.2.7. Alluvial Deposit

Alluvial Cover is classified under Quaternary deposit. Usually this unit covers small part of Becho plains, which is called Dilu plain above the Tertiary volcanics. As differentiated by WWDSE (2008), it forms flat-lying topography and marshy areas and consists of regolith, redish brown soils, talus, and alluvium.

3.3. Geological Structure of the Study area

Lineaments are dominant in the study area. Most of these lineaments are related to the development of the Main Ethiopian Rift system resulting in a different type of Eruption. Majority of the tributaries of Awash River and drainage system follows such lineaments in this study area.

According to Ephram Beshawered (2010), the main linear features are described by four distinct fault systems trending in NE-SW, NW-SE, N-S and E-W direction. The E-W fault system, which is the upper boundary of the Ethiopian rift margin, is running approximately E-W north of the Addis Ababa-Ambo road. They are the major fault on the western plateau part and densely affected the Tarmaber basalt in the area. The following figure indicates the geological map of study area.

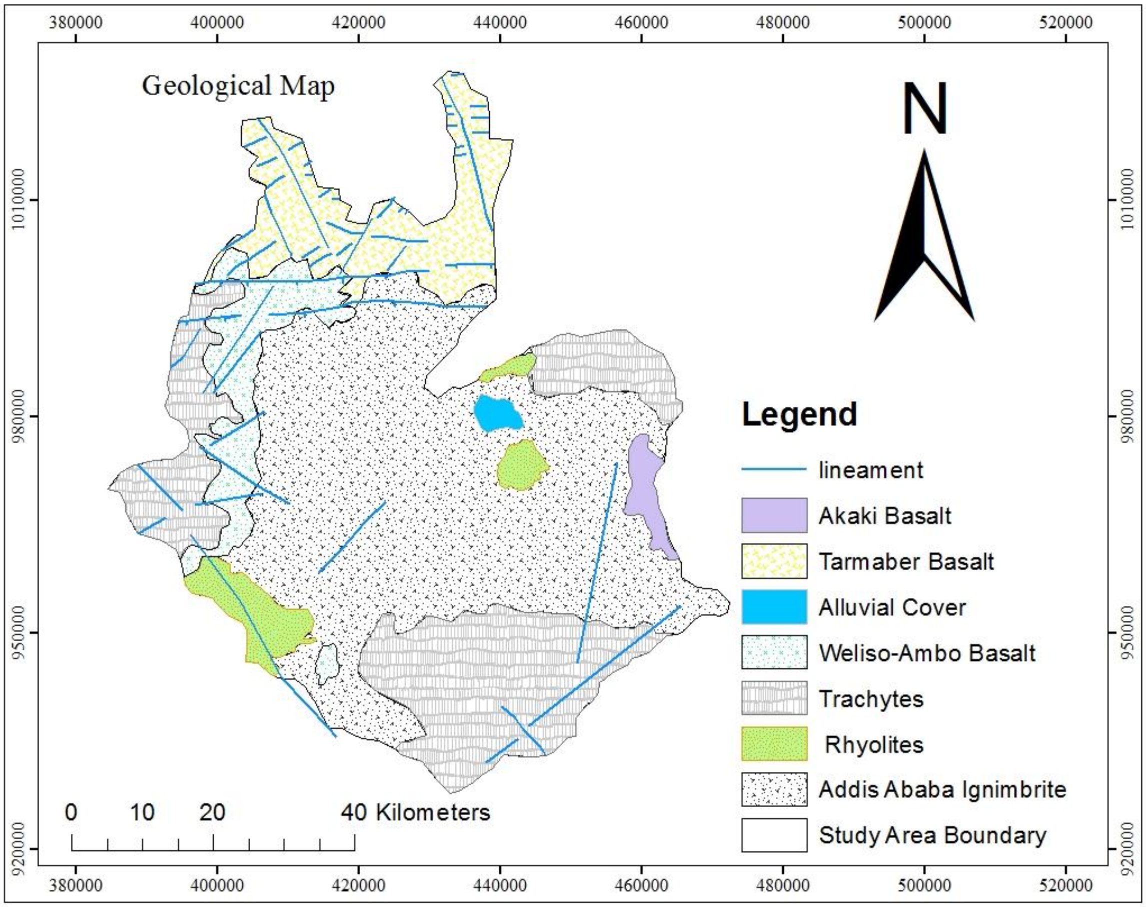

Figure 3. Geological map of the study area

Chapter Four

Hydrogeology

4.1. Hydrogeological Description

As can be understood from the above discussions, Tertiary and Quaternary Volcanic Rocks and alluvial deposits to some scale prominently cover the study area. These volcanic rocks are basalt (Tarmaber, Akaki and Weliso-Ambo basalts), Trachytes, Rhyolites and volcanic pyroclastic rocks such as welded tuffs (ignimbrites) and non-welded (Ash and tuff). Volcanic rocks can form highly permeable aquifers as a result of the type of openings found in basalts. This opening comprises interstitial spaces at the tops of flows, cavities between adjacent beds, shrinkage cracks, lava tubes, gas vesicles, fissures resulting from faulting and cracking after rocks have cooled and holes left by the burning of trees overwhelmed by lava are assist the flow of groundwater in volcanic formation Tenalem Ayenew and Tamiru Alemayehu (2001).

4.2. Hydrogeological units

The hydrogeological units of the study area are regional aquiclude, localized aquiclude, upper basalt aquifer, lower basalt aquifer, and alluvial aquifers.

4.2.1. Regional Aquiclude

The lithologic unit form Upper regional confining (aquiclude) is Addis Ababa ignimbrites, which covers majority of the plain area. This unit acts as a regional aquiclude that separates the upper and lower volcanic aquifer in Becho plain and low productive along the weathered and fractured zone (WWDSE, 2008). Addis Ababa ignimbrites of low productivity along the weathered and fractured regions and/or impermeable in different circumstances, act as aquiclude by separating the upper and lower basaltic aquifers in the north-western, north-central and north-eastern segment of the basin(WWDSE, 2008). At places where it is slightly weathered and/or fractures are absent, thus very low permeability with slight secondary process produce only in small increase in overall water circulation and storage capacity (Reys Asfaw, 2016).

Plate 4. Photo of Fractured rock exposed around Awash River gorge at Kersa warko area

4.2.2. Local Aquiclude

Becho, Rhyolites and Central Volcanic of Wechecha, Furi, and Dendi have very low permeability, except along weathered and fractured zones. They act as local barriers. Wechecha, Furi, and Dendi Trachytes have varying structures and weathering conditions. Their water conditions and storing capacities are also varying accordingly. They dominantly form volcanic domes. The water that precipitates on this dome lost as a runoff instead of vertical infiltration. This is due to that the trachytic lava domes have stepper slopes, massive and slightly weathered surfaces and the absence of thick soil development facilitates runoff to be higher. As a result, there is little groundwater stored.

On the Wechecha trachytic dome, there are very often occurrences of major tectonic displacement and deep weathering zones that have a strong effect on the hydraulic property of the rock. Moreover, the developments of minor fractures have local permeability effect and water holding properties. This is highly depending on the favorable climatic condition of the study area especially the precipitation.

4.2.3. Upper Basalt Aquifer

Upper Basalt Aquifer is composed of Quaternary of Weliso-Ambo basalts and Akaki basalts. The geological formation is highly variable from place to place i.e. massive basalts, scoraceous basalts, and scoria. When the basalts are faulted and fractured, the yield of boreholes increases and the static water level varies from place to place between the ranges 5 to 20 meters (WWDSE 2009). According to Tenalem Ayenew and Tamiru Alemayehu (2001), it is possible to find potential water bearing horizons interbedded with impervious units under confined conditions in volcanic terrain. Upper Basalt Aquifer recharged locally and in the larger part of the plain it is confined (WWDSE, 2008). The groundwater potential of this aquifer is not significant as compared to the lower basalt aquifer, however this aquifer can be exploited for the water supply of the rural villages by moderate wells depth up to 150 meters.

4.2.4. Lower Basaltic Aquifer

Lower Basalt aquifer is composed of tertiary Tarmaber basalt, which is dominantly scoraceous basalt. The scoraceous lava flow nature of this unit is highly favorable for groundwater storage and movement. This unit possesses very good secondary porosity and permeability. The permeability is highly dependent on the degree and depth of fracturing, occurrence of joints and development of thick residual soils and interconnection of vesicles. Intense fracturing developed on Tarmaber basalt gives to the good hydraulic property of the aquifer. Most fractures due to faulting are responsible for emerging of many springs. In some places the development of thick soil act as good recharging media to this aquifer by hold the precipitating water latter that will percolate through fractures to the aquifer. Columnar joints developed on Tarmaber basalt act as groundwater recharge features at topographic breaks when enhanced by weathering. The vesicular and scoraceous nature of this basalt gives to its high water bearing characteristics.

4.2.5. Alluvial Aquifer (Primary Porosity Aquifer)

Quaternary alluvium has a relatively good productivity. The small areal extent alluvial sediments of Dilu plain is unconfined aquifer consisting of coarse sediments, shallow depth and composed of silty caly sediment of low permeability. This alluvial sediment is recharged locally from rainfall and runoff. The alluvial aquifers do not form an independent aquifer. However, It forms one aquifer system with the upper basalt aquifer in the area and highly permeable. There are a number of shallow wells and dug wells drilled in this unit for the purpose of community water supply.

4.3. Groundwater Movement and Recharge

Describing where groundwater is recharged, discharged and their flow direction is important for understanding the quality of groundwater. In order to draw the groundwater flow directions and identifying the recharge and discharge areas, the parameters to be considered are slope gradient and geomorphology, geological structures, groundwater level and equipotential contour lines, and hydrochemical data. The steeper the gradient or slope, the faster the groundwater will flow and for water to move freely through a rock and the geological structures like lineaments, faults and tectonic fractures have a vital role in groundwater movement. Moreover, interconnected pores, fracture, joints, and lava flow tubes are facilitate the groundwater movement in volcanic rocks. The degree of an aquifer's porosity and permeability is also a key to movement of groundwater through an aquifer.

Groundwater movement in the study area is controlled by topography and Lithology. Topographically, the study area is structured by Ridge, Mountain, small hill, and flat area. Therefore, the groundwater flow is more in steeper gradient. Most of the lineaments of study area act as conduits to groundwater movement. Most of the streams follow these lineaments. The weathering and fracturing of the volcanic rock to ground surface cause flow of groundwater. As shown by figure 4. below, the groundwater flow of the study area is in to the Awash River.

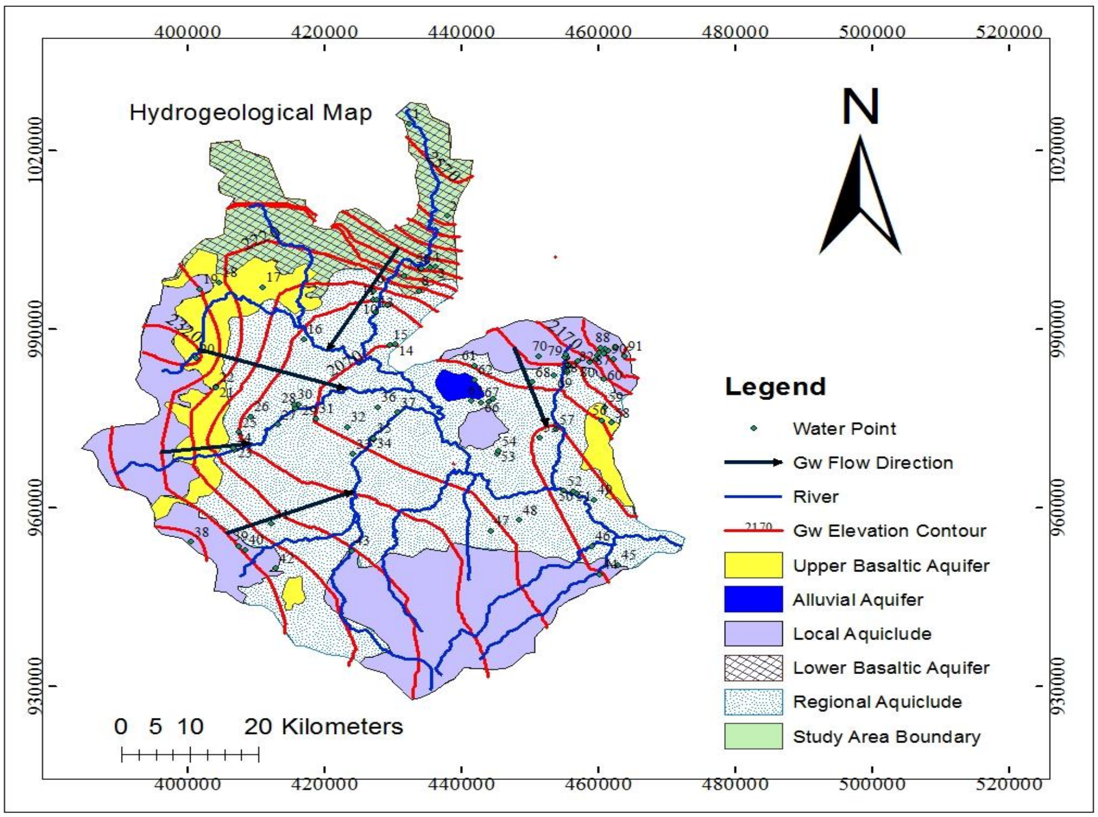

Figure 4. Hydrogeological map of study area

Chapter Five

Result and Discussion

5.1. General Hydrochemistry

The study of groundwater chemistry or hydrochemistry is scientific approach used to understand the hydrogeochemical process, water quality evolution and to examine human impact against the natural condition (Freeze and Cherry, 1980; Hem, 1985). The chemical nature of water continually evolves as it moves through the hydrologic cycle. The chemical composition of natural waters results from natural and anthropogenic sources.

In this study, the distribution of hydrochemical parameters interpreted using the hydrochemistry. This Interpretation of the distribution of hydrochemical parameters in groundwater can help in the understanding of hydrogeological conditions and can also aid decisions relating to the quality of water intended for different purpose.

5.2. Sampling Techniques and Data Analysis Method (Methodology)

Water samples were collected from different sites of the study area. From a single site, two litters volume of water samples were taken. The entire sampler bottles were washed three times before use with the water to be sampled. Then, the freshly collected samples of water were tightly canned. Finally, systematical labeling of the sample bottles were takes place immediately after canning at the field sites.

