



**JIMMA UNERSITY**

**JIMMA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**ENVIRONMENTAL ENGINEERIG CHAIR**

**EVALUATION OF THE SUITABILITY OF GROUNDWATER QUALITY FOR  
DRINKING AND IRRIGATION PURPOSES: A CASE OF GIMBI DISTRICT**

**BY: YOSEF GENETI AMEYA**

**A THESIS SUBMITTED TO SCHOOL OF CIVIL AND ENVIRONMENTAL  
ENGINEERING, JIMMA INSTITUTE OF TECHNOLOGY, JIMMA  
UNIVERSITY IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF  
DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING**

**NOVEMBER, 2016**

**JIMMA, ETHIOPIA**

JIMMA UNIVERSITY  
JIMMA INSTITUTE OF TECHNOLOGY  
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING  
ENVIRONMENTAL ENGINEERING CHAIR

EVALUATION OF THE SUITABILITY OF GROUNDWATER QUALITY FOR  
DRINKING AND IRRIGATION PURPOSES: A CASE OF GIMBI DISTRICT

BY: YOSEF GENETI AMEYA

ADVISOR: Dr.-Ing. Fekadu Fufa

CO- ADVISOR: Dr. Dejene Beyene

A THESIS SUBMITTED TO SCHOOL OF CIVIL AND ENVIRONMENTAL  
ENGINEERING, JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY IN  
PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF DEGREE OF MASTERS  
OF SCIENCE IN ENVIRONMENTAL ENGINEERING

NOVEMBER, 2016

JIMMA, ETHIOPIA

## DECLARATION

This thesis entitled “Evaluation of the suitability of groundwater quality for drinking and irrigation purposes in Gimbi district, West Wollega zone, Oromia National Regional State, Ethiopia” is my original work and has not been presented for a Masters or any other Degree in Jimma Institute of Technology (JIT) or any other university.

Yosef Geneti	-----	-----
Researcher	Signature	Date

Approved by		
Dr. Ing.- Fekadu Fufa	.....	.....
	Signature	Date

Main Advisor

Dr. Dejene Beyene	-----	-----
Co-advisor	Signature	Date

Dr. Dejene Beyene	.....	.....
Chair Holder	signature	Date

## **ABSTRACT**

*The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region. Water quality degradation is one of the major environmental problems of these days. Contamination of surface and groundwater is the most serious problems affecting the health of the population. The study was conducted to evaluate the suitability of groundwater quality for drinking and irrigation purposes in Gimbi District, Oromia National Regional State, Ethiopia. The study was to determine the basic Physical, chemical and biological parameters of groundwater and to evaluate the suitability of the water for drinking and irrigation purpose. Electrical Conductivity, Sodium Absorption Ratio, Soluble Sodium Percentage, Residual Sodium Carbonate, Magnesium Hazard and Kelley's Ratio were determined for irrigation suitability assessment. Twelve samples were collected from hand dug boreholes, hand dug wells and protected spring by purposive sampling technique and analyzed for various parameters. Interpretation of all water chemistry data were carried out using Aqua Chem software (Version 4.0), Origin Pro 8 and Microsoft excel (Version 2007). The analyzed data was presented by using table, graphs and piper diagram. Compared with WHO guideline values for drinking water, temperature range 23.60 to 26.18 °C exceeds 15°C, pH range 4.71 to 6.20 fell below the range of 6.5 to 8.5). Turbidity (1.06 to 10.33 NTU), which indicates that higher levels of turbidity than the WHO recommended limit of 5 NTU especially in locations S<sub>2</sub>, S<sub>6</sub>, S<sub>9</sub>, S<sub>11</sub>, and S<sub>12</sub>. EC (38.67 to 233 µS/cm), which was less than the WHO recommended limit of 250 mg/l. Manganese ranging from 0 to 0.31 mg/L and low concentration levels than WHO prescribed limit of 0.1 mg/l at all locations except S<sub>10</sub> and S<sub>12</sub>. Higher concentrations of iron than the WHO stipulated limit of 0.30 mg/L in locations S<sub>2</sub>, S<sub>3</sub>, S<sub>5</sub>, S<sub>8</sub>, and S<sub>12</sub>. The bacteriological analysis also revealed that all the water sources contained high Fecal and Total Coliform counts ranging 17 to 396 and 284 to 4586 cfu/100 ml respectively. This implies that the Consumption of water contaminated from water sources may cause public health problems.*

## Table of Contents

DECLARATION .....	III
ABSTRACT .....	IV
LIST OF TABLES .....	VIII
LIST OF FIGURES.....	IX
ACKNOWLEDGMENTS .....	X
LIST OF ABBREVIATIONS.....	XI
1. INTRODUCTION .....	1
1.1. Background.....	1
1.2. Statement of the problem.....	2
1.3. Objectives of the Study .....	4
1.3.1. General Objective.....	4
1.3.2. Specific Objectives.....	4
1.4. Research questions.....	4
1.5. Significance of the study .....	4
1.6. Limitation of the study .....	5
2. LITRATURE REVIEW .....	6
2.1. Groundwater occurrence .....	6
2.1.1. Hydraulic properties of the geological formations .....	6
2.1.2. Geological framework .....	6
2.1.3. Climate and groundwater occurrence .....	6
2.2. Groundwater Resource .....	7
2.3. Groundwater uses.....	7
2.4. Groundwater Quality and Sources of Pollution .....	7
2.4.1. Groundwater Contamination.....	9
2.5. Water Quality .....	9
2.5.1. Water Quality Sampling .....	9
2.5.2. Description of Water Quality parameters .....	10
2.5.2.1. Physical parameters .....	10
2.5.2.2. Chemical parameters .....	13
2.5.2.3. Bacteriological parameters.....	17

