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**COLLEGE OF DEVELOPMENT STUDIES**

**CENTER FOR ENVIRONMENT AND DEVELOPMENT**

**GROUNDWATER QUALITY DISTRIBUTION OF ADDIS ABABA BASED ON  
CHEMICAL CONTENT**

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## **ABSTRACT**

Groundwater is the main source of freshwater for use in agricultural, industrial, and drinking purposes in Ethiopia. Addis Ababa City gets more than 60 % of its water supply from groundwater.

When groundwater moves from surface to underground sources, it passes through a large number of filtering media and hence becomes filtered. The resulting physical and chemical properties of groundwater are most importantly related to its relationship with the media, which the water encountered, and its residence time. Assessments of the groundwater quality to determine their spatial distribution have significant importance for further utilization and management of the resource.

This study was focused on selected five water quality parameters: Total Dissolved Solids (TDS), Nitrates ( $\text{NO}_3$ ), Iron (Fe), manganese (Mn) and Fluoride (F). 108 samples from wells that are located within Addis Ababa city were collected and analyzed to determine their water quality. Their spatial distribution analysis carried out using ArcGIS and the overall Water Quality Index also computed.

The results of the laboratory analysis indicated that significant number of wells have a water quality that was above WHO drinking water guide line values. This study showed that there are three kinds of water exists in Addis Ababa city: Groundwater with high iron and manganese at the northern part of the city, with high Fluoride and TDS in the central part of the city which extends to eastern direction of the city and groundwater with better water quality which complied with WHO permissible value at southern part of the City.

**Key Words:** Groundwater quality, Total Dissolved Solids, Nitrate, Iron, Manganese, Fluoride

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## **ABBREVIATIONS**

AAWSA	Addis Ababa Water and Sewerage Authority
a.m.s.l	above mean see level
DRASTIC	Depth, Recharge, Aquifer, Soil, Topography, Impact, Conductivity
TDS	Total Dissolved Solids
WHO	World Health Organization
YTVL	Yerer Tullu Welele Volcanic Lineament
WQI	Water Quality Index
DO	Dissolved Oxygen
GPS	Global Positioning System
PET	Polyethylene terephthalat
GIS	Geographical Information System
DAP	Di-ammonium phosphate
DNA	Deoxyribonucleic acid

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1 Background

Water plays vital role in human life. It is extremely essential for survival of all living organisms. More than 70 percent of Earth's surface is covered with water, however only 3% of this water is available as fresh water. The major portion of fresh water is found in groundwater or in the form of icecaps and glaciers. Owing to the natural interaction among the earth's subsystems, this pure water does not exist by default and its quality can be affected by some dissolved and or suspended substances of natural or anthropogenic origin, and consequently gets polluted.

Water pollution is the state of alteration in the natural, physical, chemical, biological, bacteriological and radiological properties of water that causes in an impairment of its inherent and/or designated uses (Susan and Joy, 1998). This also disturbs the biophysical entities of a water body and negatively affects the socioeconomic values of water. Therefore, monitoring, controlling and management of groundwater quality, as the main sources of fresh water, are important facts. According to the assessment of scientists and researchers, in the 21st century, the amount of world fresh water reserves will be reduced due to the global climate change, which will lead to the freshwater shortage in most countries.

The availability of water determines the location and activities of humans in an area and our growing population is placing great demands upon natural fresh water resources (Oladipo et al., 2011). Groundwater (GW), which is the main source of freshwater for use in agricultural, industrial, and drinking purposes in Ethiopia, is one of the most suitable

fresh water resources with nearly balanced concentration of the chemicals for human consumption. Overburden by means of population pressure, unplanned urbanization, unrestricted exploration policies and dumping of the polluted water at inappropriate places enhance the infiltration of harmful compounds to the groundwater (Pandey and Tiwari, 2008).

The water quality parameters are the key concern which needs to be informed to citizens and policy makers to ensure conservation and utilization of resources (Atulegwu and Njoku, 2004). In general, the quality of water is equally important as the quantity. The factors determining the quality of groundwater are the geological setting, source rocks property, recharge water composition, soil formations, lithology and the duration of time that the water body has been trapped underground (Faniran et al., 2004). These driving factors and their interrelations create critical groundwater quality. During the last two decades, many researchers have been studying on groundwater quality in different parts of the world. The main reason for the assessment of hydrochemistry is to understand processes that determine groundwater quality, both natural and anthropologic, in order to verify whether the observed water quality is suitable for an intended use.

## **1.2 Statement of the problem**

Groundwater is a very precious resource and its protection is very much important for the present and future generations. When ground water moves from surface to underground sources, it passes through a large number of filtering media and hence becomes filtered. Also the earth cover protects the water from surface pollutants. But as the ground water moves through rocks and subsurface soil, it is polluted by the dissolved substances and underground geologic strata. Different types of rocks affect ground water in different

ways, depending on many factors such as weathering, temperature and the properties of the strata through which ground water passes. Some rocks material dissolve very easily in ground water while some do not.

Ground water can get polluted from industrial, domestic, and agricultural chemicals when they percolate down into the ground water sources. Almost all the ground water contains salts but its nature depends on many factors such as movement and source of ground water. Soluble salts found in groundwater originate primarily from solution of rock materials (Foster, 1942). Sedimentary rocks are more soluble than the igneous rocks.

Water quality varies from place to place and with depth. Utilization of ground water depends on its quality. With increase in population rate, pollution of groundwater also increases due to increasing activities such as farming activities, industrialization, and urbanization. In such type of situation it is difficult to detect changes until the continuous revision of maps and plans for the management of ground water resources of an area.

Water entering the subsurface from different sources may remain temporary as a continuous moving body or in several distinct water-bearing zones. The resulting physical and chemical properties of groundwater are most importantly related to its relationship with the media, which the water encountered, and its residence time. In addition to the natural factors a major changes in the constituents of groundwater may be resulted from the activities of man. On the other hand, the type and concentration of dissolved constituents governs the usefulness of groundwater for various purposes. Therefore, it is necessary to determine the composition of groundwater before the water can be used for the intended purpose. Assessments of the ground water quality to

determine their spatial distribution have significant importance for further utilization and management of the resource.

Addis Ababa City gets more than 60 % of its water supply from groundwater. Over exploitation of the ground water by government agencies and private land owners has been triggered by shortage of water in the city. Based on a background survey, Addis Ababa ground water has significant variation in quality at different locations. Furthermore, significant number of wells abandoned because of quality problem in Addis Ababa (Appendix II). A lot of money has to be invested to develop a well which could reach up to 20 million birr for developing one well. Therefore, it is better to know what kind of groundwater quality is expected for a particular location before making decisions to develop ground water sources.

### **1.3 Objective of the Study**

#### **1.3.1 Main objective**

The overall objective of the study was to assess the spatial water quality variation of the ground water within the Addis Ababa city boundary and determine the possible causes.

#### **1.3.2 Specific objectives**

1. Assess the Ground water quality and their variations at different locations in the study area.
2. Prepare spatial distribution maps of the selected ground water quality parameters using Geographical Information System (GIS).
3. Determine the cause of ground water quality variation in the study area.

### **1.3.3 Research questions**

1. Was there any variation on the quality of the ground water in the study area depending on their location?
2. Did the quality of the ground water comply with the drinking water quality standards?
3. What was the possible cause of variation on the quality of the Ground water in the study area?

### **1.4 Scope of the study**

The study was conducted in Addis Ababa city, Ethiopia. This study focused on assessment of the groundwater quality and their variations at different locations, prepare spatial distribution maps of the selected groundwater quality parameters using Geographical Information System and determine the cause of groundwater quality variation. This study was focused on selected five water quality parameters: Total Dissolved Solids (TDS), Nitrates ( $\text{NO}_3$ ), Iron (Fe), manganese (Mn) and Fluoride (F).

### **1.5 Significance of the Study**

Groundwater quality is demarcated by a set of health and safety principles for domestic use. Hence, Groundwater abstracted for domestic use must observe a stricter category of regulatory objectives for protecting the wellbeing and security of the consumers. In this regard and as a goal towards sustainable development, there is dire need to establish the quality and spatial distribution of the groundwater abstraction points in Addis Ababa City. This will improve monitoring and present improved management approaches related to socio economic activities and natural resources by the relevant authorities.

This study focused on getting the quality of groundwater and mapping the geographical positions where the groundwater is drawn from in the Addis Ababa City and eventually proving if its quality is suitable for domestic use. This will be beneficial to AAWSA and different borehole owners within the boundaries of Addis Ababa City in putting up the right measures to tackle groundwater quality problems.

Conducting research on such pressing issue about the quality of the ground water is relevant and timely for AAWSA, private well owners and policy makers. Besides, it would add on the existing scientific knowledge on the subject area. Furthermore, this study can be used as baseline information to understand the overall ground water quality spatial distribution of Addis Ababa region.

## **1.6 Limitation of the study**

Although this research was carefully prepared, it has the following limitations and shortcomings:

- ✚ First of all, the researcher tried to collect samples and data from all the wells as much as possible that were developed within the Addis Ababa city. But it is difficult to know how much wells were developed because there is no recorded inventory of the wells.
- ✚ Second, it was very difficult to get the necessary data for this research especially from the private well owners.
- ✚ Third, generalizations reached in this research on the overall quality of groundwater in Addis Ababa city depends on the chosen limited number of physical and chemical parameters.

## **1.7 Organization of the study**

This thesis was structured in five main chapters. The first chapter deals with introduction of the study that includes the background of the study, statement of the problem, objectives of the study, research question, scope of the study, significant and limitation of the study. Chapter two presents theoretical perspective about water quality standards, factors affecting water quality and related previous works. Chapter three discusses the methodological approaches of the study such as sampling, water quality analysis, water quality standards and ground water quality mapping. Chapter four constitutes of the results obtained from the ground water of Addis Ababa, discusses the implication of the results and their possible causes. Chapter five presents conclusions and recommendations of the study.

## **CHAPTER TWO**

### **2. REVIEW OF RELATED LITERATURE**

#### **2.1 Water Quality**

The concept of water quality is complex because so many factors influence it. In particular, this concept is intrinsically tied to the different intended uses of the water; different uses require different criteria. Water quality is one of the most important factors that must be considered when evaluating the sustainable development of a given region (Cordoba et al., 2010).

Water quality must be defined based on a set of physical and chemical variables that are closely related to the water's intended use. For each variable, acceptable and unacceptable values must then be defined. Water whose variables meet the pre-established standards for a given use is considered suitable for that use. If the water fails to meet these standards, it must be treated before use (Cordoba et al., 2010). Water quality is considered the main factor controlling health and the state of disease in both man and animals.

#### **2.2 Water Quality Standards/Guidelines**

Drinking Water Quality Guideline Values generally describe reasonable minimum requirements of safe practice to protect the health of consumers and/or derive numerical "guideline values" for constituents of water or indicators of water quality. In order to define mandatory limits, it is preferable to consider the guidelines in the context of local or national environmental, social, economic and cultural conditions (WHO, 2011).

By definition, a standard is "a rule or principle considered by an authority and by general consent as a basis of comparison. It is something normal or average in quality and the

most common form of its kind". A proper standard for drinking water quality is thus the reference that will ensure that the water will not be harmful to human health. The framework against which a water sample can be considered good or "safe" is a drinking water quality standard (Solsona, 2002).

### **2.3 Safe Drinking water**

Potable or "drinking" water can be defined as the water delivered to the consumer that can be safely used for drinking, cooking, and washing purposes. This water must meet the physical, chemical, bacteriological, and radiological parameters when abstracted from an approved source; undergo through properly designed, constructed, and operated, treatment plant and disinfection facility, and finally delivered to the consumer through a protected distribution system in sufficient quantity and pressure (Zuane, 1997).

### **2.4 Ground Water Quality**

The concept of ground water quality seems to be clear, but the way of how to study and evaluate it still remains tricky (Chenini and Khemiri, 2009; Babiker et al., 2007). Considering that the definition of water quality is not objective, but is socially defined depending on the desired use of water. Different water uses require different quality standards.