The labeled collected water samples from different water points of the study area were Twenty-six (26) as mentioned above. Of these samples, eighteen samples were taken from deep well, spring and shallow well (i.e. six samples from each water points), and five samples were taken from dug well, and the rest three samples were collected from Awash River at different sites. In order to get more knowledge about water quality of the area, different parameters such as PH, EC, TDS, sodium ,calcium, potassium, bicarbonate, sulphate, chloride etc. were analyzed. Electrical conductivity, PH, and temperature were measured in-situ. The other Parameters of collected water samples were analyzed in the laboratory of Oromia Water, Mineral and Energy Bureau, Addis Ababa University College of Natural Science Chemistry Department, and Oromia Water Work Design and Supervision Enterprise for physico-chemical parameters.

For classification of water type and HCA, thirty (30) water samples were included in database from previous work. Among these twenty-four (24) water samples are taken from Tilahun Azagegn (2014) and the rest six (6) samples are used from WWDSE (2008).

Prior to interpretation of the hydrochemistry data, the accuracy of chemical analysis was also done. The accuracy of chemical analysis was determined from Electro Neutrality (E.N) principle. The principle of Electro Neutrality requires that the sum of the positive ions (cations) in meq/l equal the sum of the negative ions (anions) in meq/l. Based on this principle, the charge balance error of chemical analysis result used in this research were estimated using major cations and anions. After calculating the charge balance error by the help of Aquachem software, the analyzed results of the primary and secondary chemical data with ionic balance below 5% were used in this study.

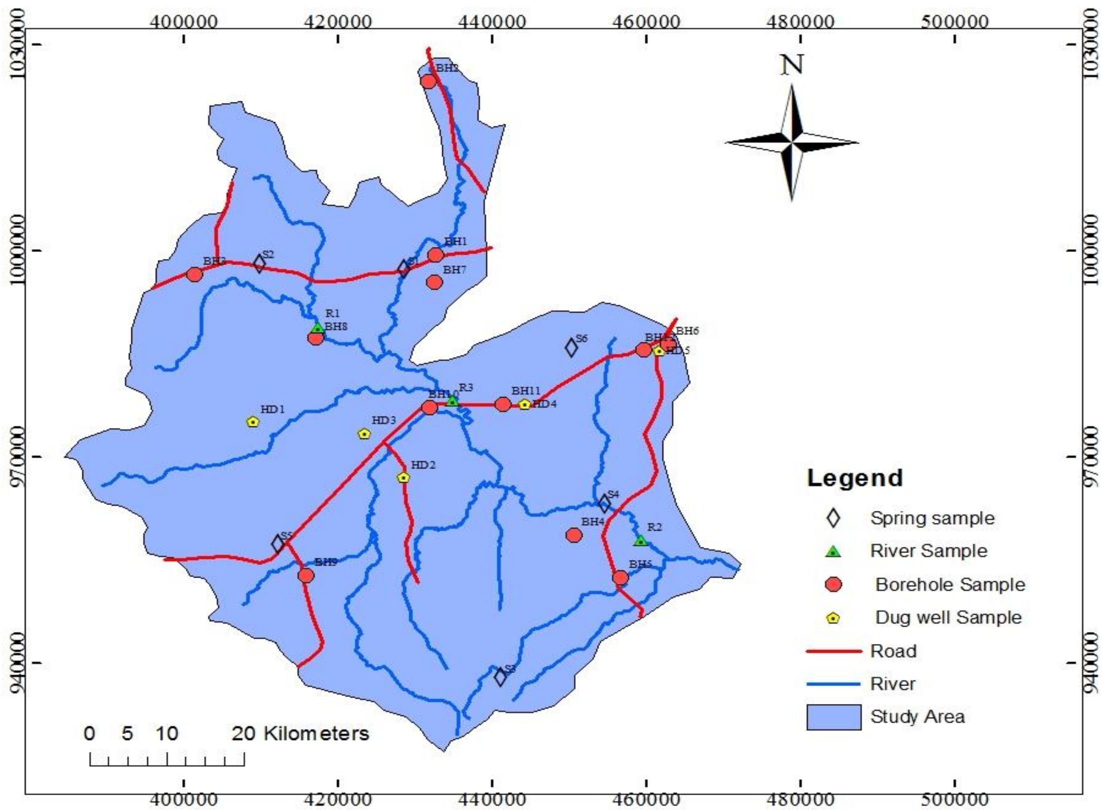

Figure 5.1. Location Map of Water Sample sites

5.3. Physico-Chemical Analysis of Water

5.3.1. In-Situ Test

In-situ test during fields are common for the parameters like EC, temperature, and PH that are easily measured by conductivity meter and PH meter. Conductivity meter and PH meter were calibrated 1411 (µs/cm) and 9.00 respectively at room temperature in Addis Ababa University by School of Earth Science laboratory assistance. These two instruments have electrodes, which are used to measure EC and temperature, and PH, respectively. During in-situ test, these electrodes were immersed in the samples, and the displayed values of measured parameters on the screen of the instruments were registered and the electrodes were immediately rinsed with distilled water.

5.3.1.1. PH

PH is the abbreviation of power of hydrogen–ion activity. The PH of water indicates whether the water is acid or alkaline. It is expressed by a series of positive number between 0 and 14. Less than 7 is acid and above 7 is basic, whereas equal to 7 is neutral. PH Parameter is well known characteristic of water that measured both in the field and in laboratory, however in situ measure is preferable because of the groundwater once outside aquifer immediately undergoes several change that affect PH (Neven, 2009).

As per the in-situ test in the fields, the PH of borehole, spring, and dug well varied from 6.42 to 7.99. The least PH value was read in the spring water (S6) that was collected during drizzle. Small drop of rain during sampling is lower the PH of spring water (S6) due to the rain water usually contain weak acid which have low PH. While the maximum value, 7.99, was recorded in spring water (S2). The World Health Organization (WHO, 2017) and (ESA, 2013) PH Standard limit for drinking water is 6.5 to 8.5. Above this value, taste problems may encounter. The pH values of the above water points in study area are not exceeds these standards. On the other hand, the PH of Awash River tested in sampling site was varying from 7.86 to 8.4. The following figure indicates the pH variation of groundwater in collected water sample. In the sample symbology, the DW represent the deep well, SH represent the shallow well, HD represent hand dug well, R represent river water sample and S represent spring water sample.

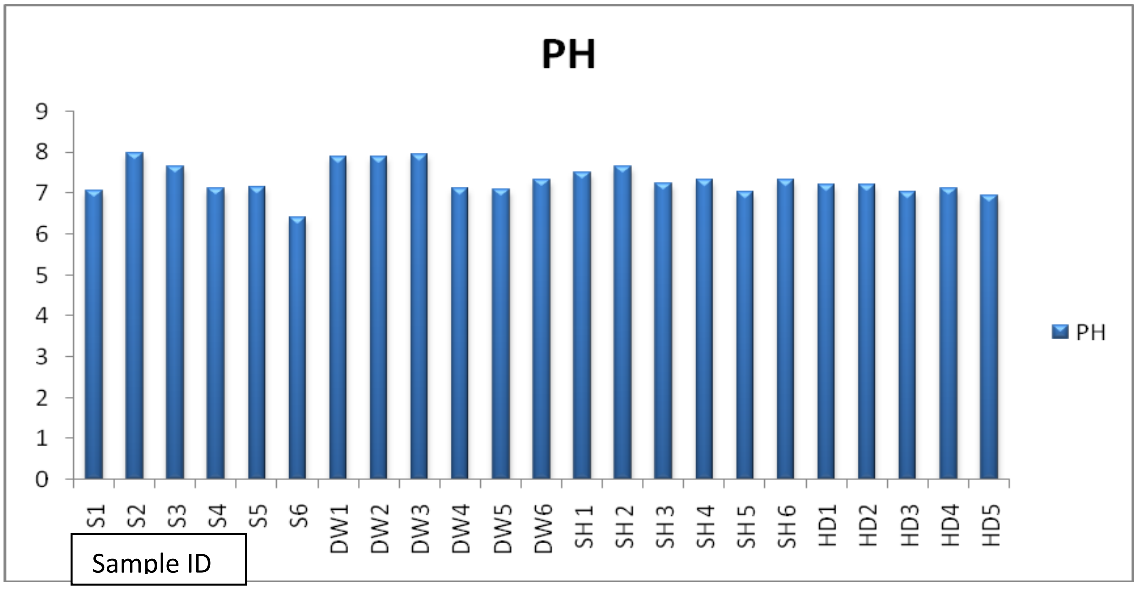

Figure 5.2. PH variation of collected groundwater samples in the study area

As can be observed from figure 5.2., the sample labeled S_6 and HD_5 pH is less than seven and so acidic, whereas DW_2, DW_3 and S_2 boreholes tend to high alkalinity level.

5.3.1.2. EC

Electrical conductivity of water is a measure of its ability to carry an electric current and expressed by mili siemens (ms) or micro siemens per centimeter (µs/cm). This is directly related to the concentration of salts dissolved in water. In this research, the value of EC in both groundwater and river water were ranged from 90.8 to 896µs/cm (appendix 2). Relatively higher value of EC is observed in water samples of hand dug (HD1), spring (S2), shallow wells (SH2 and SH1) with value of 711,722,744, and 896 µs/cm, respectively.

The values measured in all samples are below the value of (SON, 2007), which is 1000 µs/cm. Though ESA (2013) guidelines for drinking water quality do not suggest the standard for EC, previous study near the study area, Addis Ababa city, indicates that EC varies from 100µS/cm to ~600µS/cm for surface water and from ~300 µS/cm to

~1200μS/cm for groundwater (Tamiru Alemayehu, 2008). However, the lowest value that was measured in the spring sample water (S3), which is emerged from mountain is by far below ~300 μS/cm. The low TDS and EC value of highland springs, well and rivers indicate that the groundwater in the area consists of meteoric water which originates from direct precipitation circulating at shallow depth (Tenalem Ayenew, 1998). Low value of EC indicates that the groundwater in the area is less mineralized and contains small dissolved salts.

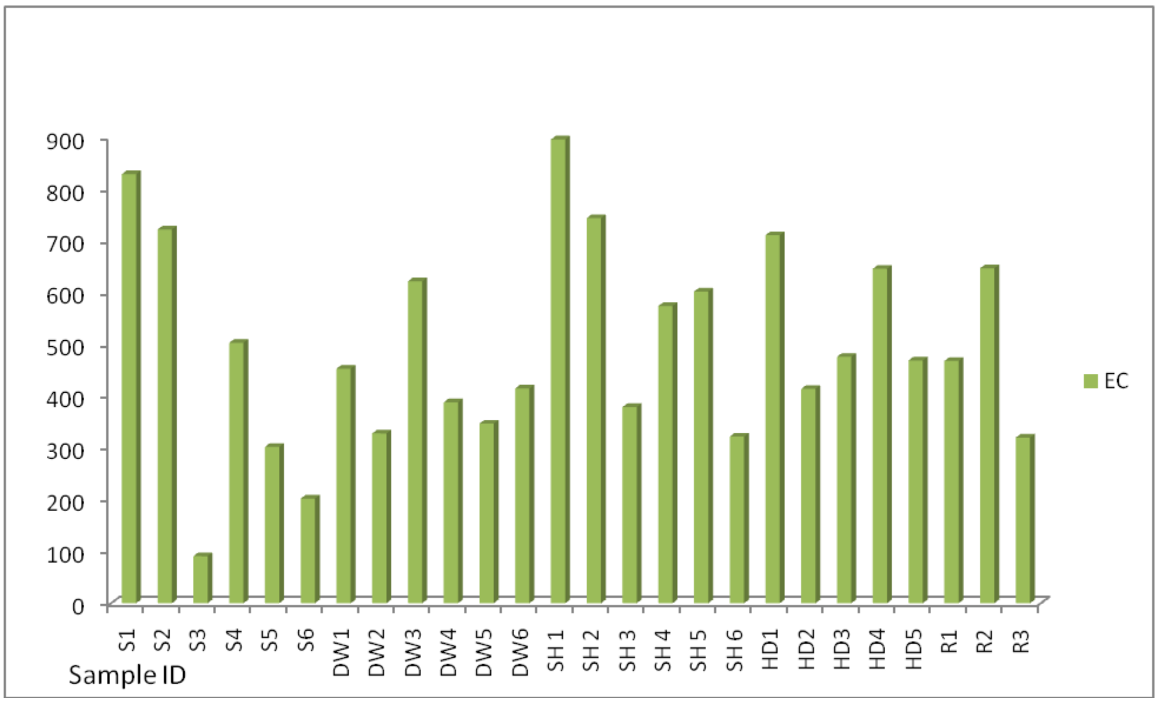

Figure 5.3. Electrical Conductivity (EC) variation of collected water samples in the study area

5.3.1.3. Temperature

Temperature has impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect a taste. The parameters such as turbidity, odor, and electrical conductivity may affected by temperature. Water temperature determines the suitability of water for drinking purpose, industrial application and aquatic ecosystem functioning. High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems. The temperature of study area varies from 19 to 25.7. These parameters were measured both in the fields and in the laboratories.