2.6.	Guidelines for water quality parameters.....	18
2.7.	Perception of drinking water .....	19
2.7.1.	Physical and aesthetic parameters .....	20
2.8.	The use of Groundwater for irrigation purpose .....	20
2.9.	Aquachem water quality database.....	25
3.	MATERIALS AND METHODS .....	26
3.1.	Study area .....	26
3.2.	Study period and design .....	27
3.3.	Sample size and sampling procedures.....	27
3.4.	Instruments and apparatus .....	29
3.5.	Study variables.....	30
3.6.	Sample analysis.....	30
3.7.	Ethical consideration.....	30
3.8.	Data quality assurance and quality control.....	31
3.9.	Plan for dissemination.....	31
4.	RESULTS AND DISCUSSION.....	32
4.1.	Physical Parameters .....	32
4.1.1.	Temperature .....	32
4.1.2.	pH.....	33
4.1.3.	Electrical Conductivity .....	33
4.1.4.	Total Dissolved Solids.....	34
4.1.5.	Dissolved Oxygen .....	35
4.1.6.	Turbidity .....	36
4.2.	Chemical Parameters.....	37
4.2.1.	Total Hardness .....	37
4.2.2.	Total Alkalinity .....	38
4.2.3.	Bicarbonate .....	39
4.2.4.	Chloride .....	40
4.2.5.	Nitrate (NO <sub>3</sub> <sup>-</sup> ).....	41
4.2.6.	Sulfate (SO <sub>4</sub> <sup>2-</sup> ) .....	42
4.2.7.	Calcium.....	43
4.2.8.	Magnesium.....	44

4.2.9.	Sodium.....	45
4.2.10.	Potassium.....	46
4.2.11.	Iron .....	47
4.2.12.	Manganese .....	48
4.3.	Biological Parameters .....	49
4.3.1.	Fecal Coli form (FC) .....	49
4.3.2.	Total Coli form (TC) .....	50
4.4.	Hydro-geochemical facies .....	52
4.5.	Evaluation of water quality for irrigation.....	53
4.5.1.	Electrical Conductivity .....	53
4.5.2.	Sodium Adsorption Ratio (SAR) .....	54
4.5.3.	Soluble Sodium Percentage .....	55
4.5.4.	Residual Sodium Carbonate.....	56
4.5.5.	Magnesium Hazard (MH).....	56
4.5.6.	Kelley’s Ratio .....	57
5.	CONCLUSIONS AND RECOMMENDATIONS .....	61
5.1.	Conclusions .....	61
5.2.	Recommendations.....	62
	REFERENCES.....	63
	ANNEXES.....	68

## LIST OF TABLES

Table 2.1: Source of chemical contamination for groundwater .....	8
Table 2.2: Classification of irrigation water based on Electrical Conductivity.....	12
Table 2.3: Water quality counts per 100ml and the associated risk .....	18
Table 2.4: Drinking water quality standards of Ethiopia and WHO .....	19
Table 2.5: Major, secondary and trace constituents of Groundwater .....	21
Table 2.6: Irrigation water classification based on SAR .....	22
Table 2.7: Classification of irrigation water based on SSP.....	23
Table 2.8: Suitability of groundwater for irrigation according to RSC value.....	24
Table 3.1: GPS reading of the selected sites in the study area.....	28
Table 4.1: Minimum, maximum and mean physic-chemical and biological parameters .....	51
Table 4.2: Groundwater type of study area.....	52
Table 4.3: Minimum, maximum and mean of metal analysis of groundwater in study area. ....	57
Table 4.4: Study area physical and biological parameters comparisons with standards .....	58
Table 4.5: Study area chemical parameters comparisons with standards of WHO.....	59
Table 4.6: Irrigation water quality parameters .....	60



## LIST OF FIGURES

Figure 3.1: map of the study area .....	26
Figure 3.2: map of sample site .....	29
Figure 4.1: Variation of groundwater temperature in study area .....	32
Figure 4.2: Variation of groundwater pH in study area.....	33
Figure 4.3: Variation of groundwater EC in study area.....	34
Figure 4.4: Variation of groundwater TDS in study area .....	35
Figure 4.5: Variation of groundwater DO in study area .....	36
Figure 4.6: Variation of groundwater turbidity in study area .....	37
Figure 4.7: Variation of groundwater TH in study area .....	38
Figure 4.8: Variation of groundwater TA in study area .....	39
Figure 4.9: Variation of groundwater bicarbonate in study area.....	40
Figure 4.10: Variation of groundwater chloride in study area .....	41
Figure 4.11: Variation of groundwater nitrate in study area .....	42
Figure 4.12: Variation of groundwater sulphate in study area.....	43
Figure 4.13: Variation of calcium in groundwater in study area.....	44
Figure 4.14: Variation of magnesium in groundwater in study area .....	45
Figure 4.15: Variation of sodium in groundwater in study area .....	46
Figure 4.16: Variation of potassium in groundwater in study area .....	47
Figure 4.17: Variation of iron in groundwater in study area.....	48
Figure 4.18: Variation of manganese in groundwater in study area.....	49
Figure 4.19: Variation of FC in groundwater in study area .....	50
Figure 4.20: Variation of TC in groundwater in study area.....	51
Figure 4.21: Piper plot describing hydro geochemical facies of the study area.....	53
Figure 4.22: Classification of irrigation water quality, with respect to salinity and sodium hazard.	55

## **ACKNOWLEDGMENTS**

First of all, I would like to thank Almighty God for His protection and guidance in all aspects of my life. I would like to express my gratitude to my advisor Dr.-Ing. Fekadu Fufa for his guidance and endless support throughout this study, for his encouraging, valuable feedback and insight that have greatly influenced and accelerated this study. I would like to extend my great appreciations to Dr. Dejene Beyene for his close supervision, patience, advice and constructive suggestions from the start to the completion of the research.