Understanding hydraulic properties of the aquifer and hydro-chemical characteristics of its water is crucial for groundwater development planning and management in the study area. Generally, the motion of groundwater along its flow paths below the ground surface increases the concentration of the chemical species (Domenico and Schwartz, 1990).

The groundwater chemistry could reveal important information on the geological history of the aquifers and the suitability of groundwater for drinking, domestic, industrial and

agricultural purposes (O'Neil, 1993). Groundwater quality reflects inputs from the atmosphere, soil and water rock interactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes (Apello and Postma, 1993).

Ashley, (1995) worked on the occurrence of fluoride in groundwater in the Rift valley of Ethiopia and its control. About 50% of all the underground water used in urban areas of developing countries is derived from wells, springs and bore holes and more than 1000 million inhabitants in Asia and 150 million in Latin America rely on such resources (Clarke et al., 1995).

Mitra, (1998) investigated spatial and temporal variation of ground water quality in sanddune area of Aomori, prefecture in Japan using Water Quality Index (WQI) and finally explained the WQI are composite influence of individual water quality parameters on overall quality of water.

Suk, (1999) used the various geo statistical concepts for interpretation of complex data sets to understand the water quality parameters. There are a number of methods to analyze water quality data that vary depending on informational goals, the type of samples, and the size of the sampling area. One of the most effective ways to communicate information on water quality trends is by the use of the suitable indices (Dwivedi and Pathak, 2007). Indices are based on the values of various physicochemical and biological parameters in a water sample. Initially, WQI was developed by Horton (1965) in the United States of America by selecting 10 most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, chloride, etc.

## 2.5 Factors Affecting Water Quality

Water is vital to the health, well-being, food security and socioeconomic development of mankind. However, the presence of contaminants in natural freshwater continues to be one of the most important environmental issues in many areas of the world, particularly in developing countries, where several communities are far away from potable water supply. Low-income communities, which rely on untreated surface and groundwater sources for domestic uses are the most exposed to the impact of poor water quality. Unfortunately, they are also the ones that do not have adequate infrastructure to monitor quality of the water they use regularly and implement control strategies (Ayoko et al., 2007). Thus, environmental pollution, mainly of water sources, has become public interest.

Furthermore, the chemical composition of ground water is controlled by many factors that include the composition of precipitation, mineralogy of the watershed and aquifers, climate and topography. These factors can combine to create diverse water types that change in composition spatially and temporally (Chenini and Khemiri, 2009).

**Compositional Variations with Time:** Seasonal water quality changes could produce discomfort among consumers, primarily because the aesthetic quality of the water has changed from what they are used to. It is interesting to note that the water quality symptoms that are most noticeable by the consumers are the result of fairly innocuous constituents, i.e., the ones that are not particularly harmful to health, while constituents that may cause harm to public health are often not readily detected by human senses (Dennis, 2002).

**Temperature:** At any given temperature, there is a specific concentration of dissolved mineral constituents in the groundwater that is in contact with that mineral. The actual concentration of minerals in water is temperature dependent, e.g., at higher temperatures, groundwater can dissolve more of the mineral. Even changes in groundwater temperature by only 5 to 10°C can cause detectable changes in TDS. To some individuals, an increase in the temperature of their drinking water alone can be perceived as inferior quality and generally less palatable taste.

For groundwater deeper than 50 to 75 feet, seasonal changes are generally less than one degree (Heath, 1989) and temperature variations do not play a significant role in groundwater composition. But, for shallow groundwater, larger seasonal variations, related to warming of or cooling at the surface are common, and may be on the order of 5 to 10 degrees or more.

Another source of temperature change in shallow groundwater, and occasionally deeper water, is the introduction of water from the surface during high-recharge time periods. For shallow groundwater, seasonal temperature-driven fluctuations in groundwater TDS may occur (Dennis, 2002).

**The Natural pH of Groundwater:** pH is a measure of the acidity or alkalinity of groundwater: the lower the pH, the more acidic is the water, and conversely the higher the pH the more alkaline is the water. At a typical groundwater temperature, a pH of 7 is considered neutral. Therefore, a pH less than 7 is acidic and a pH greater than 7 means the water is alkaline. The pH is actually a measure of the hydrogen ion (H<sup>+</sup>) availability (activity). The hydrogen ion is very small and is able to enter and disrupt mineral structures so that it may contribute dissolved constituents to groundwater. Consequently,

the greater the H<sup>+</sup> availability in water i.e. the lower the pH, the higher the TDS content of the water. Natural rainwater is slightly acidic because it combines with carbon dioxide (CO<sub>2</sub>) normally present in the atmosphere (Krauskopf, 1997; Dennis, 2002).

**Oxidizing-Reducing (Redox) Reactions:** Oxidizing-reducing reactions result in a change of the charge of an ion as it gains or loses an electron. These reactions are almost always facilitated by bacteria that are able to gain energy from the reactions. The solubility of some elements in water depends on whether they are oxidized or reduced. The redox potential can be correlated with the amount of dissolved oxygen. As the oxygen content drops, the environment becomes more reducing (the redox potential drops). The natural environment, therefore, may control in which state the element occurs. For example, iron (Fe) can exist in either as reduced (Fe<sup>2+</sup>) or oxidized (Fe<sup>3+</sup>) ionic states (note the different charge).

Iron is more soluble in the reduced state than it is in the oxidized state, where it often forms an iron oxide mineral (Fe<sub>2</sub>O<sub>3</sub>) or iron hydroxide mineral (Fe(OH)<sub>3</sub>). Therefore, if the local environment produces the reduced iron form, the water will have higher concentrations of iron. The most common cause of reducing reactions is organic matter, either in solid form or as dissolved organic carbon (DOC). The oxidation of an organic molecule (contributing electrons) can result in iron, in a solid iron oxide mineral (Fe<sub>2</sub>O<sub>3</sub>), being dissolved into the water as reduced iron (Fe<sup>2+</sup>) (accepting electrons). Manganese (Mn) behaves in a similar manner to iron.

It is important to note that oxidizing and reducing reactions have to take place simultaneously, i.e., for a reducing reaction (accepting electrons) to occur, an oxidizing reaction (giving up electrons) must also take place at the same time. Also, not all

molecules are oxidized or reduced at the same redox potential. With decreasing redox potential the following reducing reactions will occur: nitrate to nitrogen gas,  $\text{Fe}^{3+}$ (insoluble) to  $\text{Fe}^{2+}$  (soluble), sulfate to hydrogen sulfide and, at very low redox potential, methane formation (Drever, 1982).

Exploitation of groundwater resources beyond their potential renewal capacity, results in a hydrological deficit. Generally, this is expressed as a decline in groundwater levels but in coastal aquifers this may cause intrusion of seawater.

## **2.6 PREVIOUS WORKS**

Reviewing last literatures and articles shows that various studies and researches have been done about groundwater quality in Ethiopia, particularly in the rift valley. Some of them have studied on only physical and chemical parameters, while some other researchers studied the parameters in combined mode and bacteriological situation. Furthermore, some studies are available about quality and chemical components of water. Tamiru Alemayehu *et al.* (2003) made a study on ground water vulnerability mapping of the Addis Ababa water supply aquifers, and they have conducted the risk assessment of groundwater pollution through DRASTIC mapping of water supply aquifers, and finally, they reported that main sources of pollutants that deteriorate the quality of water in the Addis Ababa region are wastes generated from industries, domestic activities, garages, health centers and fuel stations.

Demlie *et al.* (2006) conducted a study on soil and groundwater pollution of an urban catchment's of Addis Ababa by trace metals and indicated that a relatively high content of the analyzed trace metals in the soil is attributed to anthropogenic and geogenic sources. The same work was done by Tamiru Alemayehu (2006); accordingly heavy

metal content analyses of rocks, soils, streams, springs and boreholes have been carried out to identify the presence of potentially harmful solutes. He has reported that rock and soil outcrops of Addis Ababa are anomalously rich in heavy metals derived from hydrothermal activity and he has concluded that heavy metal concentrations in the surrounding rocks and soils are related to geogenic sources whereas anthropogenic contribution as a cause of these concentrations is minor.

Tenelam Ayenew (1998, 2001) has described the hydro-chemical and signatures of different water types of Addis Ababa. Accordingly, he concluded that very dilute Ca-HCO<sub>3</sub>, Ca-Na-HCO<sub>3</sub> type water in the North Entoto range is draining the Entoto silicics, Ca-Mg-HCO<sub>3</sub>, Mg-Ca-HCO<sub>3</sub> type water drains the Addis Ababa basalt in the central part of the Addis Ababa region and the Bishoftu basalt aquifers in the South, and Na-HCO<sub>3</sub> type water of the 'Filwuha' thermal system, which have rock dominated hydrochemistry. While a Ca-NO<sub>3</sub> and Ca-Cl type water circulating in the Central part of the Addis Ababa is a result of anthropogenic influences, Similarly Tamiru Alemayehu (2004) identified four kinds of water in Addis Ababa: Na-HCO<sub>3</sub>, Na-Ca-HCO<sub>3</sub>, Ca-Mg-HCO<sub>3</sub> and Ca-Mg-Cl., Most of the river water belongs to Na-HCO<sub>3</sub> and Na-Ca-HCO<sub>3</sub> types. The chemistry of spring water becomes a Ca-Mg-Cl and Ca-Mg-HCO<sub>3</sub> type. A shift of the water chemistry towards SO<sub>4</sub><sup>2-</sup> Cl type is mostly related to the infiltration of contaminants into the subsurface rather than natural dissolution processes.

Geology of Addis Ababa city is classified into volcanic rocks of Entoto trachyte, Entoto mixed rocks, Fanta basalt, Cheleleka basalt, Repi basalt (trachy basalt and basalt), lower ignimbrite, Wechecha-Furi-Year trachyt and trachy basalt, Wechecha-Furi-Yerer ignimbrite, Quaternary olivine basalt, Quaternary Scoria, Tertiary sediment and Lake

sediment (Asegid, 2007). And they are correlated with the volcanic rocks of central Ethiopia. And the sedimentary rocks are Tertiary intra-volcanic lake sediments.

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

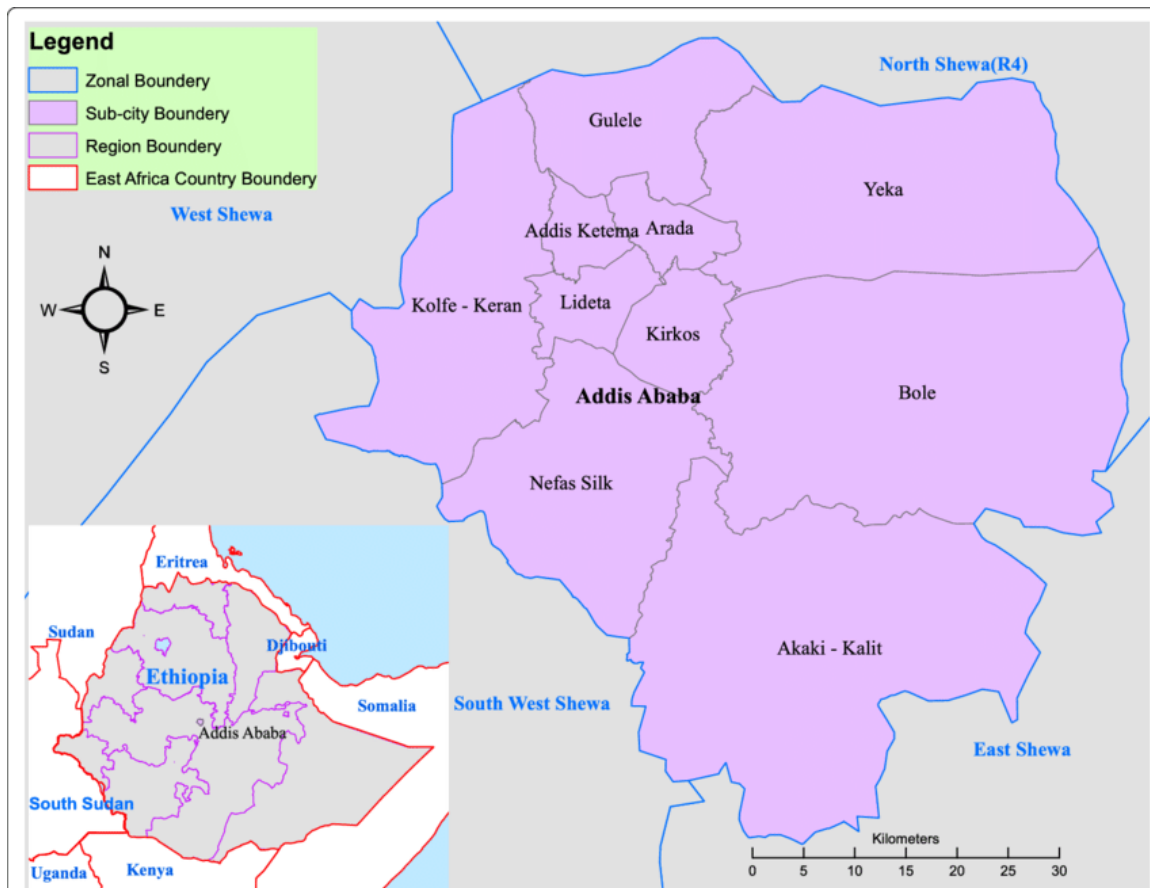
All of the above listed studies, although they vary in scope and degree of geological and geochemical information, have stressed that the quality of ground water is often affected by uncontrolled waste disposal of domestic, municipal and industrial effluents as well as the geological formation.