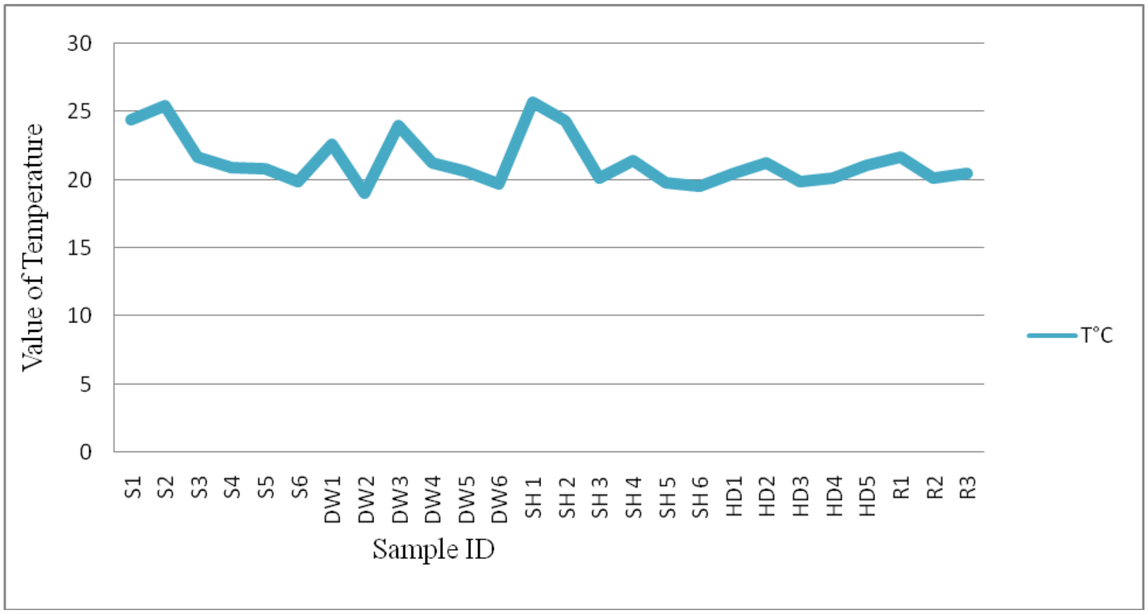

Figure 5.4. Variation of Temperature in water samples of the study area

5.3.2. Laboratory Analysis

Physiochemical parameters analyzed in the laboratory were turbidity, total hardness, TDS, major ions, minor ions, trace element (Chromium, Manganese and Copper), and other chemical parameters. The result obtained for the twenty-six water samples from different water points (borehole, hand dug well, spring and river) show the characteristics of the overall water quality.

5.3.2.1. Turbidity

Turbidity is the physical parameter of water quality, which shows the presence of suspended solids in water and causes the muddy or turbid appearance of water body (Tiwari et al., 2015). It is caused by suspended matter, organic particles, in organic particles and microscopic organisms. According to the WHO (2017, 2008), the maximum permissible level of turbidity for drinking water is 5 (NTU). The turbidity of water for analyzed water samples were varies from NIL to 63 (NTU). Most of the rivers are highly turbid and with no or little river bed sediment; this is because of the upstream dominancy of rivers, steep slope and undulating terrain of the area (GSE, 2010). The turbidity level in study area is higher in river sample (R3) which is 63 (NTU) (Appendix 3). The turbidity of dug well labeled HD_1 and HD_3 and spring water S_4 and S_6 are above WHO (2017, 2008) standards.

5.3.2.2. Total Dissolved Solids (TDS)

TDS constitute of inorganic salts. It principally consists calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates, and small amounts of organic matter that are dissolved in water (WHO, 2008). Total dissolved solids show that the salinity of groundwater in the water sample. In the study area, TDS value varied from spring water sample (S3) 79mg/l to shallow well water sample (SH1) 400 mg/l. The total dissolved solids spring water (S3) collected from Tuka Godeti area is very small value, which indicates that there is active recharge and shallow groundwater. Figure 5.5 indicates the relationship between EC and TDS in the water samples of the study area. The standard limit of TDS of drinking water is 1000mg/l as given by both WHO (2017, 2008) and ESA (2013). Accordingly, the entire samples were found within standard permissible limit (Appendix 2). The chemical analysis shows that there is a straight line regression (R2= 0.969) relationship between the EC and TDS.

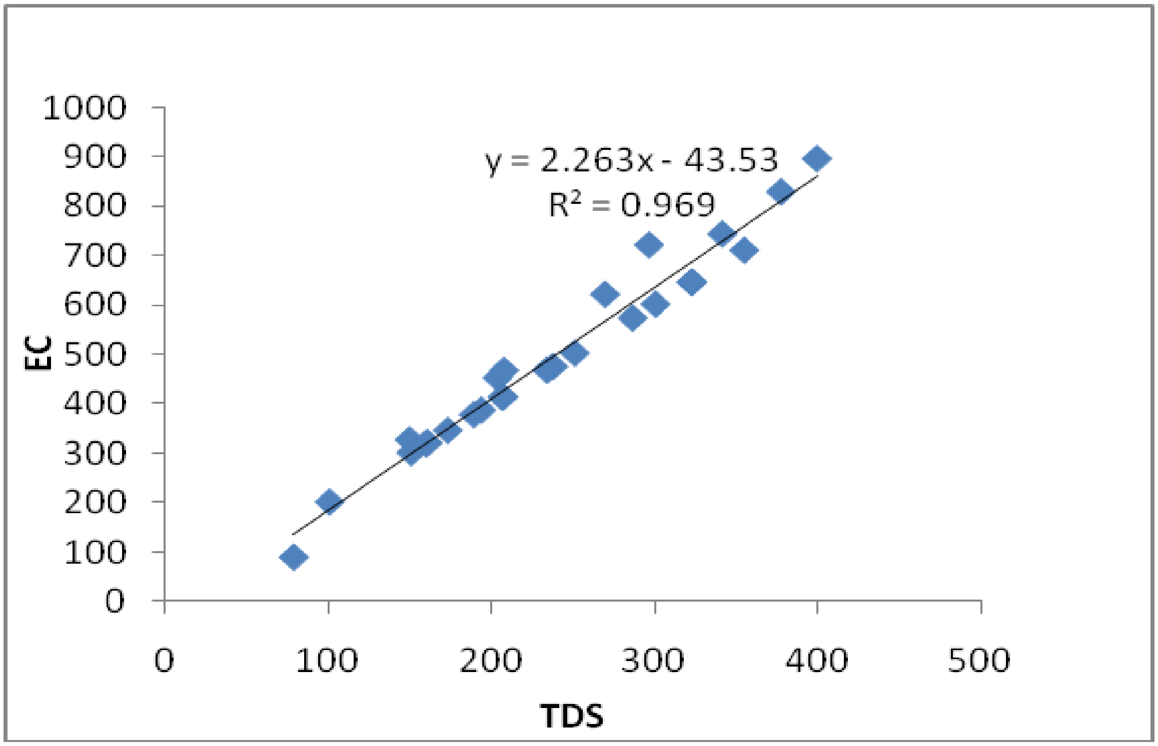

Figure 5.5. Relationship between EC and TDS

5.4. Chemical Composition

All elements in periodic table can be occurring in groundwater and surface water. However, the amount of element is varying from one place to another depending on geo-environmental setting of the area. Based on the abundance of periodic element in water, three ions and pairs of ions can be listed. The first category is Major ions, which include major cations and anions such as sodium, calcium, chloride, sulfate, and others. These constituents are mostly present at concentrations in the range of a few mg/l to several hundred mg/l. The second category is minor ions that contain iron, manganese and fluoride. Their concentration is less than 1mg/l. The final category is trace element with concentration lower than 0.1mg/l such as Arsenic, Uranium, and others.

In this study, the chemical compositions of water that were analyzed are major ions that include sodium, calcium, magnesium, bicarbonate, chloride, and sulphate, whereas the minor ions are fluoride, iron, etc. Major ions, minor ions, trace element and other chemical parameters are discussed as follow.

5.4.1. Major Cations

As already mentioned above, the major cations analyzed for collected water samples are sodium, calcium, magnesium, and potassium. As the chemical analyses of the samples show, sodium is the most dominant cation in study area that is followed by calcium, magnesium, and potassium, respectively. The presence of the volcanic acid, such as ignimbrite, trachytes, and rhyolite attributed to the dominance of Sodium in the study area. The source of sodium is minerals, and rocks such as feldspars, clay, halite and other evaporates. The concentration of sodium in study area varies from 9.58mg/l to 255.1mg/l. The WHO and Ethiopian drinking water standard for sodium is 200mg/l (Table 5.4). Except R2, HD_1 and SH_4, all collected water samples are below the maximum permissible level. The high concentration of sodium in river water 2 (R_2) at Kersa Warko sampling site is caused by the polluted Atebela river, which contains industrial effluents like sodium ion that released from tannery industries in Sebeta town and joins the Awash river at Melka Kunture (plate 2.1).

The main source of Calcium ion in study area is the basic volcanic rocks, which include Tarmaber, Akaki, and Weliso-Ambo basalt. As per the analyzed results, the concentration of the ions in the target area ranges between 3.61mg/l and 94.4mg/l. The minimum value is recorded in the spring water sample labeled (S3) from Tuka Godeti area, whereas the maximum value is recorded in hand dug well (HD4) around Tefki area (Appendix 2). The maximum standard calcium fixed for drinking water by (ESA, 2013) is 75 mg/l. In general, all the collected water samples from hand dug well contain high value of calcium.

The magnesium ion in study area ranged from 2.36mg/l at spring water sample labeled (S3) to 18.72mg/l at borehole water sample labeled (SH5) (Appendix 2). These values are within the maximum standard limit for mg, which is 50mg/l as fixed by ESA (2013). The spring water (S3) has minimum value of both calcium and magnesium, which indicate the area is low water-rocks interaction. The concentration of calcium expected in water that has been in contact with igneous is low due to the rate of decomposition of most igneous-rock minerals is slow (Hem, 1985) the decomposition of anorthite can be presented as

$$CaAl_2Si_2O_8+H_2O+2H^+=Al_2Si_2O_5(OH)_4+Ca^{2+}$$

The potassium concentration of water samples collected from borehole, spring and dug well varies from 1.2mg/l at deep well labeled (DW2) in Asiko area and 5.8mg/l at deep well labeled (DW4) in Roge area. Concerning the river water samples, sample labeled (R2) containing a minimum value of 2.55 mg/l potassium, whereas river water sample labeled (R1) contains the maximum value of potassium that is 5.97mg/l. The standard limit of potassium given by ESA (2013) is 15mg/l. Therefore, almost all the analyzed water samples values showed below the standard limit of potassium (Appendix 2).

5.4.2. Major Anions

The major anions include bicarbonate, nitrate, chloride, and sulphate ions. Of these parameters, the dominant anion is bicarbonate. Bicarbonate is commonly the primary anion in groundwater. It is derived from the carbon dioxide released by the organic decomposition in the soils, where CO2 is generated by root respiration and decay of humus that in turn combines with rainwater to form bicarbonates (Drever, 1988, and Todd, 1980). The concentration of bicarbonate in the study area ranges between 44.8 mg/l to 866 mg/l. In the present study there is high concentration of bicarbonate in entire samples (appendix 2) consequently the dominant water type is bicarbonate type. This anion is the most dominant constitute of all the other constituents. Except the spring water sample collected from Kimoyee have no bicarbonate. There is no specification on the maximum acceptable limits of bicarbonate either by WHO or by Ethiopian standard for drinking water.

On the other hand, the Nitrate concentration of the study area ranges from Nil at hand dug well water sample labeled (HD1) in Kelecho Gerbi kebele to 35.36 again at hand dug well water sample labeled (HD4) in Tefki area (appendix 2). These values are within the acceptable limits of both WHO and Ethiopian Standards, which is 50mg/l.

According to Shayaq Ali et al. (2015), high concentration of Nitrate is associated with agricultural activities, which are a major problem in some shallow aquifers. For instance, the high Nitrate concentrations in sample labeled (HD4) indicates that the area is affected by anthropologic source in related to agriculture fertilizers and animal manures.

When we come to chloride, the permissible level of chloride in drinking water is 250mg/l based on WHO and Ethiopian Standard. In the present study, the results of chloride in all sampling sites are between 3.6mg/l and 22 mg/liter (appendix 2). Accordingly, the chloride levels measured in all sampling points are below the permissible level for drinking water.

The main sources of sulphate in groundwater are oxidation of sulphides from igneous rocks, fertilizers, rainwater, industrial discharge, and deposition from burning of fossil fuel. The sulphate concentrations for collected samples were very low. It was measured between 0.01mg/l at sample labeled (SH5) and 15mg/l at sample labeled (SH2) with the exception of three samples (DW4, DW5, and SH4) without sulphate concentration. The acceptable limit for sulphate as given in Ethiopian standard is 250 mg/l (Table 5.4). The following table 5.1 indicates the summary statistics of the major ions in analyzed sample. All the parameters expressed in mg/l unit.

Parameters	Min	Max	Average	St. Dev.	Dev. Coef	Q25	Q50	Q75	Sample No
Na	9.58	255.1	91.51	71.66	78.31	22.28	76.9	125.3	26
Ca	3.61	94.4	45.67	27.98	61.28	17.57	41	64.4	26
K	1.2	5.97	3.684	1.438	39.02	2.475	3.4	4.6	26
Mg	2.36	18.72	8.851	3.653	41.28	6.575	8.39	10.56	26
Cl	3.6	22	10.85	5.112	47.13	7.55	10	13.1	26
HCO3	44.8	866	371.7	260.2	70.01	135.1	388	486.5	25
SO4	0.01	15	5.392	3.925	72.79	1.75	4.75	7.25	23
NO3	0	35.36	8.555	7.189	84.03	2.868	7.89	11.75	25

Table 5.1.Summary statistics of the major ions

More over box and whisker plot is used for describing the descriptive statistics, showing the general variability in constituent concentration of hydrochemical data. The following figure 5.6 shows that descriptive statistics of major ions using the box and whisker plot.

