



**GROUNDWATER QUALITY ASSESSMENT AND  
CHARACTERIZATION OF AQUIFERS IN GUDER RIVER  
WATERSHED, SNNPR, ETHIOPIA**

**MSc THESIS**

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**HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA**

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CHARACTERIZATION OF AQUIFERS IN GUDER RIVER  
WATERSHED, SNNPR, ETHIOPIA**

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**A THESIS SUBMITTED TO HAWASSA UNIVERSITY  
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# EXAMINER’S APPROVAL SHEET -I

## SCHOOL OF GRADUATE STUDY

### HAWASSA UNIVERSITY EXAMINER’S APPROVAL SHEET-I

#### (Submission-ii)

We undersigned, the member of board of examiners of the final MSc open defense by Temesgen Ayano Sediso have read and evaluate his thesis entitled **“Groundwater Quality Assessment and Characterization of Aquifers in Guder River Watershed, SNNPR, Ethiopia”** and examined the candidate. This is, therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree.

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## **DEDICATION**

I dedicate this thesis manuscript to all my family members for nurturing me with care and love and, for their dedicated partnership in the success of my life.

Name: Temesgen Ayano Sediso

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Date\_\_\_\_\_

## **STATEMENT OF AUTHOR**

I, the undersigned hereby, declare that this MSc. thesis work is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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## LISTS OF ACRONMYS AND ABBREVIATIONS

APHA_____	American Public Health Association
BH_____	Borehole
DEM_____	Digital elevation model
DWQI_____	Drinking Water Quality Index
EC_____	Electrical conductivity
EGS_____	Ethiopia geological survey
Eq_____	Equation
FAO_____	Food and agriculture organization
GIS_____	Geographic information system
GPS_____	Global positioning system
Gw_____	Groundwater
HD_____	Hand dug well
HU_____	Hawassa University
HZWMED_____	Hadiya Zone Water, Mines and Energy Development
IWQI_____	Irrigation Water Quality Index
m. a.s.l._____	Meter above sea level
MER_____	Main Ethiopian Rift
n_____	Number of samples
Na%_____	Sodium percent
RSC_____	Residual sodium carbonates
SAR_____	Sodium adsorption ratio
SDSWE_____	South Design and Supervision works Enterprise
SNNPR_____	South Nation Nationalities Peoples Region
SNNPRWMEB_____	South Nation Nationalities Peoples Region Water,Mines and Energy Bureau
Sw_____	Shallow well
SWWCE_____	South Water Works Construction Enterprise
T.D.S_____	Total Dissolved solids
TH_____	Total hardness
TSC_____	Total sum of cations
US_____	United States
USAID_____	United states agency for international development
UTM_____	Universal Transverse Mercator
WHO_____	World Health Organization
WQI_____	Water quality index

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## **ABSTRACT**

*Groundwater quality problems and improper management of aquifer either from geogenic or anthropogenic sources has become a thing of health concern and aquifer damage in Guder River Watershed, Southern Ethiopia. This study was conducted to assess groundwater quality and characterize the aquifer. In order to assess the water quality, 30 groundwater samples were gathered and examined for 17 parameters such as pH, temperature, EC, TDS, TH, K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>2+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, F<sup>-</sup>, PO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>. The research depend on secondary and primary data which was collected from SWWCE, SDCSE, SNNPRWMEB and HZWMED, literature, journals and reports, and field observation on site. The chemical parameters were analyzed and water quality index was determined. To characterize the aquifer of the study area pumping test data, well completion reports, well logs and geology of the area were analyzed. The chemical analysis concentration of the pH, EC, TDS, Na<sup>+</sup>, HCO<sub>3</sub><sup>-</sup> and F shows an increasing trend from the highland water toward the rift floor water along the groundwater flow path. In this regard, water quality indices were considered for drinking and irrigation purposes. Finally, the analytical results were taken to generate the numerical spatial distribution of parameters using geographic information system (GIS) environment. Results of groundwater quality assessment and aquifer characterization show that Ca<sup>2+</sup> and HCO<sub>3</sub><sup>-</sup> are the main cation and anion in the groundwater, respectively. According to the results of the drinking water quality index showed that groundwater sampling were classified 70% as excellent, 27% as good, 3% as poor, and 0% as very poor and unfit for drinking purposes. In addition, Irrigation water quality index illustrated that 100% samplings were placed in the “good” and “excellent” class. The pumping tests analysis results indicate that the hydraulic conductivity of the study area ranges from  $1.26 \times 10^{-5}$  -  $4.39 \times 10^0$  m/sec and transmissivity were  $1.16 \times 10^{-3}$  -  $7.71 \times 10^{-2}$  m<sup>2</sup>/sec this indicates that the productivity of the wells in the watershed ranges from low to high productivity from high land water. In general, the hydraulic conductivity and transmissivity decreases radially from the center of Boyo plain towards the periphery of the area. The findings of this study was not only useful for understanding of groundwater sustainability for different purposes but also useful for supporting water management and protection in the future.*

**Keywords:** *Aquifer characterization, Groundwater quality, Guder River Watershed, Water quality indices.*

# 1. INTRODUCTION

## 1.1. Background

Water is essential for human survival hence termed as water is life. Groundwater plays an important role all over the world for the survival of both flora and fauna. It is not only the basic need for human existence but also a vital input for all development activities. The demand for water in Ethiopia has increased rapidly with the construction of power plants, development of industry, irrigated agriculture, urbanization, to improve living standards and eco-environmental construction. Groundwater is a strategic resource in all climatic regions of Ethiopia, contributing about 80% of the domestic supply of urban and rural populations (Kebede, 2013).

Natural resources are degraded continuously due to rapid population, global climate change, poor management and misunderstanding of the nature of resources which is resulted from lack of coordination and integrated approaches. Among all, water is the prime natural resource which is basic for healthful functioning of any ecosystem. This natural resource is limited in its nature, spatially and temporally and all humankind always competes for usage leaving behind sustainability issues (Mulatu et al, 2021).

Dealing the quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes. The quality of groundwater depends on many factors such as infiltrating rainwater, geological structure and mineralogical composition of aquifer, dissolution and precipitation of mineral, seawater intrusion and anthropogenic influences (Unicef, 2010). According to Yohualashet (2020) more than 90% of the dissolved solids in groundwater can be attributed to eight ions: sodium ( $\text{Na}^+$ ), calcium ( $\text{Ca}^{2+}$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{2+}$ ), sulfate ( $\text{SO}_4^{2-}$ ), chloride ( $\text{Cl}^-$ ), bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3^{2-}$ ) but lately (Hiscock, 2005) eliminate  $\text{CO}_3^{2-}$  and  $\text{K}^+$  so that attribute to 6 ions regardless of whether the water is dilute or has salinity greater than seawater. Therefore, characterizing the chemistry of groundwater is an indicator of hidden minerals present in the terrain and controlling mechanism responsible for these mineral formations.

An aquifer is an underground layer of water-bearing permeable rocks or unconsolidated materials from which groundwater can be extracted using water well. Aquifer characterization takes into account how the different geological formations get a water-bearing nature; how the arrangement of these water-bearing geological formations with adjacent impervious layer looks like and the potentiality nature of the aquifer (Enideg, 2012).

Currently, in the study watershed, groundwater is serving as a main water sources for domestic water supply, industrial, agricultural and livestock purposes. A number of deep wells, shallow wells, hand dug wells have been drilled in different parts of the watershed for these purposes both by government and non-governmental organizations. However, there is no systematic study conducted on groundwater quality and aquifer characteristics of the watershed to support the water management and protection in the future despite, the lack of alternative water sources, the groundwater is used for multipurpose including sustaining life (Belay, 2015).

Thus, in the outlook of the above, the study was aimed to characterize the aquifer system and assess the quality of groundwater for drinking consumption and irrigation purpose. The chemical parameters were analyzed and water quality index was determined. Aquifer characterization was conducted by using the use of existing pumping test data, geologic map, hydrogeological map, soil map, and lithology obtained from well logs as well as well inventory. Besides, the quality of groundwater for drinking purpose was evaluated using water quality index technique. Moreover, calculation of Na%, PI, SAR and EC were conducted to evaluate suitability of the groundwater for irrigation use.

The research has believed to give insight into characteristics of aquifer system and groundwater quality for irrigation and drinking purpose of the area, which is very important in water resource management and development methods by giving directions for groundwater management options.

## **1.2. Statement of problem**

The demand for water in Ethiopia has increased rapidly with the construction of power plants, development of industry, irrigated agriculture, urbanization, to improve living standards and eco-environmental construction (Unicef, 2010).

The quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes. Voluminous body of literature cited in there by (Birhanu, 2007) suggests the effect of physical, chemical, biological and radiological drinking water quality parameters on health. Some of quality problem on health occurs are: Cardio vascular diseases (heart disease, hypertension, and stroke), is associated with hardness. High concentration of fluoride in natural water can be resulting dental fluorosis. High level of sulphate cause diarea and dehydration. Sodium is considered harmful in drinking water at high concentrations to persons suffering from cardiac, renal, circulatory diseases and influenced blood pressure. High content of Calcium and Magnesium cause Kidney stone.

World Health Organization, (2016) reported that every year more than 3.4 million people die as a result of water-related diseases and a leading cause of death around the world. World Bank, (2017) reported over 75 percent of the Ethiopian population usually uses an unimproved water source. Groundwater quality should be continuously monitored for irrigation and drinking purpose so that the risk from geochemical contaminants can be reduced by appropriate treatment methods (Alliance, 2021).

Traditionally Ethiopian economy is mainly depend on agriculture, and groundwater is one of the important sources of irrigation in particular for the study area. According to Singh & Hussian, (2016) groundwater resources are affected in principle by three major activities: excessive use of fertilizers and pesticides in agricultural areas, untreated/partially treated wastewater to the environment and excessive pumping and improper management of aquifers result. Most peoples in the study area rely on agriculture, which may result in the release of fertilizer and pesticide inputs into groundwater. Besides, it was recognized by (Mulatu et al, 2021) that some shallow wells and springs in the study area becoming dried, yield decreasing and the borehole water table decline.

To the best of my knowledge, there is no systematic study conducted on characterization of the aquifer and quality status assessment of groundwater for different purpose. Thus, the aquifer productivity, hydrogeochemistry, and suitability of the groundwater is not well known in Guder River Watershed. Therefore, this study is conducted to assess groundwater quality and aquifers characteristics for the suitability of the groundwater for drinking and irrigation purposes and proper management of aquifers.

### **1.3. Objectives**

#### **1.3.1. The main Objectives**

The main objective of this work was to assess groundwater quality and characterize the aquifers system in Guder River Watershed.

#### **1.3.2. Specific objectives**

The specific objectives of this study were:-

- To determine the physico-chemical parameters of groundwater by showing spatial distribution,
- To determine water quality index and assess the water quality for drinking and irrigation purpose,
- To characterize aquifer systems.

### **1.4. Research questions**

- ✓ How to determine the physio-chemical parameters of groundwater by using spatial distribution of different water quality parameters ( drinking and irrigation)?
- ✓ How to determine water quality index and assess the water quality for drinking and irrigation purpose?
- ✓ How to characterize aquifer systems to describe hydraulic parameters in the study area?

## **1.5. Significance of the research**

Results of this research will provide a scientific basis for understanding the aquifer system. In addition to this, it will indicate physico-chemical parameters of groundwater, the quality of water for drinking and irrigational purpose in the study area. This will give the general answer about the hydrogeological behaviour of water in the watershed. And also be helpful to planners in the development and management of aquifer characterization and aquifer related works in the study area, and be essential to propose the mechanism of sustaining and obtaining the maximum benefit from the aquifer(s) in the given terrain i.e. without affecting the aquifers.

## **1.6. Scope of the Study**

In this study, a groundwater quality assessment and characterization of aquifer in Guder River Watershed has been conducted. The Physico-chemical properties of the groundwater were determined. The major cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Na}^+$ ) and anions ( $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ) with some minor ions ( $\text{K}^+$ ,  $\text{Fe}^{2+}$ ,  $\text{NO}_3^-$ ,  $\text{F}^-$ ,  $\text{PO}_4^{2-}$ ) in groundwater from springs and wells were analyzed. The in-situ measurements were conducted to analyze pH, TDS, EC and temperature of the groundwater. The chemical quality of the groundwater in the study area was determined to assess the suitability of the groundwater for drinking and irrigation purposes. Moreover, for some selected samples based on the aquifer system of the study area was characterized by using existing well log and pumping test data.

## **1.7. Limitation of Study**

Like any other other research works, this study has a number of limitations. The main problem that were encountered during the reseach study are scarcity of sufficient stratigraphical data to map stratigraphic layers, problem associated groundwater quality index for drinking shows difference in some parameters results. There is no funding for this research study for carrying out field work and collecting data. The financial resource problem faced me to undertake all the water quality analysis because I am self sponsored student which pay for all activity including for education and for thesis work.

## **2. LITERATURE REVIEW**

In this study, the literature review focuses and discusses about the general background and previous groundwater studies that were related to quality and aquifer characterization of groundwater in around Guder River Watershed area and other areas. In addition, this review section explains the various complementary different methods and tools that were used to analyze and interpret the groundwater data that were collected.

### **2.1. Groundwater quality and sources of pollution**

Groundwater quality is a hidden issue inside a hidden resource, and as a result far too little attention is given to it. Once groundwater has become polluted, it is usually a very long, complex and expensive task to restore the water quality. For these reasons that monitoring, prevention and remediation of groundwater pollution is a vital management issue (Tenalem et al, 2008).

The quality of water either it is surface water or ground water affected by both natural influences and human activities (Seifu et al, 2005). Similarly (Dagneew.et al, 2010) stated that while water contains natural contaminants, it is becoming more and more polluted by human activities such as, inadequate wastewater management, dumping of garbage, poor agricultural practices, and chemical spills at industrial sites. Even though water may be clear, it does not necessarily mean that it is safe for us to drink. It is important to judge the safety of water by taking the following three types of parameters into consideration (Abraham et al, September 2011).

- Microbiological\_ bacteria, viruses, protozoa and helminths (worms)
- Chemical \_ minerals, metals, chemicals and pH
- Physical \_ temperature, color, smell, taste and turbidity

The World Health Organization WHO (2011) and (Report n.d.2010) divides the sources of chemicals into the following five groups shown in Table 2.1 below.

**Table 2.1: Sources of chemical contamination**

Source of Chemicals	Examples	Common chemicals
Naturally occurring	Rocks and soils	Arsenic, Chromium, Flouride, Iron, Manganese, Sodium, Sulfate, Uranium
Agricultural activities	Manure, Fertilizer, Intensive animal practices, Pesticides	Amonia, Nitrate, Nitrite
Industrial sources and human dwellings	Mining, Manufacturing and processing industries, Sewage solid waste	Nitrate, Amonia, Cadmium, Cyanide, Copper, Lead, Nichel, Mercury
Water treatment	Water treatment chemicals, Piping materials,	Aluminium, Chlorine, Iodine, Silver
Pesticides used in water for public health	Larvicides used to control insect vectors of disease	Organophosphorus compounds (e.g. Chloropyrifos, Diazinon, Malathion) and Carbamates (e.g. Aldicarb, Carbofuran, Oxamyl)

(Source WHO, 2011)

Even though there is few data exist for the general state of groundwater quality across Ethiopia, but from those available, the quality is shown to be highly variable, ranging from fresh waters in many of the springs to more saline waters in parts of the Rift valleys (Alliance, 2021). The groundwater quality of Ethiopia is both anthropogenically and naturally affected (Hem, 1959). The main quality controls (Ayenew, 2005) are: Geomorphological and geographical conditions, Climate, Geology (geological structures, rock composition, weathering, magmatism, geothermal activities,), Physico\_chemical factors (temperature, pressure, chemical properties of elements, solubility of chemical compounds, pH, Eh, etc.), Biological factors (effects of micro-organisms, plants and animals) and anthropogenic influences. According to Hamid et al (7 August 2018) conducted hydrogeochemical characterization of groundwater in aquifer in Almadinah Almunawarah City, Saudi Arabia. His study was carried out to chemically characterize groundwater and to investigate possible sources of pollution in the aquifer system of Al Medina Al Munawarah city.

Duplicate groundwater samples were collected from 33 wells in clean polyethylene bottles. All sampling bottles were soaked with 1:1 HNO<sub>3</sub> and washed using detergent. Temperature (T°C), electrical conductivity (EC), total dissolved solids (TDS), and hydrogen ion concentration (pH) were measured at the wellhead using portable Hanna Instruments. Analysis of major cations and anions (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, F<sup>-</sup>) were carried out following (APHA(American Public Health Association) 2005). In his result, it is indicated that the analyzed nitrate exceeds the WHO, (2011) drinking water standards of 50 mg/l and the reason is suggested that NO<sub>3</sub><sup>-</sup> originates from fertilizers application and leakage of sewage. (Kebede, 2013) worked on hydrogeochemical investigation of groundwater in the shallow coastal aquifer of Khulna District, Bangladesh. To investigate the hydrogeochemical characteristics of groundwater and its suitability, they collected twenty samples from the shallow wells of the study area.

One of their study objective was an assessment of groundwater quality by evaluating the physicochemical parameters such as temperature, pH, EC, TDS and major ions i.e. Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup> and NO<sub>3</sub><sup>-</sup>. pH of the water samples was measured on spot by using pH meter (EcoScan Ion-6, Singapore); TDS were measured by (HANNA HI8734, Romania) portable meter. EC and salinity were measured by portable EC meter (HANNA HI8033, Romania). For ion analysis Gallenkamp flame analyzer was used for Na<sup>+</sup> and K<sup>+</sup> and, ICS-5000 DIONEX SP, ion chromatography (IC) for Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup> analysis. To assess water quality the following parameters were calculated:

$$\text{Total hardness (TH)} = 2.497 (\text{Ca}^{2+}) + 4.115 (\text{Mg}^{2+}) \text{-----Eq.2.1}$$

$$\text{Soluble sodium percentage (SSP) or Na \%} = \frac{(\text{Na}^{+} + \text{K}^{+}) \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+} + \text{K}^{+}} \text{-----Eq.2.2}$$

$$\text{Sodium adsorption ratio (SAR)} = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \text{-----Eq.2.3}$$

$$\text{Residual sodium carbonate (RSC)} = (\text{CO}_3^{2-} + \text{HCO}_3^{-}) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \text{---Eq.2.4}$$

$$\text{Magnesium adsorption ratio (MH)} = \frac{\text{Mg}^{2+} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+}} \text{-----Eq.2.5}$$

Their study reveals that the shallow groundwater aquifers of the study area are strongly affected by salinity. According to chloride classification majority of samples were grouped in brackish and brackish-salt category, indicating the unsuitability of this water for agricultural activity. Besides this, in SSP or Na % classification of groundwater for irrigation purposes, the majority of the samples grouped in the unsafe zone and minor representations also fall in safe zone.

Abreha (2014) compiled a hydrogeological and hydrochemical map of Bure map sheet (NC-37/5)(18,000 km<sup>2</sup>) at a scale of 1:250,000. The main objective was to prepare hydrogeological and hydrochemical maps of Bure map sheet (NC 37-5) at a scale of 1:250,000 and elaborate the accompanying explanatory report. To analyze the geochemical properties of water, representative water samples were taken during the field trip. 144 water points were sampled, among these, 58 were taken from boreholes, 64 from cold springs and 22 from hand-dug wells. Chemical analysis of inorganic major anions (HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-</sup> and Cl<sup>-</sup>) and cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>) and minor chemical constituent and ions (SiO<sub>2</sub><sup>2-</sup>, F<sup>-</sup> and NO<sub>3</sub><sup>-</sup>) with electrical conductivity (EC) and pH were performed in the central laboratory of the Geological Survey of Ethiopia (GSE).

Based on the result of the study the aquifer is divided into (I) Porous aquifer developed in quaternary undifferentiated alluvial and elluvial sediments developed in river and stream valleys, depressions and marshy areas and in the plateaus (II) Fissured and karstic aquifer in marble at the western lowland. (III) Fissured aquifer developed in quaternary Scoroaceous basalts, Cenozoic volcanic rocks and Mesozoic sandstone developed in the plateaus. (IV) fissured aquifer developed in metamorphic rocks and intrusive in the low land and gorges and some volcanic cones and plugs.

Besides this, most sampled water has been found beyond and below the WHO standard for drinking, agricultural and industrial purposes. 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 (Dagim et al, 2017).

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 (Birhanu, 2007). Water quality is considered the main factor controlling health and the state of disease in both man and animals.

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).

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 (Resources, August. 2019).

The concept of ground water quality seems to be clear, but the way of how to study and evaluate it still remains tricky (Nwankwoala, Eludoyin, and Obafemi 2012). 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.

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 (Enideg, 2012). 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 (Gebreezgi, 2020).

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 (Abbasnia et al. 2018). 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 (Ayenew, 2005).

## **2.2. The need for drinking and irrigation purpose**

The groundwater has become a potential supply for irrigation and home use all across the planet. In this situation, it is crucial to evaluate the groundwater's quality before using it for irrigation or home needs. We must understand that groundwater in its natural state, unaffected by anthropogenic activity, will naturally include a range of dissolved solutes (Alliance, 2021)

The majority of the liquid fresh water on Earth is stored below in aquifers rather than in lakes or rivers. In fact, during dry spells, these aquifers offer a valuable base flow that supplies water to rivers. Because of this, they are a valuable resource that must be safeguarded to ensure that groundwater can continue to support both the human population and the diverse ecosystems that rely on it. According to Morris and colleagues, 40 percent of the world's food is generated by irrigated agriculture, which mostly depends on groundwater. Two billion people directly depend on aquifers for drinking water. Aquifer development will be essential to economic growth in the future, and dependable water supplies will be required for home use as well as irrigation.

The MDG target is defined in terms of sustainable access to an affordable supply of drinking water because access to water is a requirement for health and livelihood. Human rights, social progress, and economic growth all depend on the availability of better and higher quality water supply and sanitation infrastructures (Ochocho, 2018).

The most urgent demand for better and clean drinking water, acceptable forms of sanitation, and access to water for other household purposes is among the poor and marginalized people living in rural and periurban areas (Alliance, 2021). According to the WHO (2000), around 1.8 million people worldwide die from diarrheal infections each year as a result of contaminated drinking water. Ethiopia is a nation whose efforts to build a water supply and sanitary infrastructure are still in their infancy.

Even while there are better water sources, they are frequently out of reach and inconveniently situated for the recipient homes. Some of the fundamental issues include the stakeholder management system, issues with water quality, and inaccessible water sources (Soleimani et al. 2020). Ethiopia's topography is characterized by rough terrain on which women and children must carry heavy containers up and down steep slopes in order to travel great distances. The weight of a full water can can reach 65 kilos. Additionally, the absence of a reliable supply of healthy water has a number of unfavorable effects, such as making people more susceptible to health issues due to the effort required to fetch dangerous water from, typically remote, traditional, or unimproved water sources. As a result, the majority of children miss out on the opportunity to go to school, while mothers waste 10 to 50 percent of their workday gathering water from filthy water points (Resources, August. 2019).

WHO defines basic access as having at least 20 liters of drinking water per person available each day, a source that is no more than 1 km from the dwelling, and a collection process that takes no more than 30 minutes. The minimum absolute daily water need per person per day, according to the UNDP (2008), is 50 liters (13.2 gallons), of which 5 liters are used for drinking, 20 for sanitation and hygiene, 15 for bathing, and 10 for food preparation. However, millions of people struggle to survive on 10 liters (2.6 gallons) of water per day due to a lack of access to clean water (ADF, 2005).

A water carrying trip that takes 30 minutes or less, including waiting time, would be a better sign of access in highly inhabited areas(Addisie 2022). According to ADF (2005), in some places, more than one-third of women spent more than two hours on each water collection trip. This reality is made worse by the inefficient supply, which is a result of poor condition and cannot satisfy the full population from separate villages sharing the same water source. Longer lines are also frequent during the dry seasons (Admasu et al., 2002). In the long run, this will result in household water insecurity (a lack of water availability for drinking, cooking, and sanitation) in rural regions, particularly for those homes where the demand is higher due to big family sizes (Collick, 2008, as cited by Demeke, 2009). These circumstances make it challenging to consider personal hygiene and sanitation, particularly in rural areas. Despite its shortage, many people prioritize using water for drinking and cooking. Unprotected springs and hand-dug wells are frequently used for drinking and culinary reasons in rural communities. Rivers, however, are also used for drinking purposes in addition to washing clothes.

This leads to economic catastrophes as well as illness and death. Therefore, access to clean water is crucial for reducing poverty and is a crucial part of primary healthcare. Improved domestic water sources increase knowledge in the individual and society as well as awareness of other important issues like sanitation and hygiene (Sobsey, 2002). Future issues in many nations, particularly in arid and semi-arid regions, will be brought on by the issue of over-exploitation of water resources as a result of rising demand. A rise in the need for water for diverse civil, industrial, and agricultural activities has been observed in recent decades as a result of economic development and the population's rapid growth.

The restricted amount of land that is appropriate for agriculture, the rising pressure on agricultural productivity, and the decline in the quantity and quality of water for irrigation are all effects of this need. One of the most essential ways to assess the pollution and water quality and its suitability for various uses is to apply current technology in the management of agricultural land for irrigation, such as water quality models (WQI) (Hamid Soleimani, 7 August 2018). In general, the following variables affect the quality of irrigation water: -

i. **Salinity Hazard**

Water quality is highly dependent on the quality and quantity of dissolved salts found in it. The high salt levels in irrigation water will lead to the accumulation of salts in the root zone and the emergence of salinity problems as it reduces the amount of available water for absorption by the roots. It can also lead to a decrease in plant growth and wilting if the soil is not washed with low-salt water.

ii. **Permeability and Infiltration Hazard**

The rate of water infiltration as a function of many water qualities and soil factors (soil structure, soil texture, and soil organic content), and problems of permeability when using water with high levels of sodium (expressed in SAR) is of essence, as the sodium works to break the soil pools and dispersing soft minutes to the clogging of soil pores. The most important factors affecting the permeability is soil salinity and sodium adsorption ratio.

iii. **Specific Ion Toxicity**

Some ions (sodium, chloride, and boron) cause toxicity problems to the plant at high concentrations in irrigation water and increasing concentrations in plant tissues lead to deterioration of growth and production. However, the degree of toxicity depends on plant type and absorption rate. Perennial plants are more sensitive to these ions than annual plants. In general, toxicity problems are associated with salinity and permeability problems.

iv. **Miscellaneous Effects**

Some water standards which have an impact on the quality of irrigation water include the pH, this affects the balance of carbonate and water content of the mineral elements. When water is acidic, it hinders the absorption of calcium ions and magnesium and aluminum by the roots, while alkaline water provides a suitable condition for the absorption of many of the elements and nutrients by the plant root environment but is responsible for the accumulation of calcium carbonate. The normal range of irrigation water is from pH 6.5 to 8.4. The pH of water changes with the production of hydrogen or hydroxyl ion in different chemical reactions with the redox potential, temperature, and pressure.

Also, the bicarbonate and carbonate ions responsible for raising the value of pH more than 8.3 and encourages the deposition of calcium and magnesium ions leaving sodium ions prevalent in the soil solution, which affects the soil and plants. As for nitrate ions, they are a source of nitrogen for plants, but their increased application to soil has a detrimental effect on the plant production and delaying the maturity of crops and fruits as well. But their accumulation causes health risks to consumers such as children's disease, diabetes, dysfunction of the thyroid gland, immunity and many cancers(Yadav 2016).

Groundwater is an important source of fresh water for human consumption, irrigation and industrial use in many countries of the world. However, residential, industrial, commercial, agricultural and other anthropogenic activities together with natural conditions often lead to a deterioration in groundwater quality. That is why an assessment of the quality of groundwater is of great importance for society. Water quality assessment includes an evaluation of the physical, biological and chemical properties of water in relation to the natural quality, intended use and human effects that can influence the health of aquatic systems(Ackah et al. 2011).

To assess the suitability of groundwater for human consumption, it is essential to determine and evaluate its quality. Researchers have used different methods to express water resources quality. Traditionally, water engineering professionals compare individual chemical parameters with recommended allowable limits. In many regions with scarce water resource, however, the use of water at concentrations slightly above these limits is generally not harmful. Horton proposed a water quality index (WQI) to describe the suitability water for human consumption in a single score that can be ranked into categories using terms such as excellent, good, poor, very poor and unsuitable for use, which are easy to understand for decision makers and consumers. Various methods have been proposed to derive WQI scores. A weighted WQI score is usually used in which ratios of concentrations of water quality parameters and their recommended standard values are weighted and combined in a single number. Recent applications of the weighted WQI approach in groundwater quality studies have been presented. All methods used to derive WQI scores are similar, the only difference being the number of parameters (observations) used and their corresponding weights (Ali et al., 2015).