## CHAPTER THREE

### 3. RESEARCH METHODOLOGY

#### 3.1 Description of the study area

Addis ababa is the capital city of Ethiopia which was founded 1886 at the Western shoulder of the Main Ethiopian Rift. It is also the largest city in the country by population, with a total population of 4,793,699 according to the 2007 census. This city covers 527 square kilometers of area in Ethiopia. The population density is estimated to be nearly 9,096 individuals per square kilometer available. It is geographically bounded by UTM coordinates of about 978000N, 1005500N and 456000E, 495000E (Figure 1).



**Figure 1:** Location map of Addis Ababa

### **3.1.1 PHYSIOGRAPHY**

In Addis Ababa, elevation ranges generally between 2326 m and 3380 m a.m.s.l. However, the portion of the area with elevation greater than 3200 m a.m.s.l is negligibly small. A considerable portion of the northern part is within the elevation range of 2670 m and 3000 m a.m.s.l. This area is very sloppy, however, both elevation and slope decreases progressively towards the South. A large portion of the central part of the project area falls in a narrow elevation range of 2313 and 2491 m a.m.s.l. Proceeding further South wards, the topography becomes very gentle and a very wide area falls under a smaller elevation range of 1958 m and 2135 m a.m.s.l. The lowest elevation is found at the Southern border of the Addis Ababa which is about 1780 m a.m.s.l.

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

### **3.1.2 DRAINAGE**

The Addis Ababa area is located in Akaki catchment's which consists of Akaki River catchments and numerous small rivers. The dominant ones are the Big Akaki, which drains the Eastern part of the catchment's area, and the Little Akaki that drains the Western part of the catchments and their respective tributaries. The two rivers form one of the biggest tributaries of the Awash River called Akaki River that feeds Abba Samuel Lake, leaves the lake in the south and passes through a gorge up to 100 m deep which

extends for about 8 km before it joins the Awash River. Almost all the streams in the Akaki River catchments originate from the Northern part of Addis Ababa.

### **3.1.3 CLIMATE**

Having a maximum and minimum elevation range a little above 3000m and a little below 2400m, respectively, most part of Addis Ababa region falls under the Weina Dega (Sub tropical) category. Accordingly, the climate of Addis Ababa area is typically characterized by two distinct seasonal weather patterns: the wet season which extends from June to September, contributing about 70% of the annual rainfall, and the dry season which covers the period from October to May with a minor rainy season in March and April, which is well known for its frequent failure. Such climates which are characterized by alternating wet and dry seasons may favor weathering of the rocks and dissolution of minerals.

### **3.1.4 PRECIPITATION**

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

The monthly mean rainfall records for annual rainfall at Intoto station (at an elevation of 2900 m a.s.l), Addis Ababa Observatory (at an elevation of 2408 m a.s.l.), Bole (at an elevation of 2324 m a.s.l.), and Akaki Mission (at an elevation of 2170 m a.s.l.) were 1088.5 mm, 1251.5 mm 1164 mm and 1087.01 mm respectively. Thus, the city receives

annual average rainfall of about 1123 mm and the long term mean annual rainfall observed at Addis Ababa Observatory is about 1256 mm.

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

### **3.1.5 REGIONAL GEOLOGY**

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

According to the general geological description of the Awash River basin most of the highlands are covered with early Cenozoic Trap Series volcanic (dominantly basalt, rhyolite and ignimbrite).

All the rocks are faulted in the rift and adjacent rift escarpments. The rift is distinctly separated from the plateau by a series of step-faults. A major fault running East-West via Kesem River,

Addis Ababa-Ambo cuts across the Western rift escarpment and uplifted its Northern block (Zanittin *et al.*, 1978) about 8 million years ago. This fault marks the outer boundary of the Western Ethiopia rift margin immediately North of Addis Ababa - Ambo (Zanittin *et al.*, 1974).

### **3.1.6 LOCAL GEOLOGY**

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

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

Entoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian (Haileselassie and Getaneh, 1989). The rhyolitic lava flow outcrop on the top and the foothills of the Entoto ridge, predominantly in the Western side of Addis Ababa basalts overlie Entoto silicics and outcrops mainly occur in the Entoto Mountain, central Addis Ababa, along Akaki River course (South) in the vicinity of Legedadi dam to the north of Gefersa dam and Southern part of the city.

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

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

## **3.2 METHODOLOGY**

Procedures used for groundwater sampling and laboratory analysis methods used for the determination of various physical and chemical parameters are discussed. Besides the GIS based analysis and management of water quality data are discussed here.

### **3.2.1 Water Sampling**

The purpose of sampling is to obtain a small portion of the water, which represents the real characteristics of the main groundwater resource. Increasing the number of sampling points can provide more information about the status of the groundwater. Therefore, all the data obtained from the ground water quality has significant importance and every well has to be assessed. Therefore, the sample size used for this study was to include all wells as much as possible. So there were 108 wells identified and accordingly 108 samples were collected.

The ground water samples were collected manually from the wells using clean PET bottles, of one liter capacity. Each PET bottle was rinsed with the pumped water for three times. The bottles were filled completely, immediately sealed with stoppers to exclude air, labeled, and brought to the laboratory. GPS readings were taken at the sampling locations. Analyses of ground water samples were performed in AAWSA laboratory.

### **3.2.2 Water Quality Analysis**

All the analytical procedures used in the physicochemical analysis of the water samples were executed according to standard method of water and waste water analysis (APHA,

1998). The collected samples were analysed for physico-chemical parameters as total dissolved solid (TDS), nitrate (NO<sub>3</sub>), Iron (Fe), Manganese (Mn) and Fluoride (F). All the water quality parameters are expressed in mg/l. Table 1 provides information about the equipments, chemicals and methods of analysis used for the determination of water quality parameters.

**Table 1:** Types of methods, equipment, and chemicals used during analysis

S. No	Parameter/unit	Method	Reagent/Apparatus
1	Total dissolved solids (mg/l)	Electrode Method	EC/TDS meter
2	Nitrate (mg/l)	Cadmium reduction method	Nitraver 5 Nitrate Reagent/ Spectrophotometer
3	Iron (mg/l)	Ferover Method	Ferover Iron Reagent/ Spectrophotometer
4	Manganese (mg/l)	PAN method	Ascorbic Acid powder pillow, Alkaline Cyanide Reagent, PAN indicator/ Spectrophotometer
5	Fluoride (mg/l)	SPADNS method	SPADNS reagent/ Spectrophotometer

### 3.2.3 Water Quality Standard

Each parameter was compared to desirable standard limit of that parameter stipulated for drinking water as prescribed by the WHO Drinking Water Quality Guideline Values for drinking and public health purposes. The WHO drinking water quality guideline values for the analyzed parameters is presented in table 2 below.

**Table 2:** WHO drinking water quality guideline values (WHO, 2011)

S.No	Parameter	Measuring unit	WHO (2011)
1	TDS	mg/l	< 600
2	Nitrate as N	mg/l	< 11
3	Iron	mg/l	< 0.3
4	Manganese	mg/l	< 0.1
5	Fluoride	mg/l	< 1.5

### 3.2.4 Water Quality Index

The calculation of the WQI was done using weighted arithmetic water quality index which was originally proposed by Horton (1965). The weighted arithmetic water quality index (WQI) is in the following form:

$$WQI = \frac{\sum w_i q_i}{\sum w_i}$$

Where  $n$  is the number of variables or parameters,

$w_i$  is the relative weight of the  $i$  th parameter

$q_i$  is the water quality rating of the  $i$  th parameter.

The value of  $q_i$  is calculated using the following equation:

$$q_i = 100 [(V_i - V_{id}) / (S_i - V_{id})]$$

Where  $V_i$  is the observed value of the  $i$ th parameter,

$S_i$  is the standard permissible value of the  $i$ th parameter

$V_{id}$  is the ideal value of the  $i$ th parameter in pure water.

All the ideal values ( $V_{id}$ ) are taken as zero for drinking water except pH and dissolved oxygen (Tripathy and Sahu, 2005).

The unit weight ( $w_i$ ) is calculated using the following equation:

$$w_i = k / S_i$$

Where  $S_i$  is the standard permissible value of the  $i$ th parameter

$k$  is the constant of proportionality and it is calculated by using the following equation:  $k = [ 1 / (\sum 1/ S_i=1,2,..n) ]$

**Table 3:** Classification of water quality based on weighted arithmetic WQI method

WQI	STATUS
0 - 25	Excellent
26 - 50	Good
51 - 75	Poor
76 - 100	Very Poor
Above 100	Unsuitable for drinking

### 3.2.5 Groundwater quality mapping

Geographical information system (GIS) method has been used to spatially represent water quality data sets for the purpose of generating maps and making spatial comparisons of groundwater quality of Addis Ababa region. The spatial distribution analysis of the physico-chemical water quality parameters was carried out using the ARCmap software. Microsoft excel was used to interpret and make analysis of data in the area under study.

## CHAPTER FOUR

### 4. RESULT AND DISCUSSION

#### 4.1 PHYSICOCHEMICAL ANALYSIS

Laboratory analysis was carried out on water samples collected from 108 wells which are located within Addis Ababa city administration boundary for the selected water quality parameters, such as total dissolved solids (TDS), nitrate (NO<sub>3</sub>), iron (Fe), manganese (Mn) and fluoride (F) using standard methods.

**Table 4:** groundwater quality data and recommended permissible limits (in mg/L)

S. No	Parameters	Minimum	Maximum	Mean	Std Dev	WHO Std
1	TDS	57	2292	390.06	448.55	600
2	Nitrate	0*	176	9.75	24.27	11
3	Iron	0*	4.35	0.27	0.67	0.3
4	Manganese	0*	0.74	0.07	0.15	0.1
5	Fluoride	0.01	29.3	2.6	5.7	1.5

(\*0 values indicate undetectable concentration.)

The physicochemical analysis results of the selected water quality parameters for water samples collected from 108 wells are presented in Appendix I.

##### 4.1.1 Total Dissolved Solids (TDS):

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. Concentrations of TDS in water vary considerably in

different geological regions owing to differences in the solubility of minerals (WHO, 2011).