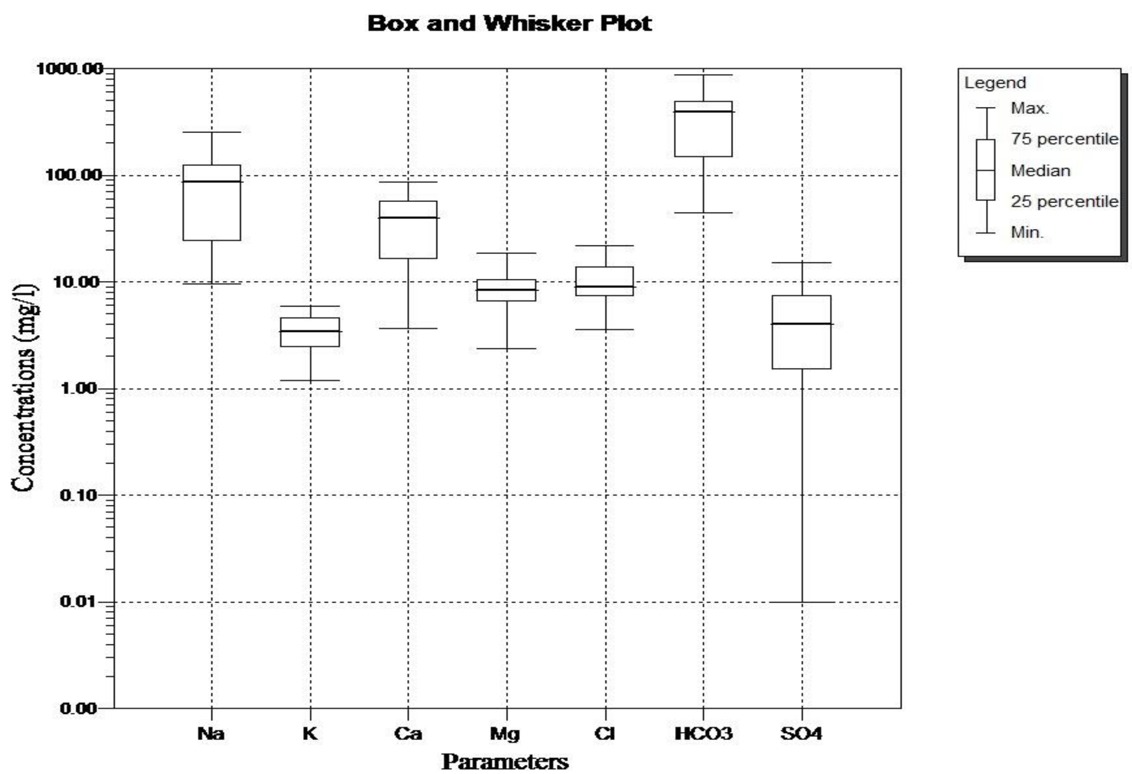

Figure 5.6. Box and Whisker plot shows concentration of major ions in study area

5.4.3. Minor ions

The high fluoride concentration at rift margins in the Upper Awash is associated with regional fault systems, which indicate that the fault systems prefer deeper groundwater to emerge as thermal spring or the deep zone of the aquifer is penetrated by drilling along fault zones (Tilahun Azagegn, 2014).

There is no wide variation of fluorides concentration in the study area. All analyzed water samples contain fluoride which ranges from 0.15 at (DW1) to 1.6 at (SH4) except one sample no contain fluoride concentration (Appendix 3). The standard limits of fluoride given by WHO is 1.5mg/l (Table 5.4). From the analyzed samples, only one sample shows fluoride concentration greater than this standard.

The maximum concentration of iron for collected water samples in the study area is 1.1mg/l that labeled (R1) at Kore area, whereas the minimum value becomes 0.01mg/l that labeled (S5) at Tulu Bolo area. Therefore, high and low concentrations of iron were registered for river and spring, respectively. Moreover five sample such as spring water sample (S2) at Barodo area, shallow well (SH2) at Keta area, deep well at Roge (DW4) and Lemen (DW5), and hand dug well at Wasarbi area have no iron concentration (Appendix 3). Comparatively the water samples collected from river have higher iron concentration than samples collected from borehole, hand dug well, and spring. From all the analyzed samples, the results of six samples (SH1, S6, S1, R1, R2, and R3) are above the standard limit (0.3mg/l) set by both WHO and Ethiopian standard for drinking water (Table 5.4).

5.4.4. Trace elements

As a variety of major ions and minors ions occurs in groundwater, a variety of trace elements also exists in groundwater. However, only Cu, Mn, and Cr were discussed in this study.

Copper can enter into groundwater as a result of industrial wastage contains copper. It can also occur through corrosion of copper pipes. In this study, some of the collected water samples have no copper element. According to ESA (2013) and WHO (2017), the standard limit of copper is 2mg/l and 1.5mg/l, respectively. Therefore, the values of copper in the study area are within these standards (Table5.4).These samples, which have copper concentration were collected from plateau area.

Manganese contamination in water is resulting from industrial emission, soil erosion, and volcanic emissions. The chemical analysis of water samples show that in the study area Manganese ranges from 0.01 to 0.05mg/l except few samples, which lack Mn (Appendix 3). The values of Manganese in the study area are within the standard of ESA (2013) (Table 5.4).

Chromium is naturally occurring metallic element and most frequently occur in igneous rocks. In the study area, the value of chromium varies from shallow well water (SH2) 0.01mg/l to deep well water (DW2) 0.26mg/l. However, few water samples has no Chromium at all (appendix 3).As set by both ESA (2013) and WHO (2017), the standard limit of chromium for drinking water is 0.05mg/l. Accordingly, six water samples of the study area have a Chromium element above standard limit (table 5.4). Almost the water samples taken from plateau area have Chromium value above standard limit. Gradually increasing in trace element composition along the groundwater flow direction suggest continuous groundwater flow from the plateau (Seifu Kebede et al, .2010)

5.4.5. Other Chemical Parameter

Other chemical parameter includes total hardness and total alkalinity. The total hardness represents the total concentration of calcium ion and magnesium ion in water in unit’s mg/l as equivalent $CaCO_3$. Table 5.2 indicates the degree of hardness of the water which is classified in terms of calcium carbonate concentration.

Hardness	Range of concentration as $CaCO_3$ (mg/l)
Soft	0-75
Medium hard	75-150
Hard	150-300

Table 5.2. Hardness classification of water (source Sawyer and McCarty, 1967)

According to Ethiopian standard, the maximum permissible limit of total hardness should not be exceeded 300mg/l as $CaCO_3$. As the laboratory results show, the values are ranged from 54mg/l at spring water (S6) to 416 at Shallow well water (SH1) mg/l of $CaCO_3$ (Appendix 3). Alkalinity is the presence of one or more ions in water including hydroxides, carbonates, and bicarbonates. The total alkalinity is similar with the bicarbonate anion indicating that it is mostly caused by bicarbonate (Ketema Wogari, 2006).The total alkalinity of analyzed samples show no wide variation with bicarbonate.

5.5. Water Types in the study

The piper trilinear diagram is the widely used diagram to represent the hydrochemical facies of water (piper, 1944). This piper plot helps us to classify water based on chemistry and compare the chemical trend between different water samples. The primary and secondary data chemical analysis results are plotted on piper diagram (figure.5.7).

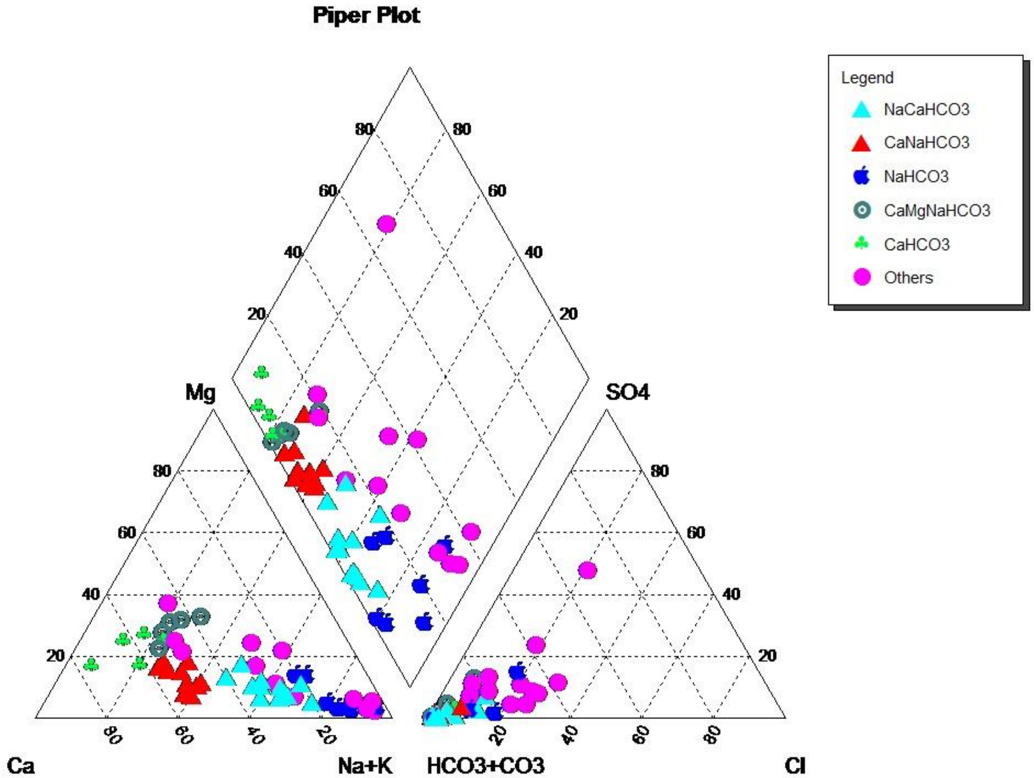

Figure 5.7. Piper plots of the hydrochemical data showing groundwater type

Depending on major cation and anion dominance the water types in the study area were identified. Majority of water point in the study area belongs to NaCaHCO3 and CaNaHCO3.The value of TDS of water sample belongs to NaCaHCO3 is <360mg/l. Some deep wells, shallow wells, springs, and hand dug wells associated with NaCaHCO3, with dilute chemistry (low TDS). The three Deep wells DW4, DW5, and DW6 in the area have TDS Value 194,173.5 and 207.5 mg/l, respectively. Relatively, the hand dug wells which characterized by this water type have high TDS. The NaCaHCO3 water type represents the intermediate stage of geochemical evolution with significant travel distance from recharge area and/or at a relatively deeper part of the aquifer or mixing effect of local recharge with regional flow system (Tilahun Azagegn, 2014).

CaNaHCO3 associated with moderately mineralized waters and the TDS value of this water type ranges from 159 to 540mg/l in study area. Water samples collected from the area covered by Tertiary Acidic Volcanic Rocks, which includes Addis Ababa ignimbrite, trachytes, and rhyolites, are characterized by this water type. This part of the area is where water systems are tapping the weathered and fractured rocks rich in Ca- and Na- plagioclases that could be responsible to have such water chemistry (Andarge Yitbarek, 2009). Hand dug wells (HD2, HD3 and HD5) belong to this water type. These hand dug well samples were collected from different geologic unit. For instance HD5 was taken from Delati area which covered by trachytes.

The CaHCO3 and CaMgHCO3 also distributed in the study area. As presented on piper plot (Fig.5.7), CaHCO3 and CaMgHCO3 are associated with the shallow depth well and characterized by very low TDS. These types of waters are often considered as recharge area waters and represents early stage of geochemical evolution and rapidly circulating shallow depth relatively low residence time in sub surface, which have low water-rock interaction. (Seifu Kebede et al., 2005, 2007). In the study area, few samples belong to these types of water having TDS value less than 435mg/l.

The well in the study area having moderately high TDS 354 to1010 mg/l fall in the NaHCO3 type in piper plot. This type of water is the sample water in which sodium and bicarbonate dominate the cations species and anions group, respectively. Along regional flow path, dilute recharge waters evolve to NaHCO3 composition with intensive ion exchange that replaces the whole calcium in the water. Groundwater circulation and ion exchange play major role in determining the water type and water chemistry. The CaHCO3, CaMgHCO3 and CaMgNaHCO3 water change to CaNaHCO3 and NaCaHCO3. At discharge area the Ca ion replaced by Na ion and the water type is NaHCO3.

The other water types that are included in the study area are NaHCO3Cl, NaCaHCO3Cl and NaCaHCO3SO4.

On the other hand, three water samples were taken from Awash River at three localities and their water type were identified. The TDS of Awash river sample ranges from 160mg/l to 323.5mg/l. Awash River at Kersa Worko and Dibu localities are characterized by NaCaHCO3. Some samples of groundwater are characterized by NaCaHCO3 that has the same chemistry with river water, which indicates as groundwater is recharged by rivers. The river water sample (R1) show mixed hydrochemical type NaCaMgHCO3Cl). The presence of high concentration of chloride and sodium show a complex process of rock-water interaction and ion exchange (GSE, 2010). Figure 5.8 show the water types of Awash River at three localities.

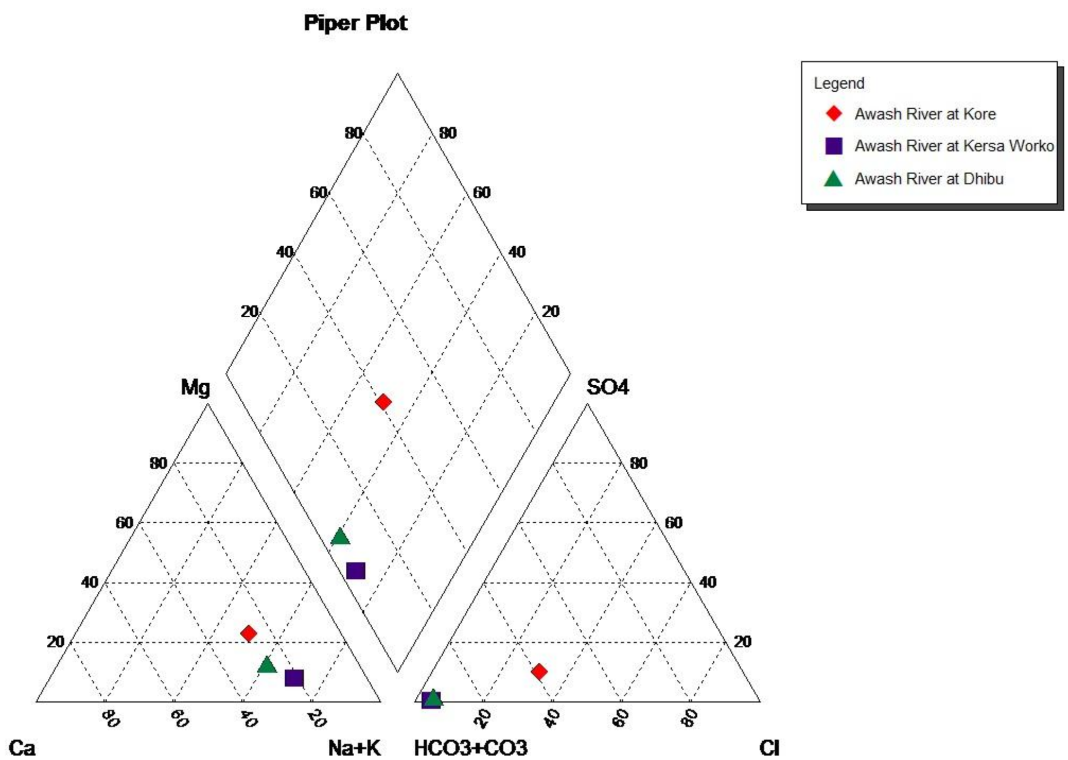

Figure 5.8. Piper plot of river water

The value of TDS in both primary and secondary data is less than 800mg/l. However, there is an outlier, which has high value (appendix 4). As shown on the map (Fig. 5.9), a relatively high value of TDS is distributed at central part of study area. This may be related with lithology. On the other hand, few water samples of highland areas in urban centers such as Sebeta and Ginchi also indicate TDS values above 400 mg/l. The reason behind this may be urban sewage disposal and industrial discharge. As described by Tenalem Ayenew et al. (2008), the highland waters are homogeneous in their chemical composition and characterized by low TDS.