Groundwater is a life-sustaining and crucial resource of the planet. Water crises and quality are major concerns in many countries, especially arid and semi-arid regions where water shortages are common, and little attention has generally been given to assessing water quality. Arid and semi-arid regions suffer from multiple critical issues such as scarcity of water resources and extensive exploitation of groundwater for different uses. These problems will certainly cause a decline in water tables and the degradation of groundwater quality (Kebede, 2013).

Aquifers are especially vulnerable to the effects of uncontrolled extraction and insufficient land use, putting groundwater quality at danger. The quality of water at these resources needs proper attention, especially since pure water is essential for drinking, agriculture, and residential use (Ackah et al. 2011).

Groundwater monitoring is critical to meeting growing water needs in respect of availability and quality, and it must be implemented. The physicochemical properties of water may be utilized to fully comprehend and identify elements influencing groundwater quality as well as to give vital information for water management. Water characteristic, which is established on physicochemical criteria, gives current information on water facies, various geochemical controlling mechanisms, and water classes. Water chemistry and geochemical characteristics provide a good basis for examining trends, describing particular sustainability issues, and transferring knowledge on sources of water, geochemical dynamics, quality of water, and water susceptibility for drinking and irrigation (Abbasnia, 2018).

The geochemical characteristics of groundwater are essentially governed by recharging, aquifer metrics, contact time, and specific geochemical mechanisms such as dissolution, mineral solubility, and ion exchange processes. Therefore, water quality management should be decided by a complete groundwater quality evaluation with respect to physicochemical features and variables influencing water quality (Seifu et al, 2005). The WQIs are derived from a big data collection containing different water quality metrics from various places. Several WQIs were developed to serve as indicators for assessing water availability in both potable supply and agricultural usage. The basic goal of WQIs is to convert large numbers of complicated datasets into quantitative water quality data, contributing to a better understanding of water quality.

The drinking water quality index (DWQI) may be developed as a reliable tool described as a value that represents the combined impact of many water quality variables. Therefore, DWQI is calculated by analyzing the cumulative impact of man-made and natural activities based on certain factors in the hydro-geometric properties of the groundwater sample (Abraham et al, September 2011).

Irrigation water quality indicators (IWQIs), such as TDS, potential PS, SAR, and RSC, can satisfy the requirements for suitable controls and further evaluating water validity for agricultural applications based on experience and judgment. For instance, the IWQI is an important and unique model of these indices used in agricultural output optimization and water quality evaluation. In order to determine the DWQI and IWQI, a complex series of computations must be performed on data from the physicochemical elements to arrive at a single figure that demonstrates the suitability of the water quality level for drinking and irrigation purposes (Nata et al, 2009).

### **2.3. Water Quality parameters**

Potable water, often known as drinking water, is described as having appropriate physical, chemical, and bacteriological criteria that allow it to be used safely for drinking and cooking (WHO, 2004). According to WHO, drinking water is considered safe if and only if there are no substantial health concerns both during the scheme's lifespan and when it is consumed. Water quality for home and drinking purposes is the main topic of this thesis (West 2015).

### **2.4. Hydrogeology**

Hydrogeology can be defined as the study of ground water with particular emphasis given to its chemistry, mode of circulation and relation to geology environment (Sharp 2007). The occurrence of ground water is mainly influenced by lithology, geological structures, and geomorphology and climate conditions. Lithology, geological structures and geomorphologic setting of the area strongly influence the quantity, quality and movement of groundwater. Since the climate condition throughout the area seems uniform, it has the same effect through the entire area.

The geology of the area provides usable ground water and good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers. Fractures, joints and weathering surfaces of different lithological units play a vital role in facilitating the infiltration amount and rate and also ground water flow.

The majority of productive aquifers are characterized by their high degree of weathering and intense fracturing. Fractured volcanic rocks and karst limestone are the major potential rock units for storage and movement of ground water. In addition, the intergranular pore spaces of sandstone and alluvium also have significant role in occurrence of ground water. The main recharge for ground water of the area is precipitation, although surface water and Perennial River and streams are also act as local recharges(Characterization et al. 2017).

#### **2.4.1. Hydrogeological Classification /Characterization**

The classifications of different lithological units are made based on hydro geological characterization of various rock types. This classification is also based on existing data. This study used the qualitative and quantitative parameter to classify the hydro geological units in to aquifer/aquitards system. Since the quantitative parameters such as permeability, transmissivity, aquifer thickness and yield are not sufficient to make classifications, it is obligatory to assess the qualitative parameters in order to achieve on complete classification. The qualitative classification is based on the ground water point data and pump test data, the major hydro geological units are characterization into porous, fissured and/or karst permeability and impermeability rocks (Eargena, 2018).

The quantitative data division of lithological units is based on the hydrogeological characteristics of various rock types, such as permeability, aquifer thickness and yield obtained from different organizations. An aquifer is a body of porous rock or sediment saturated with groundwater. Groundwater enters an aquifer as precipitation seeps through the soil.

It can move through the aquifer and resurface through springs and wells. Aquifers are characterized by petro-physical properties such as hydraulic conductivity (alternatively called permeability ), transmissivity (product of hydraulic conductivity and aquifer thickness) and diffusivity (ratio of transmissivity and storage coefficient).

The two most important characteristics of aquifers that determine the way in which they respond to changes in their use are the way in which groundwater flows through the strata and the way in which water is released from storage within the strata. The aquifer properties of the aquifer essentially depend upon the composition of the aquifer. The most important properties of the aquifer are porosity and specific yield which in turn give its capacity to release the water in the pores and its ability to transmit the flow with ease.

## **2.5. Hydrochemistry**

The groundwater in the Ethiopian rift is both anthropogenically and naturally affected. In some cases, the chemistry of groundwater is controlled by the quality of surface water due to hydraulic connection. This will be true in urban centers. The main quality controls are: geomorphological and geographical conditions, climate, geology (geological structures, rock composition, weathering, magmatism, geothermal activities, etc.) Physico-chemical factors (temperature, pressure, chemical properties of elements, solubility of chemical compounds, pH, Eh, etc.) biological factors (effects of micro-organisms, plants and animals) and Anthropogenic influences (Enideg, 2012).

Organic matter in the soil is degraded by microbes, producing high concentration of dissolved carbon dioxide ( $\text{CO}_2$ ). This process lowers the PH by increasing carbonic acid ( $\text{H}_2\text{CO}_3$ ) concentration in soil water. The production of carbonic acid starts a number of mineral weathering reactions, which result in bicarbonate ( $\text{HCO}_3^-$ ) commonly being the most abundant anion in the water. As a result of chemical and biological interaction between groundwater and geological material through which it flows, and to a lesser extent because of contribution from atmosphere and surface water bodies, groundwater contains a wide variety of dissolved inorganic chemical constituents in varies concentrations (Birhanu, 2007). The objectives of chemical hydro geological investigations are to determine the sources, concentration and fate of dissolved constituents within the physical frame work of flow and transport.

The term “water chemistry” (or water quality) refers to the quantities of these various substances (commonly called solutes) that are present in a particular water sample, making up its chemical composition. Water acquires very small quantities of some solutes from dust and gases when it falls through the atmosphere as precipitation, but it typically acquires the majority of its solutes once it reaches the land surface. Solute concentrations that were already present in the water increase in concentration because of the processes of evaporation and transpiration, for the most part, remove water while leaving the solutes behind.

Hydrochemistry can also assist in understanding the evolution of water quality, to examine natural base line conditions against which human impacts can be recognized and to take a look at some ways in which the protection and management of groundwater resources can be achieved. Some information on key minor and trace elements (Fe, Mn and F, for example) is also a requirement for understanding the geochemical environment of water, as well as, its portability.

Chemical reactions in which elements participate involve changes in the arrangement and association of atoms and molecules and interactions among electrons that surround the atomic nuclei. The field of natural water chemistry is concerned principally with reactions that occur in relatively dilute aqueous solution, although some natural waters have rather high solute concentrations. The reacting systems of interest are generally heterogeneous—that is, they involve both a liquid phase and a solid or a gaseous phase, or all three. The scale of changes of the dissolved constituents is dependent on the physical and chemical properties of the surrounding rocks, the water temperature, salinity of water and its chemical content, the volume of water in movement and its velocity, periodic change of recharge water and the hydrologic and human factors.

The way in which solutes are taken up or precipitated and the amount present in solution are influenced by many environmental factors, especially climate, structure and position of the rock strata and biochemical effect associated with life cycle of plants and animals, both microscopic and macroscopic (Hem 1970). As a check on the chemical analysis, a cation-anion balance is usually performed. This is accomplished by converting all the ionic concentrations to units of equivalents per liter.

The anions and cations are summed separately, and the results are compared. If the sum of the cations is not within a few percent of the sums of the anions, then either there is a problem with the chemical analysis or one or more ionic species that have not been identified are present in significant amounts (Ackah et al. 2011). Recognition of the anion evolution sequence as a characteristic feature of many groundwater systems resulted from the compilation and interpretation of chemical data from regional flow systems. The anion evolution sequence and the tendency for total dissolved solids to increase along the paths of groundwater flow are generalizations that, when used in the context of more rigorous geochemical reasoning, can provide considerable information on the flow history of the water. Large variations in the major cations commonly occurs in groundwater flow systems. For major cation and anion data to provide greatest insight into the nature of groundwater flow systems, interpretations must include consideration of specific hydro chemical processes that can account for the observed concentrations (Carolina and Carolina 1980).

### **Physical and Chemical Properties of the Waters.**

In recent years it has been recognized that the quality of groundwater is of nearly equal importance to quantity (Birhanu, 2007). Physical characteristics of water that can be altered after sampling due to the physical and chemical changes of water and storage conditions should be measured during the field survey. These physical (water quality) parameters measured in the field are Temperature, pH, EC, TDS and Eh.

### **Temperature**

Temperature of groundwater is reported in 0C and obviously must be measured immediately after collecting the sample (Abebe 2006). This high range of temperatures is caused by a variety discharge mechanisms and, to a larger extent, by differences in the depth of circulation and local heat gradient values. Groundwater colder than local annual surface temperature occurs at high altitudes and is caused mainly by snowmelt recharge. Groundwater with a temperature close to the local average annual surface temperature belongs to the shallow active water cycle, circulation being limited up to 100m, and rarely 200m depth. Groundwater that is more than 6<sup>0</sup>C above local average annual surface temperature circulates to appreciable depths, deducible from the heat gradient.

### **Electrical Conductivity (EC)**

Electrical conductivity of water is its ability to conduct an electric current at a specified temperature and it is usually measured in micro siemens per centimeter or micromhos per centimeter. The values of EC increase with temperature, between 20°C and 30°C, an increase in 1°C, increases the EC by two percent on the average (Hem 1970).

### **Total Dissolved Solids (TDS)**

Total Dissolved Solids include all solid materials in solution, whether ionized or not. As it is related to the sum of the concentrations of all ions, it is directly related to the electrical conductivity. All natural surface waters and some groundwater carry both dissolved and suspended particles. The amount of the latter present in groundwater before it is brought to the land surface generally is small. But, in river water the concentration of suspended material may be large, and at high stage of flow in many streams it generally exceeds the Total Dissolved Solids concentration (Ayenew and Ababa 2005).

### **Graphical presentations**

Over the years, a considerable number of techniques for graphical representation of analyses have been proposed. Some of these are useful principally for display purposes that is, to illustrate oral or written reports on water quality, to provide means for comparing the analyses with each other, or to emphasize differences and similarities. Graphical procedures do this much more effectively than numbers presented in tables (Güler et al. 2002).

Most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species and all the graphical methods use a limited number of parameters, usually the available data, unlike the statistical methods that can utilize all the available parameters. In addition to the types of graphs suitable for displays and comparison of analyses, graphical procedures have been devised to help detect and identify mixing of waters of different composition and to identify some of the chemical processes that may take place as natural waters circulate.

Graphing techniques of the latter type may be useful in the study of data prior to preparing reports or arriving at conclusions.

## **2.6. Aquifer characterization**

### **2.6.1. Hydrogeological units(Sharp 2007)**

**An aquifer** is defined as a saturated permeable geological unit that stores and transmits economic quantities of water to wells. The excellent aquifers are unconsolidated sands and gravels of alluvial deposits, but permeable sedimentary rocks such as sandstone and limestone, and highly fractured and/or weathered volcanic and crystalline rocks can also be classified as aquifers.

**An aquitard** is a semi-permeable geological unit that store but transmit very small amount of water. When viewed over large areas and long periods, its permeability is not sufficient to justify production wells being placed in it. But they are equally important like aquifers, because they retain the groundwater by overlaying and underlying. Clays, loams, and shales are typical examples of aquitards.

**An aquifuge** is an impermeable geological unit that neither store nor transmit water at all. Dense unfractured igneous or metamorphic rocks are typical examples of aquifuges. However, in nature truly impermeable geological units seldom occur. All of them leak to some extent, and must therefore be classified as aquitards. In practice, however, geological units can be classified as aquifuges when their permeability is several orders of magnitude lower than that of an overlying or underlying aquifer.

### **2.6.2. Aquifer types**

#### **2.6.2.1. Confined Aquifer**

A confined aquifer is bounded above and below by an aquiclude. In a confined aquifer, the pressure of the water is usually higher than that of the atmosphere, so that if a well taps the aquifer, the water in it stands above the top of the aquifer, or even above the ground surface. We then speak of a free-flowing or artesian well.

### **2.6.2.2. Unconfined Aquifer**

An unconfined aquifer, also known as a water table aquifer, is bounded below by an aquiclude, but is not restricted by any confining layer above it. Its upper boundary is the water table, which is free to rise and fall. Water in a well penetrating an unconfined aquifer is at atmospheric pressure and does not rise above the water table.

### **2.6.2.3. Leaky Aquifer**

A leaky aquifer, also known as a semi-confined aquifer, is an aquifer whose upper and lower boundaries are aquitards, or one boundary is an aquitard and the other is an aquiclude. Water is free to move through the aquitards, either upward or downward. If a leaky aquifer is in hydrological equilibrium, the water level in a well tapping it may coincide with the water table. The water level may also stand above or below the water table, depending on the recharge and discharge conditions.

In deep sedimentary basins, an inter bedded system of permeable and less permeable layers that form a multi-layered aquifer system, is very common. But such an aquifer system is more a succession of leaky aquifers, separated by aquitards, rather than a main aquifer type.

## **2.7. Determination of aquifer parameters from pumping test data**

### **2.7.1. Hydraulic parameters**

Hydraulic conductivity (K), Transmissivity (T) and Storativity(S) (specific yield for unconfined aquifers) are the hydraulic properties of aquifers and soil materials that determine how fast water moves into, and out of subsurface materials and how piezometric surfaces or water tables are affected. Much of the success in predicting underground movement depends on how accurate the pertinent hydraulic parameters can be evaluated. Hydraulic conductivity is a measure of the ability of a fluid to move through interconnected void spaces in the sediment or rock. It is a function of both the medium and the fluid. Transmissivity is the rate at which water flows through a vertical strip of the aquifer or it can also be defined as the product of the average hydraulic conductivity and the saturated thickness of the aquifer (Gebre, 2010).

### **2.7.2. Hydraulic conductivity**

This is the most important parameter, because the other parameter as Transmissivity is obtained as a function of hydraulic conductivity; i.e. by multiplying K with aquifer thickness. Storativity is mostly the prominent character of unconfined aquifers and it ranges from 0.01 to 0.3, for confined ones storativity is very negligible and ranges from 0.00005 to 0.005; because in confined aquifers, assuming the aquifer remains saturated change in pressure produce only small change in storage volume (Tenalem and Tamiru,2001); because the water is under pressure, and when it is removed, other pressurized water nearby replaces. Thus, Hydraulic conductivity is the most important character of all aquifer types (i.e. confined, unconfined and leaky).

Hydraulic conductivity is governed by the size and shape of the pores, the effectiveness of the interconnection between pores, and the physical properties of the fluid.

If the interconnecting pores are small in size, the volume of water passing from one pore to the other is restricted and the resulting hydraulic conductivity is quite low. Similarly, if the fluid is viscous due to dissolved materials, the hydraulic conductivity will be low.

### 3. MATERIAL AND METHODS

#### 3.1. Description of the Study Area

##### 3.1.1. Location and Accessibility

The study area, Guder river watershed (Figure 3.1) lies in the southern plateau of the country, in the center of the Rift valley river basin in South Nation Nationalities peoples regional state, Ethiopia. The study area contains Hadiya zone, and some portion of Kembata Tembata and Silte Zones. Geographically it is bounded between UTM zone 49°00'00" to 84°00'00"E and 246°00'00" to 131°00'00"N. It covers a total area of 660.58km<sup>2</sup>. The study area is located 200 km Southeast of Hawassa, the capital city of SNNPRS. The area is accessible by two routes from Addis Ababa. One is 232 km and all pathways are asphalt road, using the Addis Ababa – Butajira – Hosanna. The other alternative is 280km through Addis Ababa – Woliso –Wolkite – Hosanna asphalt road.

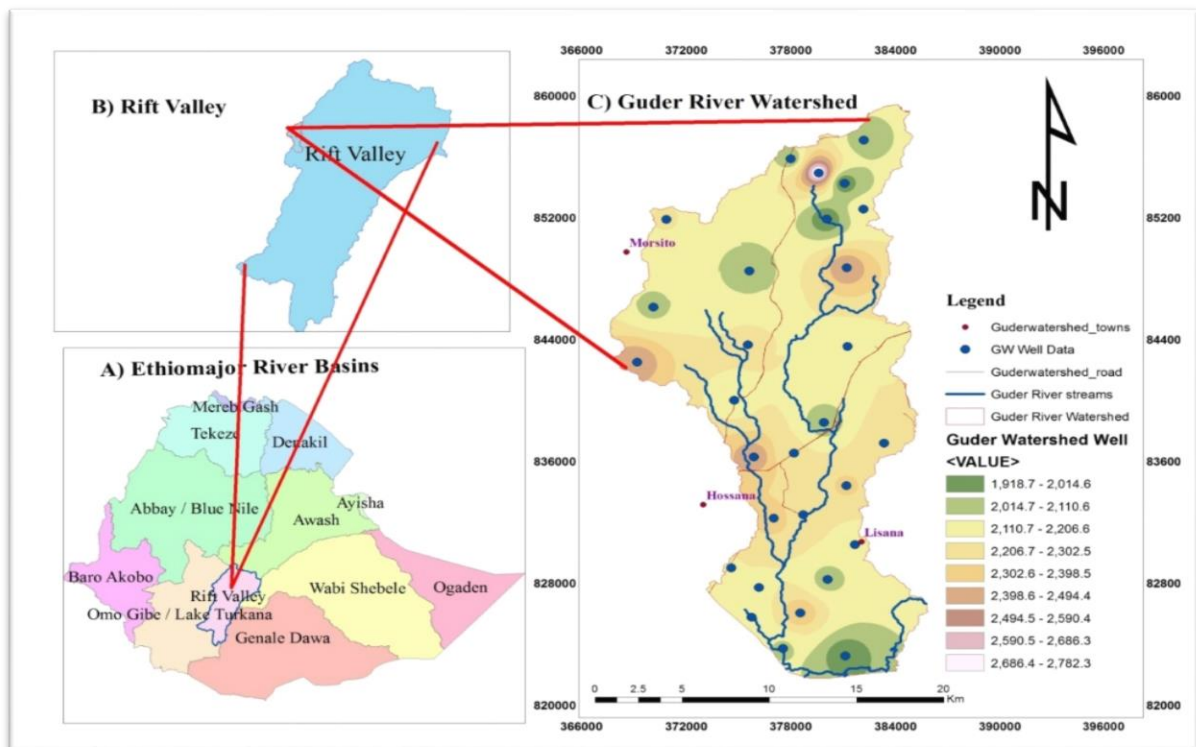


Figure 3.1: Location Map of the study area

### **3.1.2. Physiography and Drainage**

Most part of Lemo, Misha, shashogo woredas and some parts of silte and kambata Tembaro zones areas are categorized as the transitional escarpment zones with altitude ranges of 1,884 – 2,944m above mean sea level. The physiography of the study area is generally, characterized by a dendrite drainage pattern along the Guder River cuts, The drainage pattern of the study is also observed to be highly controlled by structures, which occupy weak zones mainly exposed in the quarry site of northeast and southwest part of the survey along the Guder River (Figure 3.2).

The study area, which is the center of the Rift valley basin, belongs to the northeastern massifs of Ethiopia lying in the rolling plains at the foot of the Mugo ridge (recharge zone of Guder River Watershed). The study area's physiographic structure is a result of rifting, erosion, and deposition processes, as well as volcano-tectonics. Due to these Earth Processes, the Guder river watershed is between 1,884 and 2,944 meters above sea level.

The Misha Woreda, Lemo, Meserake, and Meerab Azernet Berbere Woredas, as well as a portion of the Angacha and Danboya woredas, are all included in the rough topography known as the highlands. The shoulder of these mountainous ranges is where the majority of springs in the study area originate. The rift floor and the plateau have very different topographies. A closed surface water drainage system is present in the watershed.

The Guder River is one of the perennial river that feed the main Bilate River. This river come from the shoulders of mountain ridges that, from the west, border the area. A substantial amount of water is fed during the rainy season by intermittent rivers like Metenchose and Jeto, which originate from the steep fault escarpment.

When compared to the rift floor, the drainage density is much higher at the plateau and escarpment (Gintamo, 2010). It is a result of the study area's intense volcanic and faulting activity. Before reaching the primary drainage system, tiny streams frequently sink into the ground. Metenchose Stream serves as a good example. It reaches Lake Boyo.

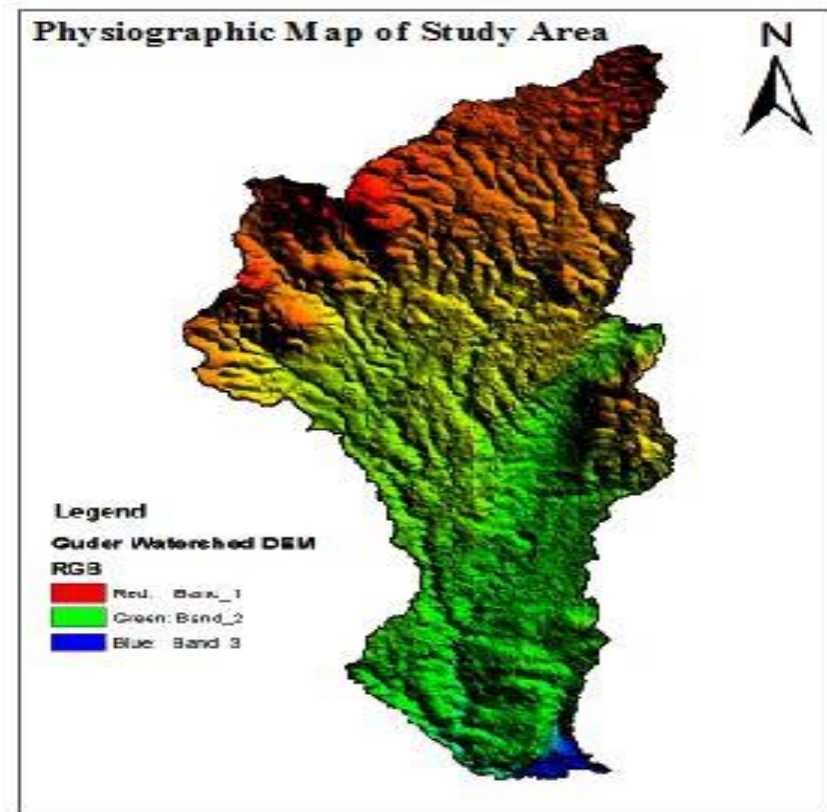


Figure 3.2: Physiography and drainage pattern of the study area (DEM)

### 3.1.3. Climate

According to "climate-data.org" in <https://en.climate-data.org/location/3664/> the area is characterized by a warm and temperate climate and gets a major rainfall even during the winter season. The average temperature and precipitation of the study area is as described as in the Figure 3.3. It is seen that from the (Figure 3.3) that the area records highest average temperature of 18.6°C in March, whereas, the lowest average temperature measured in August is about 15.8°C.

The wettest month (August) measures the highest precipitation (167mm) while the lowest precipitation is record in December (17.5mm) (Yehualaw, 2020). The study area's climate is semi-arid in the rift valley and humid to sub-humid in the highlandds. The main rainy season is when the temperature is lowest; there is little seasonal temperature change.

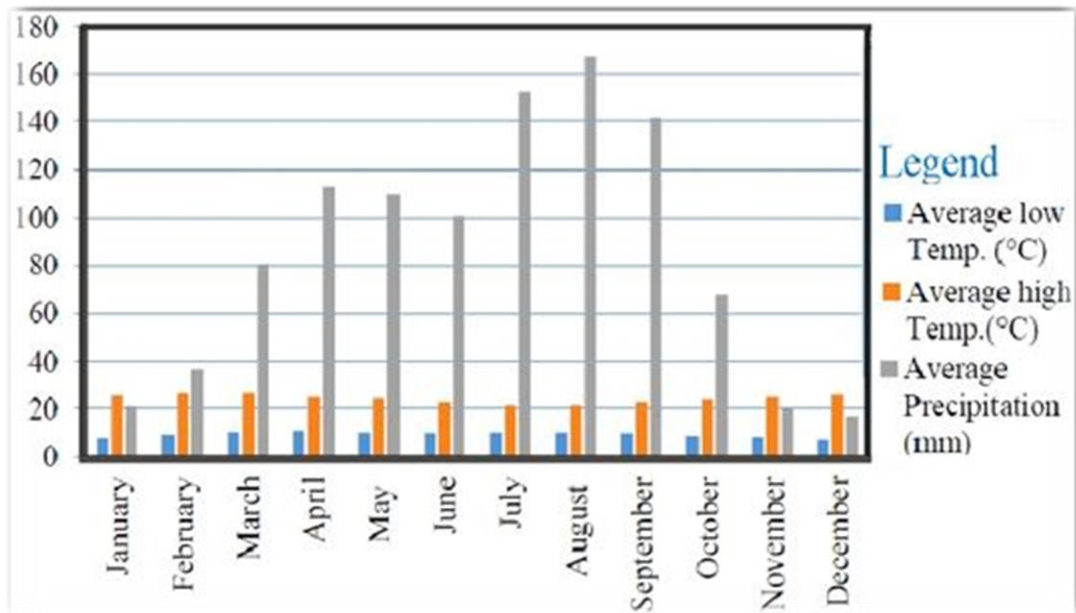


Figure 3.3: Temperature and precipitation of of the study area(<https://en.climate-data.org/location/3664/>)

### 3.1.4. Soil

The major soil type in the Main Ethiopian Rift valley clearly shows the influence of the parent materials in the extent of degree of weathering (Tenalem et al, 2008). The main parent materials are basalt, ignimbrites, tuff, lava, gneiss, volcanic ash, alluvium, lacustrine sediment, pumice. According to Food and Agriculture Organization of the United Nations (Caracalla, Rome,2007) soil classification; there are two soil units in the study area, Guder River watershed (Figure. 3.4). These are;

**Chromic Luvisols (LV);** this type of soil is occurred typically forest area of humid to sub-humid area. The soil is generally well drained, deep to very deep, fine to medium textured, clay loam and sandy loam soils. It is dominant soil type in the highland western and northwestern part of the basin.

**Humic Nitisols (NTu);** this type of soil is predominately found in level to hilly land under tropical rain forest or savanna vegetation. The soil is accommodates deep, well drained, red, tropical soils with diffuse horizon boundaries a sub surface horizon that has typical nutty , polyhedric, blocky structure elements with shiny ped faces.

The soil is planted to farm and plantation crops. They are generally considered to be fertile soils inspite of their low level of available phosphorus and their normally low base status. They are deep, stable soils with favourable physical properties. It is dominant soil type in the study area.