I would like to extend my thanks to Ethiopian Road Authority, Jimma University, Jimma Institute of Technology and my family for the financial support. My next gratitude goes to my friends for their material Support and moral encouragement throughout the study period.

Last but not least, I am very grateful to have a great family with enormous support, love and appreciation which gave me strength on my way.

## **LIST OF ABBREVIATIONS**

APHA	American Public Health Association
CAWST	Center for Affordable Water and Sanitation Technology
CGWB	Central Ground Water Board
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FC	Fecal Coli form
GPS	Global Positioning System
GW	Ground Water
IBE	Ion Balance Error
KR	Kelley's Ratio
M	Meter
Mg/l	Milligram per liter
MI	Millimeter
MH	Magnesium Hazard
NTU	Nephelometric Turbidity Units
OWWDSE	Oromia Water Works Design and Supervision Enterprise
pH	Power of Hydrogen
RSC	Residual Sodium Carbonate
SAR	Sodium Absorption Ratio

SSP	Soluble Sodium Percentage
TA	Total Alkalinity
TC	Total Coli form
TDS	Total Dissolved solids
TH	Total Hardness
TWDB	Texas Water Development Board
UNEP	United Nations Environment Program
UNICEF	United Nations Children's Fund
WHO	World Health Organization
μS/cm	Micro Siemens per centimeter

# **1. INTRODUCTION**

## **1.1. Background**

Water is chief natural resource essential for the existence of life and is a basic human entity. Water resources are harnessed for various purposes like drinking, agricultural, industrial, household, and recreational activities. Groundwater is one of the major sources of drinking water all over the world (Bear, 1979). Groundwater is used for domestic and irrigation purposes can vary greatly in quality depending upon type and quantity of dissolved salts. It contains a wide variety of dissolved inorganic chemical constituents in various concentrations, resulting from chemical and biochemical interactions between water and the geological materials. It is estimated that approximately one third of the world's population use groundwater for drinking (Nickson *et al.*, 2005).

This is a well-recognized fact that the groundwater, through the ages, continues to be an essential commodity for a large number of users. The chemical composition of groundwater is determined by a number of processes, which can chiefly be grouped into three - atmospheric inputs, interaction of water with soil and rock and anthropogenic activities. Precipitation, climate change and natural hazards add to the atmospheric inputs, while weathering and erosion of crustal materials result from the interaction of water with soil and rock (Babu *et al.*, 2007). Therefore, water quality issues and its management options need to be given greater attention in developing countries. Water quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices (Ramesh & Elango, 2011). The anthropogenic disturbances through industrial and agricultural pollution, increasing consumption and urbanization degrade the groundwater and impair their use for drinking, agricultural, industrial and domestic uses (Simeonov *et al.*, 2003; Sreedevi, 2004). Groundwater, being a fragile and important source of drinking water, must therefore be carefully managed to maintain its purity within standard limits. Groundwater degradation occurs when its quality parameters are changed beyond their natural variations by the removal of certain substances (Ramesh, 2001). Groundwater quality is based upon the physical and chemical soluble parameters due to weathering from source rocks and anthropogenic activities. The groundwater chemistry is controlled by the composition of its recharge components as well as by geological and

hydrological variations within the aquifer. Many time groundwaters carries higher mineral contents than surface water, because there is slow circulation and longer period of contact with sediment materials in case of groundwater (Shahnawaz and Singh, 2009). Groundwater quality reflects inputs from the atmosphere, soil and water rock reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes (Appelo and Postma, 1993).

Suitability of water for various uses depending on type and concentration of dissolved minerals and groundwater has more mineral composition than surface water (Mirribasi *et al.*, 2008). The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. Continuous monitoring of water quality parameter is highly crucial because changes in the quality of water has far as reaching consequences in terms of its effects on man and biota. Similar to other areas of the world, groundwater is the major source of drinking water in Ethiopia. More than 80% of the country's drinking water supply source is from ground water. This includes more than 25 major cities in the country according to Kebede Tsehayu *et al.*, (2004). Groundwater is an important source in study area for drinking and domestic uses, livestock watering and, to some extent, for irrigation purposes. Now a day, the need for groundwater utilization is on the increase due to expansion of irrigated agriculture and different developmental activities within the surrounding areas. The increase in the exploitation of groundwater is not only for irrigation but also for drinking purpose. Water quality data are essential for the implementation of water quality regulations for characterizing and remediating contamination and for the protection of the health of humans and the ecosystem. Regular monitoring of groundwater resources thus plays a key role in sustainable management of water resources. Irrigation water quality is generally judged by some determining factors such as sodium absorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), and electrical conductance (EC) (Richards, 1954). This study aims to evaluate the groundwater quality of the district for drinking and irrigation purposes.

## **1.2. Statement of the problem**

The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region.