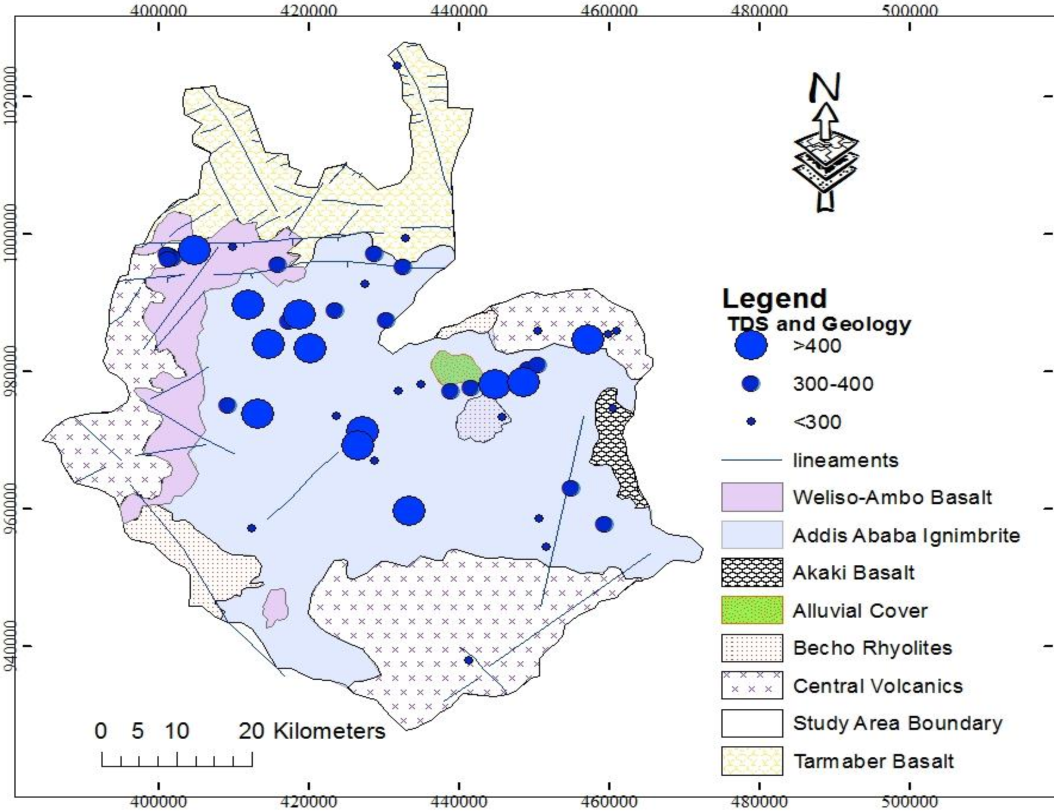

Figure 5.9. Distribution of TDS

5.6. Hierarchical Cluster Analysis (HCA) and Hydrochemical Map

5.6.1. Hierarchical Cluster Analysis (HCA)

Hierarchical Cluster Analysis (HCA) is a multivariate statistical technique to classify the water chemistry samples in to different groups. This technique is used to figure out the water chemistry evolution and to conduct geochemical modeling between different cluster (groups) and sub clusters (sub groups) (Seifu Kebede et al., 2005). As described by scholars, samples that have the same water chemistry are grouped together and interpreted in terms of their similarity of geology, climate, resident time, infiltration, recharge area, and hydrogeochemical processes (Gűler et al., 2002; Seifu Kebede et al., 2005). In this study, an add-in Microsoft Excel version XLSTAT 2018 was used to conduct the HCA. A total of fifty four water samples, which are both primary data and secondary data, are clustered into four groups and six sub-groups based on nine (9) parameters. The parameters are TDS, Na, Ca, Mg, K, Cl, NO3, SO4, and HCO3 (Appendix 2 and 4). The mean chemical composition of all parameters of the groups is derived from HCA (Table5.3). Both ground and surface water samples were used in the cluster analysis in order to test the association between the groups. Accordingly, their dendrogram or tree diagrams are generated as indicated in Figure 5.10. Dendrogram is the graphical output of clustering that presents a visual summary of clustering in simple way.

Group	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
1	238.07	43.525	4.414	5.365	20.088	14.241	9.283	166.08	7.1708
2	229.58	153.04	4.388	10.08	51.35	9.8333	2.501	578.77	5.9117
3	339.7	39.12	4.881	13.75	64.707	8.7485	5.298	331.08	9.2435
4	540.22	156.89	11.72	4.877	18.789	50.841	29.91	392.61	2.9044

Table 5.3. Mean hydrochemical data for water groups defined by HCA (all parameters in mg/l)

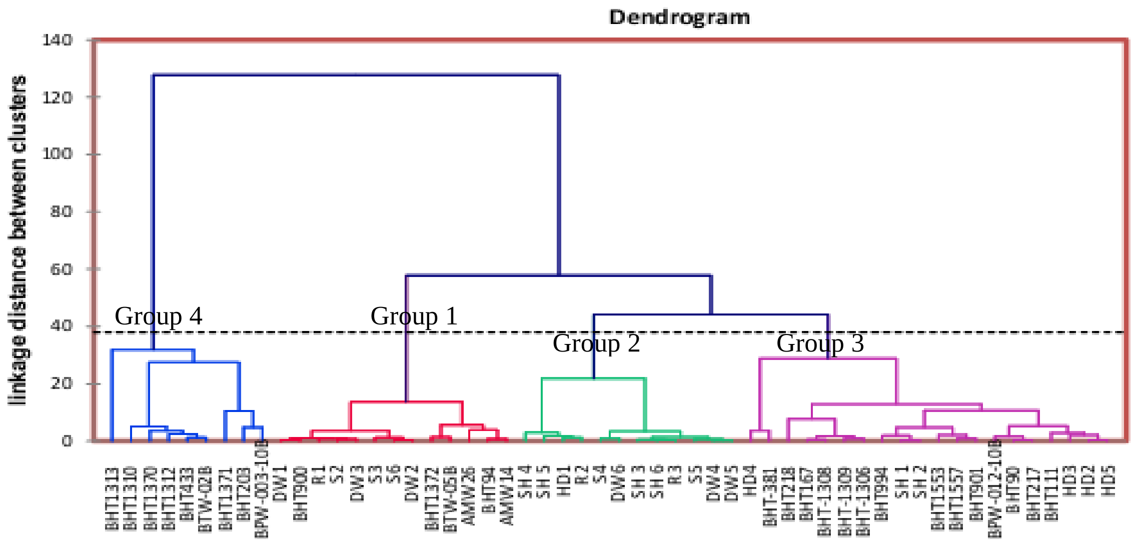

Figure 5.10. Dendrogram for the HCA showing the identified clusters and sub-clusters.

Based on this dendrogram, the following discussions are presented in four groups.

Group 1

Group one includes 13 water samples (Appendix 5). It is characterized by TDS ranges from 79mg/l to 416mg/l and has sodium, calcium, magnesium, and bicarbonate as major composition. This group is located in plateau area (fig.5.11). This group is further sub divided in to 1a and 1b sub-groups (fig.5.10) that contain eight (8) and five (5) 5 water samples, respectively.

Group 2

Group two includes twelve (12) samples (Appendix 5). These samples are located in central part of study area, which have low elevation area as compared to other areas of the target area like plateau. This group of waters mainly associated with all types of water resources such as spring, deep well, river, and shallow well. The entire sample belonging to this group were NaCaHCO3 water type except shallow well (SH) around Teji, which is NaHCO3 Water type. The TDS varies from 151mg/l to 355.5mg/l. The groundwater and river water (R1 and R2) samples categorized under this group have similar water type that shows the groundwater getting recharge from River and precipitation. The rock units are ignimbrite that covers wide area, trachyte, and ryholite. Group two further divided into Sub-group of 2a and 2b, which include four (4) and eight (8) water samples, respectively (Fig.5.10).

Group 3

Twenty (20) water samples are included in this group (Appendix 5). This group is characterized by moderately mineralized waters (TDS > 207≤597mg/l). It mainly has high calcium, magnesium, and sodium composition; and consequently it is CaNaHCO3, CaMgNaHCO3 and CaMgHCO3 water type. This group is mainly distributed in all the study areas. As other groups, this group is also divided in to two sub-groups: 3a and 3b, which include seven and thirteen water samples, respectively.

Subgroup 3a

Subgroup 3a is characterized by high value of calcium and magnesium, and it is dominated by CaMgHCO3 and CaMgNaHCO3 water type. The water contains high calcium and magnesium concentrations are localized in the highland basic volcanic areas and high value of Mg content is associated with preferential leaching of host basalts (Tenalem Ayenew et al., 2008). This sub-group is located at Ginchi area and wechecha and furi highland (Fig.5.11). These areas are mainly covered by basalt, which is composed of porphyritic basalt with large crystals of plagioclase, olivine and pyroxene, and trachyte that composed of plagioclase and sanadine phenocrysts predominating the trachyte, alkaline pyroxene and rare olivine (Tsegaye Abebe et al., 1999).

Group 4

Group four includes nine water samples (Appendix 5). This group is characterized by high value of Sodium and HCO3 composition, and the high concentration of sodium in this area is related to the abundance of acidic volcanic rocks. The TDS of this group varies from 354 to 1010 mg/l. NaHCO3 and NaHCO3Cl Water type dominate the group and relatively the water type NaHCO3 has higher TDS value than NaHCO3Cl that ranges from 490 to 1010 mg/l.

An aquifer of Dilu plain area, which is covered by alluvial deposit, is characterized by NaHCO3Cl Water type. As described by Seifu Kebede (2013), the groundwater in alluvial sediment dominantly contains high Na and Cl concentration and this high value indicate that evaporative concentration of salt prior to recharge. Since floodwater affects the area in every summer, the salt crust is formed from the evaporation of this floodwater. In this case, solar system plays a major role for evaporation process.

The NaHCO3 water type located at Becho plain is mainly covered by Acidic Volcanic Rocks, which composed of welded tuff (ignimbrite) and non-welded pyroclastics fall (Ash and tuff).

In general, except one sample of group 4, all water samples in the study area is dilute waters with TDS value below 800 mg/l that indicate the low rock-water interaction characterize all water groups in the study area.

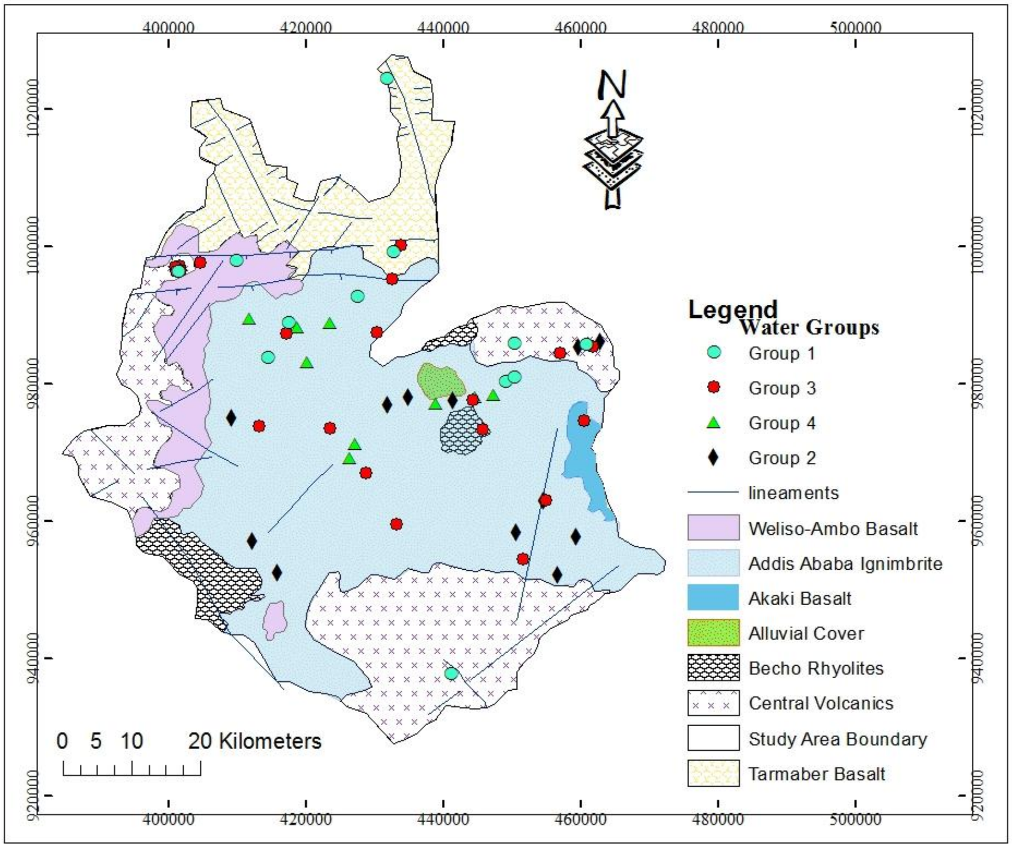

Figure 5.11. Location of Water Groups in the study area

5.6.2. Hydrochemical Map

Hydrochemical map used to interpret the spatial trends of chemical composition of water sample. In this study, hydrochemical maps determined using Stiff diagram which mapped to show the chemical evolution of major cations and anions (Fig.5.12.). The size of stiff diagram is directly proportional to the concentration of major ions indicate that there is variation in the major cations and anions concentrations of groundwaters following the groundwater flow directions.