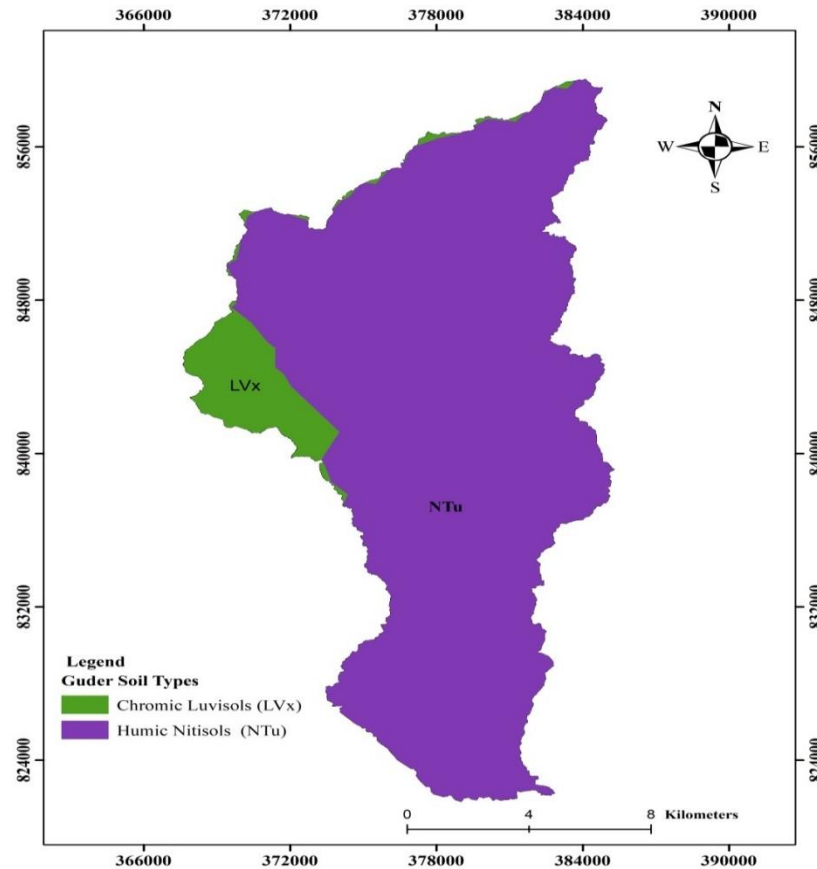


Figure 3.4: Soil types in the study area

### 3.1.5. Land Use and Land Cover

The different topographic and climatic conditions determine the ground ecological groups in the catchment, each of which is characterized by particular associations of vegetation (Mulatu et al, 2021). The land use and land cover of the study area, Guder river watershed has been changed for the past years due to different activities occurred by the people. The land cover of the study area mainly contains moderately cultivated, intensively cultivated, shrub land, forest. In general, the southern, southwestern, southeastern and some central part of the study area is intensively cultivated area.

In addition, the northern and eastern part of the study area is also moderately cultivated area. The forest and shrub coverage of the watershed is very less due to human activity and climate condition. Topography and soil types govern land use activity of the study area as shown Figure 3.5. The central portion of the area forms a gentle slope and thick soil cover due to weathering of Guder River. Almost all of the study area is covered by farmland used for agricultural products such as Wheat, Maize, Teff, Sorghum and partially for grazing land for cattle's (Zelege, 2019).

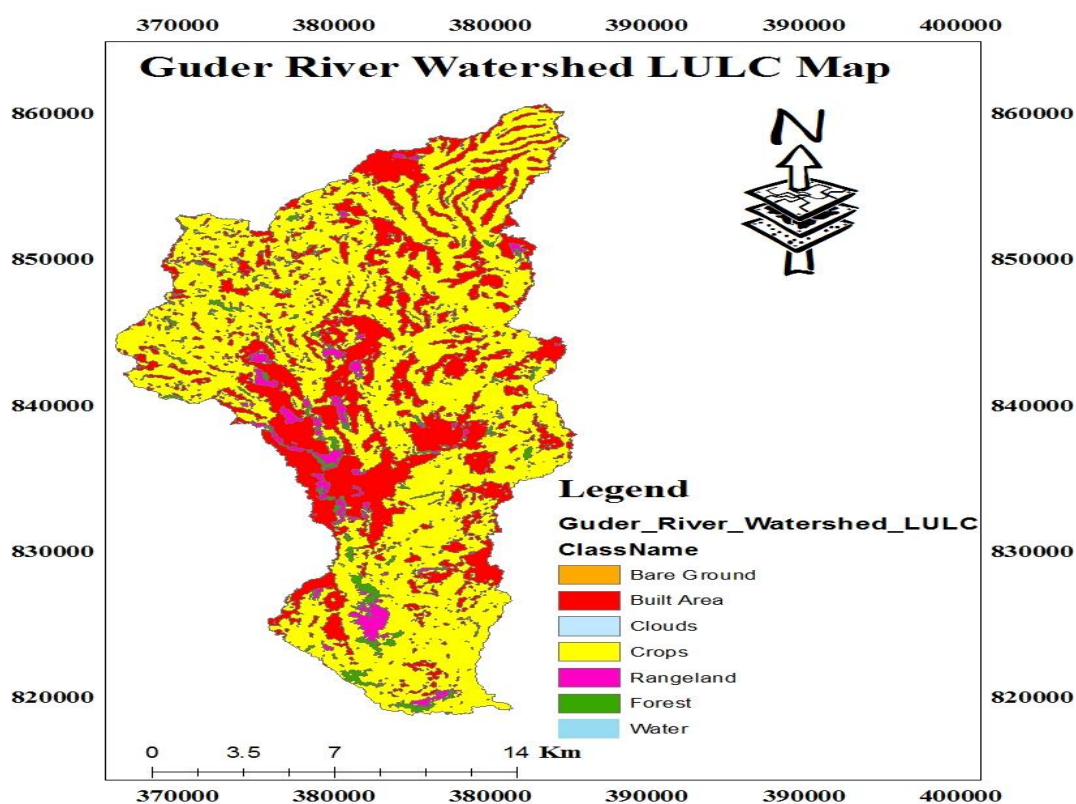


Figure 3.5: Guder River Watershed Land Use and Land Cover

### 3.1.6. Geology

The Guder River Watershed is primarily composed of Tertiary and quaternary sediments and Cenozoic volcanics. The Nazereth group (Upper Miocene to Pliocene), Dino Formation, Pleistocene Volcano-Sediments, and Recent Alluvial and Fluvial Deposits are the main formations that make up the area (Nedaw, 2019).

The study area is covered by thick soils, except at river cuts and road sections where extensive exposures of the rock units are visible. Cenozoic (young) volcanic rocks and thick residual deposits characterize the area. Local geologic setup of the study area was described based on the observations of river cut, road section, quarry sites, boreholes and drainage network patterns. The geological units of the study site are ignimbrite, pyroclastic ash tuff, volcanic ash and residual soils. The brief descriptions of these different units are as follows:

**Ignimbrite:** it is welded tuff and a special group of pyroclastic rocks. It is found exposed along the Guder River cut in the northern and southern portions of the study area. Fresh ignimbrite deposits are characterized by poorly sorted aggregates of tuff and pumice. The weathered and highly fractured ignimbrite is found in the southwestern portion of the study area (Figure 3.6). It is intercalated with reddish clay soil and tuff in many parts of river exposure. The intercalation shows depositional series of pyroclastic materials.

**Pyroclastic ash tuff:** it is well- sorted and fine to medium grained. This pyroclastic unit is exposed in the eastern, western and southern portions of the study area along river cuts and road sections. It is characterized by white color and fine-grained texture (Figure 3.6). The tuff unit of the study area is relatively soft and porous that is usually formed by the compaction and cementation of volcanic ash.

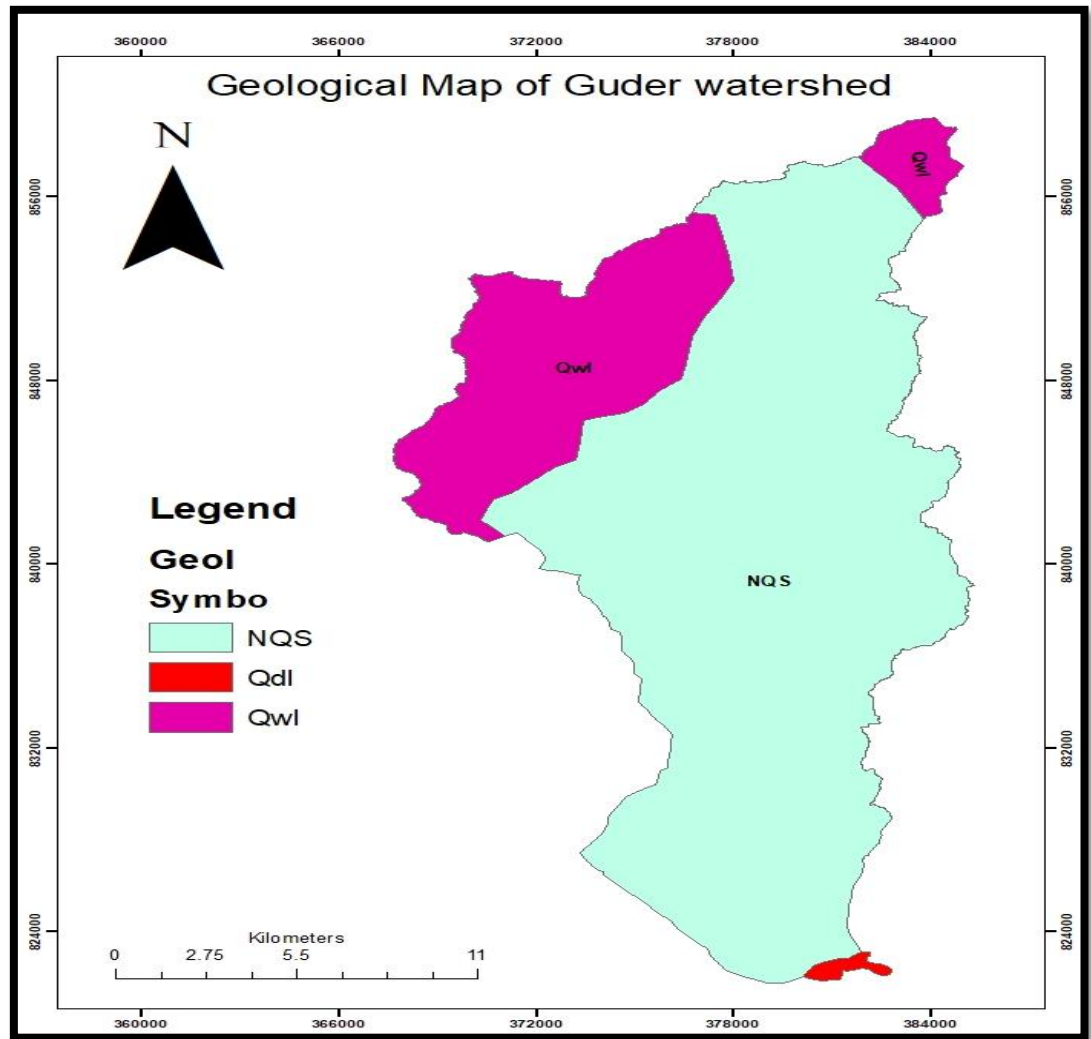


Figure 3.6: Geological map of study area

### 3.1.7. Hydrogeology

According to Tenalem et al (2008) hydrogeological conditions of the permeable rocks and high recharge rate are mainly controlled by the lithologies, geological structures and geomorphology. The groundwater reserve in rocks is low due to the fast release of the recharged water to the rift plains through large open faults (Nedaw, 2019). Previous studies have investigated and concluded that the groundwater inevitably occurs in geological formations and one requires information on how these Earth materials are formed and the changes they have undergone in order to better understand the allocation/ distribution of geological structures.

In addition, (Seifu et al, 2005) also described that groundwater circulation and storage in the volcanic rocks depends on the type of porosity and permeability formed during and after the rock formation (Eargena, 2018) have discussed the probability of obtaining high yield wells in crystalline rock areas, if drilling takes place in an area where fractures are localized. Though porosity may be high, permeability which is largely dependent on the primary and secondary structures of the rock mass affects the yield of wells in such situations (A.A. Oyedele et al, 2019). The intermountain grabens and rift floor sediments associated with fractured volcanics form the largest aquifers under water table and semi- confined conditions presented by (Abraham et al, 2016). Therefore, acquiring knowledge about the existing of aquifer materials and information on their geological setting is necessity. The map in (Figure 3.7) shows the hydrological setting of the study and its surrounding area.

#### **3.1.7.1. General description of the aquifer system in the study area**

An aquifer is a rock that holds or transmits water to wells and springs in useful or economic quantities (Sulamo 2021). According to Gululet, (2018) two major aquifer classes were identified in the Ethiopian Rift based on the mode of origin and the rock types. These are (1) extensive aquifers with intergranular permeability (unconsolidated sediments: alluvium, and lacustrine sediments) and,

(2) extensively fractured and weathered volcanics (basalts, rhyolites, trachytes and ignimbrites). The most important aquifers are thick pyroclastic deposits, volcanic rocks within structural discontinuities in the rift and escarpments, which provide the best aquifer materials defined by (Ethiopia, 2013). According to Gululat (2018) the following aquifer/ aquitard were defined.

#### **3.1.7.2. Hydrogeology and Aquifer Type of the Study Area**

The hydrogeology of the area shows aquifers and aquitards defined based on the character of the groundwater flow (pores and fissures), the yield of springs and the hydraulic characteristics of boreholes. Common aquifers are geological formations of unconsolidated sand and gravel, sandstone, limestone and fractured volcanic rocks. Examples of common aquitards are clays, shales and silt (Zelege, 2019).

### **Extensive and Moderately Productive Porous and/or Fissure Aquifers**

Quaternary volcanic rocks like scoria basalt, weathered and fractured ignimbrites have dominant fissured permeability and represent porous aquifers of the area. According to Mulatu, (Yehualaw, 2020), the western part of highland areas including Lisana and Angacha Woreda have relatively high precipitation and are categorized as moderately productive aquifers.

### **Local and Moderately Productive Fissured Aquifer**

Permeability is largely a function of the primary (porosity) and secondary structures (joints and fractures) within the rock. Welded ignimbrites usually alternate with non-welded ones and are intercalated with tuff, pumice and lacustrine sediments. Including some parts of Gode and Belesa in the neighborhood of the study area have relatively low to moderate aquifer.

### **Formation Consisting of a Minor Fissured Aquifer-Aquitard**

Aquitards are unites where groundwater is neither stored nor transmitted, i.e. and there is minimal flow through the rock. It is hard to get shallow wells in Misha Woreda and some part of Lemo Woreda due to less fractured rocks, as presented by (Belay, 2015).

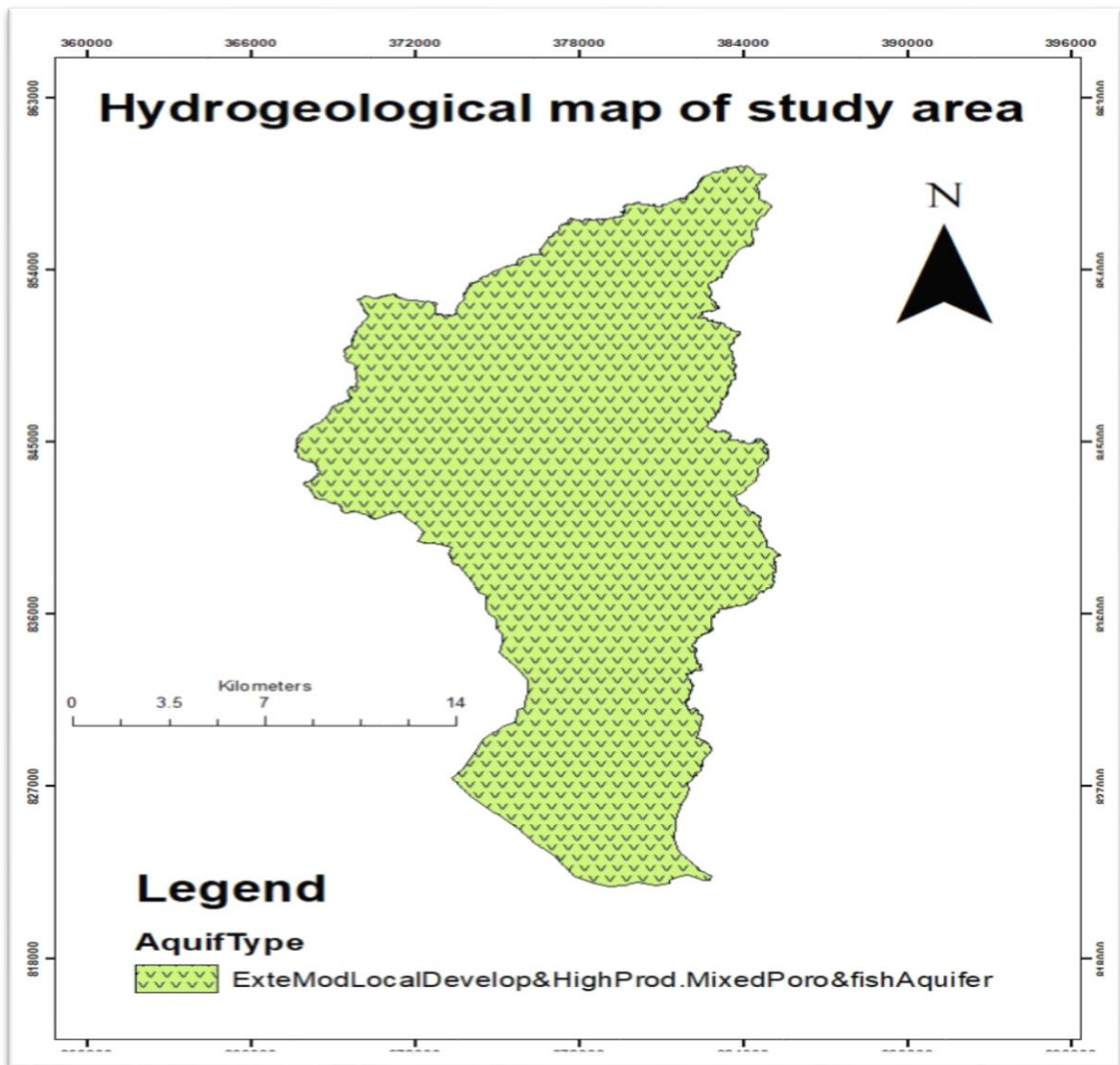


Figure 3.7: Hydrogeological map of study area

According to Sintayehu Legesse (2009), Aquifer type is extended moderately locally developed and high productive mixed porous and fissure aquifer. The hydrogeological lithology of the study area is dominantly Ignimbrite.

### 3.2. Data Collection and Analysis

This research work will begin with primary data collection in the field and secondary data collection from respective organization and all relevant available data related to geology, hydrogeology and hydro geochemistry will be collected.

### **3.2.1. Determination of the Physico-Chemical Parameters of Groundwater**

To accomplish the objectives of the study, groundwater samples were collected from deep borehole, shallow borehole, hand dug well and springs. The distribution of sample sites made evenly to identify reference areas, to give a representative sample distribution. Their distribution consisted of a total of 30 samples from which 21 samples were primary and 9 were secondary samples (Appendix 1.1) as shown below in Figure 3.8.

Sampling point for groundwater chemistry investigation was selected based on diverse in the geological formation, geomorphology, land use pattern, population density, etc. Duplicate water sample was collected from 30 different groundwater location points that are commonly utilized for drinking and irrigation purposes after pumping about 10 minutes to get fresh water. Besides, the absolute location for each water point was recorded using GPS. The samples were collected and sealed securely using a one-liter plastic bottle after washing the device (plastic bottles and its capes) several times by the water to be sampled to prevent mixing up of water if remained in the bottle prior to sampling and to remove other unwanted ordinary materials. The samples were collected following the standard methods of sampling protocol (APHA, 2005) in the dry season February 2022. The Collected samples were protected from direct sunlight during transportation to the laboratory and were transported within four days.

Field parameters of the samples (pH, EC, Temperature) were measured at the time of sampling. Such measurements are always important for confirmation between field and laboratory measurements and are good indicators about sample preservation or change of chemical constituents during transportation. Physico-chemical analysis has been carried out in the Regional Water and Irrigation Development laboratory. Most of the sample used in this study collected from from SNNPR Water, Mines and Energy Bureau, South water works construction enterprise, south design and construction supervision enterprise, and Hadiya zone water, mines and energy department.

The Collected samples were protected from direct sunlight during transportation to the laboratory and were transported within four days. In situ measurements for pH, total dissolved solids (TDS), electrical conductivity (EC) were measured using multiple parameter portable water analyzer kits (HANNA) which was calibrated appropriately before use and checked at each station with a standard solution. Temperature was measured using a mercury thermometer, immersed immediately to water long enough to permit complete equilibrium. The general computing methodologies have been presented in section 4.1.

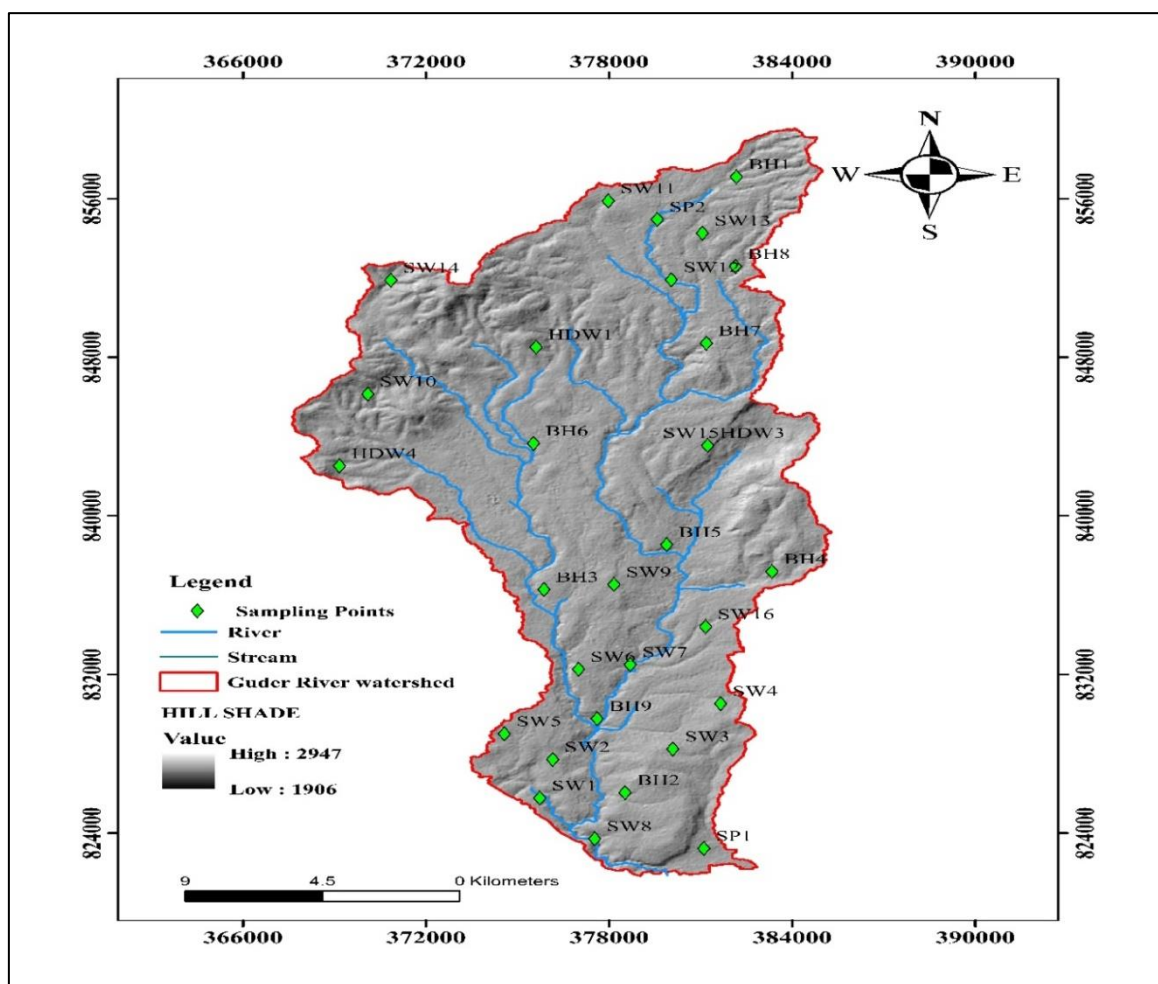


Figure 3. 8: Location Map of Water Sample sites in the study area

### **3.2.1.1. Physical Parameters**

#### **Hydrogen Ion Concentration (P<sup>H</sup>)**

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 (Dagim et al, 2017).

#### **Electrical Conductivity (EC)**

Electrical conductivity of water is ability to conduct an electric current at a specified temperature and it is usually measured in micro Siemens per centimeter ( $\mu\text{s}/\text{cm}$ ) (Weast, 1968). This is directly related to the concentration of salts dissolved in water.

#### **Total Dissolved Solids (TDS)**

TDS constitute of inorganic salts. It principally consists of calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates, and small amounts of organic matter that are dissolved in water (WHO, 2008). Total dissolved solids shows that the salinity of groundwater in the water sample and it include all the solid substances in solution. It is directly related to the electrical conductivity.

#### **Temperature**

With respect to water quality, one important aspect of water temperature is the influence it has on dissolved gases. As the water temperature increases the solubility of gas in water decreases, water holds fewer gases. Temperature is also affecting the various parameters such as alkalinity, salinity and electrical conductivity (Hem, 1959) and (Fentie, 2020). In physical analysis of water samples, temperature is also another parameters measured in the field which is usually expressed in  $^{\circ}\text{C}$ .

### Total Hardness (TH)

Hardness results from the presence of divalent metallic cations of which calcium and magnesium are the most important once. Because of their adverse action with soap, hard waters are unsatisfactory for household cleaning purposes. The unit of hardness is generally given by mg/l. Hardness of water is the sum of calcium and magnesium expressed as equivalent amount of calcium carbonate (CaCO<sub>3</sub>). Total hardness was computed by the formula (Todd 2005) (Eq 3.1)

$$\text{Total hardness (TH)} = 2.5 (\text{Ca}^{2+}) + 4.1(\text{Mg}^{2+}) \dots\dots\dots \text{Eq.3.1}$$

Where, Ca and Mg are given in mg/l.

For classification of range of hardness concentrations (Hem, 1959) used the following classification Table 3.1 below.

Table 3.1: Classification of water on the bases of Hardness:

Hardness (mg/l CaCO <sub>3</sub> )	Classification	Number of samples	Percentage
0-60	Soft	6	20%
61-120	Moderately soft	11	36.7%
121-180	Hard	7	23.3%
>180	Very hard	6	20%

### 3.2.1.2. Chemical Parameters

The major cations and an ions analyzed in the laboratory for collected water samples were calcium, sodium, magnesium and potassium. The minor ions include Nitrate ion (NO<sub>3</sub><sup>-</sup>), Fluoride (F<sup>-</sup>) and Iron (Fe<sup>2+</sup>) are analyzed in the laboratory for collected water samples. The result obtained for the 30 water samples from different water points (borehole, hand dug well, spring and shallow well) show the characteristics of the overall water quality.

## **3.2.2. Determination of Water Quality Index and Assessment of Water Quality For Drinking and Irrigation Purposes**

### **3.2.2.1. Groundwater Suitability For Drinking Purpose**

Parameters, such as  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{F}^-$ , pH, EC, TDS and TH are regarded as critical determinants for most development studies of water quality (Adewumi *et al.*, 2018). To determine the suitability of water for drinking purposes the study has used the water quality index (WQI), which has been considered as one of the most reliable tools to classify water contamination levels for both ground and surface water (Singh & Hussian, 2016). WQI is based on a scale of 0–300 where lower values indicate good water quality, whereas higher values are an indication of contaminated water (Singh & Hussian, 2016). Detailed methodologies are briefly described in section 4.2.1.

Use of a water quality index (WQI) is one of the most effective approaches to communicate information on the quality of any water to decision makers. The WQI is a mathematical equation used to transform large numbers of water quality data into a single number (Abbasnia, 2018). It promotes understanding of water quality issues by integrating complex data and generating a score that describes water quality status (Abraham *et al.*, September 2011). The WQI has been calculated to evaluate the suitability of groundwater quality of study areas for drinking purposes.

The World Health Organization WHO (2011) standards for drinking purposes have been considered for the calculation of WQI. To compute WQI four steps are followed (Gebrehiwot *et al.*, 2011). First, each of the 12 parameters pH, TDS,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{F}^-$  and  $\text{Fe}^{2+}$  was assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 4.1). The maximum weight of 5 has been assigned to TDS; weight of 3 has been assigned to parameters pH, chloride ( $\text{Cl}^-$ ), sulphate ( $\text{SO}_4^{2-}$ ) and sodium ( $\text{Na}^+$ ); weight of 2 has been assigned to parameters calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), and bicarbonate ( $\text{HCO}_3^-$ ) depending on their importance in the overall quality of water for drinking purposes (Bawoke and Anteneh 2020). Potassium ( $\text{K}^+$ ) is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment.