Industrial waste and the municipal solid waste have emerged as one of the leading cause of pollution of surface and ground waters. In many parts of the country available water is rendered non-potable because of the presence of heavy metal in excess. The situation gets worsened during the summer season due to water scarcity and rain water discharge. Contamination of water resources available for household and drinking purposes with heavy elements, metal ions and harmful microorganisms is one of the serious major health problems. Safe water is a precondition for health and development and a basic human right, yet it is still denied to hundreds of millions of people throughout the developing world (UNICEF, 2008). Water quality degradation is one of the major environmental problems of these days. Contamination of surface and ground waters is the most serious problems affecting the health of the population. Water related diseases caused by insufficient safe water supplies coupled with poor sanitation and hygiene cause 3.4 million deaths a year, mostly among children (UNICEF, 2008). Consumption of contaminated or polluted water can give rise to many diseases and even death when contaminated with organic and/or chemical pollutants (Bartran and Balance, 1996). Water quality being the physical, chemical and biological characteristics of water is mainly assessed with reference to a set of standards; and the most common standards used to assess water quality relate to human welfare and health of ecosystems. Despite continuing efforts by governments, civil society and the international community, over a billion people still do not have access to improved water sources (UNICEF, 2008). In developing countries sources of pollution from domestic, agricultural, industrial activities are unregulated (UNEP, 2005).

The problems of groundwater quality are much more acute in the areas which are densely populated, highly industrialized and have shallow groundwater tables (Patil and Patil, 2010). The rapid growth of urban areas has further affected groundwater quality due to overexploitation of the resources and improper waste disposal practices. Hence, there is always a need for and concern over the protection and management of groundwater quality (Patil *et al.*, 2001). Water quality and the risk of water-associated diseases are serious public health concerns in many developing countries including Ethiopia. This is mainly due to lack of proper research and subsequent monitoring of water quality parameters for most of the towns in Ethiopia. The populations of study area obtain their drinking water from a groundwater source. So far, there is no research activity conducted on the

groundwater supply system of the district that may enable one to know the quality of drinking water and the effectiveness of the groundwater supply systems.

Further intensive study of the concerned area is required to have a detailed examination of groundwater quality for drinking and irrigation use. Since the investigator is parts of this society and becomes one of the dis-advantageous groups he prefers this burning issue to deal with and want to see the problem from its grass root level. Again there is no research that has been attempt on this topic in this area that is the other goal of the researcher to focus on this topic. Thus, in this study an attempt was made to assess the geochemical analysis of groundwater.

### **1.3. Objectives of the Study**

#### **1.3.1. General Objective**

The general objective of this study is to evaluate the suitability of groundwater quality for drinking and irrigation purposes in Gimbi district, West Wollega Zone, Oromia National Regional State, Ethiopia.

#### **1.3.2. Specific Objectives**

The specific objectives of the study include:

- ❖ To determine the basic physicochemical parameters of groundwater.
- ❖ To evaluate the quality of groundwater for drinking purpose.
- ❖ To evaluate the quality of groundwater for irrigation uses.
- ❖ To analyze biological parameters of groundwater.

### **1.4. Research questions**

1. What are the basic physicochemical constituents of the groundwater?
2. Does the groundwater meet the standards for drinking purpose?
3. Does the groundwater suitable for irrigation uses?
4. What are the levels of biological parameters in the groundwater?

### **1.5. Significance of the study**

The study will contribute to improve the understanding of the factors that affect groundwater quality for drinking and irrigation uses. The generated data will contribute for



the sustainable management of groundwater resources in the study area. This helps to understand and implement groundwater quality management strategies. The information generated can represent an important preliminary tool in decision making pertaining to the management of groundwater quality. This study may have undeniable importance in revealing the hidden problems and understanding the ongoing human activities in the study area, besides defining the status and magnitude of impact on the environment. The investigator also optimistically believes that, the primary beneficiary of this research output will be the community in the study area in general and government body in particular. Finally it will help as a reference or literature for practitioners who are interested to investigate this issue in the future. Furthermore it will serve as a lighting house for future researches in this particular area.

#### **1.6. Limitation of the study**

The study did not cover all the area in the district province due to resource and time limitations. Some difficulties were faced in accessing data and resources from the local authorities. The overall quality assessment of groundwater in this study depends on chosen physical and chemical parameters. The detail information regarding the groundwater construction was unknown. There may be seasonal variation because study was done during the rainy season. However, the researcher was spent a great deal of time within the study period to collect adequate data to maintain the quality of results.

## **2. LITRATURE REVIEW**

### **2.1. Groundwater occurrence**

Groundwater may be found almost anywhere in the world and in almost all types of geological formations. However, its distribution in terms of quality and quantity varies from one place to another and from one geological formation to another (Fetter, 1994). Freeze and Cherry (1979) noted that there are at least three factors that influence groundwater occurrence: hydraulic properties of the geological formations, geological framework, and climate.

#### **2.1.1. Hydraulic properties of the geological formations**

Geological formations differ considerably in their ability to store and transmit water. Therefore knowledge of typical values of porosity and permeability of different geological formations is a prerequisite for successful groundwater exploration (Fetter, 1994). Virtually all groundwater originates as surface water (Freeze and Cherry, 1979) and in order to reach the saturated zone, water must not only be available at the surface; it must also be able to infiltrate to the saturated zone. The availability of water at the surface depends on climate, while the infiltration rate depends on the thickness and permeability of the unsaturated zone as well as topography (Fetter, 1994).

#### **2.1.2. Geological framework**

The occurrence, distribution, movement, and composition of subsurface waters are intricately linked to the structure and nature of the geological formations (Freeze and Cherry, 1979). One of the primary objectives of hydro geological investigations is to identify geological formations and structures of importance for the occurrence of groundwater and understand the different types of geological formations, as well as the events that produce them and their fundamental properties (Fetter, 1994).