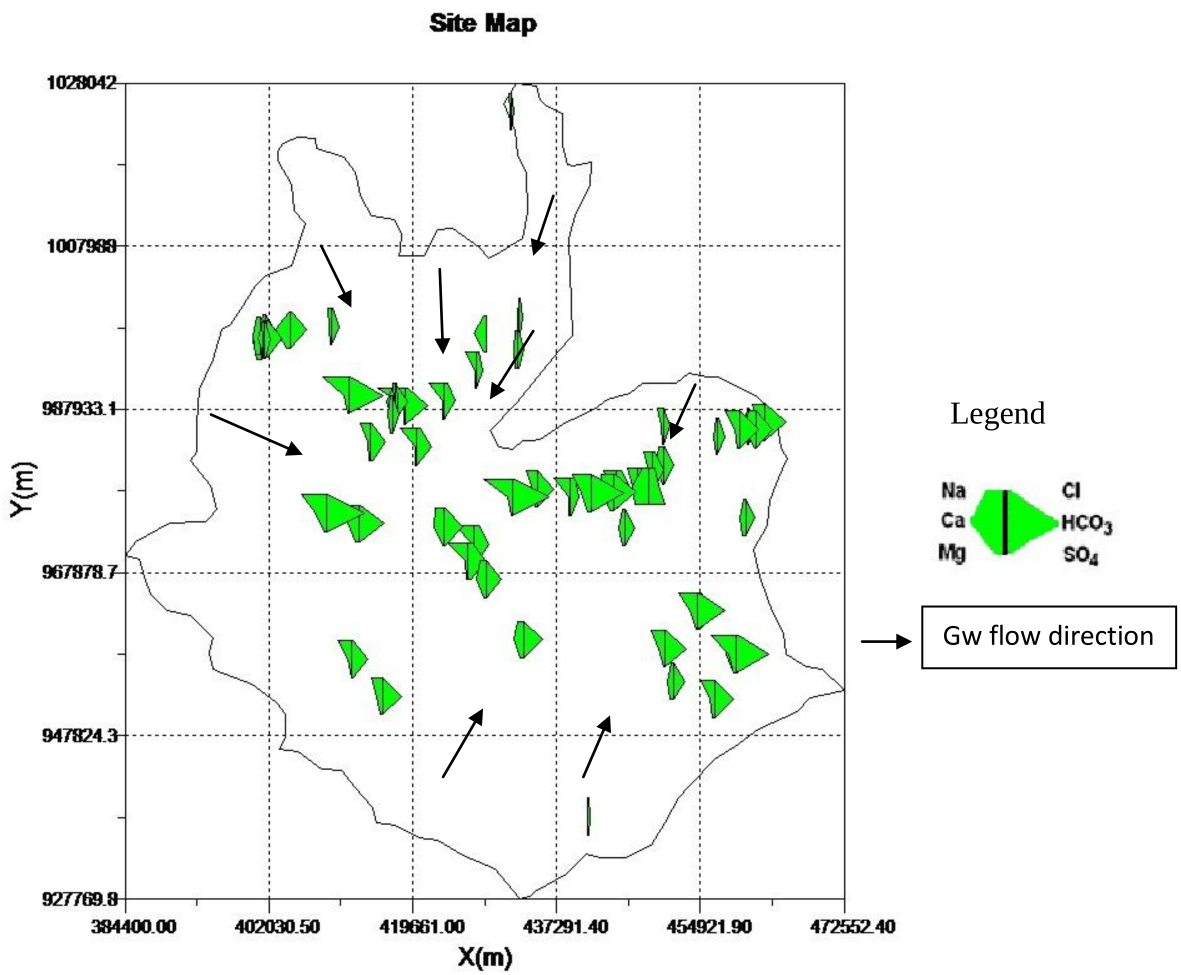

Figure 5.12. Hydrochemical map

5.7. Water Quality Assessment for Different Application

The main purpose of water quality analysis is to check the suitability of water for different purposes such as domestic, agriculture, and industrial. By looking the water, one cannot say this water is used for different purposes unless water quality analyses are conducted. Based on the analysis result of major and important parameters, suitability of groundwater can be determined. For drinking water different countries have different guideline value represents the maximum level of concentration of constituents.

According to Freeze and Cherry (1979) water for any purpose is classified in to four categories based on TDS. These are water having TDS value 0 to 1000mg/l is fresh water, values between 1000-10,000mg/l indicate brackish water, and Saline water has value of 10,000 to100, 000mg/l and value greater than 100,000mg/l is Brine water.

Both primary data and secondary data shown in appendix 2 and 4 respectively indicate that the groundwater in the study area is fresh water except one sample (BHT1313) which has TDS value 1010mg/l.

5.7.1. Water quality for Domestic use

In above section, different physiochemical parameters were described. The water quality of study area is compared with the water quality standards of WHO and ESA to understand the groundwater suitability for drinking purpose as follows.

Physiochemical parameters	Ethiopian Standard mg/l	WHO maximum allowable concentration mg/l	In Study Area Ranges From minimum to maximum	Number of sample exceeds the standard limit
PH	6.5-8.5	6.5-8.5	6.42-8.4	None
EC (µs/cm)	-	-	90.8 -896	-
TDS(mg/l)	1000	1000	79-400	None
Turbidity(NTU)	5	5	Nil to 63	5
Sodium (mg/l)	200	200	9.58-255.1	3
Calcium(mg/l)	75	200	3.61- 94.4	6 as ES and none as WHO
Magnesium(mg/l)	50	150	2.36-18.72	None
Potassium (mg/l)	15	12	1.2-5.97	None

Bicarbonate(mg/l)	-	-	44.8-866	-
Nitrate(mg/l)	50	45	0-35.36	None
Chloride (mg/l)	250	250	3.6- 22	None
Sulphate (mg/l)	250	400	Nil to 15	None
Fluoride (mg/l)	1.5	1.5	0.15-1.6	1
Iron (mg/l)	0.3	0.3	0.01-1.1	6
Manganese (mg/l)	0.5	0.1	Nil to 0.5	None as ESA & 3 above WHO
Chromium (mg/l)	0.05	0.05	Nil to 0.26	6
Copper (mg/l)	2	1.5	Nil to 0.31	None
Total Hardness(mg/l)	300	300	54-416	4

Table.5.4. WHO & Ethiopian Standard drinking water quality

5.7.2. Water Quality for Agriculture

In the study area, the cultivation of crop is mainly dependent on rainy seasons. Despite the presence of main perennial surface water and good groundwater potential resource the habit of cultivation using irrigation is not common. However, in some places there is a habit of using small scale and mechanized irrigation activity. So other than for drinking purpose, the water quality of the study area should be delineated and analyzed for irrigation purpose.

Water quality used for agricultural is determined depend on the effect of water on the quality, yield of crops, on drainage and characteristic changes in the soil (Richards, 1954; Wilcox, 1955). The quality of water for irrigation should be free from the impurities, which retard plant growth, is not satisfactory for irrigation.

The widely chemical parameter used for estimating the level of suitability of water for irrigation is electrical conductivity, sodium percentage (%Na) and sodium adsorption ratio (SAR).

5.7.2.1. Electrical Conductivity (EC)

The US salinity criteria are depending on the electric conductivity (EC) values. The EC value of the study area varies from 90.8 to 896 us/cm. The value of EC measurements show that both ground and surface water of the study area is suitable for irrigation purpose except two samples are saline groundwater. Spring sample (S1) from Kimoye area and Shallow well (SH1) from Indode area has relatively higher EC value of 829 and 896us/cm, respectively. These could be hard for irrigation purpose of most crops; however, it may be satisfactory for plants having moderate salt tolerance.

5.7.2.2. Sodium percentage (%Na)

Sodium percentage also used for evaluating the suitability of water quality for irrigation. High value of sodium concentration in groundwater has effect on soil permeability and soil structure there by results in little or no plant growth (Domenico PA and Schwartz FW, 1990). The %Na is calculated with respect to relatively proportions of cations like calcium, potassium and magnesium in water using the following formula.

$$\%Na = \frac{(Na+K)100}{Ca+Mg+Na+K}$$

Where, the concentrations of ions are expressed in meq/l

The calculated value of %Na in study area varies from 26% to 79% and few water samples collected from study area is greater than 60% (appendix 6). Irrigation water having sodium percentage more than 60% may lead to sodium accumulation and destruction of soil structure (Naseem S. et al,. 2010).Table 5.5 shows the Classification of water for irrigation purpose based on SAR, EC and %Na.

5.7.2.3. Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio is one of the most used water quality criteria for irrigation purpose. In 1954 the United States Salinity Laboratory proposed that the sodium effect be calculated by the sodium adsorption ratio (SAR method). The SAR value can be calculated from the following formula.

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}}$$

, where the concentration of sodium, Calcium, and magnesium ions are expressed in mill equivalent per litter.

The chemical analysis shows that most of the water samples analyzed have SAR value less than 10 that is Excellent for irrigation.

The criteria used to determine the suitability of water for irrigation based on SAR value, salinity hazard, and sodium hazard is summarized in table 5.4, which is adapted from Tenalem Ayenew and Tamiru Alemayehu (2001).

Water class	EC(us/cm)	Alkali Hazard(SAR)	%Na
Excellent	<250	Up to 10	<20
Good	250 to750	10-18	20-40
Medium (permissible)[x]	250 to 2250	18-26	40-60
Bad (doubtful) [x]	2210 to4000	>26	60-80
Very bad (unsuitable) [x]	>4000		>80

[x] Note that terms in the brackets are used to express %Na

Table 5.5. Classification of water for irrigation purpose based on SAR, EC and %Na.

Depend on the salinity hazard and sodium hazard Wilcox's diagram used for the classification of water for irrigation by plot the EC value against %Na using Aquachem 4.0 is indicated as follows.

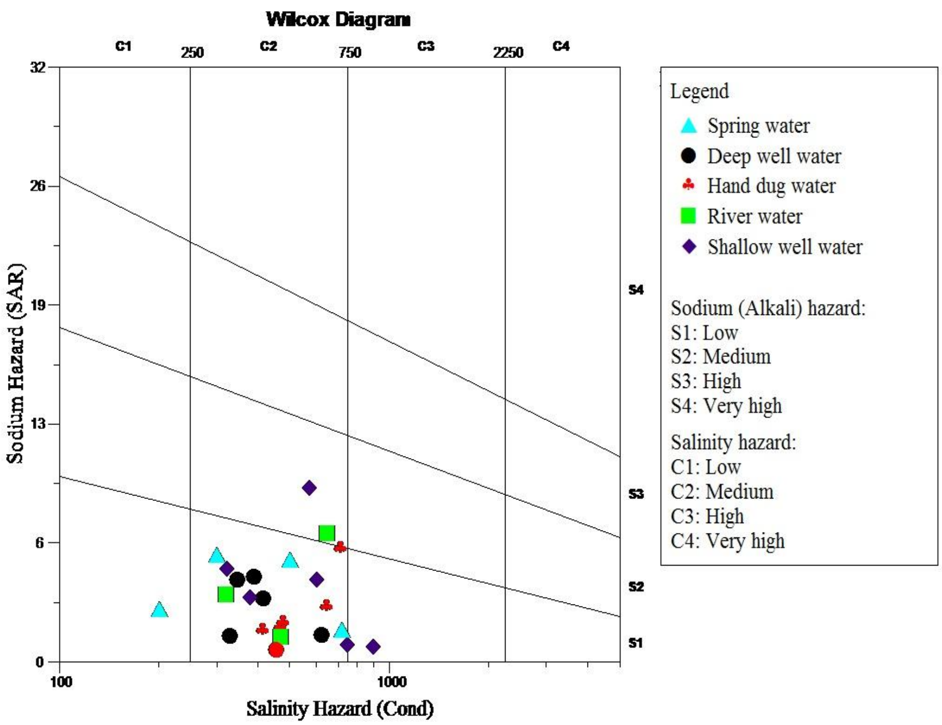

Figure 5.13. Wilcox Diagram of Sodium Hazard versus Salinity Hazard in the Study area.

As shown on above figure, most of the groundwater and river water plotted on low sodium hazard and medium salinity hazard are S1 and C2, which indicate that most of sample waters in the study area are good for irrigation. The result further indicate that the shallow water sample (SH4) taken from Teji area and river water sample taken from Kersa Warko area are plotted on the medium alkali hazard (S2) and medium salinity hazard (C2). These indicate that the water points contain high value of sodium concentration. The value of sodium of Awash river at Kersa Warko is due to industrial waste product contain sodium ion join the river at Awash Melka Kunture as already mentioned. The high alkali hazard of shallow well at Teji is may be due to the road construction material added to the area since the well is located near to the road.

Water sample from Shallow well (SH3) is the only well plotted on high salinity (C3) and the only spring water sample (S6) plotted on low salinity (C1) (fig 5.13).

5.7.3. Industrial Purpose

The quality of water required at different industries are widely varies based on the type of industries' processes and products. Even within a single industry, criteria cannot be established, instead, only recommended limiting value or ranges can be formulated. The water quality Parameters usually important for industry is hardness, salinity, and silica content.

Industry and process	Turbidity	Colour	Taste and odor	Dissolve solid	Hardness as $CaCO_3$	Alkalinity	PH
Food processing factory	1-10	5-10	low	850	10-250	30-250	>7.5
Tanning	20	10-100	low		50-500	130	6.0-8.0
Textile	0.3-25	0-70	low	0-50			

Table 5.6. Parameters limiting concentration recommend for industrial process (Todd, 1980)

Comparing the analysis result of sample data within the above table shows that all the sample in the study area fit for all industrial type except the hand dug sample (HD1) from Sarmeti area that has a value of 36.4 NTU and water sample from awash river at Dibu area, which has value of 63 NTU concerning the turbidity value (appendix 3). The hardness of the study area varies from 54 to 416mg/l. Accordingly, most of the sample data are not fit for Food processing factory due to high value of hardness >250mg/l (appendix 3).

Chapter Six

Conclusion and Recommendation

6.1. Conclusion

The study area, Western part of Upper Awash, is located in Awash basin; central Ethiopia. The absolute geographical location of the area is between 9°15'N-8°30'N latitude and 38°00'E-38°45'E longitude with an area and perimeter of 4,574.24 square kilometers and 392.68 kilometers, respectively. The rock formation of the study area is volcanic rocks such as Ignimbrite, Trachytes, Tarmaber Basalt, Rhyolites, Alluvial deposit and Basalts. The study area is comprises rugged mountains, flat lands and plains at its central and characterized by dendritic drainage pattern. The major land use/cover (LULC) of study area consists the cultivated agricultural land, grass land, wetland and shrub land. Aquifer in the area includes regional and local aquiclude, upper and lower basaltic aquifer and primary porosity aquifer.