The rest of other parameters such as nitrate (NO<sub>3</sub><sup>-</sup>), fluoride (F<sup>-</sup>) and iron (Fe<sup>2+</sup>) were assigned weights between 1 and 5 based on their relative significance in the water quality evaluation. In the second step, the relative weight (Wi) is computed using a weighted arithmetic index method given below (Hamid Soleimani, 7 August 2018) in the following equation 3.2 and calculated relative weight (Wi) values of each parameter are given in Table 3.2.

$$Wi = \frac{wi}{\sum_{i=1}^n wi} \text{-----Eq.3.2}$$

Where,

Wi is the relative weight,

wi is the weight of each parameter, and

n is the number of parameters.

Table 3.2: The WHO Standards, assigned weight (wi) and calculated relative Weight (Wi) for each Parameter

S.No	Chemical parameters	WHO standard (2011)	Weight(wi)	Relative Weight(Wi)
1	PH	6.5-8.5	3	0.083
2	TDS	1000	5	0.138
3	Ca <sup>2+</sup>	75	2	0.055
4	Mg <sup>2+</sup>	50	2	0.055
5	Na <sup>+</sup>	200	3	0.083
6	K <sup>+</sup>	12	1	0.027
7	HCO <sub>3</sub> <sup>-</sup>	120	2	0.055
8	SO <sub>4</sub> <sup>-2</sup>	250	3	0.083
9	Cl <sup>-</sup>	250	3	0.083
10	NO <sub>3</sub> <sup>-</sup>	50	4	0.111
11	F <sup>-</sup>	1.5	4	0.111
12	Fe <sup>2+</sup>	0.3	4	0.111
			∑wi=36	∑Wi=0.995

In the third step, a quality rating scale ( $Q_i$ ) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of WHO (2011) and then multiplied by 100.

$$Q_i = (C_i/S_i) \times 100 \dots\dots\dots \text{Eq.3.3}$$

Where,

$Q_i$  is the quality rating,

$C_i$  is the concentration of each chemical parameter in each water sample in mg/l, and

$S_i$  is the (WHO, 2011) drinking water standard for each chemical parameter in mg/l.

In the fourth step, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation as given below (Table 4.2)

$$SI_i = W_i \times Q_i \dots\dots\dots \text{Eq.3.4}$$

Where,

$SI_i$  is the sub index of  $i$ th parameter;

$W_i$  is relative weight of  $i$ th parameter, and

$Q_i$  is the rating based on concentration of  $i$ th parameter,

### 3.2.2.2. Groundwater Suitability For Irrigation Purposes

To determine the suitability of groundwater for irrigation use in the study area, several indices were used. Amongst, EC and TDS were used to determine for salinity hazard, SAR, and Na% were used to measure for sodicity hazard. Also, PI were evaluated. The general computing methodologies have been presented in section 4.2.2.

The quality of water for irrigation is determined by how the long term use of the water affects soil and plant health, the use of water with inferior quality for irrigation could lead to reduced crop yield (Province and Arabia 2022). The quality of water for irrigation should be free from the impurities, which retard plant growth, is not satisfactory for irrigation. The widely chemical parameters used to assess the quality of water for suitability of irrigation included total salt concentration measured by electrical conductivity (EC) (salinity hazard), the relative proportion of sodium which indicate the sodium hazard, which are: sodium percentage (%Na) and sodium adsorption ratio (SAR)(Appendix 1.3).

### **Electrical Conductivity (EC)**

The salinity hazard increases the osmotic pressure of the soil water and restricts the plant roots from absorbing water; this results in a physiological drought condition (Gebrehiwot, Tadesse, and Jigar 2011). The US salinity criteria are depending on the electric conductivity (EC) values.

### **Sodium Adsorption (SAR)**

The sodium adsorption ratio is one of the most used water quality criteria for irrigation purpose. Because sodium reacts with soils and reduce its permeability which makes cultivation difficult. 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.

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+}) / 2}} \text{-----Eq.3.5}$$

Where, the concentration of Sodium, Calcium, and magnesium ions are expressed in meq/l.

### **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 (Wekesa 2022). The %Na is calculated with respect to relatively proportions of cations like calcium, sodium, potassium and magnesium in water using the following formula.

$$\%Na = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \text{-----Eq.3.6}$$

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

### **Permeability Index (PI)**

The quality of irrigation water can affect the permeability of the soil after long term use; this can be measured by computing the Permeability index (PI). PI is influenced by sodium, calcium, magnesium and bicarbonate contents of the soil. It can be classified into three classes; class I and II can be categorized as good for irrigation with  $\geq 75\%$  and  $75 - 25\%$  respectively permeability while class III water is classified as unsuitable with  $< 25\%$  of permeability (Batarseh et al. 2021).

PI is calculated using the formula:-,  $PI = \frac{(Na^+ + \sqrt{Hco3^-})}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100$ -----Eq.3.7.

Where, all ionic concentrations are expressed in meq/l.

### **3.2.3. Characterization of Aquifer Systems**

Existing data, indirect and direct approach was used in order to characterize the different aquifer units in the area. The characterization involves the use of existing pumping test data, lithology obtained from well logs, water table depth, structures and topography so as to see the vertical and lateral distribution and the nature of the aquifers. Characteristics of different aquifers in the study area is done by collecting all the secondary and primary data available. The secondary data are the well completion reports of Boreholes. The well completion report includes all the necessary drilling history of the well and pumping test data. Aquifer characterization was made by using surface geology, borehole lithological log and pumping test data analysis. To identify the surface geology, the geological map of the scale 1: 250,000 were used and digitized on the Arc GIS software. From these map different lithological units and fault lines were produced and identified. A total of 30 borehole pump test data is taken and have been put into Aquitest Software for execution of aquifer parameter like Transmissivity.

The hydraulic conductivity is then determined from transmissivity as the aquifer thickness is known. The classification of different lithological units is made based on hydrogeological characterization of various rock types. This study used the qualitative and quantitative parameters to classify the hydrogeological units.

#### **a) Qualitative Parameters**

##### **Units with porous permeability**

In this types of hydrogeological unit groundwater accumulated in and flows through pores of an unconsolidated or semi-consolidated material. Porous materials of Quaternary age are represented either by lacustrine sediments with subordinate alluvial, colluvial and eluvial sediments developed in depressions of lakes and/or along valleys of former and existing rivers or by pumiceous pyroclastic, re-sediment pumice and unwelded tuff materials.

### **Units with fissured permeability**

In this types of hydrogeological unit groundwater accumulated in and flows through the weathered and fractured part of volcanic rocks. The porosity of lava flows may be high but the permeability is largely a function of a combination of the primary and secondary structures (joints and fissures) within the rock. The weathered and fractured surfaces play a significant role in ground water accumulation and flow.

### **Units with Mixed Porous and Fissured permeability**

The aquifer consists of various types of permeability; inter granular and fractured permeability. The intercalated sediment does not act as an independent aquifer but rather it contributes to the safe yield of the wells.

#### **b) Quantitative Parameters**

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

## 4. RESULTS AND DISCUSSION

### 4.1. Determination of the Physico-Chemical Parameters of Groundwater in the Watershed

#### 4.1.1. Physical Parameters

##### 4.1.1.1 Hydrogen Ion Concentration (pH)

In the study area, pH values range from 6.38 to 7.7 in the groundwater samples. The minimum pH value was read in the borehole (HDW4), while the maximum value, 7.7 was recorded in bore hole (BH6). The World Health Organization (WHO, 2011) and (ESA, 2013) pH Standard limit for drinking water is 6.5 to 8.5. The pH values of the above water points in study area do not exceed these standards. Generally the value of pH indicates an increasing from the highlands to lowlands of groundwater samples of the study area. pH value increases towards the rift floor indicating higher rock-water interaction in Figure 4.1 below.

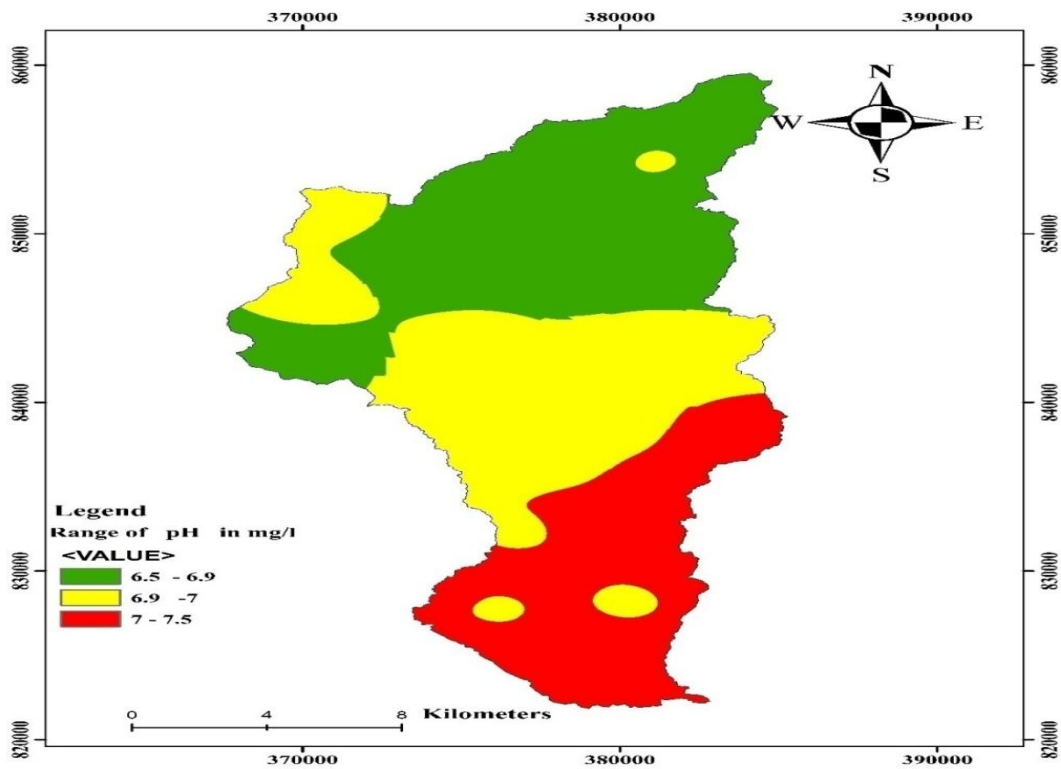


Figure 4.1: pH spatial variation of groundwater samples in the study area

#### **4.1.1.2 Electrical Conductivity (EC)**

In this research, the value of EC in groundwater was ranged from 18.54 to 1096 $\mu$ s/cm. Relatively higher value of EC is observed in water samples of shallow well (SW2) which is 1096  $\mu$ s/cm and borehole (BH2) with lower value of 18.54  $\mu$ s/cm, respectively. The low TDS and EC value of highland springs, and wells indicate that the groundwater in the area consists of meteoric water which originates from direct precipitation circulating at shallow depth (Ayenew, 2005). Low value of EC indicates that the groundwater in the area is less mineralized and contains small dissolved salts. In groundwater generally, dissolved solid concentrations increase along flow paths both EC and TDS value depicts an increasing trend from highland towards the rift floor deep groundwater and this is directly related to high water-rock interaction accompanied with increasing geothermal gradient along the flow path.

#### **4.1.1.3 Total Dissolved Solids (TDS)**

In the study area, TDS value varied from shallow well sample (SW4) 10.28 mg/l minimum value to shallow well water sample (SW2) 548 mg/l maximum value respectively. Shallow groundwater in recharge areas is lower dissolved solids than the water deeper in the same system and lower in dissolved solids than water in shallow zones in the discharge areas (Kumar and Shukla 2014). This implies that as the water goes from the highland through fractured and unconsolidated sediments it acquires dissolved solids more and more depending on all the parameters that govern the evolution of groundwater chemistry from southern recharge zone to northern discharge zone of study area (Figure 4.2 below).

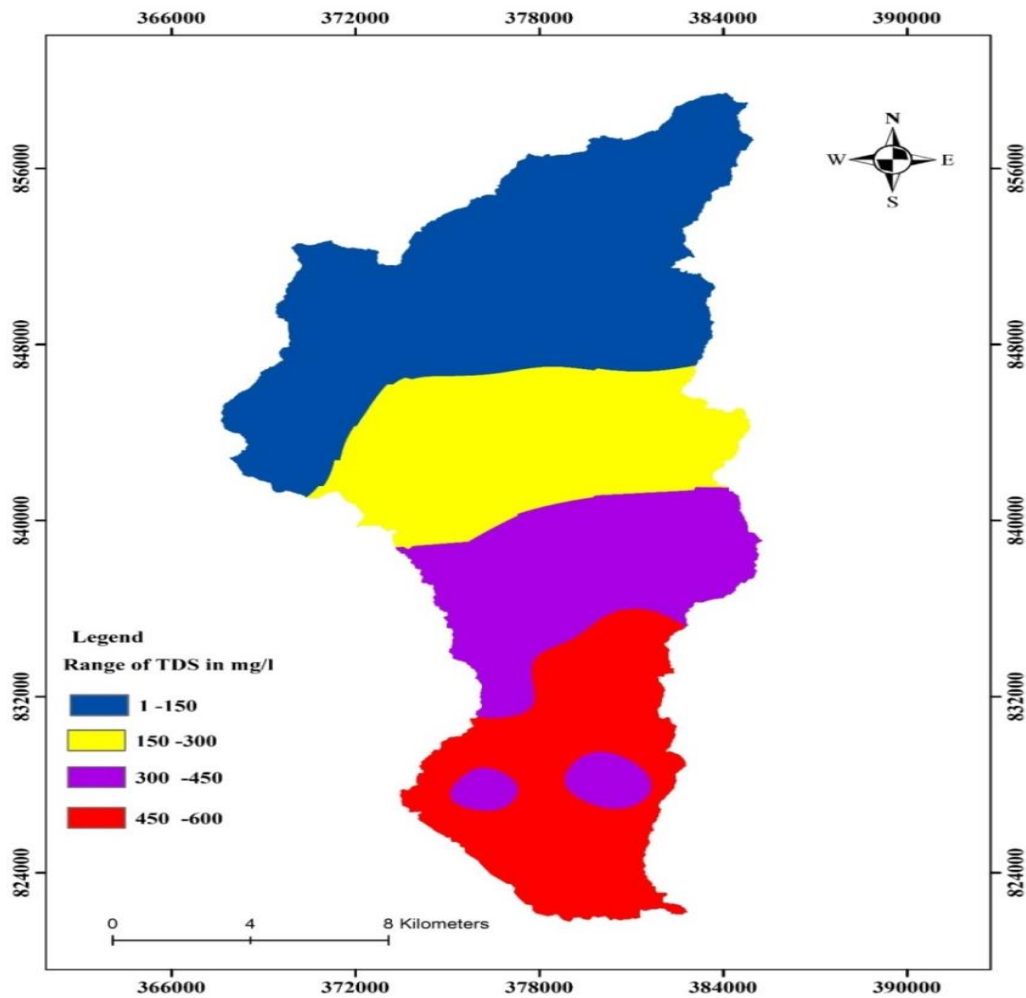


Figure 4.2: Guder River watershed Spatial distributions of TDS (mg/l)

#### 4.1.1.4 .Temperature

The temperature of study area varies from minimum value of 19.3<sup>0</sup>C at bore hole (Bh5) to maximum value of 31.4<sup>0</sup>C at shallow well (SW12). The average temperature of the groundwater is nearly the same as the overlying atmospheric temperature. This, therefore, has an effect on mineralization in the groundwater (Shishaye 2016).

#### **4.1.1.5. Total Hardness (TH)**

Based on above classification of water (Table 3.1) above indicates that 20% of the groundwater samples fall into the soft category, 36.7% moderately soft classification, 23.3% hard and 20% fall within the very hard classification.

### **4.1.2. Chemical Parametres**

#### **4.1.2.1. Major Cations**

##### **4.1.2.1.1 Calcium Ions ( $\text{Ca}^{2+}$ )**

Calcium is the most abundant cation in the area followed by Sodium, Magnesium and Potassium in the study area. Calcium is present in all waters as  $\text{Ca}^{2+}$  and is readily dissolved from rocks rich in Calcium minerals. Acidic rain water can increase the leaching of calcium from soils. From the water sample analysis results in the study area the concentration of Calcium in groundwater sources shows variability and is generally from minimum value of 5.6 mg/l at bore hole (BH7) to 112 mg/l maximum value at shallow well (SW4). The high concentration of  $\text{Ca}^{2+}$  in this study area indicates the weathering of basic volcanic rocks containing silicate mineral (amphibole and plagioclase feldspars) is dominant mineral in the highland and escarpment aquifer which reflects relatively high  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the highland and rift escarpment of groundwater. The maximum standard calcium fixed for drinking water by (WHO, 2011) and (ESA, 2013) is 75 mg/l. In the study area from the collected water samples from about five samples exceeds (WHO, 2011) and (ESA, 2013). Those samples are the hand dug well (HDW4) 75.2mg/l, borehole (BH2) 78mg/l, shallow well (SW7) 89mg/l, borehole (BH4) 98.34 and shallow well (SW4)112 mg/l in increasing order respectively contains high value of calcium.

According to (Ayenew and Ababa 2005) the high  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  content in the highlands are related to the dominance of the basic volcanic (basalt) rock in clear contrast with the rift floor acidic volcanic such as ignimbrite, tuff and pumice. Generally the spatial map of  $\text{Ca}^{2+}$  concentration in the study area shows decreases from highland towards lowland rift floor along flow the groundwater flow direction as shown in Figure 4.3.

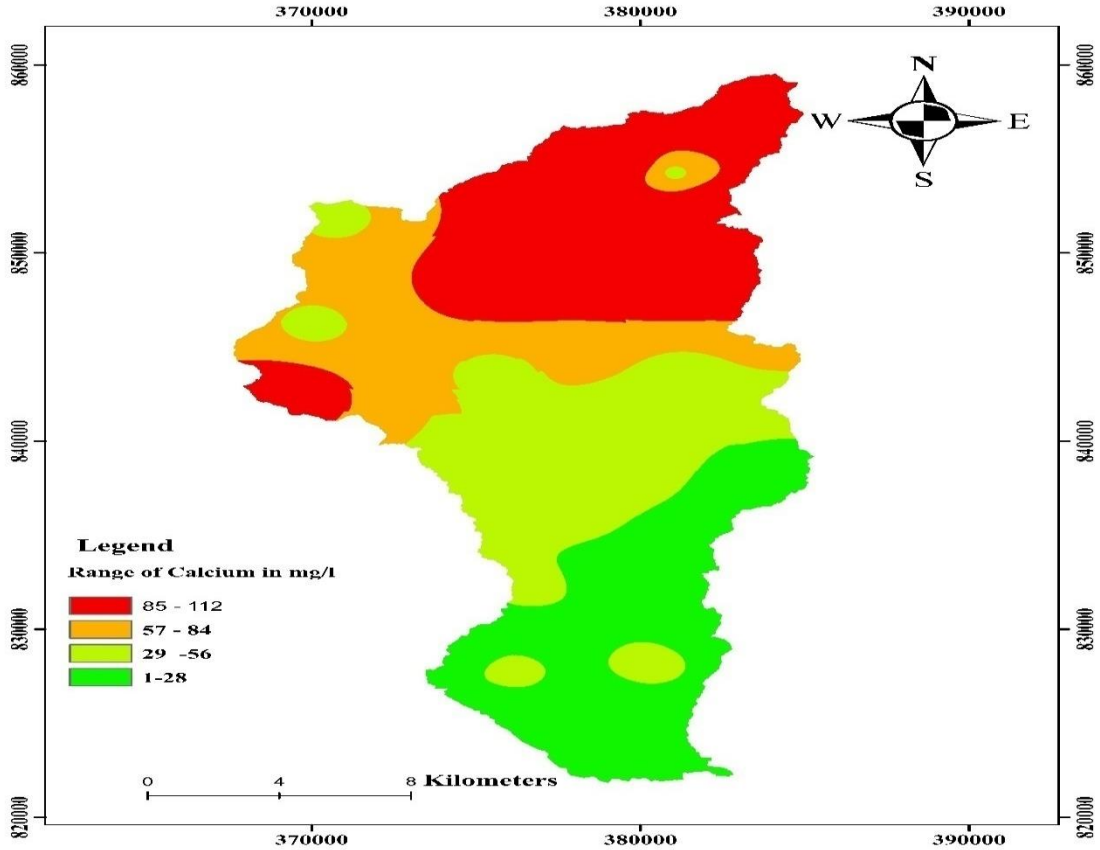


Figure 4.3: Spatial Map of the Calcium in the study area

#### 4.1.2.1.2 Magnesium Ions ( $Mg^{2+}$ )

Magnesium is also found in considerable amounts, next to calcium and sodium cation concentration in the groundwater of the study area, ranging from hand dug well (HDW1) 1.21 mg/l to bore hole (BH2) 32 mg/l as shown in Figure 4.4 below. Magnesium is common in natural water as Magnesium ion, and along with calcium, is a main contributor to water hardness. In the study area, Magnesium arises mainly from the weathering of rocks containing Ferro magnesium minerals. From sample analysis result of different water source bodies, the concentration of Magnesium is generally less than that of Calcium. These values are within the maximum standard limit for  $Mg^{2+}$ , which is 50mg/l as fixed by (WHO, 2011) and (ESA (2013)).

In the study area, the laboratory results of Magnesium is shows decreasing trend from highland towards rift floor and lower than the standard limit of  $Mg^{2+}$ , which is 50mg/l as fixed by (WHO, 2011) and (ESA,2013) respectively.

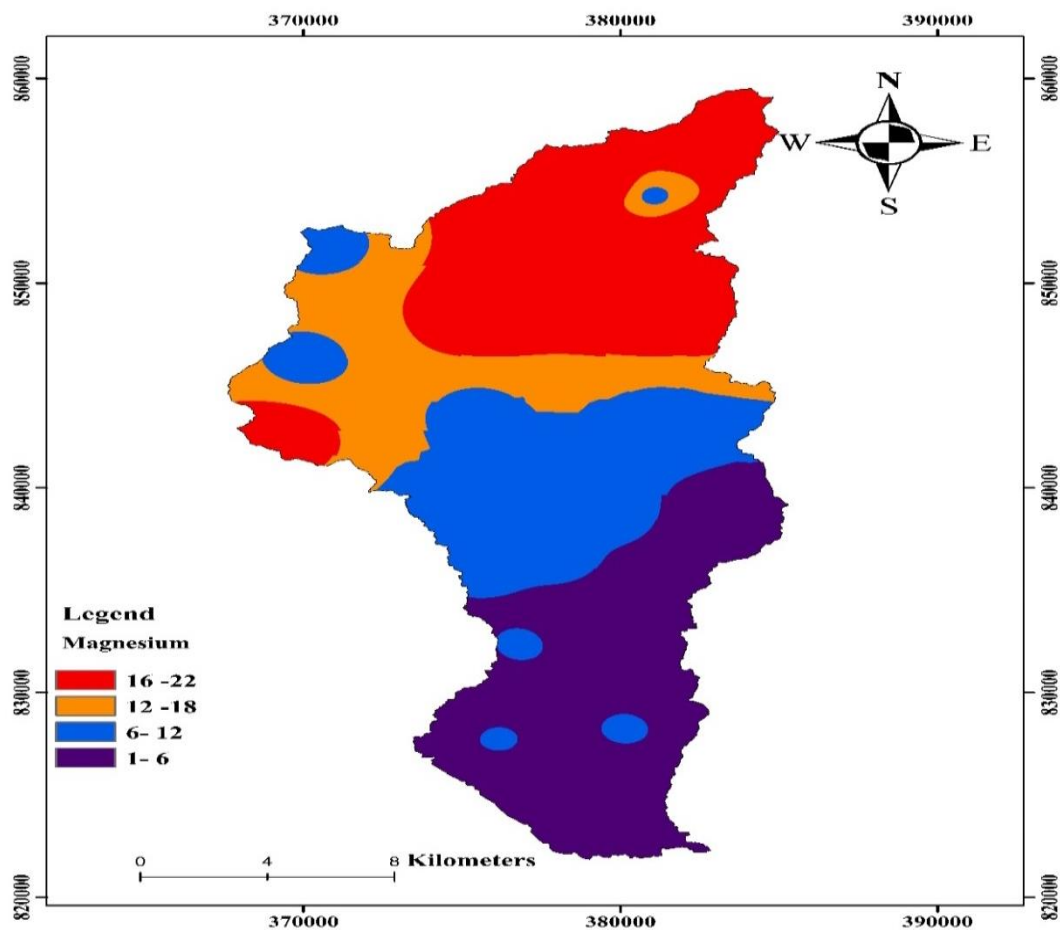


Figure 4.4: Spatial Map of the Magnesium in the study area

#### 4.1.2.1.3 Sodium Ions ( $Na^+$ )

All natural waters contain some sodium since its salts are highly water soluble & their concentrations in natural waters vary considerably. As the chemical analyses of the samples show, sodium is the second most dominant cation in study area that is followed by 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 (WHO, 2011) and (ESA, 2013) guideline value for sodium standard limit drinking water is 200mg/l. The concentration of sodium in study area varies from minimum value spring (SP2) 2 mg/l to shallow well (SW13) maximum value 121mg/l. This result indicates that all collected water samples are below the maximum permissible level in the study area. Cation exchange is a reaction in which the calcium and magnesium in the water are exchanged for sodium that is adsorbed to aquifer solids such as clay minerals, resulting higher sodium concentrations (Hem, 1959). In the study area, all groundwater samples shows similar increasing trend from recharge (highland topography) to discharge zones.

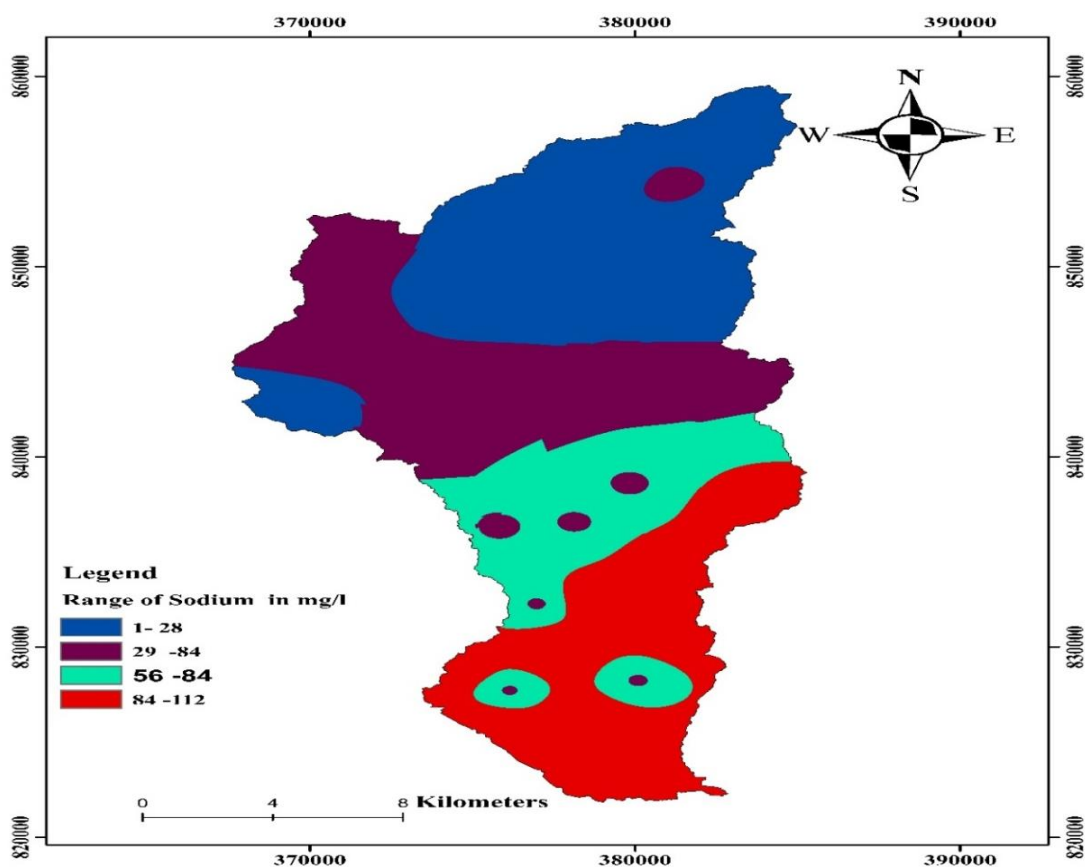


Figure 4.5: Spatial Map of the Sodium in the study area

#### **4.1.2.1.4 Potassium Ions (K<sup>+</sup>)**

Potassium is the least abundant cation in the study area. It is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering. It is usually found in the ionic form and the salts are highly soluble. The potassium concentration of water samples collected from borehole, spring and dug well varies from shallow well (SW13) 1.87mg/l and 22.5 mg/l at hand dug well (HDW4) in study area. The standard limit of potassium given by (ESA, 2013) and WHO (2011) is 15 mg/l and 12 mg/l respectively. Therefore, one sample of 22.5 mg/l at hand dug well (HDW4) exceeds Ethiopian drinking water standards and two samples 22.5 mg/l at hand dug well (HDW4) and 13 mg/l at hand dug well (HDW3) are above permissible limit of World Health Organization. The remains all the analyzed water samples values showed below the standard limit of potassium.