What gives groundwater its taste is the amount and type of dissolved minerals contained in it. Pure water, i.e., having no dissolved minerals, doesn't occur naturally, and if it did, it would have no taste. So, it is not pure water people want, but it is water that tastes good and is safe to drink (Dennis, 2002). The amount and type of dissolved minerals in water is what gives waters their individual taste. Factors that control the dissolved minerals in groundwater include:

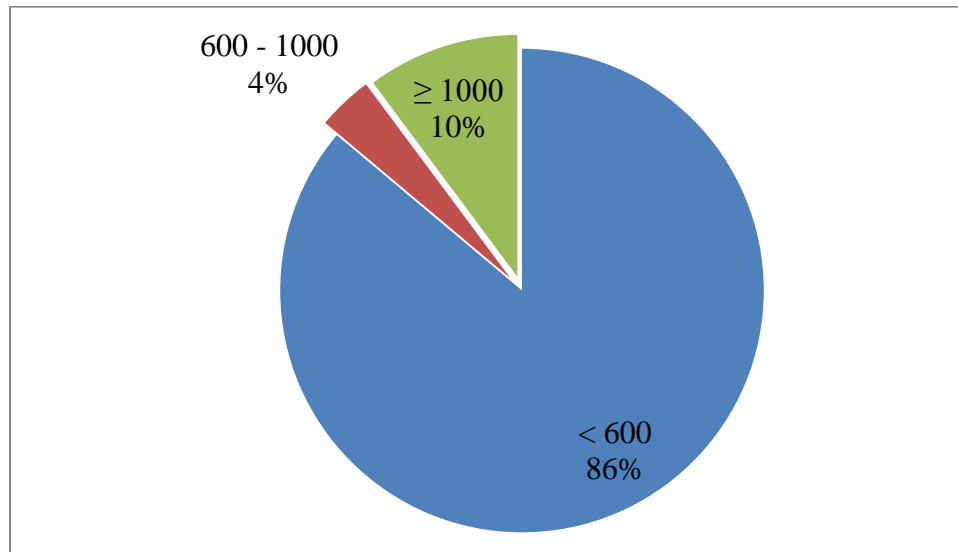
- The types of minerals that make up the aquifer in contact with the groundwater,
- Residence time of the groundwater in the aquifer, the longer the groundwater is in contact with the minerals, the greater the extent of its reaction with those minerals and the higher will be the content of dissolved minerals, and
- The physical and chemical state of the groundwater, such as pH, Temperature and Dissolved oxygen. The higher the temperature and the lower the pH & dissolved Oxygen the higher the dissolved mineral content of the groundwater (Dennis, 2002).

The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

The results of the laboratory analysis indicated that 4 wells have TDS value between 600 mg/l to 1000 mg/l. 11 wells have above 1000 mg/l TDS value. The rest 93 wells have

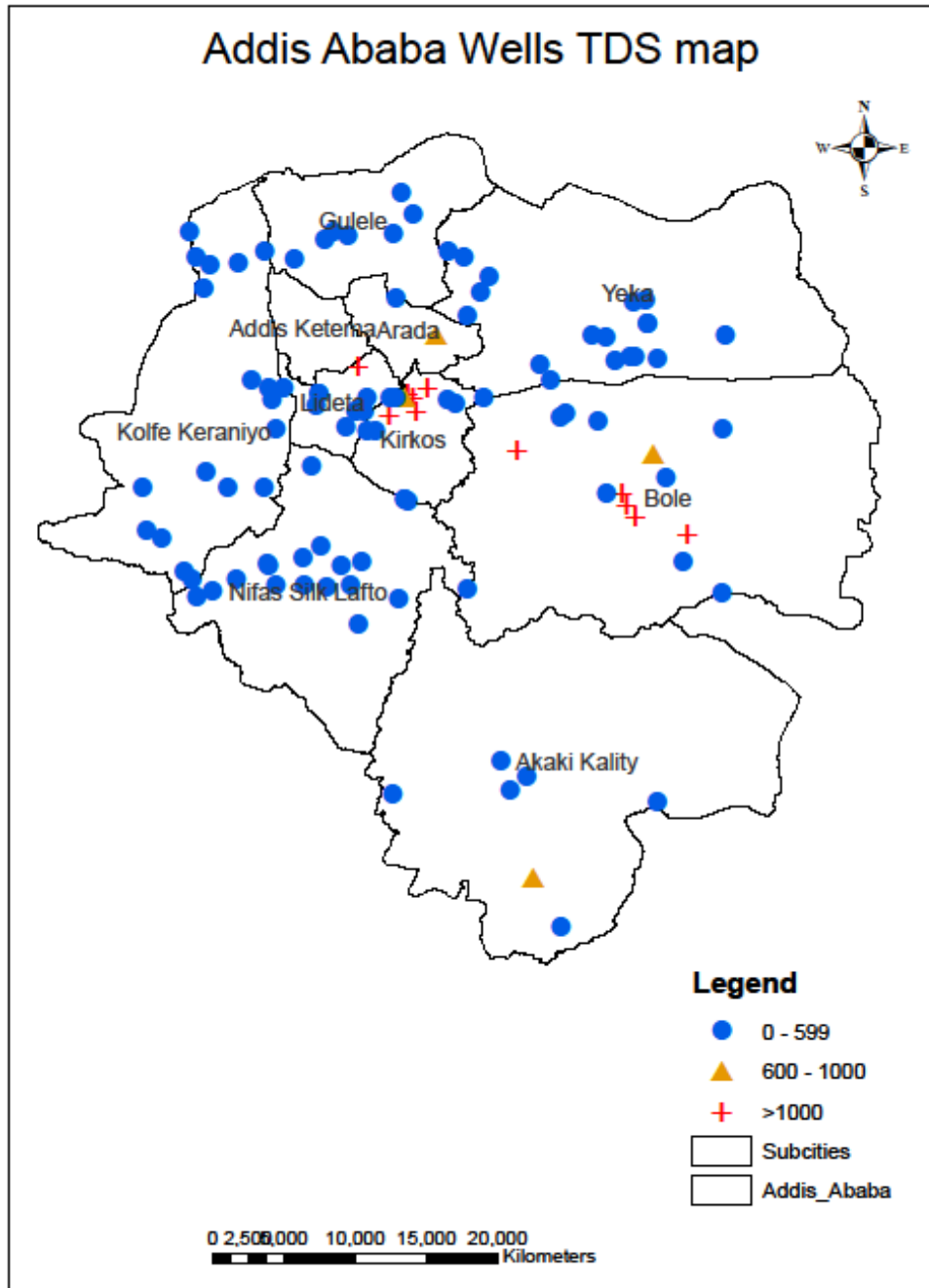
TDS value below 600 mg/l which is the maximum allowable limit according to the WHO Drinking Water Quality Guideline Values.

**Figure 2:** TDS content distribution



Spatial distribution map of TDS content of groundwater in Addis Ababa region is shown in Fig 3 below:

Figure 3: TDS distribution map of Addis Ababa.



The laboratory analysis results of groundwater samples collected from wells located in Addis Ababa indicated that TDS was lower for most parts of Addis Ababa region. High TDS areas are observed at the central part (Filwuha area) which extends to eastern part of the city. These localized high TDS area shows northwest-southeast direction following the main rift valley direction. The high TDS content of the groundwater are mainly attributed to the thermal water effects that facilitated the dissolving processes of minerals.

#### **4.1.2 Nitrate:**

Nitrate, the end product of the biological nitrification process of ammonia and organic nitrogen to nitrite by *Nitrosomonas* bacteria and then nitrite to nitrate by *nitrobacter* bacteria, is the most common chemical contaminant present in ground waters and the concentration levels are increasing from time to time by antropogenic activities. The distribution of  $\text{NO}_3$  in groundwater is controlled by a number of factors. They include availability of irrigation, domestic waste from urban settlements, industrial sources, ground water flow, and aquifer heterogeneity and dissolved oxygen concentrations. The common nitrogen compounds found in naturally occurring waters include ammonia ( $\text{NH}_3$ ), nitrite ( $\text{NO}_2^-$ ), nitrate ( $\text{NO}_3^-$ ), and the ammonium ion ( $\text{NH}_4^+$ ). Nitrogen is also found in many organic compounds such as proteins and protein derivatives and urea; and inorganic compounds particularly fertilizers such as DAP. In general, inorganic nitrogen salts are quite soluble in natural waters.

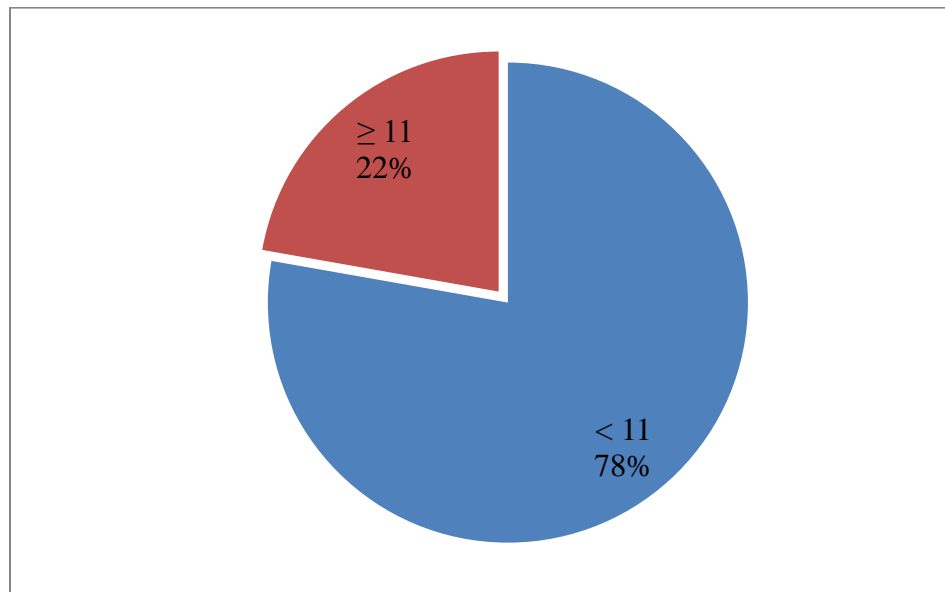
Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (WHO, 2011). Higher Nitrate content is

attributed mainly to over application of fertilizers, inadequate manure management practices, sewage effluent, septic tank, open dump sites of solid wastes etc.

Drinking of water with high concentration of nitrate could cause methemoglobinemia in infants less than 6 month of age. This disease is caused by the bacterial reduction of nitrate to nitrite in the intestinal tract. The nitrite then enters the blood-stream and combines with the hemoglobin to form methemoglobin, which reduces the blood's capacity to transport oxygen. Severe methemoglobinemia may result in brain damage and death. Besides, it has been reported by the WHO that prolonged intake of high level of nitrate results in gastric problems due to the formation of nitrosamines in adult man.