#### **2.1.3. Climate and groundwater occurrence**

Water on earth resides in the atmosphere, on the surface of the earth, and below the surface of the earth. However, water does not remain in anyone of these environments indefinitely but it is constantly moving among them. This unending circulation of the earth's water is called the hydrologic cycle (Freeze and Cherry, 1979). The cycle has no beginning or

ending. Various estimates of the quantity of water in different components of the hydrologic cycle have been made and all of them show that groundwater constitutes an insignificant proportion of the earth's total water balance (Freeze and Cherry, 1979).

## **2.2. Groundwater Resource**

Groundwater is resource found under the land surface in the saturated zone. It constitutes about 95 percent of the freshwater on our planet (discounting that locked in the polar ice caps) (UNEP, 2003). Most of the Earth's liquid freshwater is found, not in lakes and rivers, but stored underground in aquifers. These aquifers provide a valuable base flow supplying water to rivers during periods of no rainfall. Therefore it is an essential resource that requires protection.

## **2.3. Groundwater uses**

Over 1.5 billion people worldwide depend on groundwater for drinking water and of the world's water that is usable by humans, 98% is stored in aquifers ([www.groundwater.org](http://www.groundwater.org)). The chemical constituents of the groundwater determine its usefulness for drinking and domestic use, industry and agriculture (Fetter, 1994). Principally water is used at household level for drinking, hygiene and sanitation. Many studies on the multiple use of water have identified and quantified the livelihoods benefits from using water (Van Koppen *et al.*, 2006). In the developed world groundwater has been used as a pivot for development. As groundwater is an integral component of the hydrological cycle, the health of the streams, lakes, wetlands, and associated ecosystems depends upon groundwater. Although groundwater is a renewable resource, it is not limitless and requires wise management to protect its integrity, security and sustainability.

## **2.4. 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 are vital management issue (UNEP, 2003). The quality of water either it is surface water or groundwater affected by both natural influences and human activities (Chilton, 1996). Similarly (CAWST, 2013) 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 (CAWST, 2013). Microbiological (bacteria, viruses, protozoa and helminths or worms), Chemical (minerals, metals, chemicals and pH) and Physical (temperature, color, odor, taste and turbidity). The World Health Organization WHO (2011) divides the sources of chemicals into the following five groups: Naturally occurring, Agricultural activities, Industrial sources and human dwellings, Water treatment and Pesticides use for public Health.

Table 2.1: Source of chemical contamination for groundwater (WHO, 2011)

Source of Chemicals	Examples	Common Chemicals
Naturally occurring	Rocks and soils	As, Cr, F, Fe, Mn, Na, $\text{SO}_4^{2-}$ , uranium
Agricultural activities	Manure, fertilizer, intensive animal practices, pesticides	$\text{NO}_3^-$ , $\text{NO}_2^-$
Industrial sources and human dwellings	Mining, manufacturing and processing industries, sewage solid waste, urban runoff, fuel leakages	$\text{NO}_3^-$ , Cd, cyanide, Cu, Pb, Ni, Hg
Water treatment	Water treatment chemicals, piping materials	Al, Cl, I, Ag
Pesticides used in water for public health	Larvicides used to control insect vectors of disease	Organophosphorus compounds(e.g., chlorpyrifos, diazinon, malathion)and carbamates(e.g., aldicarb, carbaryl, carbofuran, oxamyl)

#### **2.4.1. Groundwater Contamination**

The sources of groundwater contamination are many and the contaminants numerous (Fetter 1994). While industrial effluent may find its way into the groundwater, suburban areas have its groundwater with high levels of nitrate due to use of lawn fertilizers and septic tank discharge while agricultural areas, have high levels of fertilizers found in groundwater and also specialized synthetic organic and inorganic chemicals as well (Fetter, 1994). Landfills in urban and rural areas are known sources of groundwater contamination. While most of the elements are actually necessary to support healthy ecosystems such as, nitrates, and phosphorous associated with groundwater, it is not the simple presence of these items that is problematic, but the excess amounts that pollutes groundwater resources for both human use and natural ecosystems (TWDB, 2002).

#### **2.5. Water Quality**

According to Hounslow (1995), water quality is defined by the physical, chemical and biological characteristics and a composition of water sample. The chemical composition of groundwater is the combined result of water composition that enters the groundwater reservoir and the reactions with minerals present in the rocks (Iliopoulos et al., Zhu, 2002). The quality of water varies due to variation both in the natural geological and hydro geological conditions and human impact. Water rock interaction plays an important role in controlling water quality. The main mineral characteristics of water, especially groundwater are determined by weathering reaction taking place close to the earth's surface and there is a wide diversity of chemical composition related to the geology of the catchment or aquifer. The primary purpose of water analyses is to determine the suitability of water for a proposed use. The three main classes of use are domestic, agricultural and industrial.

##### **2.5.1. Water Quality Sampling**

Sampling could be defined as a process of selecting a portion of material small enough volume to be transported conveniently and handled in the laboratory. However, the main difficult with sampling is representativeness and integrity (Madrid and Zayas, 2007). The number of samples to be taken for a given investigation must be determined from both statistical and economic considerations (Hounslow, 1995). Water samples collection

procedures (how often and when); type of container and method of preservation must be known before water sample collection. Besides, data must also be collected at a minimum level of sensitivity and completeness to satisfy the information needed for the sampling program (Barcelona et al., 1985). According to Hounslow (1995), some chemical variables including temperature, dissolved oxygen, pH and alkalinity must be determined in the field, at time of sampling.