In most natural water, the concentration of K<sup>+</sup> is much lower than the concentration of Na<sup>+</sup> (Kumar and Shukla 2014). In the study area, the much higher concentration of Na<sup>+</sup> than K<sup>+</sup> is observed this may be due to cation exchange process and the maximum concentration of K<sup>+</sup> is due to the weathering K<sup>+</sup> source minerals bearing acidic volcanic rocks (k-feldspars/orthoclase and mica) relatively higher in the rift floor than the highland and escarpment water samples in the study area.

#### **4.1.2.2. Major Anions**

##### **4.1.2.2.1 Bicarbonate Ions (HCO<sub>3</sub><sup>-</sup>)**

It is derived from the carbon dioxide released by the organic decomposition in the soils, where CO<sub>2</sub> is generated by root respiration and decay of humus that in turn combines with rainwater to form bicarbonates (Todd 2005). Bicarbonate is the dominant anion in study watershed. It was found ranges from a minimum at spring (SP2) 37 mg/l for at recharge area to maximum 589 mg/l for shallow well (SW11) at discharge zones of the study area. There is no specification on the maximum acceptable limits of bicarbonate either by WHO or Ethiopian standard for drinking water but threshold value is 120 mg/l. In the investigated area Concentration of bicarbonate in water samples in general increases from recharge areas to discharge zones along flow path.

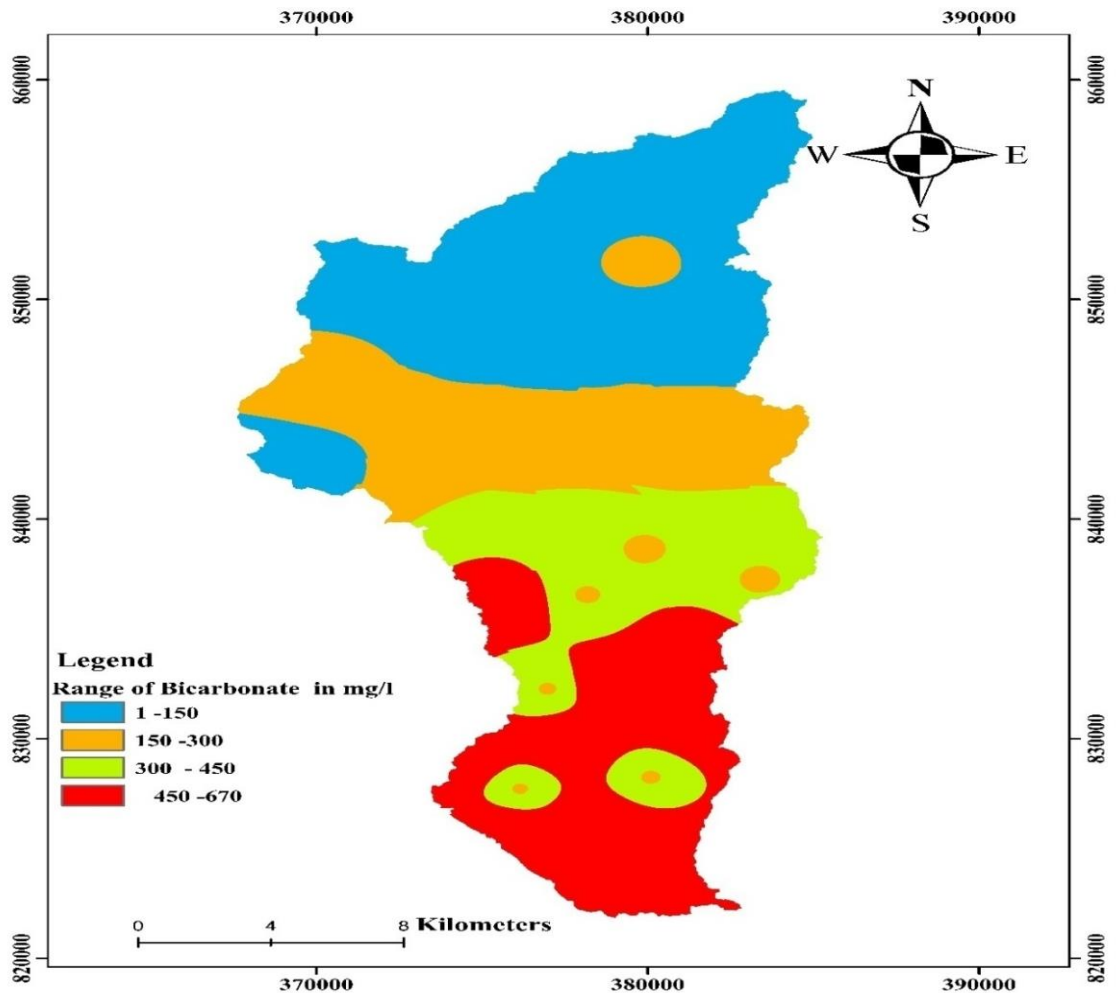


Figure 4.6: Spatial Map of the Bicarbonate in the study area

#### 4.1.2.2.2 Carbonate Ions ( $\text{CO}_3^-$ )

The majority of the study area waterpoint samples result were found nill for  $\text{CO}_3^-$  except three waterpoint samples ((SW11: 23 mg/l), (SW5:10.4 mg/l) and (BH2; 5.8 mg/l)).

#### 4.1.2.2.3 Sulphate Ions ( $\text{SO}_4^{2-}$ )

The standard limit of Sulphate given by (WHO, 2011) and (ESA ,2013) is 250 mg/l. In the study area the concentration of sulphate waters ranges from 0 to 0.02 mg/l for spring (SP1) to 25 mg/l for hand dug well (HDW3). All samples do not exceed WHO and Ethiopian drinking water standard.

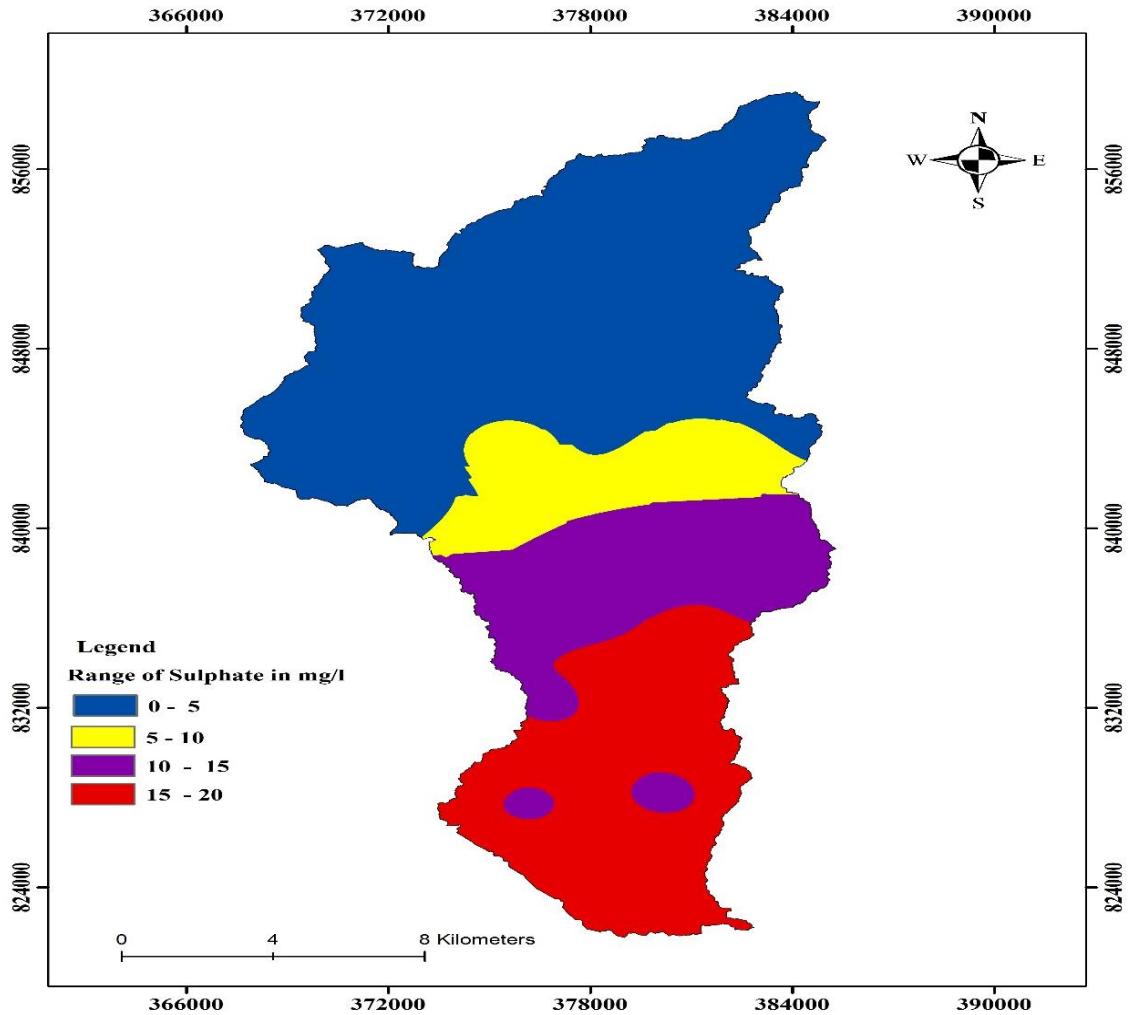


Figure 4.7: Spatial Map of the Sulphate in the study area

#### 4.1.2.2.4 Chloride Ions (Cl<sup>-</sup>)

Chloride is another anion known by its conservative nature in the chemical evolution process and good indicator of the relative age of groundwater compare to other major ions. Even though, more important source of Cl<sup>-</sup> is association with sedimentary rocks, volcanic gases from geothermal fields may also introduce in the groundwater system and in some rift lakes (Maghraby 2014). As chloride is frequently associated with sewage, it is often incorporated in to assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies.

The chloride, the permissible level of chloride in drinking water is 250mg/l based on WHO and Ethiopian Standard. High chloride concentration in the groundwater show contamination from pit latrine, and waste disposals. In the study area, the chloride value for almost all samples taken from groundwater is under range of limit of standards, ranging from 0 to 0.05 mg /l at shallow well (SW14) to 8.8 mg/l at shallow well (SW12). Generally, Cl concentration increase from highlands and rift escarpment towards the floor of the rift.

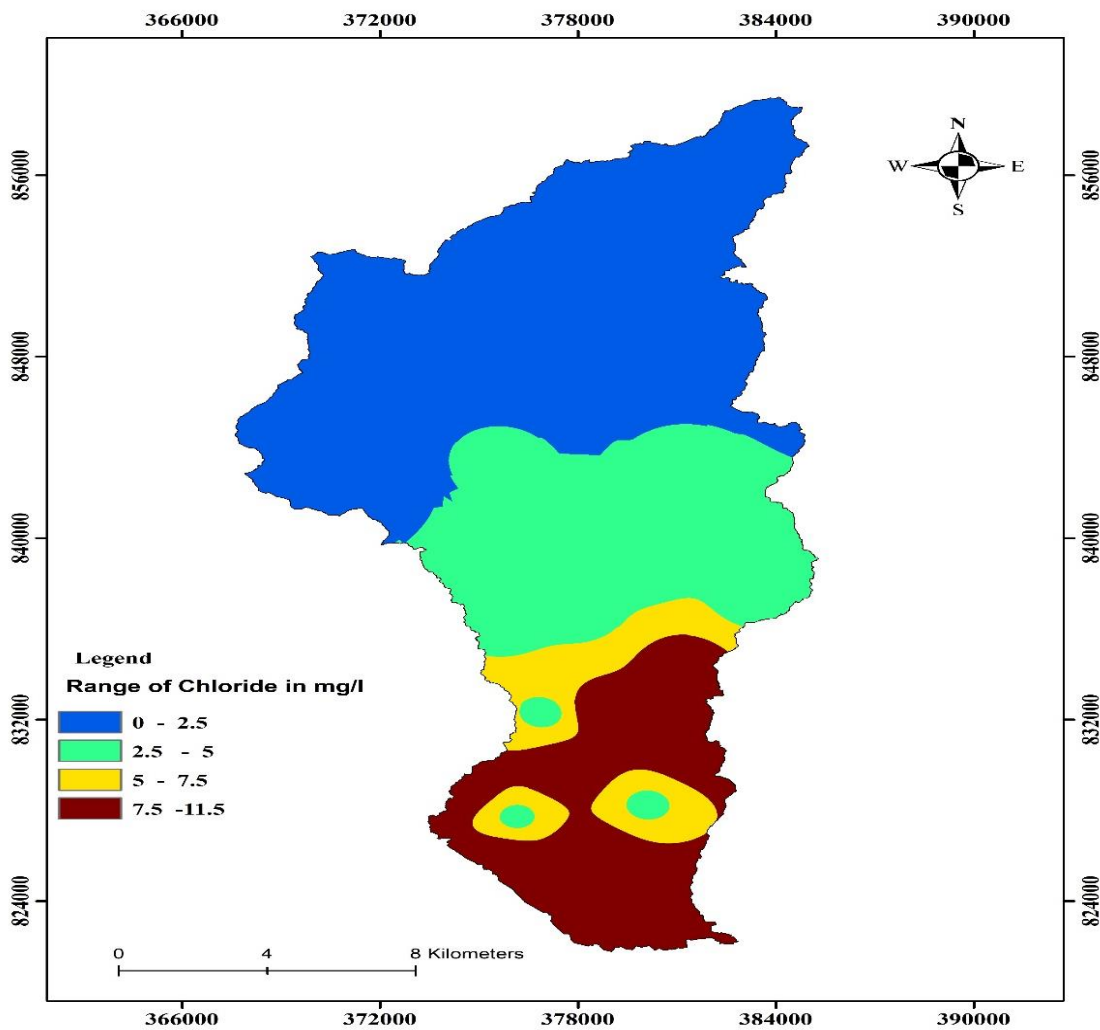


Figure 4.8: Spatial Map of the Chloride in the study area

### 4.1.2.3. Minor Ions

#### 4.1.2.3.1. Nitrate Ion ( $\text{NO}_3^-$ )

The Nitrate concentrations in the water samples of the study area ranges from trace amount of shallow well (SW12) 0.1 mg/l to shallow well (SW11) 26 mg/l. All the waters samples are below the Nitrate guideline values of WHO (2011) and Ethiopian drinking water quality guidelines of (50mg/l). According to (Simsek et al. 2008), 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 shallow well (SW11) indicates that the area is affected by anthropologic source in related to agriculture fertilizers and animal manures.

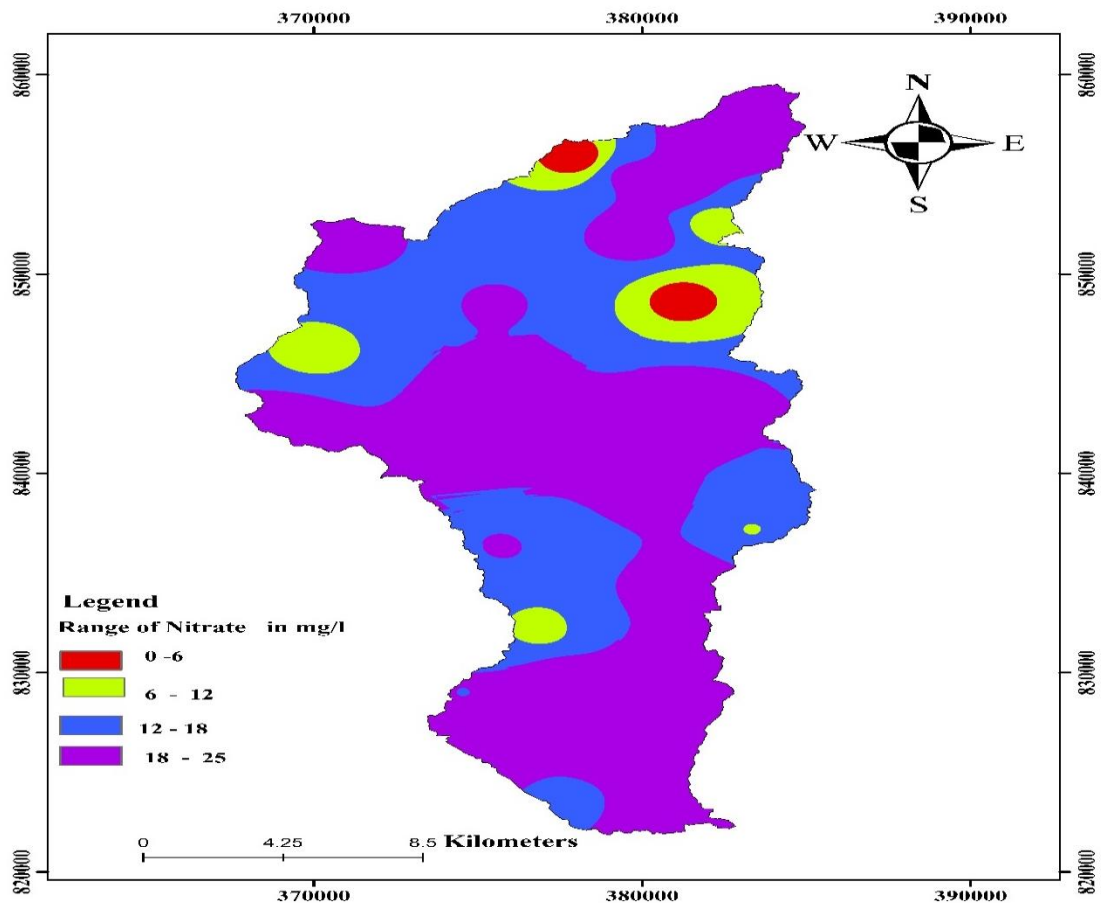


Figure 4.9: Spatial Map of the Nitrate in the study area

#### **4.1.2.3.2. Fluoride (F<sup>-</sup>)**

Most of the fluoride in groundwater comes from acidic volcanic rocks such as pumice, obsidian, pyroclastic deposits, ignimbrite and rhyolite. The natural concentration of fluoride depends on the geological, chemical and physical characteristics of the aquifer, the porosity, the acidity of the soil and rocks and the temperature and the action of other chemical elements. The high permeability and large rock water interaction makes the leaching process more effective in pumice. As pumice fall deposits are wide spread in the study area, these rocks represent first order potential reservoir of fluoride. Groundwater with high fluoride content is found mostly in calcium-deficient groundwaters (Tewodros et al, 2009).

In some parts especially in the rift zone and samples from some wells which are associated with fault zones show higher fluoride concentration than the normal drinking water standard. Higher concentration fluoride in the study is associated with recent acidic volcanic rocks (Redda et al, 2006). The standard limits of fluoride given by WHO and Ethiopian drinking water quality guidelines are 1.5mg/l. All analyzed water samples contain fluoride which ranges from shallow well (SW9) 0.08 mg/l to 3.07 at shallow well (SW13). But in the study area three samples shows greater than above standard fluoride concentration from the analyzed samples such as bore hole (BH8) 1.51mg/l, shallow well (SW12) 1.7mg/l and shallow well (SW13) 3.07 mg/l respectively.

It has to be noted that fluoride concentrations above 1.5 mg/l causes dental fluorosis.

The concentrations of fluoride show variations from recharge area to discharge zones. High concentration of fluoride in the rift is due to the very recent nature of the volcanics and fumarolic activities existing in the area. This is because in that area the deposits of clay and gravel have been derived from the nearby volcanic products which have high fluoride content.

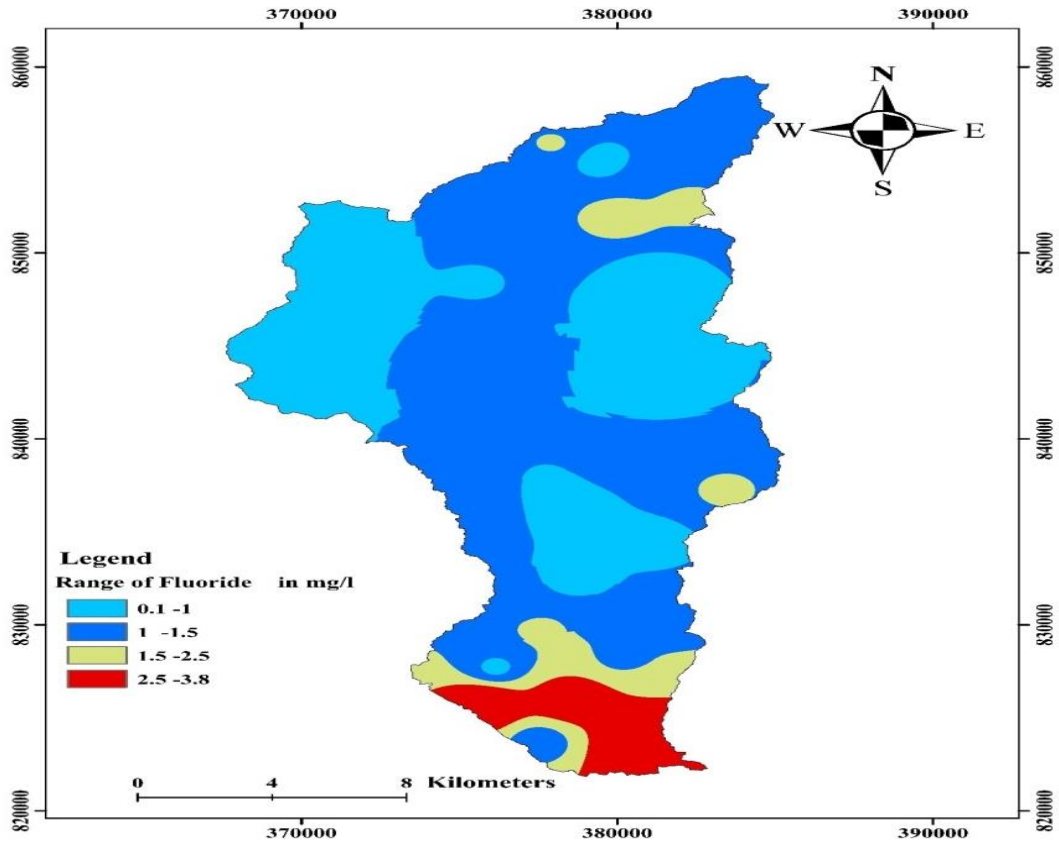


Figure 4.10: Spatial Map of the Fluoride in the study area

#### 4.1.2.3.3. Iron ( $\text{Fe}^{2+}$ )

The minimum concentration of iron for collected water samples in the study area is 0.03 mg/l at shallow well (SW6), whereas the maximum value becomes 3.5mg/l at shallow well (SW9). Therefore, low and high concentrations of iron were registered respectively. Comparatively the water samples collected from borehole, shallow well and spring have higher iron concentration than samples collected from hand dug well. From all the analyzed samples, the results of six samples spring (SP2) 0.56mg/l, shallow well (SW11) 0.6mg/l, shallow well (SW16) 0.72mg/l, bore hole (BH2) 0.82mg/l, bore hole (BH7) 1.74mg/l and shallow well (SW9) 3.5mg/l respectively are above the standard limit set by both WHO and Ethiopian standard for drinking water of (0.3mg/l).

This is due to the water continues to infiltrate deeper into the ground the oxygen may react with reduced iron minerals such as pumice which adds to the acidity in groundwater. Additionally, improperly constructed wells can result in poor water quality in the study area. 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 (Terra, Rof, and Eccaluva 2008).

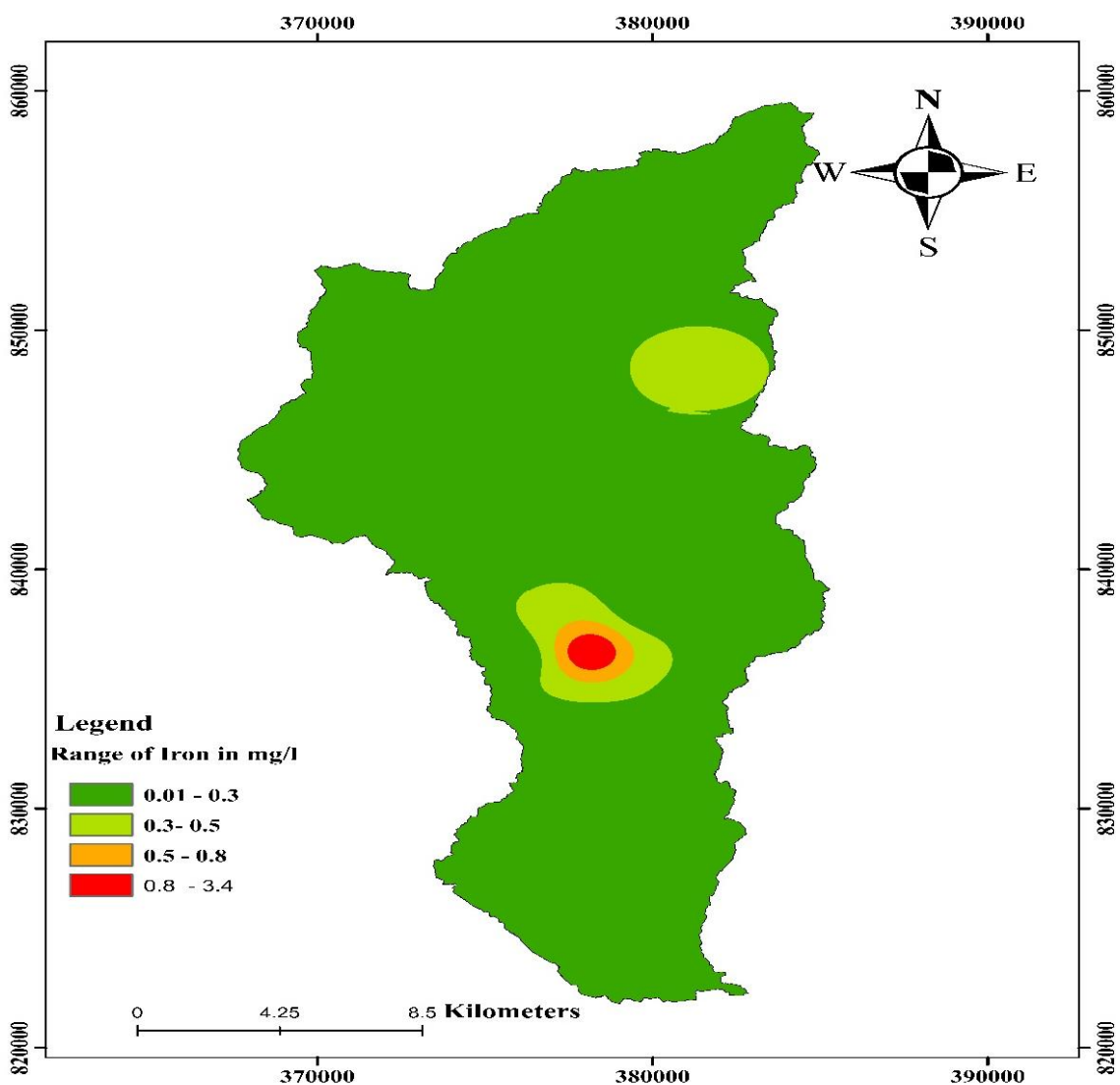


Figure 4.11: Spatial Map of the Iron in the study area

## 4.2. Determination of Water Quality Index and Assessment of Water Quality For Drinking and Irrigation Purposes

### 4.2.1. Groundwater Suitability For Drinking Purpose

Table 4.1: WQI and water classification of each groundwater samples of study area

S.No	ID	WQI	WQI classification
1	BH1	38.3	Excellent
2	SP1	39.57	„
3	BH2	69.309	Good
4	SW1	34.8	Excellent
5	SW2	31	„
6	SW3	36.1	„
7	SW4	45.57	„
8	SW5	41.63	„
9	SW6	40.13	„
10	SW7	45.16	„
11	SW8	37.25	„
12	BH3	35.93	„
13	SW9	151.122	Poor
14	BH4	50.4	Good
15	BH5	51.703	Good
16	BH6	39.45	Excellent
17	SW10	31.7	„
18	BH7	81.25	Good
19	BH8	69.98	Good
20	SW11	81.206	Good
21	SP2	34.65	Excellent
22	SW12	44.15	„
23	SW13	65.47	Good
24	SW14	33.862	Excellent
25	HDW1	23.01	„
26	SW15	30.72	„
27	HDW2	31.23	„
28	HDW3	44.9	„
29	HDW4	46.38	„
30	SW16	58.78	Good

The overall Water Quality Index (WQI) was calculated by adding together each sub index values of each groundwater samples as follows:

$$WQI = \sum SI_{i-n} \dots \dots \dots \text{Eq.4.1}$$

Computed WQI values are usually classified into five categories (Table 4.2): excellent, good, poor, very poor and unfit water for drinking purposes (Abraham et al, September 2011).