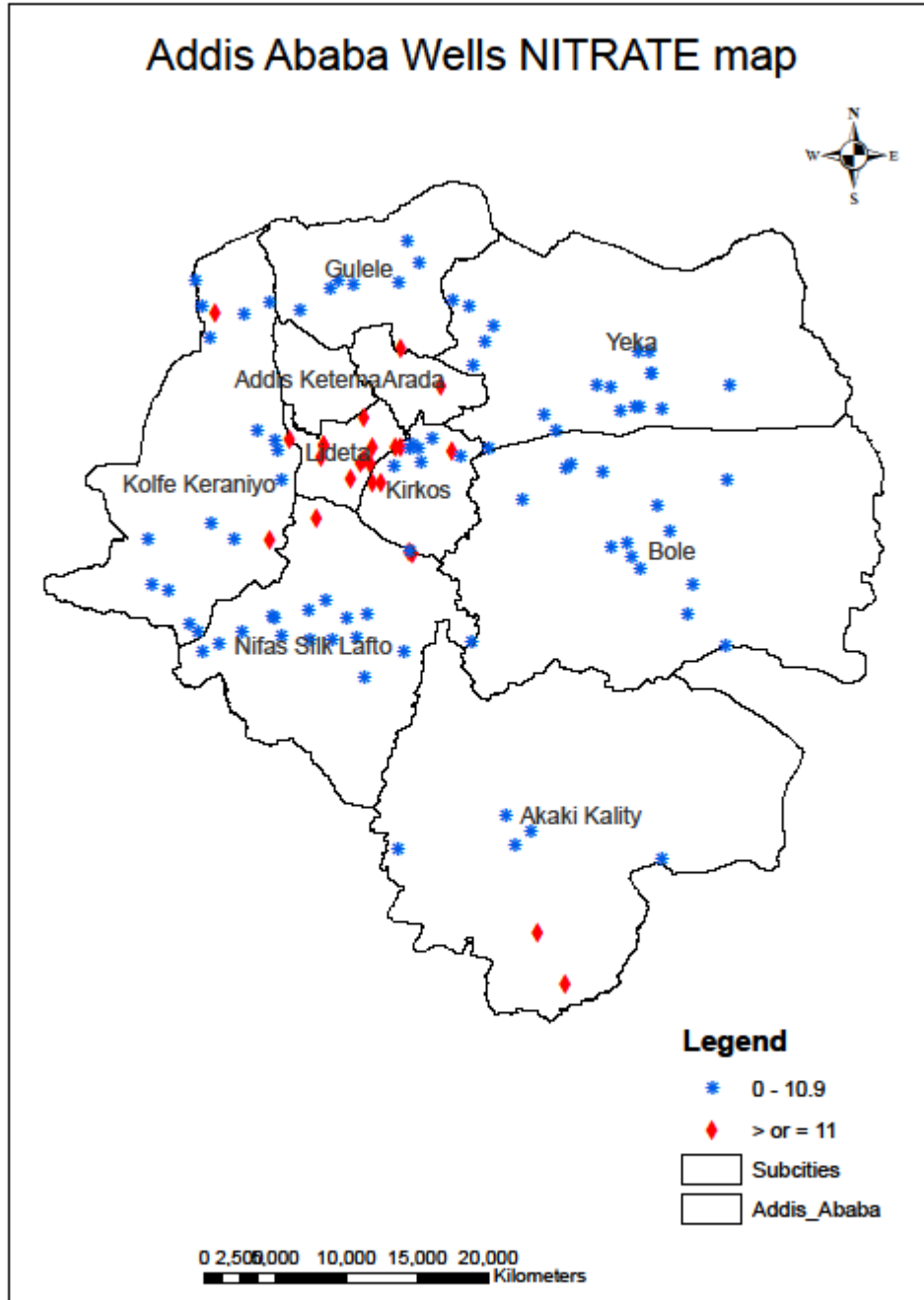
The results of the laboratory analysis indicated that 24 wells have above 11 mg/l Nitrate value. 84 wells have Nitrate value below 11 mg/l which is the maximum allowable limit according to WHO Drinking Water Quality Guideline values.

**Figure 4:** Nitrate content distribution



Spatial distribution of Nitrate in groundwater samples collected from Addis Ababa wells is shown in Fig 5.

**Figure 5:** Nitrate distribution map of Addis Ababa.



As depicted on the map shown in Figure-5 above, the results of laboratory analysis indicated that Nitrate was found in lower concentration in most parts the ground water of Addis Ababa. High nitrate contents which is greater than 11mg/l is observed at the central part of the city around Mexico, Lideta and Merkato areas and at most southern part of the city. The central part of the city is the oldest urban center and densely populated area. The communities residing in these areas generally use onsite waste disposal systems such as dry pit latrines and septic tanks, which are not water tight and the liquid waste percolates to the ground. Poor management of sewage has been practiced for years which are the main cause of high Nitrate concentration in ground water of these areas.

Southern part of the city is mainly agricultural land and farming activity was practiced for long period of time. Inorganic fertilizers such as UREA and DAP were applied that could percolated down to the ground water which caused the high nitrate concentration.

#### **4.1.3 Iron:**

Iron is the second most abundant metallic element in the Earth's outer crust; iron concentrations present in groundwater generally are very low. The occurrence of iron in aqueous solution is dependent on environmental conditions, especially oxidation and reduction condition. Flowing surface water, that is fully aerated, does not contain more than a few micrograms per liter of dissolved iron at equilibrium in the pH range 6.6 to 8.5. In groundwater, however, much higher levels can occur.

The iron contained in groundwater originates by solution at sites of either reduction of ferric hydroxides or oxidation of ferrous sulfide (Hem, 1989) and the process is strongly influenced by microbiological activity. The solubility of iron is the function of oxidation

and pH condition; iron is relatively soluble at a lower pH less than 5 under moderate oxidizing conditions, mostly the iron ion is re-precipitated (Hem, 1989).

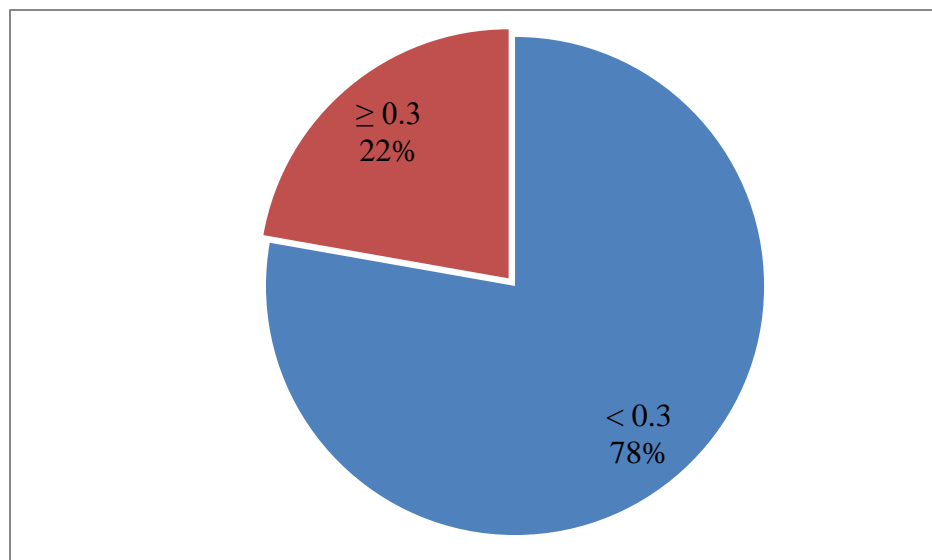
Iron is an essential element in the metabolism of animals and plants. The most well-known role that iron plays in human nutrition is in the formation of the protein hemoglobin, which transports oxygen to all cells of the body. Iron is also used in cellular metabolism and is found in many of the body's enzymes. Low iron stores in the body can lead to iron deficiency, anemia and fatigue. The immune system is also affected. In young children this negatively affects mental development, leads to irritability and causes concentration disorder.

If present in water in excessive amounts, however, it forms red oxy-hydroxide precipitates that stain laundry and plumbing fixtures and, therefore, is an objectionable impurity in domestic and industrial water supplies. Chronically consuming excess amounts of iron can lead to a condition known as iron overload. This condition is usually the result of a gene mutation. Left untreated, iron overload can lead to haemochromatosis, a severe disease that can damage the body's organs. Early symptoms include fatigue, weight loss, and joint pain, but if haemochromatosis is not treated, it can lead to heart disease, liver problems and diabetes.

Anaerobic conditions of groundwater may contain ferrous iron at concentrations up to several milligrams per liter without causing discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown colour to the water.

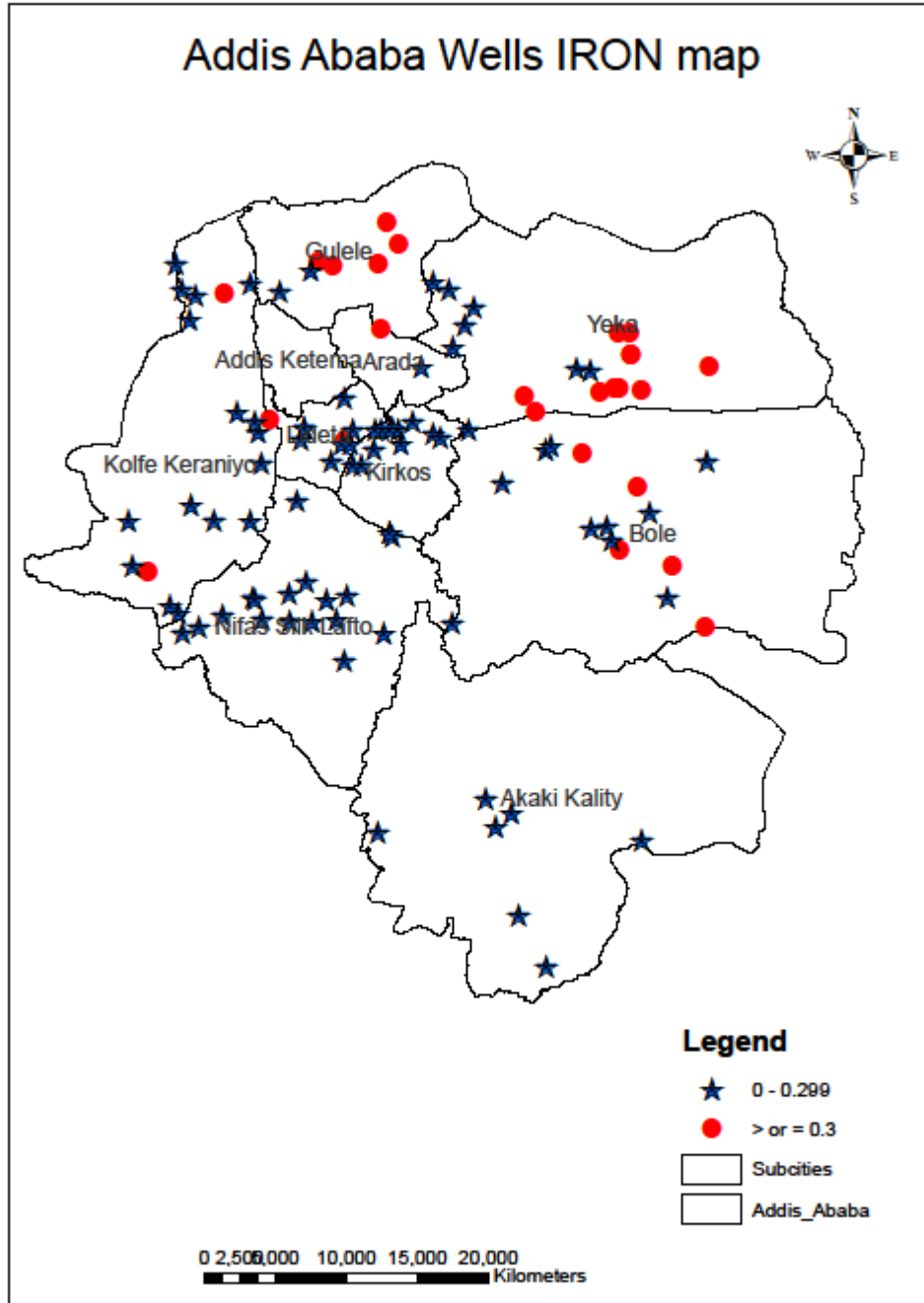
Iron also promotes the growth of “iron bacteria”, which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/l, iron stains laundry and plumbing fixtures (WHO, 2011). The results of the laboratory analysis indicated that 24 wells have above 0.3 mg/l Iron value. 84 wells have Iron value below 0.3 mg/l which is the maximum allowable limit according to WHO Drinking Water Guideline values.

**Figure 6:** Iron content distribution



Spatial distribution of Iron content of groundwater in Addis Ababa region is shown in Fig 7.

Figure 7: Iron distribution map of Addis Ababa.



The map on the distribution of Iron in groundwater indicated that northern and north eastern parts of Addis Ababa ground water (along the slope of Entoto Mountain) have high Iron content. The concentration of Iron in groundwater from the central and southern part of the city is low.