The main objective of this study is to evaluate the water quality in terms of physiochemical and determining its criteria for drinking, irrigation, and industrial purposes. The chemical analyze result of collected samples from study area show the value of PH and EC varies 6.42 to 8.4 and 90.8 to 896µs/cm, respectively. In terms of TDS, it varies from 79 to 400 mg/l that indicates low degree of water-rock interaction. The total hardness of sample analyzed also varies from 54 to 416mg/l, which show that some of the water samples are hard water and most of it is soft and medium water. The dominant cation in study area is in order sodium >calcium >magnesium> potassium and the dominant anions is bicarbonate. Most of the water samples are within the WHO allowable concentration and Ethiopian Standard guidelines for drinking water. However few sample area above these limits.

For further analysis, primary data and secondary data from previous work were also used in Aquachem database and Hierarchical Cluster Analysis (HCA). Based on the dominant cations and anions, the water types in the study area were identified by using Aquachem database. These water types include NaCaHCO3, CaNaHCO3, CaHCO3, CaMgNaHCO3 and NaHCO3. Majority of the water point in the study area belongs to NaCaHCO3 and CaNaHCO3. The value of TDS of water sample belongs to NaCaHCO3 is <360mg/l. Some deep well, shallow well, spring and hand dug well associated with NaCaHCO3 with dilute chemistry (low TDS). CaNaHCO3 associated with moderately mineralized waters and the TDS value of this water type ranges from 159-540mg/l in study area. Water sample collected from the area covered by Tertiary Acidic Volcanic Rocks, which includes Addis Ababa ignimbrite, trachytes and Rhyolites were characterized by this water type.

On the other hand, four groups or clusters with different characterstics were identified using Multivariate analysis techniques. Group 1 is characterized by TDS ranges from 79mg/l to 416mg/l and has sodium, calcium, magnesium and bicarbonate as major composition and located in plateau area. Group 2 is located in central part of the study area, which has low elevation area when it is compared with other areas like plateau. The entire samples belong to this group are NaCaHCO3 water type except shallow well (SH) around Teji that is NaHCO3 Water type. The TDS of the group varies from 151mg/l to 355.5mg/l. The groundwater and river water (R1and R2) samples categorized under this group have similar water type, which shows the groundwater getting recharge from River and precipitation.

Group 3 is characterized by moderately mineralized waters (TDS >207≤597mg/l). This group mainly has high calcium, magnesium and sodium composition and consequently CaNaHCO3, CaMgNaHCO3 and CaMgHCO3 water type. Most of the samples were clustered in this group and distributed in all the study area. Group 4 is characterized by high value of Sodium and HCO3 composition and the high concentration sodium in this area is related with the abundance of acidic volcanic rocks. The study area is characterized by dilute water, which indicates the low rock-water interaction.

The sodium adsorption ratio is one of the most used water quality criteria for irrigation purpose. Based on sodium absorption ratio, the chemical analysis shows that most of the water sample analyzed has SAR value less than 10 that is Excellent for irrigation.

In general this study shows that the water quality of the study area is good for drinking, irrigation and industrial purpose in terms of physiochemical parameters with few exceptions.

6.2. Recommendation

- ✓ Manage waste product released from the study area urban industry and factory, for instance Sebeta, is highly recommended.
- ✓ More study is needed to investigate the water quality in detail in the area by using other methodologies like inverse geochemical model and isotope analysis.
- ✓ Most of the rural people depend on: river water, hand dug well, hand pump well, deep well, and spring water. However, some rural people face scarcity of water during winter season and go far distance for searching it. Hence, I recommend drilling additional boreholes for these societies to solve the problems.
- ✓ Water quality data is not stored and managed in Zonal offices this should be improved in future.
- ✓ Detail investigation of hydrogeological and hydrogeochemical is needed in the study area in future study.

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Appendices

Appendix 1. Data used for groundwater contour line

Label	UTME	UTMN	Depth	Type	Z-Dem	SWL	GW elevation
1	432432	1024464	161	Deep Well	2598.559	11	2587.559
2	437892	1008952	13	Dug Well	2588.693	4	2584.693
3	436160	1000453	153	Deep Well	2357.003	37	2320.003
4	435382	1000251	206	Deep Well	2351.505	10	2341.505
5	434015	1000129	147	Deep Well	2338.867	5	2333.867
6	434091	1000046	102	Shallow well	2344.137	4	2340.137
7	431584	998853	0	Spring	2310.401	0	2310.401
8	433722	996293	50	Shallow well	2160.118	1	2159.118
9	427164	996290	37	Shallow Well	2151.982	0	2151.982
10	427193	994953	0	Spring	2123.348	2	2121.348
11	427635	994816	125	Deep Well	2117.376	7	2110.376
12	429252	993949	45	Shallow Well	2109.182	15	2094.182
13	427395	992768	220	Deep Well	2099.458	6	2093.458
14	430267	987498	38	Shallow Well	2069.817	5	2064.817
15	429529	987244	37	Shallow Well	2072.206	4	2068.206
16	416945	988222	49.2	Shallow Well	2101.722	7	2094.722
17	410870	997013	0	Spring	2190.158	0	2190.158
18	404656	997733	81	Shallow Well	2228.681	22	2206.681
19	401801	996640	246	Deep Well	2304.717	20	2284.717
20	401219	985083	50	Shallow Well	2388.651	17	2371.651
21	404051	980357	83	Shallow Well	2223.625	4	2219.625
22	404050	980200	99	Shallow Well	2223.062	10	2213.062
23	406762	969708	120	Deep well	2143.083	8	2135.083
24	406603	970020	40	Shallow Well	2148.014	6	2142.014
25	407400	972711	172	Deep Well	2133.748	19	2114.748
26	409122	975187	15	Dug Well	2103.729	14	2089.729
27	413137	973900	311	Deep well	2085.866	10	2075.866
28	415715	976666	7	Dug Well	2074.681	6	2068.681
29	416140	977209	8	Dug Well	2074.825	7	2067.825
30	415528	977263	8	Dug Well	2074.58	7	2067.58
31	418707	974898	12	Dug Well	2078.408	10	2068.408
32	423375	973439	20	Dug Well	2087.716	19	2068.716
33	424094	968971	24	Dug Well	2097.665	22	2075.665
34	427126	971361	308	Deep Well	2082.062	4	2078.062

35	427135	971582	312	Deep Well	2081.942	5	2076.942
36	427829	976797	64	Shallow Well	2068.658	3	2065.658
37	430627	975957	70	Shallow Well	2068.953	2	2066.953
38	400409	954207	48	Shallow Well	2378.888	22	2356.888
39	407460	953526	36	Shallow Well	2279.101	9	2270.101
40	408475	952876	50	Shallow Well	2273.885	10	2263.885
41	412197	957215		Spring	2174.673	0	2174.673
42	412826	949736	50	Shallow Well	2265.077	0	2265.077
43	424000	952736	112	Shallow Well	2176.674	5	2171.674
44	460062	948743	109	Shallow Well	2107.469	48	2059.469
45	462875	950361	187	Deep Well	2075.03	119	1956.03
46	458959	953532	130	Deep Well	2016.014	67	1949.014
47	444245	956023	158	Deep Well	2217.587	96	2121.587
48	448328	957872	139	Deep Well	2132.488	85	2047.488
49	459285	961268	0	Spring	2075.51	0	2075.51
50	456740	962388	39	Shallow Well	2004.567	3	2001.567
51	456314	962592	290	Deep Well	2017.884	0	2017.884
52	454852	962780	56	Shallow Well	2001.207	2	1999.207
53	445144	969045	86	Shallow Well	2086.599	45	2041.599
54	445354	969451	71	Shallow Well	2090.583	39	2051.583
55	451420	971692	60	Shallow Well	2067.699	58	2009.699
56	460464	974637	61	Shallow Well	2092.531	38	2054.531
57	453850	973096	59	Shallow Well	2054.627	56	1998.627
58	461900	974300			2130.585	38	2092.585
59	460950	976800	0	spring	2107.216	0	2107.216
60	460810	981473	102	Shallow well	2219.067	67	2152.067
61	441831	983807	50	Shallow Well	2076.002	6	2070.002
62	441901	981393	7	Dug Well	2064.844	6	2058.844
63	441366	977899	10	Dug Well	2064.298	8	2056.298
64	444624	978143	65	Shallow Well	2063.949	10	2053.949
65	444000	977700	100	Shallow Well	2069.415	17	2052.415
66	442842	977555	100	Shallow Well	2068.017	14	2054.017
67	442811	977625	179	Deep well	2068.843	10	2058.843
68	450359	981037	280	Deep Well	2076.24	11	2065.24
69	453538	982154	80	Shallow well	2087.746	8	2079.746
70	451249	985378	0	spring	2148.395	0	2148.395
71	455426	982736	150	Deep well	2102.376	16	2086.376
72	455450	983014	120	Deep Well	2107.742	15	2092.742
73	455550	983750	181	Deep Well	2134.675	47	2087.675

74	455525	984000	124	Deep Well	2143.725	63	2080.725
75	455350	985100	128	Deep Well	2182.328	70	2112.328
76	457030	984617	140	Deep Well	2208.17	89	2119.17
77	455300	985250	101	Shallow well	2188.38	38	2150.38
78	455000	985200	126	Deep Well	2232.735	51	2181.735
79	455287	985619	0	spring	2214.892	0	2214.892
80	458646	984363	161	Deep Well	2186.326	44	2142.326
81	459676	984947	96	Shallow Well	2203.535	28	2175.535
82	459831	985582	0	spring	2222.442	0	2222.442
83	460121	985966	120	Deep well	2249.126	40	2209.126
84	460850	985850	106	Shallow well	2248.226	43	2205.226
85	461412	986324	145	Deep well	2274.595	45	2229.595
86	460937	986565	114	Shallow well	2271.057	46	2225.057
87	460500	986500	100	Shallow well	2289.809	27	2262.809
88	460295	986769	158	Deep well	2305.932	31	2274.932
89	462500	987000	137	Deep well	2305.189	84	2221.189
90	462260	984901	180	Deep well	2287.652	83	2204.652
91	463742	985378	125	Deep well	2358.894	18	2340.894

Appendix 2. Primary data (Major ions)

Note: - S: Spring, DW: Deep well, SH: Shallow well, HD: Hand dug well and R: River unit is mg/l for major ions and TDS.

Sample ID	Location Name	UTME	UTMN	T	PH	EC	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
S1	Kimoyee	428640	997249	24.4	7.06	829	378	19.4	4.14	8.39	89.4	10.7	6	_	
S2	Baradoo	409765	998106	25.4	7.99	722	297	33.66	1.51	6.43	20.4	14.2	3.5	158.1	12
S3	Tuka Godeti	441128	937902	21.7	7.66	90.8	79	9.58	4.31	2.36	3.61	3.6	6	44.8	2
S4	Balci Jimjima	454546	963154	20.9	7.11	503	251.5	167.8	5.8	9.12	56.8	8	7	637	14.08
S5	Tulubolo	412213	957245	20.8	7.16	302	151	126.1	5.5	4.32	29.6	10	9	378	8.36
S6	Bole	450350	985917	19.9	6.42	202	101	46.7	3.4	5.28	12.8	12	4	168	7.51
DW1	Arada	432734	999365	22.6	7.89	453	204	10.64	2.2	6.79	12.8	3.6	9	73.2	13.2
DW2	Asiko	431686	1024561	19	7.9	328	150	19.68	1.2	3.36	9.88	14.2	5.5	59.1	8
DW3	Awash Bole	401474	996479	24	7.95	622	270	26.68	5.49	7.83	14.7	7.1	8	124.28	7.78
DW4	Roge	450602	958545	21.2	7.12	388	194	124.5	5.8	6.72	46.4	8		480.5	6.16
DW5	Lemen	456651	952335	20.6	7.09	347	173.5	116.4	4.5	7.68	41	8		441.2	9.68
DW6	Alemgena	462787	986359	19.7	7.34	415	207.5	107	3.4	10.6	57.6	12	1	492.5	12.38
SH 1	Indode	432523	995327	25.7	7.5	896	400	19.83	1.6	10.2	32.9	14.2	13	151.5	11
SH 2	Keta	417150	987324	24.3	7.65	744	342	21.67	3.01	8.52	32.1	7.1	15	146	9.2
SH 3	Abatare	415935	952699	20.1	7.24	379	189.5	99.8	4.6	9.6	48.8	6	1	439	2.21
SH 4	Teji	431879	977130	21.4	7.33	574	287	255.1	3.6	8.16	43.2	10		848.6	4.84
SH 5	Bonde	441480	977639	19.8	7.04	602	301	166.4	4.6	18.7	78.4	8	0.01	771	0.44
SH 6	Sebeta	459710	985471	19.5	7.33	322	161	128.7	5.5	11	32.8	8	1	451.59	6.19
HD1	Sarmexii	409122	975187	20.5	7.21	711	355.5	226.1	3.5	11.5	86.4	6	6	866	0
HD2	Wasarbi	428642	967086	21.2	7.22	414	207	57.3	2.7	9.12	71.2	10	7	349	9.68
HD3	Citu	423533	973509	19.9	7.02	476	238	76.9	2.3	10.6	83.2	16	3	440.56	0.44
HD4	Tefki	444308	977778	20.1	7.13	646	323	112.8	2.9	16.8	94.4	22	3	536.49	35.36
HD5	Daleti	461708	985469	21.1	6.95	469	234.5	65.1	2.4	7.2	81.6	8	2	398	12.76
R1	Kore	417517	988937	21.7	8.4	468	208	22.89	5.97	6.29	12.2	21.3	9	69.5	14
R2	Kersa Worko	459325	957871	20.1	7.86	647	323.5	222	2.55	13	57.6	22	1	751.79	0.44
R3	Dibu	434890	978182	20.5	8.37	320	160	96.6	3.3	10.6	37.6	12	4	388	6.16

Appendix 3. Primary data (Minor ions and Trace element)