Table 4.2: Water Quality Classification Based On WQI Value

S.No	WQI value	Water quality	Water samples	Percentage (%)
1	<50	Excellent	21	70%
2	50.1-100	Good	8	27%
3	100.1-200	Poor	1	3%
4	200.1-350	Very poor	-	-
5	>350.1	Unfit water for drinking	-	-

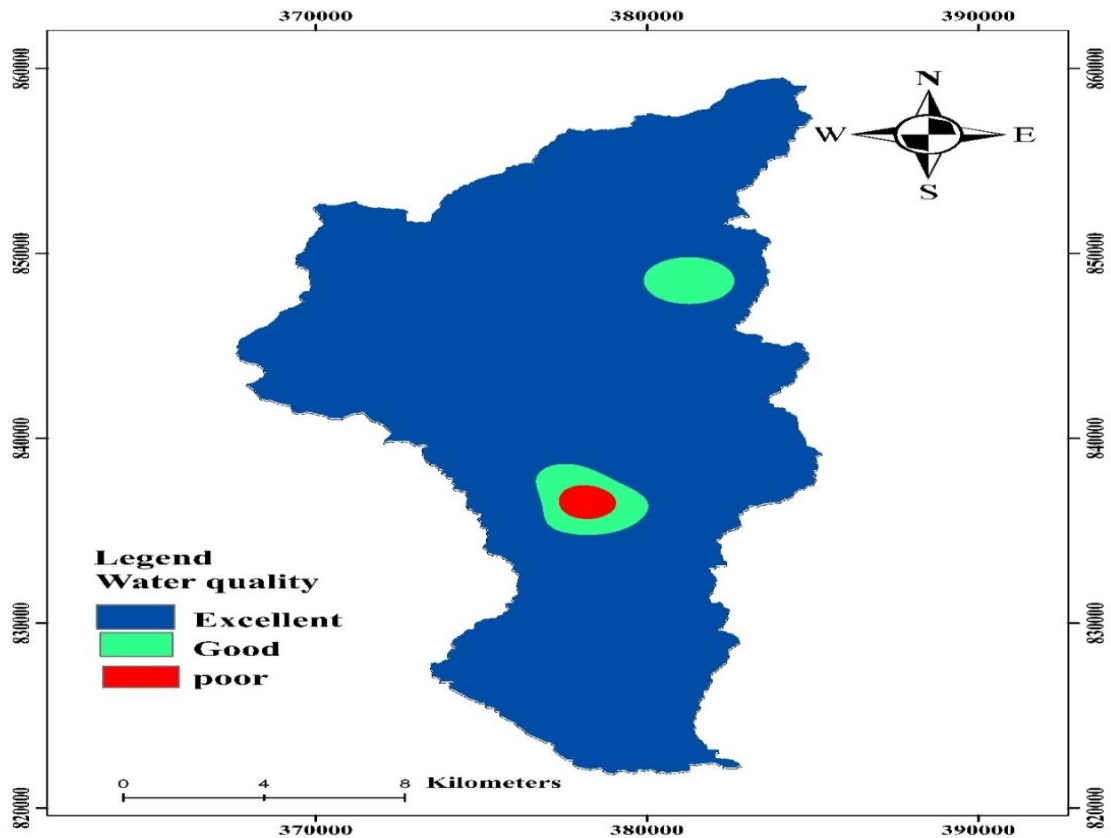


Figure 4.12: Map of water quality index in study area

## 4.2.2. Groundwater Suitability for Irrigation.

### 4.2.2.1. Electrical Conductivity (EC)

Table 4.3 below shows the classification of water based on EC (US salinity Laboratory, 1954). The EC value of the study area varies from 18.54 to 1096  $\mu\text{s}/\text{cm}$ . Based to this classification of the groundwater samples 15 have low salinity hazard, this is due to the low TDS in the groundwater. This value of EC measurements shows that groundwater of the study area is suitable for irrigation purpose. From remain analyzed samples, 14 have medium EC value however, and it may be satisfactory for plants having moderate salt tolerance. Except 1 sample is relatively has high EC or salinity hazard of groundwater in the study area (appendix 1.2). Shallow well (SW2) from keilama area has relatively higher EC value of 1096  $\mu\text{s}/\text{cm}$ , respectively (Apendex 1.3).. These could be hard for irrigation purpose.

Table 4.3: Classification of water based on EC (US salinity Laboratory, 1954)

Salinity Hazard	EC ( $\mu\text{s}/\text{cm}$ )	No. of samples	% of samples
Low	<250	15	50
Medium	250-750	14	46.7
High	750-2250	1	3.3
Very high	>2250	0	0

### 4.2.2.2. Sodium Adsorption Ratio (SAR)

The chemical analysis in the study area shows that all of the water samples analyzed have SAR value less than 10 that is Excellent for irrigation(Apendex 1.3) as shown Table 4.4 below.

Table 4.4: Classification of water for irrigation purpose based on SAR (Arab J Geosci,2012)

Water class	Alkali Hazard(SAR)	Number of Samples	% of samples
Excellent	Up to 10	30	100%
Good	10-18	0	0
Fair	18-26	0	0
Poor	>26	0	0

Depend on the salinity hazard and sodium hazard Wilcox's diagram used for the classification of Groundwater of the study area for irrigation by plot the SAR value against EC using Aquachem 4.0 as indicated in (appendix 1.2).

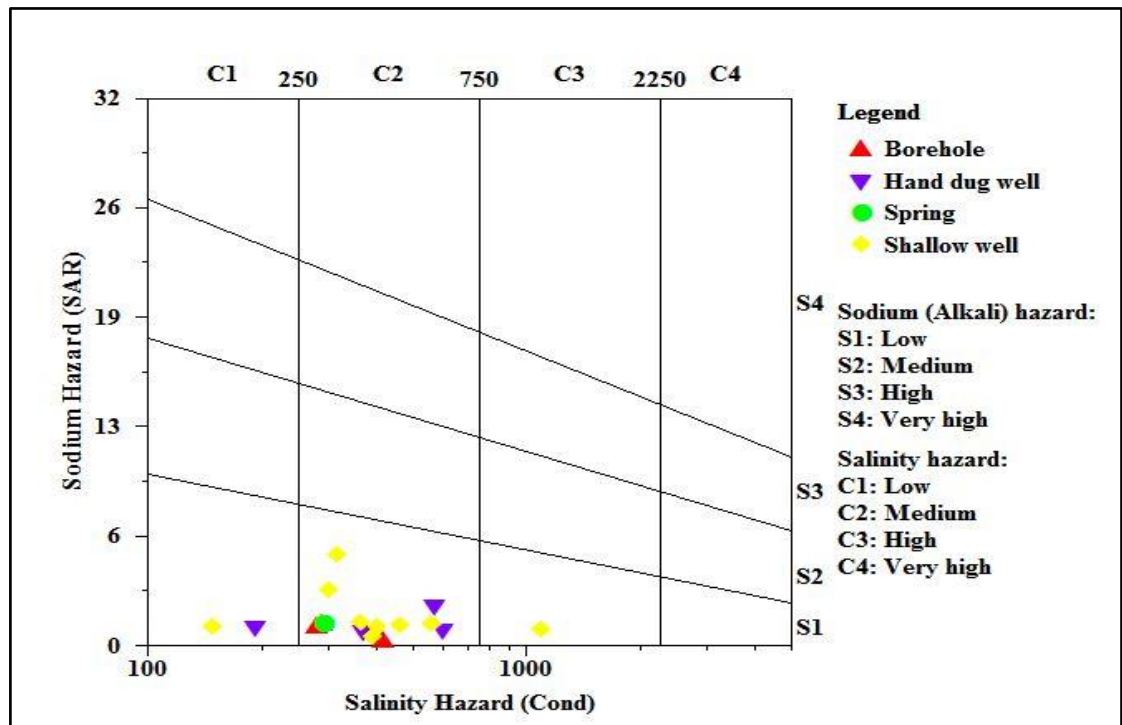


Figure 4.13: Wilcox Diagram of Sodium Hazard vs. Salinity Hazard in the Study area(Ivil et al. 2020).

As shown on above Figure 4.13, the results indicates that all of the groundwater plotted on low sodium hazard S1 this shows that groundwater samples of the study area is suitable for irrigation. In terms of salinity hazard of the study, most groundwater samples have low to medium salinity (C1 to C2), which indicate that almost of sample waters in the study area are good for irrigation except one sample which have high salinity hazard (C3).

#### 4.2.2.3. Sodium percentage (%Na)

Table 4.5: Classification of water based on percentage Na<sup>+</sup> (US salinity Laboratory, 1954)

Na%	Class	Number of samples	% of samples
<20	Excellent	1	3.34%
20-40	Good	13	43.33%
40-60	Permissible	13	43.33%
60-80	Doubtful	3	10%
>80	Unsuitable	0	0

The calculated value of %Na in study area varies from 3.34% to 43.33% and few 3 water samples collected from study area is greater than 60%. Irrigation water having sodium percentage more than 60% may lead to sodium accumulation and destruction of soil structure (Soleimani et al. 2020) (appendix 1.2).

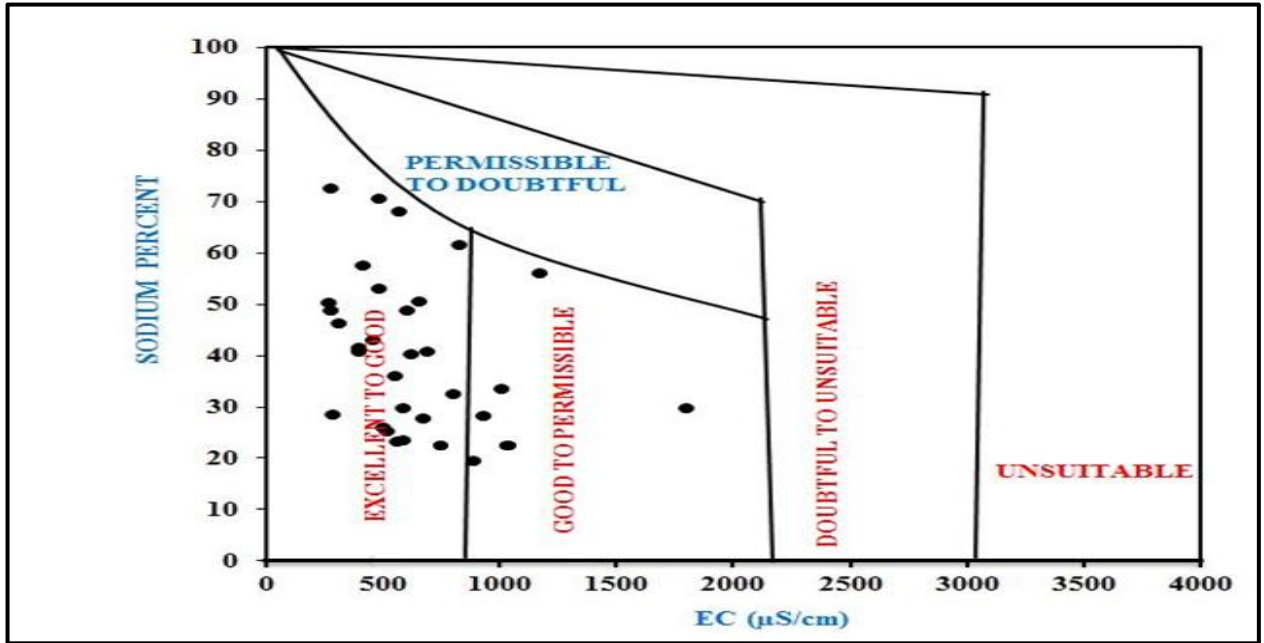


Figure 4.14: Wilcox Diagram of Sodium percent vs. Salinity Hazard (EC) in the Study area (Satheeshkumar 2018).

#### 4.2.2.4. Permeability Index

Table 4.6: Classification of water for irrigation purpose based on Permeability Index.

Water class	Permeability Index	Number of samples	% of samples
class I	$\geq 75$	22	73.33%
class II	75 -25	8	26.67%
class III	< 25	0	0

According to the classification by Done in above Table (4.6) PI values, 73.33% of the samples fall in the Class I category and 26.67 % of the samples fall in the Class II category, the samples fall in the study area in the class I and class II which indicates that they are suitable for irrigation (appendix 1.2).

## **4.3. Characterization of Aquifer Systems and Units**

### **4.3.1. Hydrogeologic Units and Aquifer Systems**

Classification of the hydrogeologic units within the basin was done from the information of surface geology, borehole lithologic log data, and pump test data. The most important features of these hydrogeologic units are compiled from current and previous studies (Mesele 2017) and summarized as follows:

#### **4.3.1.1. Fractured Ignimbrite and Welded Tuff Aquifer**

This unit mainly situated in the escarpment and western rift margin composed of pyroclastic fall and pyroclastic deposits such as tuff and ignimbrite. These are less welded ignimbrites intercalated with pumice fragments, alluvial and colluvial deposits located at the foot of volcanic mountains. Ignimbrites are widely, occurring in the escarpment slopes and piedmont areas, the plains of eastern and western escarpment and on the rift floor. This type of aquifer formation mainly found in the western and southwestern transitional escarpment and some eastern part of the basin in Haiese, debub bellesa and ambicho gode area, respectively. The borehole log data indicates this type of aquifer units mainly composed of welded and unweldded ignimbrites, and welded and unweldded tuff. In the basin, the vertical distribution of aquifer in this unit shows below in the selected representative deep well log data (Figure 4.15). On the basis of the collected well log data the thickness of this unit vary from 80 m in the highland to above 200 m in the escarpment and rift floor. The water level varied from 60 m to 150 m below mean sea level and medium to high permeability and productivity.

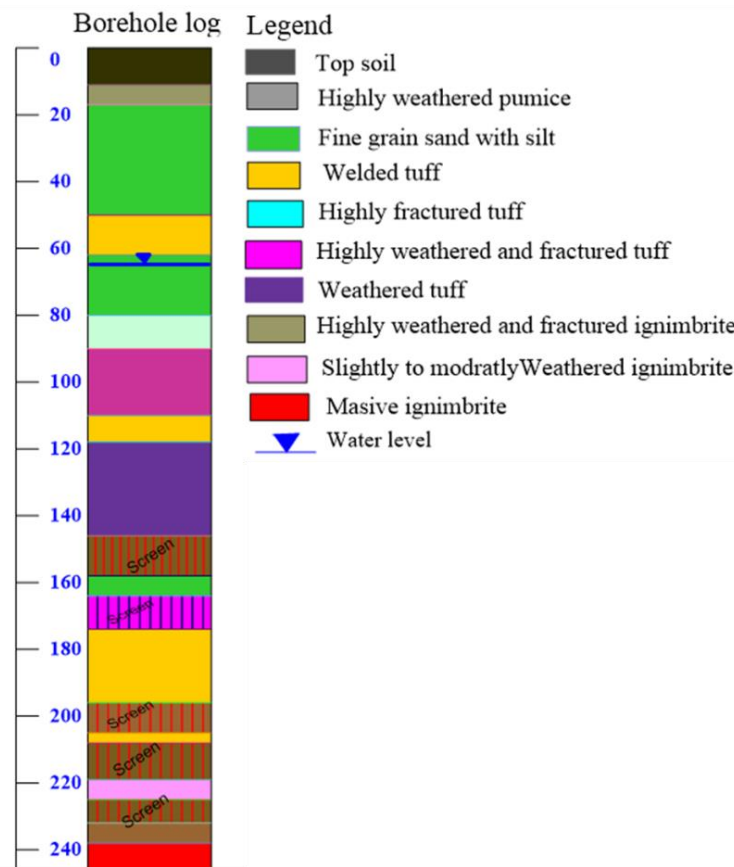


Figure 4.15: Representative well log data showing the vertical distribution of ignimbrite and tuff aquifer nature (Ana Tigo borehole) (Gintamo, 2010)

According to the pumping test data analysis, the hydraulic parameters (hydraulic conductivity and transmissivity) of this unit is evaluated. The analysis result shows that transmissivity varies from  $3.03 \times 10^{-3} \text{ m}^2/\text{s}$  to  $7.65 \times 10^{-4} \text{ m}^2/\text{s}$  and hydraulic conductivity  $1.26 \times 10^{-5} \text{ m/s}$  to  $6.45 \times 10^{-5} \text{ m/s}$ , storativity ranges from  $1.25 \times 10^{-3}$  to  $2.44 \times 10^{-5}$  are summarized as below in (Table 4.7). The characteristics of ignimbrite and tuff, due to weathering grade and fracturing, the units possess medium to high permeability, hydraulic conductivity and storativity. According to Ayenew (1998) the permeability of this unit is highly variable based on the degree of weathering and faulting and also the hydraulic conductivity and transmissivity of this unit is variable. On the basis of the collected pump test data analysis result the aquifer is confined, however, the aquifer materials are variable it is possible that some unconfined to semi confined layer might be occur at some localities. The borehole yield in this aquifer unit varies from 2.5-9 l/s with an average thickness greater than 250 m.

Finally, based on the collected data the aquifers of this unit can be classified as moderate to high productivity zone aquifer class.

Table 4.7: The collected representative aquifer parameters data

Site name	Transmissivity(m <sup>2</sup> /s)	Conductivity(m/s)	Storativity	Yield (l/s)
Lisenasena well	6.62 x 10 <sup>-4</sup>	1.26 x 10 <sup>-5</sup>	1.25 x 10 <sup>-3</sup>	9
An Tigo well	7.65 x 10 <sup>-4</sup>	1.42 x 10 <sup>-5</sup>	2.44 x 10 <sup>-5</sup>	5.7
MisrakAnilemowell	7.71 x 10 <sup>-2</sup>	1.48 x 10 <sup>-3</sup>	5.10 x 10	4.8
Bandelicho well	3.03 x 10 <sup>-3</sup>	6.45 x 10 <sup>-5</sup>	1.8 x 10 <sup>-3</sup>	3.4
Shirinto 2 well	6.8 x 10 <sup>-4</sup>	1.5 x 10 <sup>-5</sup>	1.28 x 10 <sup>-4</sup>	2.5

#### 4.3.1.2. Fractured Basalts and Basaltic Scoria Aquifer

These units are mainly out cropped in the western rift margin dominantly composed of vesicular basalts, associated scoria cones and some places gravel and fine grained sand deposit underlying thin layer of flow. This type of aquifer formation mainly found in the southwestern and some central part of the watershed in Bellesa, Fonko, Semen-Bellesa, chingo, demela, and lera area, respectively. The borehole log data indicates this type of aquifer mainly composed of scoria, vesicular-basalt, clayey silt, sand, and gravel deposit underlying thin layer of basaltic flows and the underlying silt, sand and gravel deposits contribute to the aquifer. In the watershed, the vertical distribution of aquifer in this unit shows below in the selected deep well log data (Fig.4.16).

On the basis of the collected well log data the thickness of this unit vary from 100 m in Bellesa area to 400 m in chingo area. The groundwater level in this area relatively shallow to deep probably depended on surface topography as compared to Bellesa- Semen-Bellesa– Fonko plain and chingo pediment, it's varied from 22 m shallow to 130 m deep water level below mean sea level and the aquifer is high permeability and productivity.

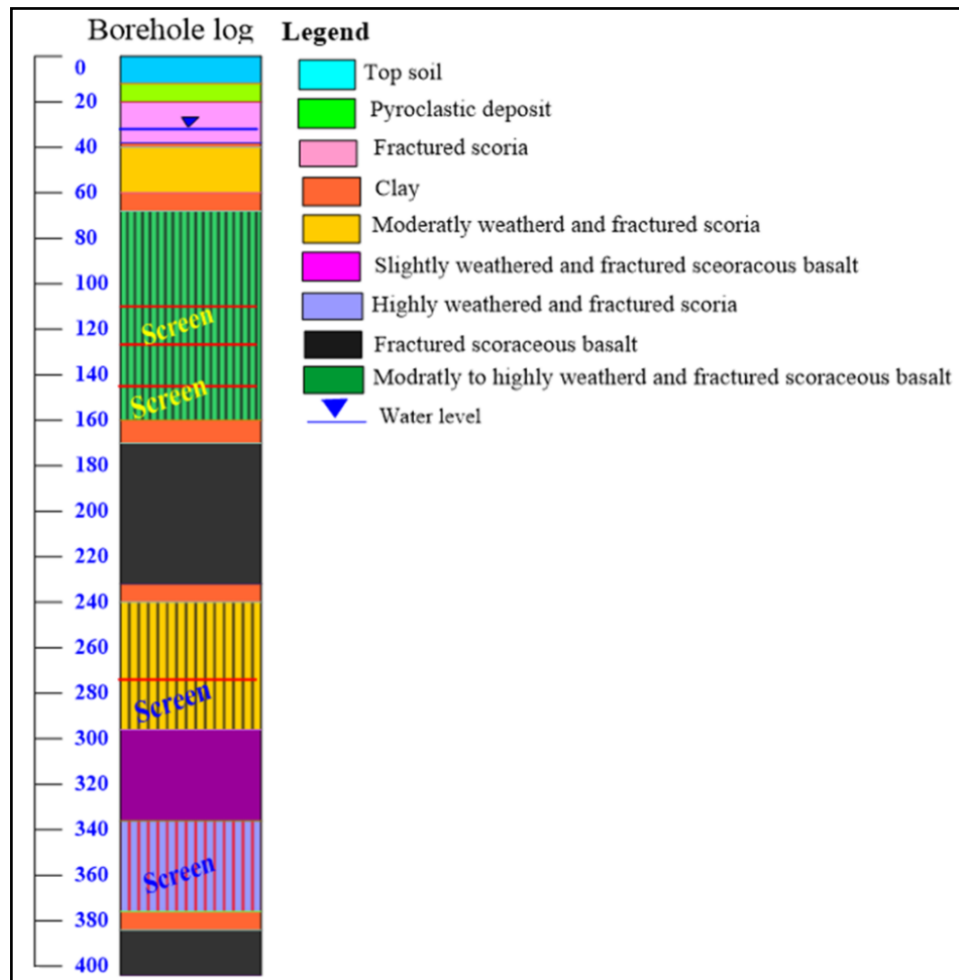


Figure 4.16: Representative well log data showing the vertical distribution of basalt and scoria aquifer nature (Duna well) (Nedaw, 2019)

According to the pump test data analysis the hydraulic parameters (transmissivity, hydraulic conductivity and storability) of this unit are evaluated. The analysis result shows that transmissivity varying between  $1.83 \times 10^{-3} \text{ m}^2/\text{s}$  to  $3.4 \times 10^{-2} \text{ m}^2/\text{s}$  and hydraulic conductivity  $1.52 \times 10^{-5} \text{ m/s}$  to  $5.29 \times 10^{-2} \text{ m/s}$ , storability  $2.25 \times 10^{-3}$  to  $4.34 \times 10^{-8}$  are summarized as below (Table 4.8). On the basis of the analysis result the aquifer types of this unit is varies from semi-confined to confined aquifer, however, the aquifer materials are variable it is possible that some confined and unconfined layer might be occur at some localities. The borehole yield in this aquifer unit varies from 9-40 l/s with an average thickness greater than 200 m. Finally, based on the collected data the aquifers of this unit can be classified as high to very high productivity aquifer class.

Table 4.8: The collected representative aquifer parameters data

Site name	Transmissivity(m <sup>2</sup> /s)	Conductivity(m/s)	Storativity	Yield(l/s)
Home agera well	2.57 x 10 <sup>-3</sup>	1.52 x 10 <sup>-5</sup>	2.25 x 10 <sup>-3</sup>	40
Biremore well	3.07 x 10 <sup>-3</sup>	1.7 x 10 <sup>-5</sup>	2.44 x 10 <sup>-5</sup>	40
Wogile Abera borehole	3.4 x 10 <sup>-2</sup>	5.29 x 10 <sup>-2</sup>	4.34 x 10 <sup>-8</sup>	12
Dinike borehole	1.83 x 10 <sup>-3</sup>	2.7 x 10 <sup>-5</sup>	3.30 x 10 <sup>-5</sup>	9

### 4.3.1.3. Quaternary Sediment Aquifer

Lacustrine sediment mainly deposited in the rift floor of the study area, mainly surrounding the lakes in low lying areas of rift floor and the other area the sediment deposited in Jemeya – BidikeLisena plain. This type of aquifer formation mainly found in the southern and southeastern part of the watershed. The aquifer composed of lacustrine, colluvial and fluvial, pyroclastic, talus and fan deposit; they store large quantities of groundwater. And also the thick sediment deposits, the sand and pyroclastic deposits such tuff and pumice is underlain by clay and silt layers, which highly reduce permeability of the groundwater. Generally, in the fluvio/volcano lacustrine sediments water strike at shallow depth. In the basin, the vertical distribution of aquifer in this unit shows below in the selected deep well log data (Figure 4.17).

Based on the collected well log data the thickness of the lacustrine sediment varies from 30 m to above 250 m. The groundwater level this part of the basin relatively shallow when compared to the others aquifer unit of the area. The groundwater level ranges from about 20 m in the vicinity of Boyolake to above 50 m below mean sea level away from the lake and some central part of the watershed and medium to high permeability and productivity.

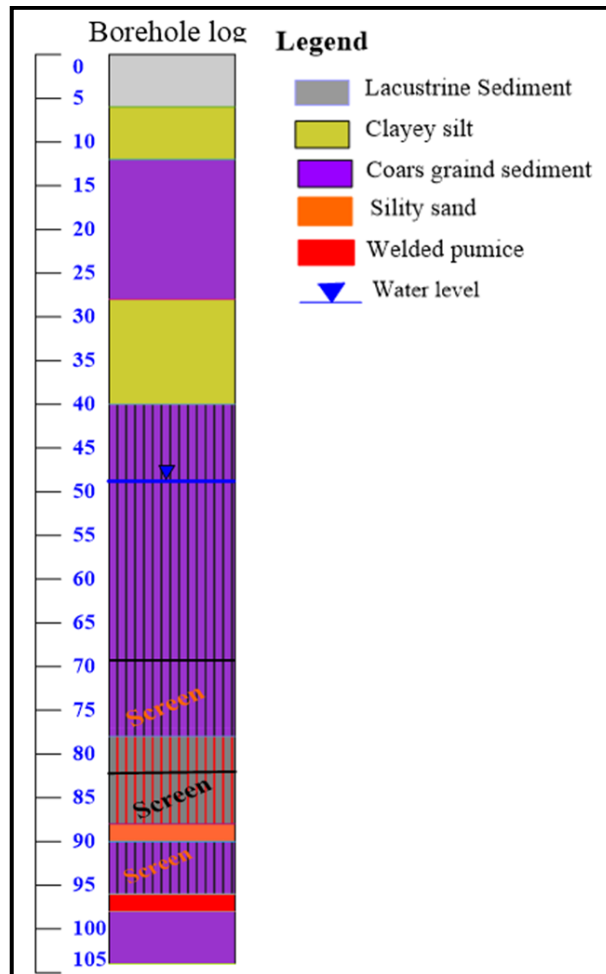


Figure 4.17: Representative well log data showing the vertical distribution of lacustrine sediment aquifer nature (Lisena town) (Gennoro, 2009)

According to (MoWR 2008) the hydraulic parameters of this unit transmissivity varies widely between 100-354.2 m<sup>2</sup>/day and hydraulic conductivity varies from 3.97m/day to 4.39 m/day are summarized below (Table 4.9).The characteristics of this aquifer poor yields for massive and/or pumices/pyroclastic deposit and good yields for well jointed or fractured ignimbrite, low to medium potential for lacustrine sediments. The aquifer is basically unconfined, however, the aquifer materials are variable it is possible that some confined and semi confined layer might be occur at some localities. The boreholes yield in this aquifer unit varies from 4.2 - 6.5 l/s with an average thickness greater than 60 m. Finally, based on the collected data the aquifers of this unit can be classified as moderate to high productivity aquifer class.