The high Iron at the northern and north eastern part of the city was mainly due to (Hem, 1989):-

The northern and north eastern part of the city receives the highest rain falls. Therefore, an effect of dilution and enrichment often occurs on the solutes leached from the acidic rocks (Entoto rhyolite) is high and as a result it contributed to the high concentration of iron to ground water due to the following reasons:

- Hydrothermally altered rhyolitic rocks of Entoto area, which might have experienced hydrothermal alterations, are expected to provide much iron to the groundwater whenever they are in contact than the basalts.
- Igneous rock minerals whose iron content is relatively high include the pyroxenes, the amphiboles, biotite, magnetite, and, especially olivine are attacked by water, the iron that may be released is generally precipitated as can be observed in some boreholes along the rhyolitic Entoto mountain range such as Yaka-Kotebe areas.

#### **4.1.4 Manganese:**

Manganese is considered to be the 12th most abundant element in the biosphere. Although manganese is one of the most abundant metallic elements, there is only about 1/5th as much manganese in the earth's crust as there is iron. The chemistry of manganese is somewhat similar to that of iron as both metals participate in redox processes in weathering environment. Many igneous and metamorphic rocks contain

manganese as a minor constituent but in basalt it is a significant constituent. Lateritic weathering process produces manganese oxide accumulation in economic proportion. It is widely distributed in soil, sediment, water and in biological materials. Although manganese is essential for humans and other species of the animals as well as for plants it is toxic at higher levels.

Manganese often occurs together with iron in ground water. However, it is usually occurs in much lower concentrations than iron. Manganese is present in soil as a result of mineral weathering and atmospheric depositions, originating from both natural and anthropogenic sources. The  $Mn^{2+}$  is the only form that is stable in liquid phase of soil solution, while Mn(III) and Mn(IV) are only stable in the solid phase of soil.

Manganese mobility in soil is sensitive to soil conditions such as acidity, moisture, organic matter content, biological activity, etc. The solubility of soil manganese is thus controlled by redox potential and soil pH, where low pH or low redox potential favors the reduction of insoluble manganese oxides resulting in increased manganese mobility. At soil pH above 6, manganese forms bonds with organic matter, oxides and silicates thereby its solubility decreases. Manganese availability and solubility is thus generally low at high pH and high organic matter content, while in acidic soils with low organic matter content its availability is high. The solubility of manganese is also high in anaerobic conditions at pH above 6, as well as in aerobic conditions at pH below 5.5.

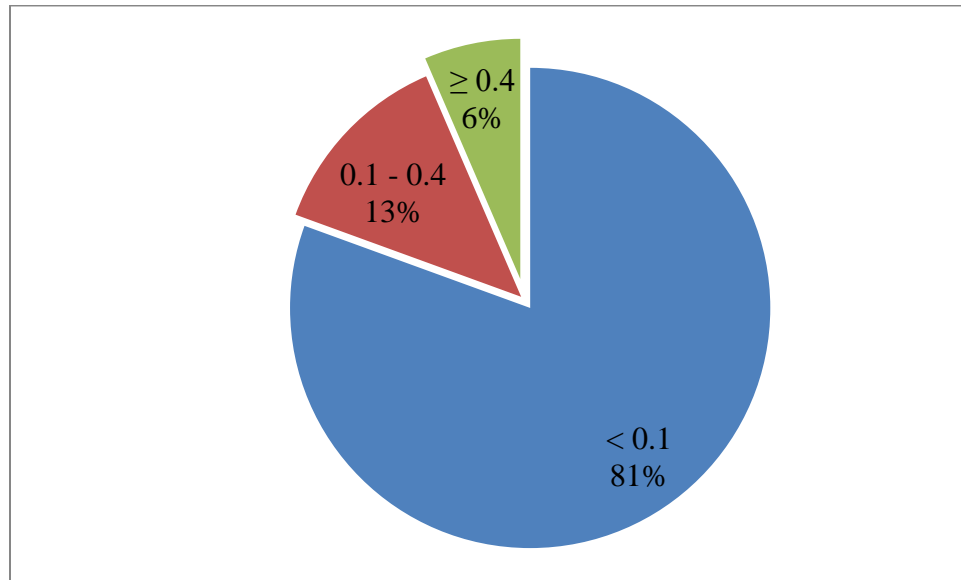
At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Manganese is an undesirable impurity in water supplies, mainly owing to a

tendency to deposit black oxide stains. Concentrations below 0.1 mg/l are usually acceptable to consumers. Even at a concentration of 0.2 mg/l, manganese will often form a coating on pipes, which may slough off as a black precipitate. The health-based value of 0.4 mg/l for manganese is higher than this acceptability threshold of 0.1 mg/l (WHO, 2011).

Manganese is easily concentrated in the brain, especially in the basal ganglia, and can cause an irreversible neurological syndrome similar to Parkinson's disease. Relatively high doses of manganese affect DNA replication and causes mutations in microorganism and mammalian cells. In mammalian cells, manganese causes DNA damage and chromosome aberrations. Large amounts of manganese affect fertility in mammals and are toxic to the embryo and fetus. The risk of damage to the central nervous system is of greater importance.

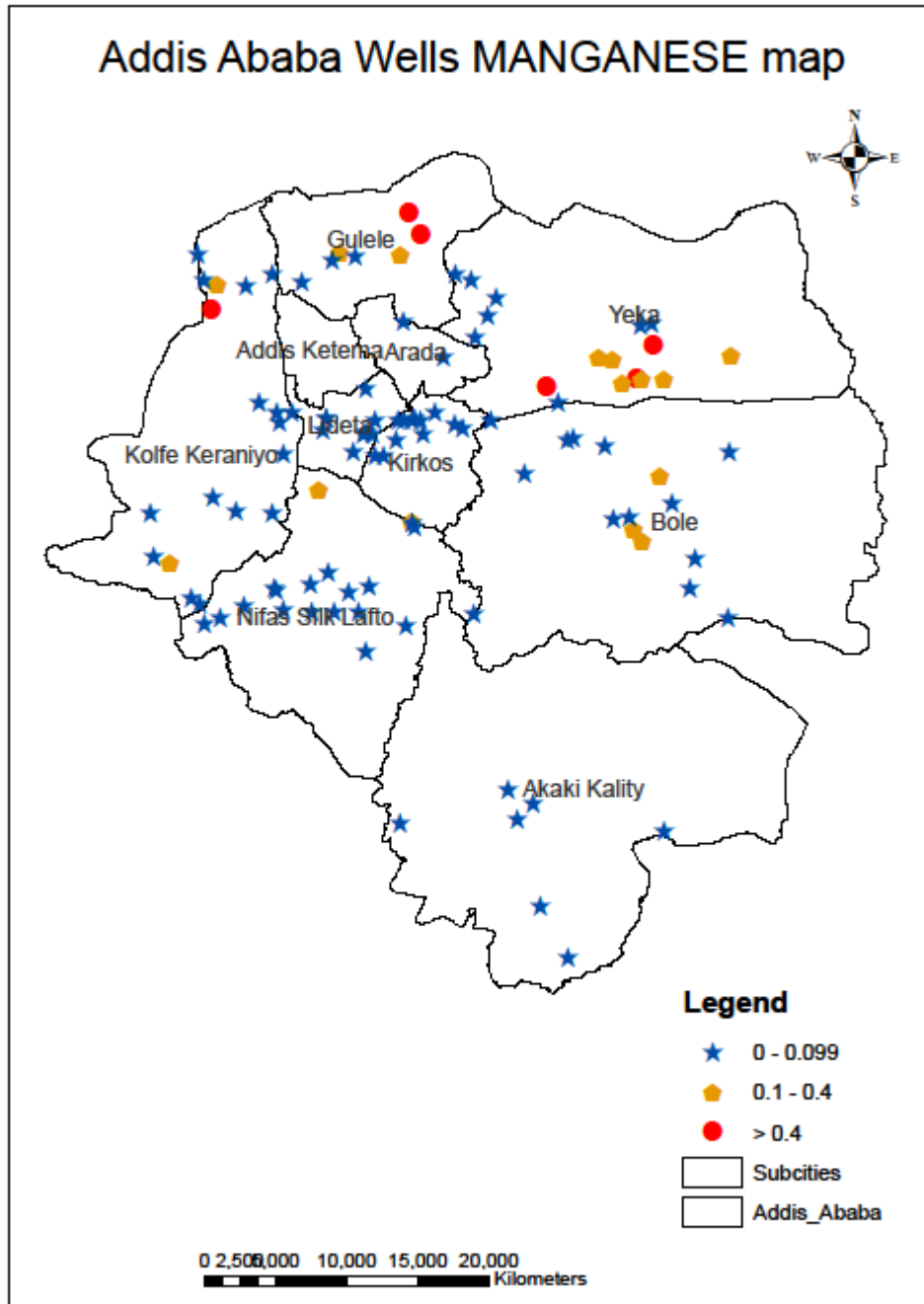
The results of the laboratory analysis indicated that 14 wells have Manganese value between 0.1 mg/l to 0.4 mg/l. 6 wells have above 0.4 mg/l Manganese value. The rest 88 wells have Manganese value below 0.1 mg/l which is the maximum allowable limit according to WHO Drinking Water Quality Guideline Values.

**Figure 8:** Manganese content distribution



Spatial distribution of Manganese in groundwater samples collected from Addis Ababa wells is shown in Fig 9.

Figure 9: Manganese distribution map of Addis Ababa.



As indicated on the map, the wells located at the northern and north eastern parts of Addis Ababa (along the slope of Entoto Mountain) have high manganese content. Central and southern parts of the city have lower Iron concentration. Many igneous and metamorphic minerals contain divalent manganese as a minor constituent (Hem, 1989).

#### **4.1.5 Fluoride:**

The occurrence of the fluoride in groundwater is predominantly geogenic. Fluoride enrichment in groundwater takes place mainly through leaching and weathering of the Fluoride bearing minerals present in the rocks and sediments which depends on several factors such as the origin of water, composition of water bearing medium, the length of time the water has been in contact with the medium, the temperature and pressure conditions, ion-exchange, rate of recharge and discharge etc. The important fluoride-bearing minerals are; fluorite (fluorspar), fluorapatite, cryolite, biotite, muscovite, lepidolite, tourmaline, hornblende series minerals, etc.

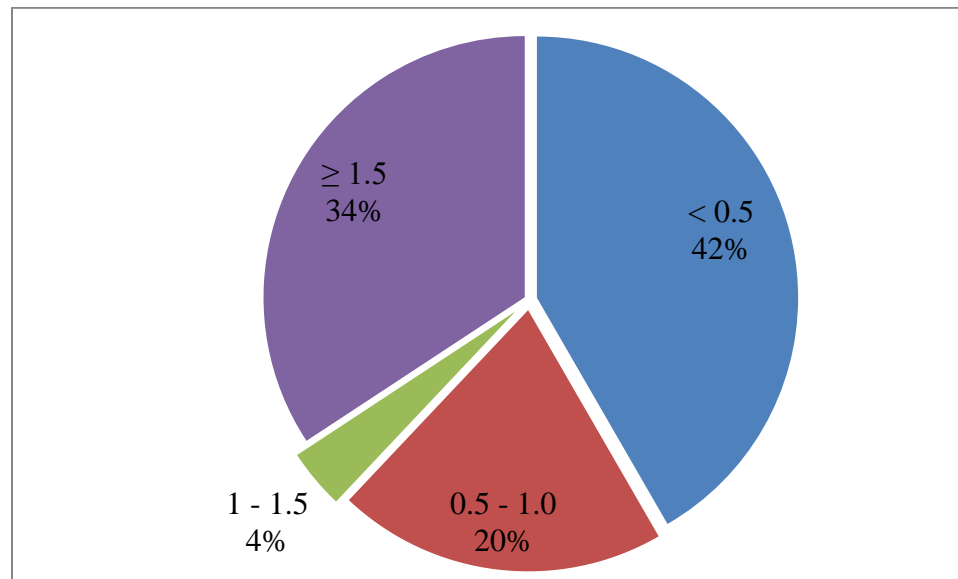
Low level fluoride is required by human system as it is helpful in preventing dental carries, while consumption of high concentrations of fluoride can lead to serious health problems. According to the world health organization (WHO, 2011) Drinking Water Quality Guideline Values, the long exposures and use of water having high fluoride in excess of 1.5 mg/l results in dental, skeletal as well as non-skeletal Fluorosis.