### **2.5.2. Description of Water Quality parameters**

It is very essential and important to test the water before it is used for drinking, domestic, agricultural or industrial purpose. Water must be tested with different physic-chemical parameters. Selection of parameters for testing of water is solely depends upon for what purpose we going to use that water and what extent we need its quality and purity. Water does content different types of floating, dissolved, suspended and microbiological as well as bacteriological impurities. Some physical test should be performed for testing of its physical appearance such as temperature, color, odor, pH, turbidity, TDS etc, while chemical tests should be perform for its dissolved oxygen, alkalinity, hardness and other characters. For obtaining more and more quality and purity water, it should be tested for its trace metal, heavy metal contents and organic i.e. pesticide residue. It is obvious that drinking water should pass these entire tests and it should content required amount of mineral level. Only in the developed countries all these criteria's are strictly monitored. Due to very low concentration of heavy metal and organic pesticide impurities present in water it need highly sophisticated analytical instruments and well trained manpower. Water sample parameters are analyzed in a laboratory. Some parameters such as temperature, conductivity, dissolved oxygen, pH, TDS are determined in the field (Hounslow, 1995). Following different physic chemical parameters are tested regularly for monitoring quality of water.

#### **2.5.2.1. Physical parameters**

##### **Temperature**

The temperature of water to a large extent determines the extent of microbial activity. Temperature is the measure of hotness or coldness of water measured either in degree Celsius or Fahrenheit by using a thermometer (APHA, 1985).

## **pH**

pH is the most important in determining the corrosive nature of water. Lower the pH value higher is the corrosive nature of water. pH was positively correlated with electrical conductance and total alkalinity (Gupta 2009). The parameter pH (negative base-10 logarithm of hydrogen ion activity in moles per liter) is one of the most fundamental water-quality parameters. It is easily measured, indicates whether water will be corrosive or will precipitate scale, determines the solubility and mobility of most dissolved constituents, and provides a good indication of the types of minerals groundwater has reacted with as it flows from recharge to discharge areas or sample sites. For these reasons it is one of the most important parameters that describe groundwater quality. The pH of neutral (neither acidic nor basic) water varies with temperature. For example, the neutral pH of pure water at 25°C (77°F) is 7.0. The neutral pH of pure water at 30°C (86°F) and 0°C (32°F) is 6.9 and 7.5, respectively (Hem, 1985).

## **Turbidity**

Turbidity is the cloudiness caused by particulate matter present in source water, re suspension of sediment in the distribution system, the presence of inorganic particulate matter in some groundwater or sloughing of bio-film within the distribution system (WHO, 2004). Turbidity is the most important problem for the aesthetic value of water quality. Although it doesn't necessarily adversely affect human health, it can protect microorganisms from disinfection effects, can stimulate bacterial growth, and indicate problems with treatment processes (WHO, 2004). For effective disinfection, median turbidity should be below 0.1 NTU although turbidity of less than 5 NTU is usually acceptable to consumers (WHO, 2004).

## **Electrical Conductivity**

Conductivity is the measure of capacity of a substance to conduct the electric current.

Most of the salts in water are present in their ionic forms and capable of conducting current and conductivity is a good indicator to assess groundwater quality. Electrical conductivity is an indication of the concentration of total dissolved solids and major ions in a given

water body. It is temperature dependent and the international unit is Siemens per meter (Hounslow, 1995; Mazor, 1991).

Table 2.2: Classification of irrigation water based on Electrical Conductivity (Richards, 1954).

Water Class	EC (micro mhos/cm)	Salinity Significance
Excellent	<250	Water of low salinity is generally composed of higher proportions of calcium, magnesium and bicarbonate ions.
Good	250-750	Moderately saline water, having varying ionic Concentrations
Permissible	750-2250	High saline waters consist mostly of sodium and chloride Ions
Doubtful	>2250	Water containing high concentration of sodium, bicarbonate and carbonate ions have high pH

### **Dissolved Oxygen**

DO is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata Vikal, 2009). In the progress of summer, dissolved oxygen decreased due to increase in temperature and also due to increased microbial activity (Moss 1972; Morrissette 1978; Sangu 1987; Kataria, 1996). The high DO in summer is due to increase in temperature and duration of bright sunlight has influence on the % of soluble gases (O<sub>2</sub>& CO<sub>2</sub>). During summer the long days and intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO<sub>2</sub> and giving off oxygen. This possibly accounts for the greater qualities of O<sub>2</sub> recorded during summer (Krishnamurthy R, 1990).

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

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions (UNICEF, 2008). The total concentration of dissolved



minerals in water is a general indication of the overall suitability of water for many types of uses (Karthikeyan *et al.*, 2013).

#### **2.5.2.2. Chemical parameters**

##### **Alkalinity**

It is composed primarily of carbonate ( $\text{CO}_3^{2-}$ ) and bicarbonate ( $\text{HCO}_3^-$ ) alkalinity acts as a stabilizer for  $\text{P}^{\text{H}}$ . Alkalinity, pH and hardness affect the toxicity of many substances in the water. Alkalinity is the presence of one or more ions in water including hydroxides, carbonates, and bicarbonates. It can be define as the capacity to neutralize acid. Moderate concentration of alkalinity is desirable in most drinking water supplies to stable the corrosive effects of acidity. However, excessive quantities may cause a number of damages. The WHO standards express the alkalinity only in terms of total dissolved solids (TDS) of 500 mg/l (Muhammad *et al.*, 2013).

##### **Total Hardness**

Hardness in water is caused primarily by the presence of carbonates and bicarbonates of calcium and magnesium, Sulphates, chlorides and nitrates. The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts. The total content of these salts is known as general hardness, which can be further divided into carbonate hardness (determined by concentrations of calcium and magnesium hydro carbonates), and non-carbonate hardness (determined by calcium and magnesium salts of strong acids). Hydro carbonates are transformed during the boiling of water into carbonates, which usually precipitate. Therefore, carbonate hardness is also known as temporary or removed, whereas the hardness remaining in the water after boiling is called constant. The total hardness of water classified in to three ranges (0-300 mg/l, 300-600 mg/l and > 600 mg/l) low, medium and high respectively (Karthikeyan *et al.*, 2013).