Table 4.9: The collected representative aquifer parameters data

Site name	Transmissivity(m <sup>2</sup> /s)	Conductivity(m/s)	Yield(l/s)
Lisena town	1.16 x 10 <sup>-3</sup>	4.36	5.3
Adancho	1.16 x 10 <sup>-3</sup>	3.97	4.2
Jemaye town	4.099 x 10 <sup>-3</sup>	4.39	6.5

According to the collected hydrogeological parameters data and groundwater level data simplified hydrogeological map of the study area is prepared (Figure 4.20). The groundwater levels in the basin were found to be variable but the depth to groundwater generally increases from the western highland toward the transition escarpment and the rift floor. Finally, on the basis of the aquifer parameters and the existing well yield the basin aquifer can be classified as moderate productive zone; transmissivity between 50-100m<sup>2</sup>/day and yields between 2-5 l/sec., moderate to high productive zone; transmissivity between 50-500 m<sup>2</sup>/day and yield between 2-25 l/sec. and high productive zone; transmissivity greater than 500 m<sup>2</sup>/day and yields greater than 25 l/sec. According to the groundwater flow direction in the groundwater table contour map (Figure 4.18).

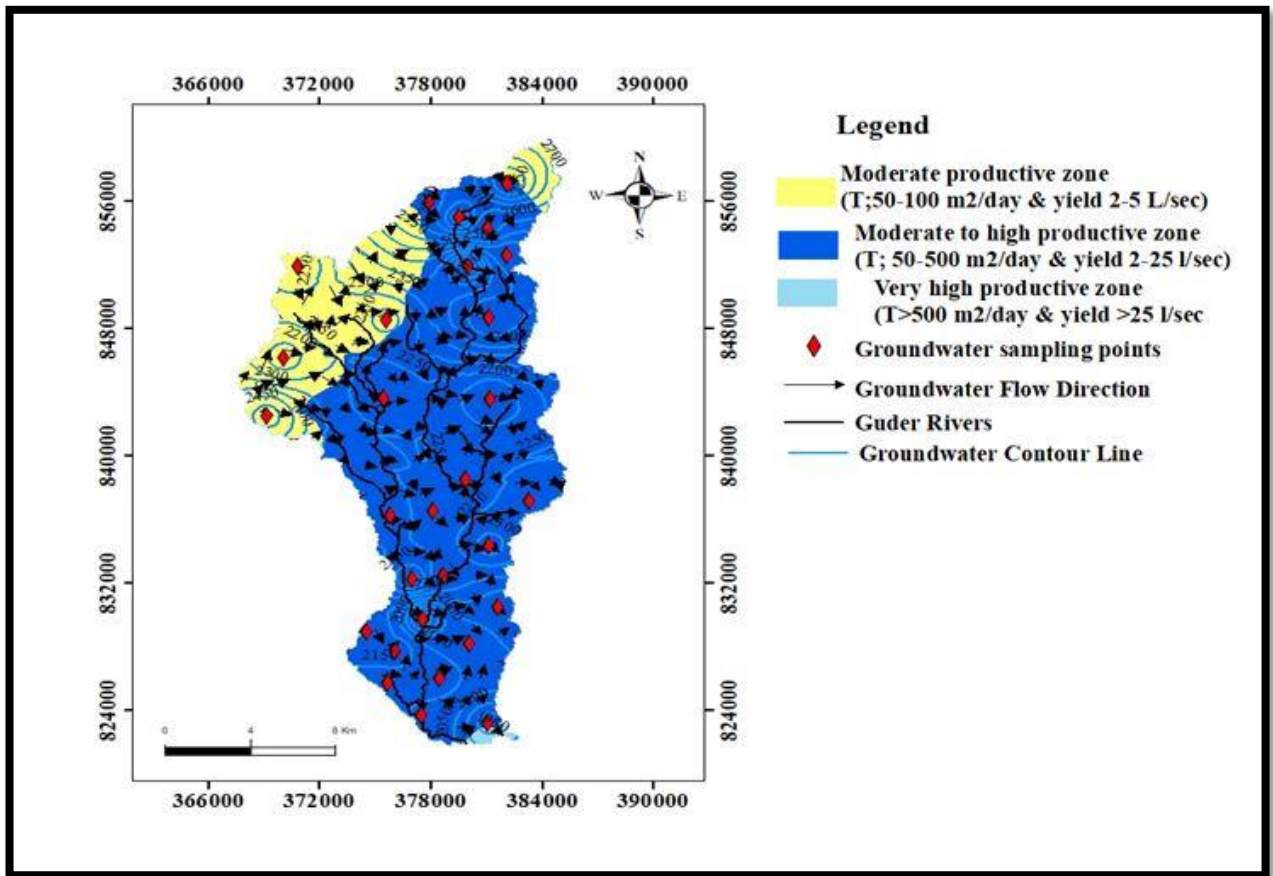


Figure 4.18: Simplified hydrogeological map of the study area(Modified GSE)

### 4.3.2. Determination of Aquifers Parameters from Pumping Test Data

#### 4.3.2.1. Aquifer Parameters from Constant Discharge of Hayse Borehole

As cited in Tenalem et al (2008) the classification of the Lithostratigraphic unit into hydro stratigraphic units requires information on the hydraulic characteristics of rocks. The hydraulic characteristics of the different volcanic sequence of the Ethiopia poorly understood. Data on specific capacity and transmissivity values have been obtained from existing boreholes. Transmissivity of an aquifer measures how much water can be transmitted horizontally. It is the product of the hydraulic conductivity times and the thickness of the aquifer (Commision, 2011).

Transmissivity (T) is a hydraulic parameter of an aquifer that is known employed in most groundwater flow equations to understand the flow dynamics and is generally estimated from pumping tests (Gebre, 2010). Spatially variable aquifer parameters are often available, yet appropriate data that covers wide area uniformly are lacking due to the fact that the cost of performing a large number of aquifer tests is relatively expensive and time consuming. Thus, simple and inexpensive parameter estimation methods that may cover extensive areas are often preferred.

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

A constant pumping test is conducted the pump was positioned at depth of 132m below the datum point, which is 0.8m above ground level (top of production casing). The yield maintained during the constant pumping test of this borehole. Constant pumping rate 60L\sec was registered for 48 hours in the well as shown from the data collection sheet, where dynamic water level was reach to 72.57m and has ended with total draw down of 51.47m, with reference to the SWL of 21.10meter.

Finally, the collected pumping test data was analyzed using Aquitest software the methods of analysis chosen are time draw down method after cooper and JACOP confined aquifer, Theis analysis method confined aquifer for constant discharge and Recovery method after Theis & Jacob confined aquifer for recovery test.

The analysis presented here is of a pumping test in which drawdown at a piezometer distance,  $r$  from the abstraction well is monitored over time. This is also based upon the Theis analysis. According to the analysis result the hydraulic parameters of the aquifer are as indicated Figure 4.19 & 4.20 below.

Time-Drawdown plot with discharge

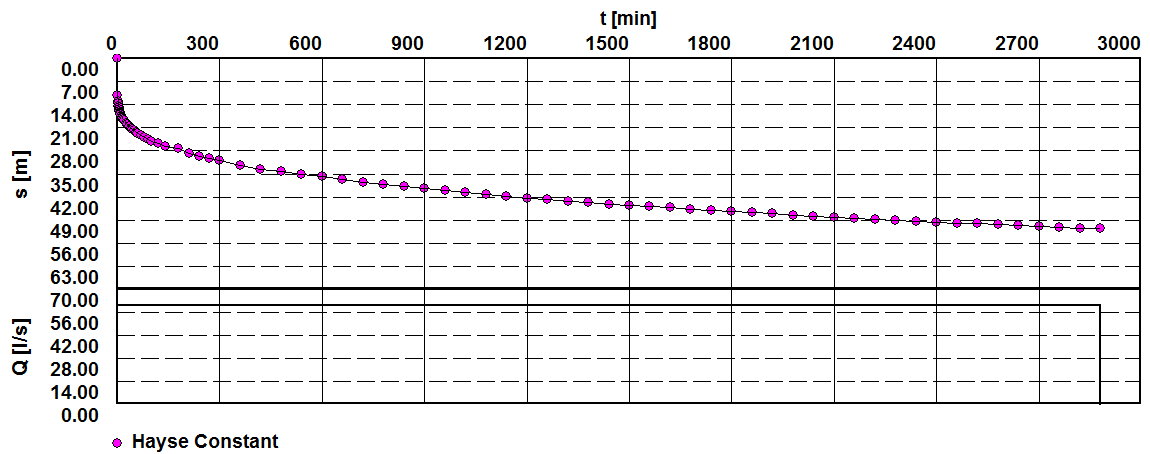
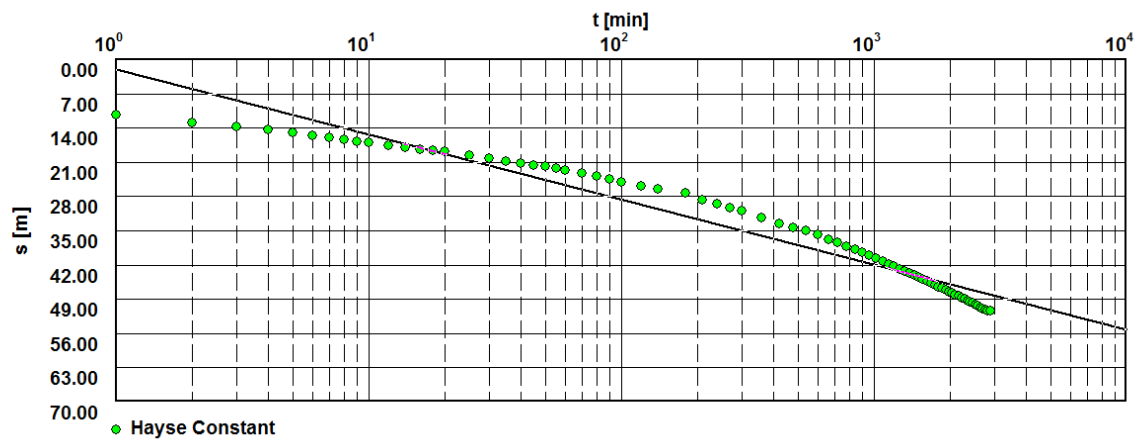


Figure 4.19: Time Draw Down plot for constant test

Analysis after COOPER & JACOB I - Confined aquifer



Transmissivity [ $m^2/min$ ]:  $4.96 \times 10^{-2}$   
 Hydraulic conductivity [ $m/min$ ]:  $5.51 \times 10^{-4}$

Storativity:  $1.22 \times 10^{-1}$



Figure 4.20: Cooper & Jacob time drawdown plot for constant test (Bekele, 2017)

### 4.3.2.2. Aquifer Parameters from Constant Discharge of Wachemo University Main Campus Borehole #1

#### Constant Pumping Test

A constant pumping test is conducted the pump was positioned at depth of 110m below the datum point, which is 0.7m above ground level (top of production casing). The yield maintained during the constant pumping test of this borehole. Constant pumping rate 60L\sec was registered for 48 hours in the well as shown from the data collection sheet, where dynamic water level was reach to 26.50m and has ended with total draw down of 5m, with reference to the SWL of 21.50 meter as indicated Figure 4.21 and 4.22.

Finally, the collected pumping test data was analyzed using Aquitest software the methods of analysis chosen are time draw down method after cooper and JACOP confined aquifer, This analysis method confined aquifer for constant discharge and Recovery method after Theis& Jacob confined aquifer for recovery test

Time-Drawdown plot with discharge

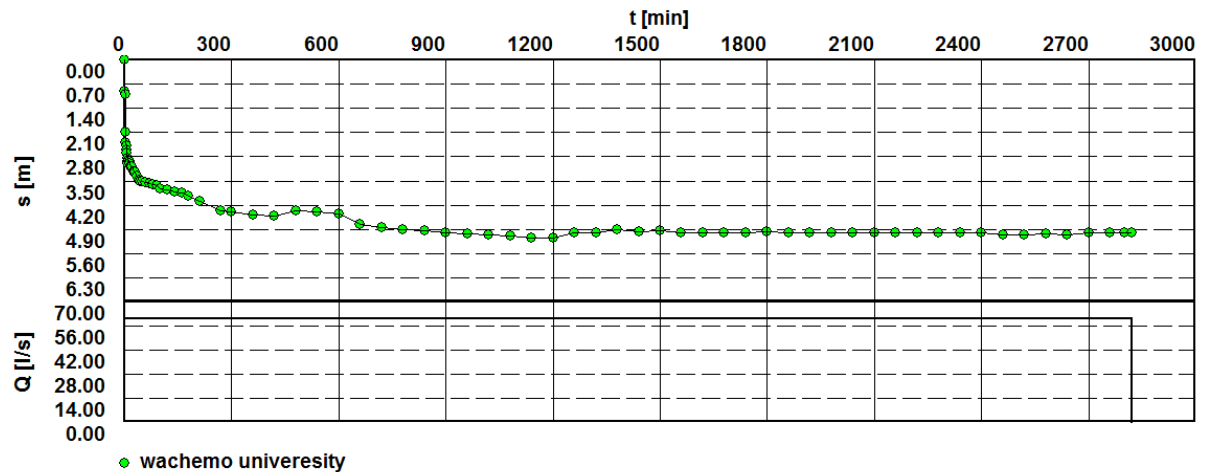


Figure 4.21: Time Draw Down plot for constant test (Zelege, 2019)

Analysis after COOPER & JACOB I - Confined aquifer

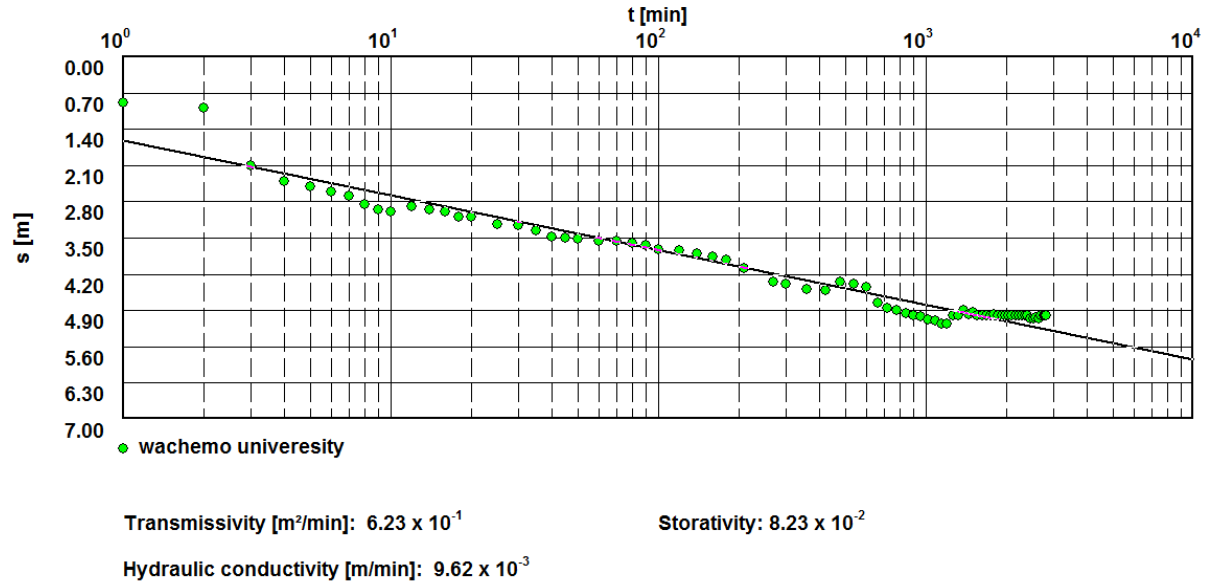


Figure 4.22: Cooper & Jacob time drawdown plot for constant test

### 4.3.2.3. Aquifer Parameters from Constant Discharge of Wachemo University Main Campus Borehole #3

#### Constant Pumping Test

A constant pumping test is conducted the pump was positioned at depth of 120m below the datum point, which is 1m above ground level (top of production casing). The yield maintained during the constant pumping test of this borehole. Constant pumping rate 70L\sec was registered for 48 hours in the well as shown from the data collection sheet, where dynamic water level was reach to 72.28m and has ended with total draw down of 8.48m, with reference to the SWL of 63.8meter as shown Figure 4.23 and 4.24.

Finally, the collected pumping test data was analyzed using Aquitest software the methods of analysis chosen are time draw down method after cooper and JACOP confined aquifer, This analysis method confined aquifer for constant discharge and Recovery method after Theis & Jacob confined aquifer for recovery test.

Time-Drawdown plot with discharge

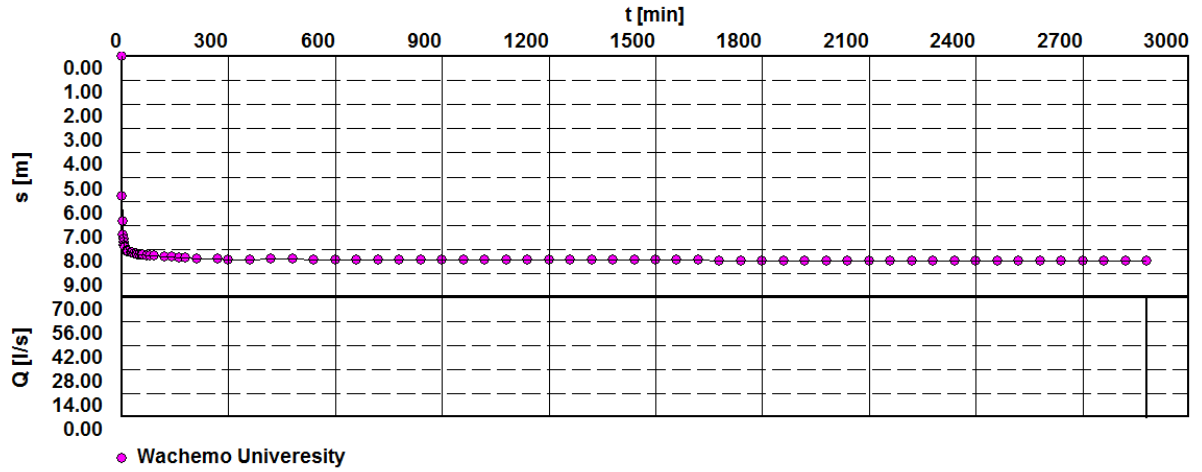
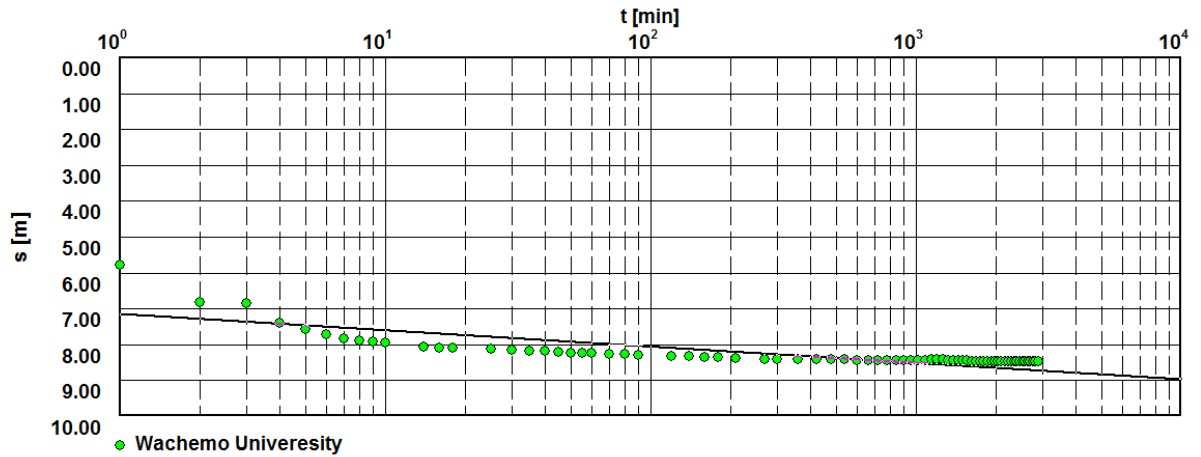


Figure 4.23: Time Draw Down plot for constant test

Analysis after COOPER & JACOB I - Confined aquifer

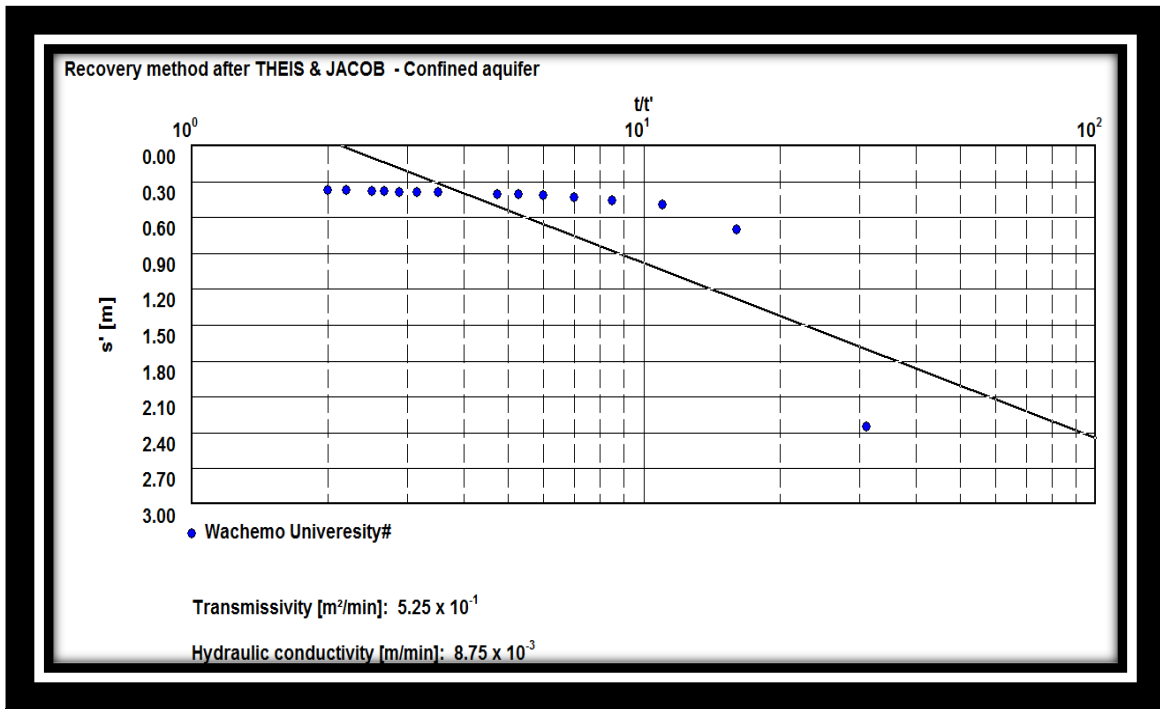


Transmissivity [ $m^2/min$ ]:  $1.69 \times 10^0$

Storativity:  $3.74 \times 10^{-14}$

Hydraulic conductivity [ $m/min$ ]:  $2.82 \times 10^{-2}$

Figure 4.24: Cooper & Jacob time drawdown plot for constant (Bekele, 2017)



## 5. SUMMARY, CONCLUSION AND RECOMMENDATION

### 5.1. Summary

The study area, Guder River Watershed lies in the southern plateau of the country, in the center of the Rift valley river basin in South Nation Nationalities peoples regional state, Ethiopia. The study area contains Hadiya zone, and some portion of Kembata Tembata and Silte Zones. Geographically it is bounded between UTM zone 367609 to 385284mE and 821766 to 859451mN. It covers a total area of 660.58km<sup>2</sup>.

Currently, in the study watershed, groundwater is serving as a main water sources for domestic water supply, industrial, agricultural and livestock purposes. A number of deep wells, shallow wells, hand dug wells have been drilled in different parts of the watershed for these purposes both by government and non-governmental organizations. However, there is no systematic study conducted on groundwater quality and aquifer characteristics of the watershed to support the water management and protection in the future.

So, this study was aimed to characterize the aquifer system and assess the quality of groundwater for drinking consumption and irrigation purpose. The chemical parameters were analyzed and water quality index was determined. Aquifer characterization was conducted by using the use of existing pumping test data, geologic map, hydrogeological map, soil map, and lithology obtained from well logs as well as well inventory. Besides, the quality of groundwater for drinking purpose was evaluated using water quality index technique. Moreover, calculation of Na%, PI, SAR and EC were conducted to evaluate suitability of the groundwater for irrigation use.

In order to assess the water quality, 30 groundwater samples were gathered and examined for 17 parameters such as pH, temperature, EC, TDS, TH, K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>2+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>3-</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, F<sup>-</sup>, PO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>. The chemical analysis concentration of the pH, EC, TDS, Na<sup>+</sup>, HCO<sub>3</sub><sup>-</sup> and F<sup>-</sup> shows an increasing trend from the highland water toward the rift floor water along the groundwater flow path. This is indicating higher rock-water interaction.

The standard limits of fluoride given by WHO and Ethiopian drinking water quality guidelines are 1.5mg/l. All analyzed water samples contain fluoride which ranges from shallow well (SW9) 0.08 mg/l to 3.07 at shallow well (SW13). But in the study area three samples shows greater than above standard fluoride concentration from the analyzed samples such as bore hole (BH8) 1.51mg/l, shallow well (SW12) 1.7mg/l and shallow well (SW13) 3.07 mg/l respectively. It has to be noted that fluoride concentrations above 1.5 mg/l causes dental fluorosis. The concentrations of fluoride show variations from recharge area to discharge zones. High concentration of fluoride in the rift is due to the very recent nature of the volcanics and fumarolic activities existing in the area. This is because in that area the deposits of clay and gravel have been derived from the nearby volcanic products which have high fluoride content.

Most of the fluoride in groundwater comes from acidic volcanic rocks such as pumice, obsidian, pyroclastic deposits, ignimbrite and rhyolite. The natural concentration of fluoride depends on the geological, chemical and physical characteristics of the aquifer, the porosity, the acidity of the soil and rocks and the temperature and the action of other chemical elements. The high permeability and large rock water interaction makes the leaching process more effective in pumice. As pumice fall deposits are wide spread in the study area, these rocks represent first order potential reservoir of fluoride. Groundwater with high fluoride content is found mostly in calcium-deficient groundwaters

The rock units that constitute the watershed and play great role as an aquifer are basalts, ignimbrite, pumice, and the other is Quaternary age deposit like alluvial deposit. These rocks get there water bearing nature mainly due to secondary processes which includes fracturing and weathering. As observed from lithological well logs of the study area, the water bearing layers are due to these secondary processes.

Gibbs plot of TDS versus  $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$  and TDS versus  $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$  diagrams water samples such as boreholes, shallow wells, hand dug wells and springs of the study area falling in the center of the curve indicate an origin from rock-water interaction. These results show that most of the groundwater samples fall in the center of the curve, which is indicative of the dominance rock-water interaction as the main process in the study area.

This result indicates that rock-water interaction/rock weathering is the main factor contributing to the water chemistry of the study area of the watershed. Additionally a very few rift floor lowland groundwaters sample indicates evaporation processes and some few groundwater samples shows highland/escarpment precipitation processes contribute in controlling the chemistry of groundwater in the study area.

To characterize the aquifer of the study area pumping test data, well completion reports, well logs and geology of the area were analyzed. The pumping tests analysis results indicate that the hydraulic conductivity of To characterize the aquifer of the study area pumping test data, well completion reports, well logs and geology of the area were analyzed. The pumping tests analysis results indicate that the hydraulic conductivity of the study area ranges from  $1.16 \times 10^{-3}$  -  $7.71 \times 10^{-2}$  m<sup>2</sup>/sec and transmissivity were  $1.26 \times 10^{-5}$  -  $7.71 \times 10^{-2}$  m/sec.