The dental fluorosis is the loss of luster and shine of the dental enamel. The discoloration starts from white, yellow, brown to black. It affects both the inner and outer surfaces of the teeth. Skeletal fluorosis is due to excessive quantity of fluoride deposited in the skeleton. Fluoride poisoning leads to severe pain associated with rigidity and restricted movements of cervical and lumber spine, knee and pelvic joints as well as shoulder

joints. Crippling deformity is associated with rigidity of joints and includes Kyphosis, Scoliosis, flexion deformity of knee joints, Paraplegia and Quadriplegia. Skeletal fluorosis affects both young children as well as adults. Fluorosis is irreversible and no treatment exists for it.

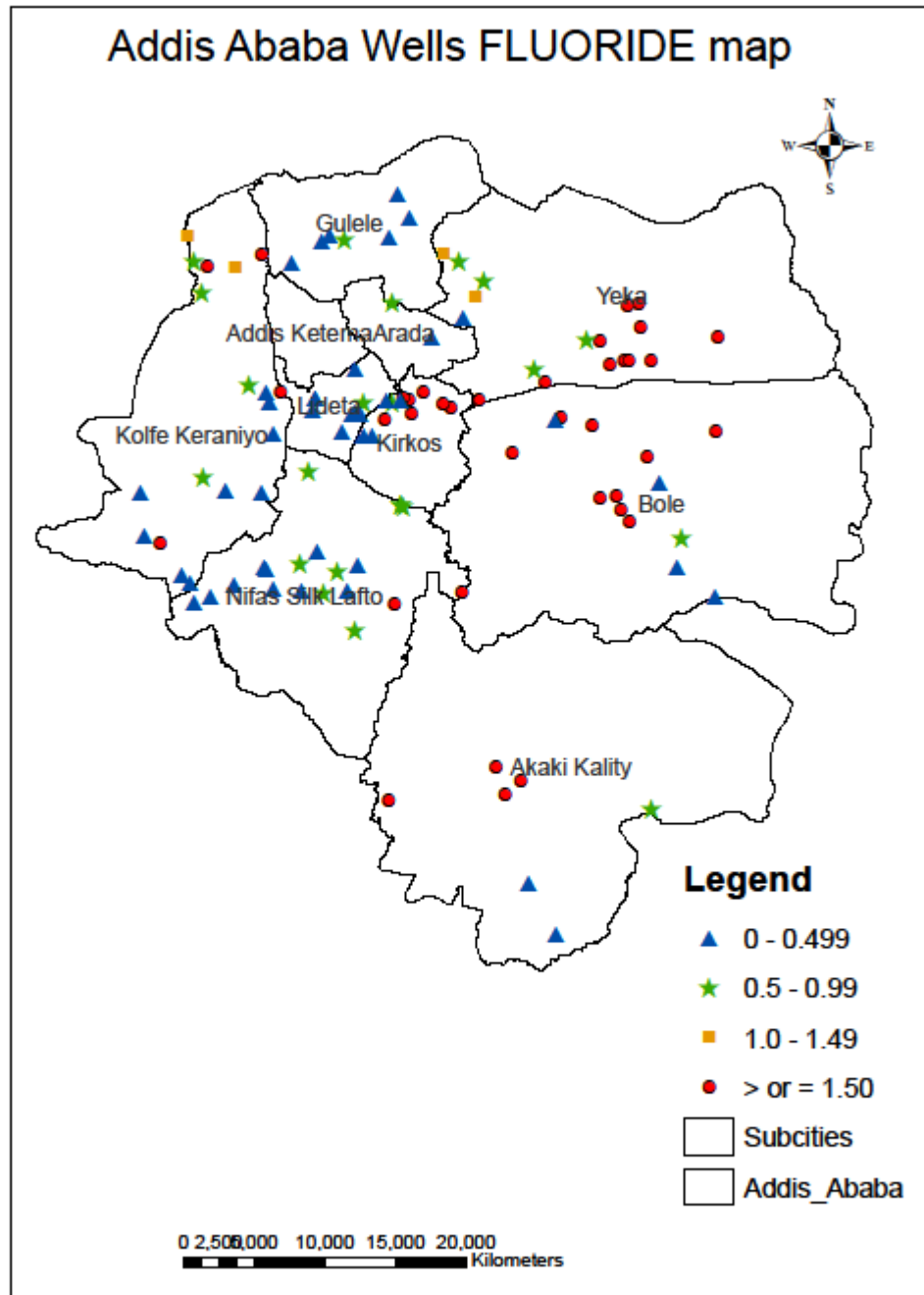
The results of the laboratory analysis indicated that 37 wells have above 1.5 mg/l Fluoride content. 45 wells have Fluoride content between 0 mg/l to 0.5 mg/l. 22 wells have Fluoride content between 0.5 mg/l to 1.0 mg/l. 4 wells have Fluoride content between 1.0 mg/l to 1.5 mg/l. 71 wells have Fluoride value below 1.5 mg/l which is the maximum allowable limit according to WHO Drinking Water Guideline values.

**Figure 10: Fluoride content distribution**



Spatial distribution of Fluoride in groundwater samples collected from Addis Ababa wells is shown in Fig 11.

Figure 11: Fluoride distribution map of Addis Ababa.

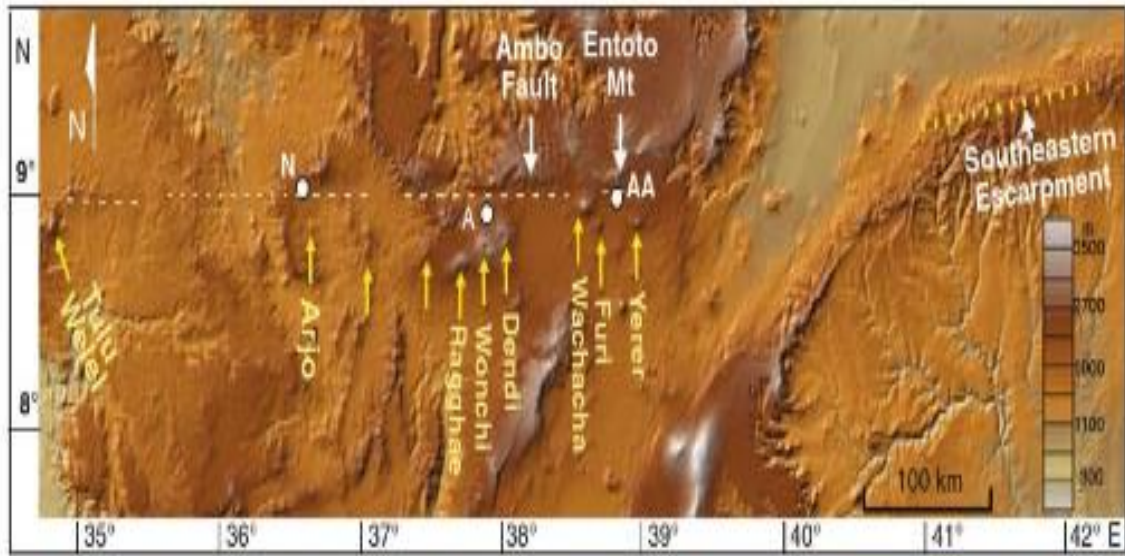


The Fluoride distribution map shows that high fluoride concentration observed in the central part of the city around the filwuha area and extends towards to the east of the city. The ground water along this direction has high temperature. According to many researchers, there is volcanic fault line along this direction which has a capacity to produce thermal hot springs.

Fluoride is not evenly distributed in the environment because of Geogenic causes. The most common natural sources of fluoride are rocks such as fluorite, fluor-apatite, and cryolite. The common sources of fluoride in surface and ground waters are natural, like the leaching of fluoride bearing rocks and dissolution of fluorides from volcanic gases (OWWDSE, 2016). Although, human beings can be exposed to fluoride through food and breathing air, the main source of human exposure to fluoride, especially in volcanic regions, is drinking water.

The geology of Addis Ababa is the result of the intersection of two major tectonic features and Cenozoic to quaternary volcanism. The two well-known tectonic features are the Yerer Tullu Welele Volcanic Lineament (YTVL) and the western margin of the Main Ethiopian Rift (MER). The YTVL is an East–West running fault and volcanic zone. Abebe et al. (1998) elaborately described the origin of the structures in YTVL, their evolution and their importance in controlling the origin of quaternary volcanic in the region. The intersection between YTVL and MER created the Addis Ababa embayment, where the rift become wider and the step faults defining the rift are subdued. Kebede et al. (2005) described this zone as ‘the YTVL hydro-geologic switch’ whereby the ground waters are drained from central part of the Plateau and flows down the rift following

regional topography. The E–W faults act as a barrier to the N–S groundwater flow around Addis Ababa resulting in the emergence of productive thermal springs in the central Addis Ababa (Seifu, 2013).



**Figure 12:** Digital elevation model of the Yerer Tulu Welel Volcanotectonic Lineament, showing the Ambo Fault and the volcanoes associated with the Lineament. AA stands for Addis Ababa, A for Ambo and N for Nekemte (Yellow arrows indicate volcanoes. Two are not named). DEM from GeoMapApp (Williams, 2016).

## 4.2 Water Quality Index

The Water Quality Index computed on 108 wells is presented below on Table 6 and the status of the wells indicated on Table 5.

**Table 5:** Status of the wells based on WQI

WQI	STATUS	Number of Wells	Percentage (%)
0 - 25	Excellent	55	50.93
26 - 50	Good	16	14.81
51 - 75	Poor	6	5.56
76 - 100	Very Poor	7	6.48
Above 100	Unsuitable for drinking	24	22.22

**Table 6:** water quality index of the wells

<b>Well ID</b>	<b>WQI</b>	<b>Well ID</b>	<b>WQI</b>	<b>Well ID</b>	<b>WQI</b>	<b>Well ID</b>	<b>WQI</b>
W1	29.63	W28	18.88	W55	123.67	W82	4.74
W2	49.62	W29	3.81	W56	25.25	W83	2.43
W3	24.65	W30	12.00	W57	359.61	W84	2.74
W4	11.76	W31	4.97	W58	27.94	W85	5.99
W5	177.04	W32	10.20	W59	42.63	W86	1.90
W6	38.01	W33	4.89	W60	54.64	W87	75.20
W7	175.83	W34	6.98	W61	40.85	W88	38.47
W8	100.60	W35	5.39	W62	213.67	W89	3.64
W9	173.80	W36	9.93	W63	732.87	W90	1.42
W10	56.60	W37	9.02	W64	36.89	W91	4.26
W11	21.14	W38	2.13	W65	225.36	W92	30.33
W12	90.81	W39	7.54	W66	57.89	W93	4.60
W13	69.48	W40	22.11	W67	293.71	W94	8.57
W14	132.95	W41	8.41	W68	370.67	W95	98.97
W15	263.28	W42	6.27	W69	11.60	W96	2.90
W16	207.55	W43	4.71	W70	3.45	W97	144.44
W17	294.79	W44	8.69	W71	10.74	W98	125.60
W18	517.05	W45	6.76	W72	0.66	W99	151.78
W19	66.03	W46	5.83	W73	92.23	W100	755.18
W20	99.65	W47	1.39	W74	94.15	W101	111.40
W21	170.94	W48	5.30	W75	68.06	W102	15.35
W22	8.89	W49	5.55	W76	43.39	W103	118.93
W23	12.72	W50	4.72	W77	43.53	W104	18.75
W24	7.36	W51	734.00	W78	1.51	W105	32.20
W25	20.32	W52	20.74	W79	3.30	W106	9.73
W26	47.60	W53	8.95	W80	2.43	W107	44.80
W27	92.36	W54	9.85	W81	16.83	W108	35.53

## CHAPTER FIVE

### 5. CONCLUSION AND RECOMMENDATION

#### 5.1 CONCLUSION

This study showed that groundwater of Addis Ababa city shows variation in water quality parameters depending on their location. The water quality variation was observed on important parameters such as TDS, Nitrate, Iron, Manganese and Fluoride concentrations.