##### **Chloride**

Chloride is minor constituent of the earth's crust. Chloride is present in all natural waters, mostly at low concentrations. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing salt, and saline intrusion (WHO, 2011). High concentration of chloride gives a salty taste to water and beverages and may

cause physiological damages. It is highly soluble in water and moves freely with water through soil and rock (CGWB, 2010). High concentrations of Chloride can make water unpalatable and, therefore, unfit for drinking or livestock watering (UNICEF, 2008). According to CGWB (2010) in ground water the chloride content is mostly below 250 mg/L except in cases where inland salinity is prevalent and in coastal areas.

### **Sulfate**

Sulfate is a combination of sulphur (S) and oxygen (O). It occurs naturally in many soil and rock formations. In groundwater, most sulphates are generated from the dissolution of minerals, such as gypsum and anhydrite. Saltwater intrusion and acid rock drainage are also sources of Sulphates in drinking water. Man made sources include industrial discharge and deposition from burning of fossil fuels (WHO, 2011). Sulphate concentrations in natural waters are usually between 2 and 80 mg/L. High concentrations greater than 400 mg/L may make water unpleasant to drink (UNICEF, 2008).

### **Nitrate**

The main source of nitrate in water is from atmosphere, legumes, plant remains and animal excreta (WHO, 2011). It also originates from sewage effluents, septic tanks and natural drains carrying municipal wastes.  $\text{NH}_4^+$  from organic sources is converted to  $\text{NO}_3^-$  by oxidation. Because of this and its anionic form  $\text{NO}_3^-$  is very mobile in groundwater (Balakrishnan et al, 2011). The concentration of nitrate in natural water is less than 10 mg/L. Water containing more than 100 mg/L is bitter to taste and causes physiological distress.

### **Fluoride**

Fluoride contamination of groundwater is a serious problem in several countries spread throughout the world as ingestion of excess fluoride, most commonly, through drinking contaminated groundwater causes fluorosis. Mainly two factors are responsible for contamination of groundwater with fluoride- geological and anthropogenic. Rock geochemistry has a major control on geological fluoride contamination. Physiological conditions of rock, like decomposition, dissociation and subsequent dissolution along with long residence time may be the responsible factors for fluoride leaching (Madhnure, 2006).

Among anthropogenic factors industrialization, urbanization and improper utilization of water resources are of prime importance, in case of the developing countries (Giesen, 1999). Long term ingestion of fluoride in high doses can lead to severe skeletal fluorosis (Susheela, 2001).

### **Sodium**

All natural waters contain some sodium since sodium salts are highly water soluble and it is one of the most abundant elements on earth. It is found in the ionic form ( $\text{Na}^+$ ), and in plant and animal matter (it is an essential element for living organisms). The WHO guideline limit for sodium in drinking water is 200 mg/l. However, groundwater concentrations frequently exceed 50 mg/l. Sodium is commonly measured where the water is to be used for drinking or agricultural purposes, particularly irrigation.

### **Potassium**

Potassium ( $\text{K}^+$ ) is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering. However, potassium salts are widely used in industry and in fertilizers for agriculture and enter freshwaters with industrial discharges and run-off from agricultural land. Potassium is usually found in the ionic form and the salts are highly soluble. It is readily incorporated into mineral structures and accumulated by aquatic biota as it is an essential nutritional element.

### **Calcium**

Calcium occurs in water mainly due to the presence of limestone, gypsum and dolomite minerals. Industrial, as well as water and wastewater treatment, processes also contribute calcium to surface waters and ground water. Acidic rainwater can increase the leaching of calcium from soils. Calcium concentrations in natural waters are typically less than 15 mg/L but for water associated with carbonate rich rocks, concentrations may reach 30 up to 100 mg/L. Salt water have concentrations of several hundred milligrams per liter or more (UNICEF, 2008).

## **Magnesium**

Magnesium arises principally from the weathering of rocks containing ferromagnesium minerals and from some carbonate rocks. Magnesium occurs in many organ metallic compounds and in organic matter, since it is an essential element for living organisms.

Magnesium occurs typically in dark colored minerals present in igneous rocks such as plagioclase, pyroxenes, amphiboles, and the dark colored micas. It also occurs in metamorphous rocks, as a constituent of chlorite and serpentine (Perk, 2006). Magnesium is common in natural waters as  $Mg^{2+}$ , and along with calcium, is a main contributor to water hardness. Natural concentrations of magnesium in fresh waters may range from 1 to 100 mg/L (UNICEF, 2008).

## **Iron**

Iron (Fe) is a naturally occurring metal that is widely present in groundwater. Iron can exists in either an oxidized (ferric) or reduced (ferrous) state. At normal groundwater pH values, ferric iron is rapidly precipitated as an iron oxide, iron hydroxide, iron ox hydroxides (rust), or poorly crystalline to amorphous material. Under reduced conditions, however, ferrous iron is stable and will remain in groundwater. There is no EPA primary drinking-water standard for iron in water supplies because there are no identified, serious health threats posed by it. There is, however, a secondary standard of 0.3 mg/L for iron because iron concentrations above this level may produce objectionable odor, taste, color, staining, corrosion, and scaling.