The factors that increases quality problem and improper management of aquifers in the watershed were the existence of anthropogenic and geogenic sources.

Generally, the groundwater of the study area shows good quality is based on standards recommendable for drinking, and irrigation uses in terms of physiochemical parameters.

Finally, the analytical results were taken to generate the numerical spatial distribution of parameters using geographic information system (GIS) environment. According to the results of the drinking water quality index showed that groundwater sampling were classified 70% as excellent, 27% as good, 3% as poor, and 0% as very poor and unfit for drinking purposes. In addition, Irrigation water quality index illustrated that 100% samplings were placed in the “excellent” class. The findings of this study was not only useful for understanding of groundwater sustainability for different purposes but also useful for supporting water management and protection in the future.

## 5.2. Conclusion

- ❖ Totally 30 groundwater samples from Hand dug well, Shallow well, Borehole (Deep well) and spring were gathered and examined. Along with 17 parameters such as pH, temperature, EC, TDS, TH,  $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Fe^{2+}$ ,  $Cl^-$ ,  $HCO_3^-$ ,  $CO_3^{2-}$ ,  $SO_4^{2-}$ ,  $F^-$ ,  $PO_4^{2-}$  and  $NO_3^-$  to determine physico-chemical parameters of groundwater were used. The chemical analysis concentration of the pH, EC, TDS,  $Na^+$ ,  $HCO_3^-$  and  $F^-$  shows an increasing trend from the highland water toward the rift floor water along the groundwater flow path.
- ❖ The high concentration of the  $F^-$  in BH8(Jiro), SW12(Odosedo) and SW13(Duna) groundwater in the southeast and southwest part of the watershed variation in spatial and vertical distribution of the fluoride due to the presence of fluoride bearing rocks and the great impact of rock water interaction in the watershed.
- ❖ Based on the dominant cations and anions, the water types in the study area were identified by using Aquachem database.  $Ca^{2+}$  and  $HCO_3^-$  are the dominant cations and anions respectively for all types of groundwater samples in the watershed.
- ❖ According to Ethiopian standard of water quality most of the water samples taken in this analysis have good quality except some samples. Among the 30 all water sample analyzed TDS 2.2%, Na 3 %, F 5.2 % ,  $NO_3^-$  4.2 % of the total samples that analyzed are above the Ethiopian water standard guideline.
- ❖ According to the results of the drinking water quality index showed that groundwater sampling were classified 70% as excellent, 27% as good, 3% as poor, and 0% as very poor and unfit for drinking purposes. In addition, Irrigation water quality index illustrated that 100% samplings were placed in the “ excellent” class.
- ❖ The pumping tests analysis results indicate that the hydraulic conductivity of the study area ranges from  $1.26 \times 10^{-5}$  -  $4.39 \times 10^0$  m/sec and transmissivity were  $1.16 \times 10^{-3}$  -  $7.71 \times 10^{-2}$  m<sup>2</sup>/sec this indicates that the productivity of the wells in the watershed ranges from low to high productivity from high land water.

- ❖ In general, the hydraulic conductivity and transmissivity decreases radially from the center of Boyo plain towards the periphery of the area.
- ❖ Knowledge of Transmissivity and hydraulic conductivity is essential for the determination of natural water flow through an aquifer .Transmissivity is one of the most fundamental parameters of an aquifer it allows to estimate water levels in and around pumping wells, to estimate groundwater flow and contaminant transport times, to characterize aquifer heterogeneity, and to parameterize numerical ground water flow models.
- ❖ The degree of groundwater productivity in the study area is entirely depends on secondary porosity and permeability that develop as a result of fracturing and weathering.
- ❖ 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.
- ❖ Because groundwater quality is a hidden problem inside a secret resource, it receives much too little attention. Restoring the water quality after groundwater has been contaminated is typically a very time-consuming, difficult, and expensive task. Because of these factors, groundwater contamination monitoring, prevention, and clean up are crucial management issues.

### **5.3. Recommendation**

- ❖ Appropriate environmental protection measures should be done on the upper parts of the Mugo ridge and on the central part of the study area along which there are high groundwater flow is expected.
- ❖ In this study, it was also planned to try monitoring of deep well, shallow well and spring groundwater, however due to time constraints it becomes impossible. For the future, it is highly recommended to perform regular monitoring of groundwater based on the results of this study, which is important to recognize groundwater fluctuation and easily to estimate the recharge.
- ❖ As there is groundwater pollution potential of shallow aquifers especially in the hand dug well, hence precautions must be made so as not to further pollute the resource.
- ❖ It is better to perform pumping test for the shallow groundwater in the focused areas that will be enables detail characterization of the aquifers.
- ❖ It is recommended to study biological and trace element analysis

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## APPENDICES

**Appendix 1.1: Hydrochemical analysis of both in-situ and laboratory results of groundwater samples data**

ID	KEBELE	X	Y	Z	TDS	PH	EC	TEMP	Na	K	Ca	Mg	Hco <sub>3</sub>	Co <sub>3</sub>	so <sub>4</sub>	Cl	No <sub>3</sub>	Fe	F
BH1	Duna	382170	857100	2057	16.5	7.31	24.6	22.5	24.5	7	12	8.6	321	0	0	0.14	0.4	0.12	0.99
SW11	Lera	377968	855885	2041	30.3	6.96	45.2	27	87.5	4.2	47.5	6.1	589	23	19	0.21	26	0.6	1.34
SP2	Weger	379577	854954	2783	19	7.4	38	25.2	2	4	6.4	1.9	37	0	0	0.8	4.4	0.58	0.17
SW13	Duna	381055	854260	1918	156	7.1	314	29.7	121	1.87	22.4	10.7	427	0	0	5	0.3	0.15	3.07
BH8	Jiro	382138	852583	2160	144	6.84	287	27	31.37	4.5	22.4	12.48	195.2	0	0	2.5	17.6	0.087	1.51
SW12	Odosedo	380037	851907	1923	153	7.6	300	31.4	57	3.16	16	4.9	207	0	1	8.8	0.1	0.2	1.7
SW14	Shiro	370842	851886	2210	72.5	6.95	148	25.1	22.85	7.5	26	5.1	153.72	0	4	0.05	4	0.14	0.32
HDW1	Shurimo	375605	848512	2036	91.35	7.1	192	26	17.1	6.1	18.8	1.21	78.08	0	10	1.25	5.9	0.04	0.61
BH7	Demale	381185	848709	2490	48	6.76	96	23.7	13.08	2.5	5.6	3.402	48.8	0	0	1.5	24.2	1.74	0
SW10	Abishera	370088	846143	2080	195	7	390	27	13.8	11	44	8.5	189	0	5.1	3.8	16.3	0.15	0.35
HDW4	Lambuda	369158	842519	2469	298.5	6.38	604	29.1	31	22.5	75.2	8.99	229.28	0	21	3	1.8	0.23	0.409
BH6	Shurimo	375518	843656	2228	140	7.7	280	24	24.84	7.7	28	4.8	183	0	0	0.75	0.92	0.25	0.94
SW15	Bendelicho	381227	843551	2149	277	7.37	559	27.2	21.9	6.2	20	2	115.9	0	0	0	1.4	0.21	0.32
HDW3	Debub Belsa	381227	843551	2149	277	7.37	559	27.2	21.9	6.2	20	2	115.9	0	0	0	1.4	0.21	0.32

BH5	Bellesa	379885	838551	2030	20	6.78	30	19.3	78	8	52	11.7	522	0	4	0.1	3.2	0.1	0.85
BH4	Ana Tigo	383338	837193	2281	19	7.1	29.5	23.2	57.3	8.8	98.34	23	293	0	3	0.06	13.2	0.06	1.43
BH3	Qelisha	375861	836288	2484	210	7.04	420	23.9	6.6	2.1	17.6	6.24	87.84	0	0	1	6.16	0.24	1.14
SW9	Gode	378158	836540	2214	22.5	6.65	34.9	23.3	92.1	12	47.9	12	457	0	0	0.07	11.1	3.5	0.08
SW6	Ambicho	376996	832267	2366	15.5	7.09	34.7	27.3	54	7.6	20	7	351	0	16	2.1	18.76	0.03	0.66
SW7	Teasa	378689	832500	2231	17.5	6.8	39.3	27	47	6.1	89	1.5	456	0	19	2.3	6.75	0.08	0.3
SW16	Lisena	381161	834413	2322	196.5	6.84	401	27.2	30	8.6	42	10.9	280.6	0	0	0	0	0.72	0.333
SW4	Lisena Town	381652	830532	2125	10.28	6.87	23.2	22.1	45	7	112	8	257	0	3	4.1	1.5	0.17	1.02
SW5	Shecha	374562	829008	2200	19	7.26	28.5	23.8	45	10.5	16	1.5	298	10.4	5	3.9	6.53	0.1	1.26
SW3	Kode	380086	828246	2064	12	7.19	26	22.3	8	6	12	10	187	0	4	2.1	1.84	0.21	1.11
SW2	Haise	376149	827717	2186	548	7.5	1096	24.9	19.4	6.8	20	9.7	159	0	0	0	5.3	0	0.36
SW1	Dinka	375726	825769	2141	231	6.7	462	23.4	34.7	4.2	36	24.3	329	0	0	0	0	0	0.32
BH2	Qusa	378520	826044	2413	11.8	7.42	18.54	23.3	43	6.1	78	32	245	5.8	0.23	0.07	1.6	0.82	0.83
SW8	Gede Genet	377525	823716	2092	183	6.5	365	23.2	32.5	8.2	30	10.9	232	0	0	0	11.4	0.1	0.68
SP1	Bidike	381102	823229	1929	146	6.9	291	24.1	28.4	9.5	19.2	12	161.04	0	0.02	5	0.54	0.25	1.07
BH9	Haise	377606	829769	2012	209	7.4	406	26.5	63.2	5.3	14	6.1	232	0	2	10	2.4	0.30	1.4

**Appendix 1.2: Data used for evaluate water quality for irrigation.**

Sample ID	Kebele	X	Y	Z	EC	SAR	%Na	PI%
BH1	Duna	376905	815437	2057	24.6	1.3	48.8	141
SP1	Bidika	379441	820102	1929	291	1.25	43	89.9
BH2	Kusa	371780	808887	2413	18.54	1	23.7	46.1
SW1	Dinika	377390	814160	2141	462	1	29.9	72.2
SW2	Haise	373368	815804	2186	1096	0.7	36	93.1
SW3	Kode	376121	822158	2064	26	0.35	26	118.6
SW4	Lisena Town	374491	819537	2125	23.2	1.1	25.5	48.8
SW5	Shecha	374009	815082	2200	28.5	2.8	70.7	144.8
SW6	Ambicho	370810	811321	2366	34.7	2.6	61.7	121
SW7	Taesa	375503	813457	2231	39.3	1.35	32.5	72.3
SW8	Gedegenet	375624	819350	2092	365	1	40	83.3
BH3	Qalisha	371830	804796	2484	420	0.34	19.7	88.5
SW9	Gode	378217	811150	2214	34.9	3	56	91.3
BH4	Anatigo	378586	809004	2281	29.5	1.35	28.5	50.4
BH5	Belesa	379646	816352	2030	30	2.5	50.3	90.9
BH6	Shurimo	379851	813520	2228	280	1.15	41.6	97.9
SW10	Abishera	376301	823773	2080	390	0.5	23.3	67.5
BH7	Demale	368736	808334	2490	96	1	53	129.6
BH8	Jiro	373580	821283	2160	287	1.4	40.8	89.8
SW11	Lera	378001	823684	2041	45.2	3	57.7	103.5
SP2	Weger	374962	805219	2783	38	0.2	28.5	153.8
SW12	Odosedo	383896	822350	1923	300	3.25	68	117.3
SW13	Duna	382871	821417	1918	314	5.5	72.6	108.9
SW14	Shiro	379351	822086	2210	148	1	48.85	95.2
HDW1	Shurimo	376281	817520	2036	192	1	46.4	105.2
SW15	Bendelich o	373368	817977	2149	559	1.3	48.8	110.1
BH3	Belesa	374395	816860	2143	369	1.65	27.8	75
HDW3	Debub Belesa	373955	811613	2338	573	2.33	50.6	86.1
HDW4	Lembuda	369264	810002	2469	604	1	29.9	56.2
SW16	Lisena	372573	808350	2322	401	1	37.75	80.2

**Appendix 1.3:** Comparison of drinking water Quality standards of study area based on WHO, 2011 & ESA, 2013

S.No	Physiochemical parameters	ESA Standard (mg/l)	WHO Standard (mg/l)	In the study area ranges of minimum to maximum	Number of sample exceeds the standard limit of ESA and WHO
1	PH	6.5-8.5	6.5-8.5	6.38-7.7	None
2	EC ( $\mu\text{s}/\text{cm}$ )	-	1400	18.54-1096	None
3	TDS(mg/l)	1000	1000	10.28-548	None
4	Temperature ( $^{\circ}\text{c}$ )	-	-	19.3-31.4	-
5	Calcium(mg/l)	75	75	5.6-112	5 as ESA and WHO
6	Magnesium(mg/l)	50	50	1.5-32	None
7	Sodium (mg/l)	200	200	2-121	None
8	Potassium (mg/l)	15	12	1.87-22.5	1 as ESA and 2 as WHO
9	Bicarbonate(mg/l)	120	120	37-589	24 as ESA and WHO
10	Carbonate(mg/l)	-	-	Nil to 23	-
11	Sulphate (mg/l)	250	250	Nil to 25	None
12	Chloride (mg/l)	250	250	Nil to 8.8	None
13	Nitrate(mg/l)	50	50	Nil to 26	None
14	Fluoride (mg/l)	1.5	1.5	Nil to 3.07	3 as ESA and WHO
15	Iron (mg/l)	0.3	0.3	Nil to 3.5	6 as ESA and WHO

Source: WHO, 2011 and ESA, 2013

**Appendix 1.4: Constant Discharge test Raw Data at HayseBH .**

Time since pumping starting		water level(m)	Draw down(m)	pumping rate	Recovery	EC (µs/cm)	Temp.(° c)	PH
hrs	minute	(m)	(m)	L/S				
	0	21.1	0					
	1	32.45	11.35					
	2	34.05	12.95	60				
	3	34.85	13.75					
	4	35.5	14.4					
	5	36.1	15					
	6	36.7	15.6					
	7	37.15	16.05					
	8	37.55	16.45					
	9	37.85	16.75					
	10	38.18	17.08	60				
	12	38.72	17.62					
	14	39.1	18					
	16	39.43	18.33					
	18	39.7	18.6					
	20	40	18.9					
	25	40.68	19.58					
	30	41.25	20.15	60				
	35	41.85	20.75					
	40	42.3	21.2					
	45	42.65	21.55					
	50	43.05	21.95					
	55	43.45	22.35					
	60	43.8	22.7					
	70	44.4	23.3	60				
	80	45	23.9					
	90	45.6	24.5					
	100	46.2	25.1					
	120	46.95	25.85					
	140	47.7	26.6					
	180	48.4	27.3					
	210	49.9	28.8	60				
	240	50.65	29.55					
	270	51.38	30.28					
	300	52.05	30.95	60				
	360	53.55	32.45					
	420	54.6	33.5					
	480	55.4	34.3					

	540	56.2	35.1					
	600	57	35.9					
	660	57.9	36.8					
	720	58.6	37.5					
	780	59.3	38.2	60				
	840	59.95	38.85					
	900	60.6	39.5					
	960	61.2	40.1					
	1020	61.82	40.72					
	1080	62.35	41.25					
	1140	62.9	41.8					
	1200	63.4	42.3					
	1260	63.9	42.8					
	1320	64.35	43.25					
	1380	64.74	43.64	60				
	1440	65.2	44.1					
	1500	65.6	44.5					
	1560	66.1	45					
	1620	66.38	45.28					
	1680	66.78	45.68					
	1740	67.2	46.1					
	1800	67.55	46.45					
	1860	67.9	46.8					
	1920	68.2	47.1					
	1980	68.55	47.45					
	2040	68.85	47.75	60				
	2100	69.17	48.07					
	2160	69.5	48.4					
	2220	69.8	48.7					
	2280	70.1	49					
	2340	70.38	49.28					
	2400	70.7	49.6					
	2460	70.95	49.85					
	2520	71.25	50.15					
	2580	71.5	50.4					
	2640	71.8	50.7					
	2700	72.1	51					
	2760	72.3	51.2					
	2820	72.5	51.4	60				
	2880	72.57	51.47					

**Appendix 1.5: Recovery test Raw Data at Hayse BH**

Time since pumping stopped		water level(m)	Residual Draw down's	Remark
hrs	minute	(m)	(m)	
	0	75.57	54.47	
	1	60.3	39.2	
	2	56.8	35.7	
	3	55.05	33.95	
	4	53.9	32.8	
	5	52.55	31.45	
	6	51.6	30.5	
	7	51	29.9	
	8	50.6	29.5	
	9	50.1	29	
	10	49.7	28.6	
	12	49.3	28.2	
	14	48.44	27.34	
	16	48.3	27.2	
	18	48.1	27	
	20	47.8	26.7	
	25	46.95	25.85	
	30	46.1	25	
	35	45.5	24.4	
	40	44.7	23.6	
	45	44.35	23.25	
	50	44	22.9	
	55	43.7	22.6	
	60	43.5	22.4	
	70	42.8	21.7	

	80	42.15	21.05	
	90	41.6	20.5	
	100	40.7	19.6	
	120	40.2	19.1	
	140	39.3	18.2	
	160	38.6	17.5	
	180	38.05	16.95	
	210	37.5	16.4	
	240	36.88	15.78	
	270	36.28	15.18	

**Appendix 1.6: Constant Discharge test Raw Data of Wachemo University Main Campus  
Borehole#3**

Time since pumping starting		water level(m)	Draw down(m)	pumping rate	Recovery
hrs	minute	(m)	(m)	L/S	
	0	63.8	0		
	1	69.59	5.79	70	
	2	70.63	6.83		
	3	79.95	16.15		
	4	71.21	7.41		
	5	71.38	7.58		
	6	71.52	7.72		
	7	71.64	7.84		
	8	71.68	7.88		
	9	71.72	7.92		
	10	71.74	7.94	70	
	12	71.80	8		
	14	71.85	8.05		
	16	71.88	8.08		
	18	71.89	8.09		
	20	71.90	8.1		
	25	71.93	8.13		
	30	71.95	8.15		
	35	71.98	8.18		
	40	71.99	8.19	70	
	45	72.01	8.21		
	50	72.03	8.23		
	55	72.03	8.23		
	60	72.04	8.24		
	70	72.06	8.26		

Time since pumping starting		water level(m)	Draw down(m)	pumping rate	Recovery
hrs	minute	(m)	(m)	L/S	
	80	72.07	8.27	70	
	90	72.09	8.29		
	100	72.10	8.3		
	120	72.12	8.32		
	140	72.13	8.33		
	160	72.14	8.34		
	180	72.15	8.35		
	210	72.19	8.39		
	240	72.20	8.4	70	
	270	72.21	8.41	70	
	300	72.22	8.42		
	360	72.22	8.42		
	420	72.21	8.41		
	480	72.21	8.41		
	540	72.22	8.42		
	600	72.23	8.43		
	660	72.23	8.43		
	720	72.23	8.43	70	
	780	72.23	8.43		
	840	72.23	8.43		
	900	72.24	8.44		
	960	72.24	8.44		
	1020	72.24	8.44		
	1080	72.24	8.44	70	
	1140	72.22	8.42		
	1200	72.22	8.42		
	1260	72.22	8.42		

Time since pumping starting		water level(m)	Draw down(m)	pumping rate	Recovery
hrs	minute	(m)	(m)	L/S	
	1320	72.23	8.43		
	1380	72.23	8.43		
	1440	72.23	8.43	70	
	1500	72.24	8.44		
	1560	72.25	8.45		
	1620	72.26	8.46		
	1680	72.27	8.47		
	1740	72.28	8.48		
	1800	72.28	8.48		
	1860	72.28	8.48		
	1920	72.28	8.48		
	1980	72.28	8.48		
	2040	72.28	8.48		
	2100	72.28	8.48		
	2160	72.28	8.48	70	
	2220	72.28	8.48		
	2280	72.28	8.48		
	2340	72.28	8.48		
	2400	72.28	8.48		
	2460	72.28	8.48		
	2520	72.28	8.48		
	2580	72.28	8.48		
	2640	72.28	8.48		
	2700	72.28	8.48		
	2760	72.28	8.48		
	2820	72.28	8.48	70	
	2880	72.28	8.48		

**Appendix 1.7: Recovery test Raw Data of Wachemo University Main Campus Borehole#3**

Time since pumping stopped		water level(m)	Residual Draw down's	Remark
hrs	minute	(m)	(m)	
	0	72.28	8.48	
	1	66.15	2.35	
	2	64.5	0.7	
	3	64.29	0.49	
	4	64.26	0.46	
	5	64.23	0.43	
	6	64.22	0.42	
	7	64.21	0.41	
	8	64.21	0.41	
	9	64.20	0.4	
	10	64.20	0.4	
	12	64.19	0.39	
	14	64.19	0.39	
	16	64.19	0.39	
	18	64.18	0.38	
	20	64.18	0.38	
	25	64.17	0.37	
	30	64.17	0.37	

**Appendix 1.8: Selected Lithological Log**

<b>Selected Lithological log</b>			
<b>1</b>	<b>Wachemo University main campus#3 BH</b>		
<b>No</b>	<b>Depth Interval, m</b>	<b>Thickness, m</b>	<b>Lithological Description</b>
1	0-27	27	Top clay soil
2	27-33	6	Highly weathered Ignimbrite with reddish clay
3	33-39	6	Highly weathered proclastic, Ignimbrite, ash tuff
4	39-48	9	Pumice with sand
5	48-57	9	Tuff
6	57-63	6	Highly weathered Ignimbrite with reddish clay
7	63-66	3	Fine Sand
8	66-72	6	Ash Tuff with little sand
9	72-78	6	Highly weathered pumice with sand
10	78-88	10	Highly weathered proclastic ash tuff
11	88-99	11	Highly weathered Ignimbrite with pumice
12	99-105	6	Highly weathered proclastic ash tuff with clay
13	105-132	27	Unwelded pumicous pyroclastic with sand
14	132-141	9	Highly weathered tuffaceous proclastic
15	141-153	12	Weathered ash
16	153-165	12	Highly weathered tuff
17	165-168	3	Pumice
18	168-171	3	Light tuff
19	171-172	1	Volcanic Ash

<b>2 Hayse BH</b>			
No	Depth range, (m)		Geologic description
	from	to	
1	0	12	Highly weathered Ignimbrite with clay
2	12	21	pumice
3	21	30	Highly weathered Ignimbrite with pumice
4	30	42	Sand with pumice
5	42	57	Sand
6	57	60	Sticky clay with weathered ignimbrite
7	60	63	Greenish fine silt
8	63	66	Moderately fractured ignimbrite
9	66	72	Silt
10	72	78	Yellowish weathered Ignimbrite with tuff
11	78	87	Fine silt
12	87	96	Fractured Ignimbrite with pumice and sand
13	96	102	Sand
14	102	105	Silt with clay
15	105	114	Fractured Ignimbrite with pumice
16	114	126	Highly fractured and weathered ignimbrite with sand
17	126	168	Reddish silt
18	168	171	Pumice with tuff
19	171	195	Fine silt with tuff
20	195	244	Fine sand with tuff and silt
21	244	271	Sand intercalation with ignimbrite
22	271	289	Highly fractured ignimbrite
23	289	300	Moderately fractured ignimbrite
<b>3 Nigist Eleni BH#1</b>			
No	Depth range, (m)		Geologic description
	from	to	
1	0	12	Weathered Tuff
2-	12	18	Slightly weathered Tuff
3	18	25	Slightly Weathered and fractured ignimbrite
4	25	28	Weathered Tuff with sand
5	28	33	Slightly Weathered Tuff
6	33	48	Slightly Weathered Rhyolite
7	48	60	Weathered pyroclastic material
8	60	66	Weathered basalt
9	66	72	Highly weathered ignimbrite
10	72	99	Highly weathered and fractured ignimbrite

11	99	105	Weathered ignimbrite
12	105	108	Slightly to highly Weathered ignimbrite
13	108	126	Highly weathered and slightly fractured ignimbrite
14	126	135	Fractured basalt
15	135	144	Slightly fractured ignimbrite
16	144	159	Fractured basalt
17	159	164	Sand
18	164	185	Slightly weathered and fractured ignimbrite
19	185	192	Slightly weathered Tuff
20	192	246	Weathered and fractured basalt
21	246	279	Weathered and fractured ignimbrite
22	279	297	Fractured and weathered basalt
23	297	316	Fresh basalt
<b>4</b>	<b>Tachigna Ambicho BH</b>		
No		<b>Depth interval(m)</b>	<b>Lithological Description</b>
	<b>From</b>	<b>To</b>	
1	0	6	clay
2	6	12	Silt
3	12	24	Sand
4	24	30	Pumice
5	30	36	Ash
6	36	42	Slightly weathered pumice
7	42	57	Weathered pumice
8	57	69	Sand with silt
9	69	72	Pumice
10	72	75	Silt with sand
11	75	78	Weathered pumice
12	78	90	Silt with sand
13	90	99	Highly weathered ignimbrite
14	99	102	Massive ignimbrite
15	102	108	Slightly weathered ignimbrite
16	108	114	Silt
17	114	129	Highly weathered ignimbrite
18	129	135	Massive ignimbrite
19	135	138	Tuff

20	138	147	Sand
21	147	150	Slightly weathered ignimbrite
22	150	153	Sand
23	153	162	Highly weathered ignimbrite
24	162	174	Slightly weathered ignimbrite
25	174	177	Pure sand
26	177	180	Slightly weathered ignimbrite
27	180	183	Highly weathered ignimbrite
28	183	195	Slightly weathered ignimbrite
29	195	198	Sand
30	198	207	Massive basalt
31	207	216	Silt with sand
32	216	220	Pure sand
<b>6</b>	<b>Hanja Gotmana BH</b>		
<b>No</b>	<b>Depth Interval, m</b>	<b>Thickness, m</b>	<b>Lithological Description</b>
1	0-7.15	7.15	Welded Tuff
2	7.15-15.6	8.45	Weathered Ash
3	15.6-40	24.4	Highly weathered ash
4	40-65	25	Slightly welded tuff
5	65-105	40	Slightly fractured & weathered Ignimbrite
6	105-120	15	Pumice
7	120-220	100	No sample due to loss of circulation
<b>7</b>	<b>Gadirete BH</b>		
<b>No</b>	<b>Depth Interval, m</b>	<b>Thickness, m</b>	<b>Lithological Description</b>
1	0-5.4	5.4	Top soil
2	5.4-18	12.6	Tuff
3	18-35.6	17.6	Fine Sand
4	35.6-70	34.4	Unwelded Ignimbrite
5	70-124.6	54.6	Weathered Pyroclastic deposit
6	124.6-148	23.4	Sand
<b>8</b>	<b>Debub Belesa BH</b>		
<b>No</b>	<b>Depth Interval, m</b>	<b>Thickness, m</b>	<b>Lithological Description</b>
1	0-5.65	5.65	Red clay
2	5.65-8.47	2.82	Ash
3	8.47-11.3	2.83	Red clay
4	11.3-16.95	5.65	White clay
5	16.95-31.07	14.12	Tuff Ash
6	31.07-33.9	2.83	Basalt
7	33.9-56.5	22.6	Welded tuff

8	56.5-67.8	11.3	Scoria
9	67.8-76.2	8.4	Scoria with deposit
10	76.2-81.9	5.7	Red ash
11	81.9-90.4	8.5	Highly weathered & fractured Basalt
12	90.4-93.22	2.82	Sand with deposit
13	93.22-112.9	19.68	Scoria with pumice and deposit
14	112.9-118.6	5.7	Highly weathered & fractured Basalt
15	118.6-121.47	2.87	Scoria with deposit
16	121.47-127.12	5.65	Highly weathered & fractured Basalt
17	127.12-152.54	25.42	Weathered Basalt
18	152.54-163.84	11.3	Scoria
19	163.84-169.49	5.65	Highly weathered Basalt
20	169.49-180.79	11.3	Highly fractured Ignimbrite with pumice
21	180.79-186.44	5.65	Highly weathered Ignimbrite with sand
22	186.44-194.92	8.48	Highly weathered basalt with deposit
23	194.92-200	5.08	Fresh Basalt