Accordingly, the followings conclusions have been drawn:

- ✚ The ground water from the northern part of Addis Ababa city, located along the foot of Entoto Mountain, has higher concentrations of Iron and manganese beyond the WHO standards,
- ✚ The ground water from central part of Addis Ababa, which starts near Filwuha area and extends to the eastern part of Addis Ababa city, particularly towards Yerer-Goro area, contains higher TDS values.
- ✚ The water quality analysis results indicated that groundwater from the central part of Addis Ababa; particularly the oldest part of the city such as Merkato, Lideta and Mexico areas contains higher concentrations of Nitrate. This could be attributed to percolation of human waste into the aquifer due to malfunctioning of onsite sanitation facilities, and
- ✚ The groundwater of central Addis Ababa, along the Addis Aleme-Yerrer fault line, which passes through Filwuha and extends to eastern part of the city, contains higher concentrations of Fluoride. This situation clearly shows the effect of Temperature on groundwater quality. In addition, this fault line divides groundwater of the city into two, namely Northern and Southern parts of the city,

and the water from the upper part of the city is does not flow to the lower part or the south.

✚ The ground water at the south and south western part of the city has water qualities that comply with the recommendation of WHO drinking water quality standards. So ground water located at the south and south eastern part of Addis Ababa city could be a potential ground water development area. However, it is not recommended to develop wells for domestic purposes at the rest part of Addis Ababa region.

✚ Previously, some researchers were assuming that the groundwater of Addis Ababa city flows north to south direction from Abay River basin to Awash River basin (From Entoto Mountain towards Akaki area). But, according to the findings of this study, the ground water quality of northern part of Addis Ababa is different from the ground water quality of the southern part of Addis Ababa city which put in doubt the N – S ground water flow assumption.

Generally, the ground water samples collected from different parts of Addis Ababa region indicated that three types of water exist in Addis Ababa city: Ground waters with high iron and manganese region located at the northern part of the city, with high Fluoride and TDS rich water confined in the central part which extends to eastern part of the city, and the groundwater quality that comply with the recommendations of WHO Drinking Water Quality Guideline Values at southern part of Addis Ababa city.

## 5.2 RECOMMENDATION

This research work was done to understand ground water quality variation and its spatial distribution in Addis Ababa city. To reach on comprehensive conclusions, further detail research work should be conducted on related topic in the project area and the following recommendations were given:-

- ✚ The groundwater water quality variation, specifically Fluoride concentration variation with depth, should be further investigated to further assess groundwater quality variation with increasing depth.
- ✚ Continuous groundwater quality monitoring should be done to determine long-term trends of ground water quality changes in the area, if any, by increasing the number of sampling points and including more borehole information data.
- ✚ Additional study on the flow path and age (residence time) of groundwater of Addis Ababa region is needed.

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## APPENDICES

### Appendix I: Result of physic-chemical water quality analysis

No	Well ID	X	Y	TDS	Nitrate	Iron	Manganese	Fluoride
1	W1	475068	1001254	134	0.01	0.04	0.033	0.97
2	W2	475945	1000580	185	1.26	0.05	0.062	0.51
3	W3	475638	999991	158	0.01	0.06	0.023	1.14
4	W4	474518	1001467	141	0.06	0.06	0.0043	1.26
5	W5	470504	1002135	100	0.06	1.03	0.135	0.01
6	W6	470218	1001886	93	0.12	0.09	0.042	0.35
7	W7	472608	1002066	92	0.42	0.519	0.188	0.47
8	W8	471026	1002023	91	0.96	0.69	0.062	0.68
9	W9	481681	994296	782	0.01	0.548	0.173	2.48
10	W10	482109	993423	480	0.44	0.069	0.072	0.01
11	W11	482719	990450	447	0.33	0.092	0.019	0.12
12	W12	482897	991485	1210	0.03	1.067	0.006	0.76
13	W13	480604	992935	1090	0.01	0.053	0.064	6.3
14	W14	481061	992052	1132	0.01	0.571	0.115	2
15	W15	480760	992453	1032	0.01	0.076	0.349	3.05
16	W16	480029	998401	177	0.03	0.066	0.278	1.61
17	W17	465998	1000153	123	0.66	0.052	0.406	0.81
18	W18	477715	997474	133	0.48	1.05	0.608	0.89

19	W19	481400	999700	209	0.06	0.39	0.043	1.51
20	W20	480999	999648	208	0.02	0.374	0.091	1.77
21	W21	484190	998500	258	0.03	0.344	0.196	1.5
22	W22	469500	989600	159	0.48	0.022	0.01	0.01
23	W23	470070	991000	149	1.25	0.034	0.014	0.01
24	W24	471125	989636	213	0.33	0.017	0.008	0.1
25	W25	466308	989421	188	0.32	0.014	0.027	0.01
26	W26	466050	993650	236	0.58	0.06	0.056	0.98
27	W27	484065	989378	273	0.03	0.424	0.083	0.01
28	W28	467135	989840	166	1.365	0.031	0.023	0.01
29	W29	468261	990357	150	1.115	0.02	0.003	0.01
30	W30	470277	989578	196	0.26	0.048	0.008	0.8
31	W31	465741	989188	133	0.48	0.01	0.005	0.19
32	W32	468512	989680	150	0.75	0.002	0.012	0.47
33	W33	471500	990500	227	1.25	0.034	0.001	0.45
34	W34	469458	990594	163	1.225	0.025	0.003	0.89
35	W35	468196	990422	154	0.8	0.004	0.005	0.47
36	W36	470790	990330	144	0.74	0.002	0.011	0.61
37	W37	465591	989872	178	0.7	0.07	0.003	0.42
38	W38	465295	990132	133	0.48	0.01	0.001	0.19
39	W39	463985	991540	132	0.61	0.05	0.004	0.23
40	W40	471400	988250	166	0.72	0.12	0.015	0.62
41	W41	470950	995225	317	21.5	0.037	0.004	0.44

42	W42	466842	993128	141	0.93	0.003	0.007	0.32
43	W43	463850	993100	132	0.61	0.05	0	0.23
44	W44	469150	1001150	89	1.86	0.1	0	0.22
45	W45	467660	996912	115	0.24	0.01	0.004	0.99
46	W46	468268	996584	110	0.36	0.03	0.004	0.19
47	W47	468380	996211	103	2.1	0.012	0	0.1
48	W48	468505	995156	131	2.4	0.047	0.002	0.01
49	W49	465500	1002150	136	0.01	0.03	0	1.01
50	W50	465717	1001230	146	0.01	0.031	0	0.72
51	W51	472900	1003550	77	0.01	3.16	0.682	0.29
52	W52	477252	982872	351	0.01	0.028	0.017	2.05
53	W53	476692	982390	361	1.1	0.022	0.001	2.04
54	W54	481828	981943	217	3	0.01	0.009	0.79
55	W55	472456	995639	2020	0.01	0.16	0.032	28
56	W56	476370	983392	274	0.06	0.01	0.023	2.58
57	W57	481462	998906	173	0.01	0.65	0.427	1.7
58	W58	472585	982237	217	0.63	0.15	0.001	4.87
59	W59	480045	992855	164	0.9	0.06	0.044	2.1
60	W60	475182	989526	214	0.23	0.28	0.034	2.67
61	W61	476933	994457	1230	0.01	0.16	0.001	8.72
62	W62	479550	998479	169	0.03	0.03	0.294	0.85
63	W63	473314	1002774	57	0.088	2.62	0.74	0.38
64	W64	472792	989152	195	1.6	0.05	0.039	1.64

65	W65	480363	997593	214	0.01	1.61	0.129	2.18
66	W66	468110	1001429	104	0.01	0.145	0.05	3.48
67	W67	466200	1001008	517	22	0.03	0.4	1.97
68	W68	467200	1001017	212	0.1	3.12	0	1.28
69	W69	471400	997400	1059	176	0	0	0.4
70	W70	470000	996400	415	50.68	0	0	0.15
71	W71	469900	996000	388	40.5	0.1	0	0.15
72	W72	478450	995600	375	0.4	0	0	0.2
73	W73	474500	996200	249	23.8	0	0	28.8
74	W74	473800	996600	2253	3.5	0.01	0	29.3
75	W75	473100	996400	2292	3.5	0	0	21.5
76	W76	473300	996300	1848	2.6	0	0	13.7
77	W77	473400	995800	1868	2.2	0	0	13.75
78	W78	473000	996300	932	1.32	0	0	0.45
79	W79	472700	996300	348	13.2	0	0	0.8
80	W80	472500	996300	516	25.1	0	0	0.3
81	W81	471600	995800	509	74.4	0.14	0	0.45
82	W82	471300	995800	498	75.3	0	0	0.1
83	W83	472000	995100	278	19.8	0	0	0.4
84	W84	471700	995100	393	25.1	0	0	0.4
85	W85	471700	996300	522	75	0	0	0.5
86	W86	468100	993100	279	16.2	0	0	0.3
87	W87	473000	992700	564	26.4	0	0.1	0.85

88	W88	473100	992600	279	13.2	0	0.05	0.7
89	W89	477500	979300	618	45.7	0	0	0.3
90	W90	475200	999200	73	2.64	0	0	0.4
91	W91	474100	998500	614	41.8	0.01	0	0.32
92	W92	471400	995900	523	97.5	0.3	0	0.3
93	W93	473000	992700	315	2	0.03	0	0.67
94	W94	478463	977506	347	14.2	0.09	0	0.2
95	W95	468800	996600	325	15.1	0.4	0	21.1
96	W96	472700	999800	411	11.6	0	0	0.7
97	W97	469750	993850	350	14.96	0	0.2	0.52
98	W98	464538	991302	168	0	0.435	0.12	1.95
99	W99	481040	997714	210	0.04	0.639	0.122	4.7
100	W100	480879	997714	203	0.2	4.35	0.57	2.45
101	W101	481823	997680	246	0.1	0.35	0.11	1.82
102	W102	474777	996040	354	2.1	0.03	0.003	3.4
103	W103	478105	996912	211	3.7	0.8	0.028	11.34
104	W104	475764	996308	165	2.4	0.02	0.016	1.8
105	W105	479750	995452	361	0.4	0.3	0	2.7
106	W106	484102	995204	153	0.49	0.019	0	2.6
107	W107	470000	996400	362	50.68	0.17	0.04	0.01
108	W108	478640	995726	482	1.2	0.26	0.0024	4.2

**Appendix II: Wells abandoned by AAWSA because of water quality problem**

<b>S.No</b>	<b>Well Name</b>	<b>Location</b>	<b>Reason For Abandoning</b>
1	SMV 1	Summit	High Fluoride Content
2	SMV 2	Summit	High Fluoride Content
3	SMV 4	Summit	High Fluoride Content
4	SMV 5	Summit	High Fluoride Content
5	EBV 3	Goro	High TDS Content
6	EBV 22	Goro	High TDS Content
7	EBV 23	Goro	High TDS Content
8	EBV 24	Goro	High TDS Content
9	Gerji Giorgis	Gerji	High TDS and Fluoride content
10	Bole High School	Bole	High Fluoride Content
11	Wondirad 1	Kotebe	High Iron & Manganese Content
12	Wondirad 2	Kotebe	High Iron & Manganese Content
13	Kotebe Hana	Kotebe	High Iron, Manganese & Fluoride Content
14	Susni Kidanemihret	Kotebe	High Iron & Manganese Content
15	Kusquam	Shiro meda	High Iron & Manganese Content
16	Sanba neqers	Shiro meda	High Iron & Manganese Content
17	Legehar Train Station	Legehar	High TDS and Fluoride content with high Temperature
18	Tsebay Maremia	Lideta	High Nitrate Content
19	Old Airport	Lideta	High Nitrate Content
20	Shegole Mesgid	Shegole	High Fluoride Content
21	Awolia	Shegole	High Fluoride Content
22	Serti	Kilinto	High Fluoride Content