Sample ID	Location Name	UTME	UTMN	Depth	Total Hardness	Turbidity	Fe	F	Cu	Cr	Mn
S1	Kimoyee	428640	997249	2134	394	_	0.59	0.33	0.31	0.22	0.13
S2	Baradoo	409765	998106	2213	284	_	Nil	0.71	0.01	Nil	Nil
S3	Tuka Godeti	441128	937902	2305	80		0.21	0.35	0.04	0.06	0.01
S4	Balci Jimjima	454546	963154	1979	180	19.4	0.09	1.3	0.05	0.03	0.1
S5	Tulubolo	412213	957245	2164	92	0.38	0.01	0.74	0.02	0.17	0.1
S6	Bole	450350	985917	2148	54	23.8	0.53	Nil	0.01	0.02	0.1
DW1	Arada	432734	999365	2364	212		0.15	0.15	0.04	Nil	0.01
DW2	Asiko	431686	1024561	2614	132	_	0.16	0.42	0.04	0.26	0.01
DW3	Awash Bole	401474	996479	2294	240	_	0.24	0.66	0.04	0.11	0.04
DW4	Roge	450602	958545	2088	144	0.2	Nil	0.85	0.04	0.03	0.1
DW5	Lemen	456651	952335	2066	134	0.37	Nil	0.98	Nil	0.02	Nil
DW6	Alemgena	462787	986359	2285	188	0.08	0.05	0.79	Nil	0.02	0.08
SH 1	Indode	432523	995327	2149	416	2	0.32	0.41	0.02	Nil	0.01
SH 2	Keta	417150	987324	2107	320	_	Nil	1.17	0.01	0.01	0.01
SH 3	Abatare	415935	952699	2219	162	0.06	0.02	0.76	0.01	0.02	0.1
SH 4	Teji	431879	977130	2060	142	0.49	0.01	1.6	Nil	0.02	0.1
SH 5	Bonde	441480	977639	2056	274	1.67	0.02	0.87	Nil	0.01	0.02
SH 6	Sebeta	459710	985471	2238	128	0.09	0.03	1.08	Nil	0.03	0.05
HD1	Sarmexii	409122	975187	2106	264	36.4	0.21	0.86	0.24	0.06	0.5
HD2	Wasarbi	428642	967086	2110	216	2.33	Nil	1.42	Nil	0.02	Nil
HD3	Citu	423533	973509	2076	252	11.76	0.03	0.98	Nil	0.01	0.1
HD4	Tefki	444308	977778	2068	306	1.1	0.08	0.82	Nil	0.01	0.1
HD5	Daleti	461708	985469	2230	234	0.13	0.01	0.57	Nil	0.02	Nil
R1	Kore	417517	988937	2083	184	4.5	1.1	0.6	0.02	Nil	0.12
R2	Kersa Worko	459325	957871	1909	198	1.35	0.67	0.85	Nil	0.03	0.2
R3	Dibu	434890	978182	2048	138	63.7	0.59	0.23	Nil	0.04	0

Appendix 4.Secondary data

ID	Location	UTME	UTMN	TDS	T	PH	Na	K	Ca	Mg	Cl	NO3	F	HCO3	SO4
BHT167	Adis Alem	433779	1000228	283.4	20	6.9	12.8	2.5	63.6	15.3	5.2	6.6	0.3	286.9	0.2
BHT111	Adis Alem Amaro#1	430267	987498	380	20	7.4	42	3.6	82.7	14.3	19.2	7	1.7	350	21.7
BHT94	WolenkomiBH	415726	995659	304.9	20	6.9	75	2.8	37.2	4.1	14.4	0.4	1.1	312.6	1.8
BHT-381	Ginchi	404656	997733	434	21.5	7.7	12	2.3	114	15.1	15.5	25	0.4	384.3	9
BHT-1308	GinchiGPW#3	401587	997298	290	20	8.4	24	4.1	48	19.2	4.7	5	0.6	275	2.4
BHT-1309	GinchiGPW#4	400975	997008	354	20	8.6	32.5	5.1	52.8	23.4	5.7	8.8	0.6	310	12.2
BHT-1306	GinchiGPW#1	401157	996412	370	20	8.4	30	5.5	67.2	22.1	1.9	3.1	0.7	360	0.7
BHT90	Ginchi ChinaBH1	401801	996640	352	20	7.6	37	6.7	72	14.4	2.8	0.5	0.7	356.2	4.2
BHT1370	STTW1	438871	977181	376	35.9	7.9	136	4.8	3.8	4.1	71	0.4	1.3	230	35.4
BHT1557	Alem-Gena-D/yohanis	445643	973409	219	20	7.1	17	4.2	50	8.3	2.9	7.5	0.8	235.7	0.5
BHT433	Tefki	444624	978143	455	23.5	7.4	116	6.6	36.4	6.1	56.6	4.8	3.6	345.9	15.6
BHT1371	STTW-2	447224	978514	383	29.2	7.1	91	8.7	36.8	8.8	42.8	0.8	0.7	229.5	72.5
BHT19	Tefki STTW-2	448502	978502	520	20	7.4	53	7	119	59.8	99	0	1.6	258.2	306
BHT1372	STTW-3	449082	980399	312	30.3	7.3	78	8.1	29.6	6.8	23.7	3.2	0.9	259.6	18.2
BHT994	Sebeta-Dragados	457030	984617	597	20	6.9	16	3.4	36	9	5	8.7	0.5	178	2.6
BHT900	Sebeta Agro No.1	460850	985850	159	20	6.7	16	3.1	28.8	4.8	3.9	14	0.5	141.5	1.8
BHT901	Sebeta Agro No.2	460464	974637	236	20	7.1	15.5	1.8	47	13.8	5.8	11.5	2.6	226.5	0.6
BHT1553	Muti Dayu	451590	954524	280	20	7.2	20	11	50.5	14.8	7.7	11.5	1.6	273.8	0.6
BHT1313	BTW4	411777	989671	1010	22	6.5	230	24	35	4.8	18	0.7	8	811	0.1
BHT1310	BTW1	418679	988365	596	22	8.5	235	3	6	4.6	41.9	1.2	1.7	525	13.8
BHT1312	BTW3	420071	983317	490	22	7.4	140	12.8	12	4.8	48.3	0.7	1.3	368.9	5.9
BHT218	Teji-Dimajalewa	413137	973900	540	27	7.6	69	13.5	94.1	21.4	4.1	7.1	2.4	588.5	1.7
BHT217	Bantu-jawarokora	433200	959670	404	23	7.3	52	8	75	13.3	9.9	1.7	1.3	445.8	0.9
BHT203	Asgori	427126	971361	572	39	7.3	160	23	9.7	2.7	63.4	0.1	2.2	366	44.1
BPT-003-10B	Ude	426362	969316	626		7.4	176	19.5	19	3.19	62.5	16.4	1.07	401.01	69.9
BPT-012-10B	Melka	454868	963109	310		6.9	49	11	56	8.16	7.27	2.43	0.61	329.4	5.65
AMW14	Harojila	450359	981037	312		7.6	45	5.4	54.6	4.32	13.4	5.33	1.13	255.45	7.65
AMW26	Kimoyekoradimaa	427395	992768	282		8.8	92	1.3	3.4	1.02	34.8	5.78	0.97	158.6	15.6
BTW-05B	Bajiga woyecha	414489	983944	416		7.7	90	12.6	21.1	10.37	18.9	0.02	0.65	334.28	30.6
BTW-02B	Necho	423439	988990	354		8.2	128	3.1	10.4	4.8	53.1	1.04	0.59	256.2	11.9

Appendix 5. Clustering of Water in the study area into groups

Group 1 Note: - P: Primary data, S: Secondary data

Sample ID	UTME	UTMN	Source of data	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
S2	409765	998106	P	297	33.66	1.51	6.43	20.43	14.2	3.5	158.1	12
S3	441128	937902	P	79	9.58	4.31	2.36	3.61	3.6	6	44.8	2
S6	450350	985917	P	101	46.7	3.4	5.28	12.8	12	4	168	7.51
DW1	432734	999365	P	204	10.64	2.2	6.79	12.8	3.6	9	73.2	13.2
DW2	431686	1024561	P	150	19.68	1.2	3.36	9.88	14.2	5.5	59.1	8
DW3	401474	996479	P	270	26.68	5.49	7.83	14.71	7.1	8	124.28	7.78
R1	417517	988937	P	208	22.89	5.97	6.29	12.2	21.3	9	69.5	14
BHT94	415726	995659	S	304.9	75	2.8	4.1	37.2	14.4	1.8	312.6	0.4
BHT1372	449082	980399	S	312	78	8.1	6.8	29.6	23.7	18.2	259.6	3.2
BHT900	460850	985850	S	159	16	3.1	4.8	28.8	3.9	1.8	141.5	14
AMW14	450359	981037	S	312	45	5.4	4.32	54.6	13.4	7.65	255.45	5.33
AMW26	427395	992768	S	282	92	1.3	1.02	3.4	34.8	15.61	158.6	5.78
BTW-05B	414489	983944	S	416	90	12.6	10.37	21.12	18.93	30.62	334.28	0.02

Group 2

Sample ID	UTME	UTMN	Source of data	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
S4	454546	963154	P	251.5	167.8	5.8	9.12	56.8	8	7	637	14.08
S5	412213	957245	P	151	126.1	5.5	4.32	29.6	10	9	378	8.36
DW4	450602	958545	P	194	124.5	5.8	6.72	46.4	8	0	480.5	6.16
DW5	456651	952335	P	173.5	116.4	4.5	7.68	41	8	0	441.2	9.68
DW6	462787	986359	P	207.5	107	3.4	10.56	57.6	12	1	492.5	12.38
SH 3	415935	952699	P	189.5	99.8	4.6	9.6	48.8	6	1	439	2.21
SH 4	431879	977130	P	287	255.1	3.6	8.16	43.2	10	0	848.6	4.84
SH 5	441480	977639	P	301	166.4	4.6	18.72	78.4	8	0.01	771	0.44
SH 6	459710	985471	P	161	128.7	5.5	11.04	32.8	8	1	451.59	6.19
HD1	409122	975187	P	355.5	226.1	3.5	11.52	86.4	6	6	866	0
R2	459325	957871	P	323.5	222	2.55	13	57.6	22	1	751.79	0.44
R3	434890	978182	P	160	96.6	3.3	10.56	37.6	12	4	388	6.16

Group 3

Sample ID	UTME	UTMN	Source of data	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
SH 1	432523	995327	P	400	19.83	1.6	10.19	32.88	14.2	13	151.5	11
SH 2	417150	987324	P	342	21.67	3.01	8.52	32.06	7.1	15	146	9.2
HD2	428642	967086	P	207	57.3	2.7	9.12	71.2	10	7	349	9.68
HD3	423533	973509	P	238	76.9	2.3	10.56	83.2	16	3	440.56	0.44
HD4	444308	977778	P	323	112.8	2.9	16.8	94.4	22	3	536.49	35.36
HD5	461708	985469	P	234.5	65.1	2.4	7.2	81.6	8	2	398	12.76
BHT167	433779	1000228	S	283.4	12.8	2.5	15.3	63.6	5.2	0.2	286.9	6.6
BHT111	430267	987498	S	380	42	3.6	14.3	82.7	19.2	21.7	350	7
BHT-381	404656	997733	S	434	12	2.3	15.1	113.9	15.5	9	384.3	25
BHT-1308	401587	997298	S	290	24	4.1	19.2	48	4.7	2.4	275	5
BHT-1309	400975	997008	S	354	32.5	5.1	23.4	52.8	5.7	12.2	310	8.8
BHT-1306	401157	996412	S	370	30	5.5	22.1	67.2	1.9	0.7	360	3.1
BHT90	401801	996640	S	352	37	6.7	14.4	72	2.8	4.2	356.2	0.5
BHT1557	445643	973409	S	219	17	4.2	8.3	50	2.9	0.5	235.7	7.5
BHT994	457030	984617	S	597	16	3.4	9	36	5	2.6	178	8.7
BHT901	460464	974637	S	236	15.5	1.8	13.8	47	5.8	0.6	226.5	11.5
BHT1553	451590	954524	S	280	20	11	14.8	50.5	7.7	0.6	273.8	11.5
BHT218	413137	973900	S	540	69	13.5	21.4	94.1	4.1	1.7	588.5	7.1
BHT217	433200	959670	S	404	52	8	13.3	75	9.9	0.9	445.8	1.7
BPW-012-10B	454868	963109	S	310	49	11	8.16	56	7.27	5.65	329.4	2.43

Group 4

Sample ID	UTME	UTMN	Source of data	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	NO3
BHT1370	438871	977181	S	376	136	4.8	4.1	3.8	71	35.4	230	0.4
BHT433	444624	978143	S	455	116	6.6	6.1	36.4	56.6	15.6	345.9	4.8
BHT1371	447224	978514	S	383	91	8.7	8.8	36.8	42.8	72.5	229.5	0.8
BHT1313	411777	989671	S	1010	230	24	4.8	35	18	0.1	811	0.7
BHT1310	418679	988365	S	596	235	3	4.6	6	41.9	13.8	525	1.2
BHT1312	420071	983317	S	490	140	12.8	4.8	12	48.3	5.9	368.9	0.7
BHT203	427126	971361	S	572	160	23	2.7	9.7	63.4	44.1	366	0.1
BPW-003-10B	426362	969316	S	626	176	19.5	3.19	19	62.46	69.88	401.01	16.4
BTW-02B	423439	988990	S	354	128	3.1	4.8	10.4	53.11	11.9	256.2	1.04

Appendix 6.Data used for evaluate water quality for irrigation.

Sample ID	UTME	UTMN	EC	SAR	%Na
S2	409765	998106	722	1.66	49
S3	441128	937902	90.8	0.96	58
S4	454546	963154	503	5.43	67
S5	412213	957245	302	5.73	75
S6	450350	985917	202	2.77	66
DW1	432734	999365	453	0.6	30
DW2	431686	1024561	328	1.38	53
DW3	401474	996479	622	1.4	48
DW4	450602	958545	388	4.52	65
DW5	456651	952335	347	4.38	66
DW6	462787	986359	415	3.4	55
SH 1	432523	995327	896	0.77	26
SH 2	417150	987324	744	0.88	30
SH 3	415935	952699	379	3.42	57
SH 4	431879	977130	574	9.33	79
SH 5	441480	977639	602	4.38	57
SH 6	459710	985471	322	4.96	69
HD1	409122	975187	711	6.06	65
HD2	428642	967086	414	1.7	37
HD3	423533	973509	476	2.11	40
HD4	444308	977778	646	2.93	45
HD5	461708	985469	469	1.85	38
R1	417517	988937	468	1.33	50
R2	459325	957871	647	6.88	71
R3	434890	978182	320	3.59	60