## **Manganese**

Manganese (Mn) is a naturally occurring cat ion that is widely present in groundwater supplies. Manganese can cause an undesirable taste as well as staining laundry when levels exceed 0.1 mg/liter. The presence of manganese may also lead to the accumulation of deposits in the piping system (WHO, 2004). There is no health-based guideline value set for iron but for manganese it is four times higher than the acceptable threshold of 0.1 mg/liter (WHO, 2004). Geochemically, manganese and iron behave similarly, so high manganese concentrations can be expected from wells and springs that produce water with high iron concentrations. There is no EPA primary drinking-water standard for manganese

in water supplies because there are no identified, serious health threats posed by it. There is, however, a secondary standard of 0.05 mg/L for manganese based on the fact that higher concentrations may produce objectionable odor, taste, color, corrosion, and staining.

### **2.5.2.3. Bacteriological parameters**

The diseases caused by water related microorganisms can be divided into four main categories:

**Water-borne diseases:** caused by water that has been contaminated by human, animal or chemical wastes. Examples include cholera, typhoid, meningitis, dysentery, hepatitis and diarrhea. Diarrhea is caused by a host of bacterial, viral and parasitic organisms most of which can be spread by contaminated water (WHO, 2006). Poor nutrition resulting from frequent attacks of diarrhea is the primary cause for stunted growth for millions of children in the developing world (Gadgil, 1998).

**Water-related vector diseases:** These are diseases transmitted by vectors, such as mosquitoes that breed or live near water. Malaria causes over 1 million deaths a year alone (WHO, 2006). Stagnant and poorly managed waters provide the breeding grounds for malaria-carrying mosquitoes.

**Water-based diseases:** These are caused by parasitic aquatic organisms referred to as helminthes and can be transmitted via skin penetration or contact.

**Water-scarce diseases:** These diseases flourish in conditions where freshwater is scarce and sanitation is poor. Examples include trachoma and tuberculosis.

Testing the bacterial contaminants in water can be simplified by utilizing the presence of an indicator organism. An indicator organism may not necessarily pose a health risk but it can be easily isolated and enumerated, is present in large numbers, is more resistant to disinfection than pathogens, and does not multiply in water and distribution systems (Gadgil, 1998). Traditionally, total coli form bacteria have been used to indicate the presence of fecal contamination; however, this parameter has been found to exist and grow in soil and water environments and is therefore considered a poor parameter for measuring the presence of pathogens (Stevens et al., 2003). Studies also show that due to their ability to grow in drinking water distribution systems and their unpredictable presence in water

supplies during outbreaks of waterborne disease, the sanitary significance or quality of water is difficult to interpret in the presence of total coli forms (Stevens *et al.*, 2003). An exception is *Escherichia coli* (*E.coli*), a thermo tolerant coli form, the most numerous of the total coli form group found in animal or human feces, rarely grows in the environment and is considered the most specific indicator of fecal contamination in drinking-water (WHO, 2004). The presence of *E. coli* provides strong evidence of recent fecal contamination (WHO, 2004, Stevens *et al.*, 2003). The risk of coli form presence can depend on the health or sensitivity of the consumer. The risks of *E. coli* presence, slightly greater than WHO Guideline's zero count per 100ml may be of only low or intermediate risk. According to IRC, 2002 as cited by Michael H., 2006 about risk classification for thermo tolerant coli forms or *E. coli* of rural water supplies in Table 2.3.

Table 2.3: Water quality counts per 100ml and the associated risk

Counter per 100ml	Risk Category
0	In conformity with WHO guidelines
0-10	Low risk
11-100	Intermediate risk
101-1000	High risk
> 1000	Very high risk

## 2.6. Guidelines for water quality parameters

Safe drinking water is required for all usual domestic purposes, including drinking, food preparation and personal hygiene. Every effort should be made to achieve drinking water that is as safe as practicable (WHO, 2011). The nature and form of drinking water standards may vary among countries and regions. There is no single approach that is universally applicable. It is essential in the development and implementation of standards that the current or planned legislation relating to water, health and local government is taken into account and that the capacity of regulators in the country is assessed. Approaches that may work in one country or region will not necessarily transfer to other countries or regions. It is essential that each country review its needs and capacities in developing a regulatory framework (WHO, 2011). Based on the water quality standards

stipulated by the WHO ranks were assigned for each parameter depending on the respective tested values, as given in the Table 2.4.

Table 2.4: Drinking water quality standards of Ethiopia and WHO (from Ethiopian standard guidelines ES 261:2001; and WHO, 2011)

Drinking Water Quality Parameter	WHO standard (mg/L)	Ethiopian Standard (mg/L)
Nitrate	50	50
Arsenic	0.01	0.01
Fluoride	1.5	1.5
Magnesium	50	50
Chloride	250	250
Calcium	75	75
Sodium	200	200
Sulfate	250	250
TDS	1000	1000

## 2.7. Perception of drinking water

In terms of drinking water quality, user perception is one of the most important things, sometimes exceeding actual quality of water especially when it concerns the quality of drinking water for the user communities (Sheat 1992, Doria 2010). There are different factors that influence the perception of drinking water quality, including: Human sensory perceptions of taste, odor and color of water are related with mental factors and some extent taste, which is the more important because it may detect water contamination related to chemicals. People may perceive risks if they experience health problem caused by water.

### **2.7.1. Physical and aesthetic parameters**

Consumer perception and acceptability of their drinking water quality depends on user sense of taste, odor and appearance (Sheat 1992; Doria 2010). That is why consumers have differing opinion about the aesthetic values of water quality. Relying on their own senses may lead to avoidance of highly turbid or colored but otherwise safe waters in favor of more aesthetically acceptable but potentially unsafe water sources (WHO, 2004). Taste and odor can originate from various natural chemical contaminants, biological sources, microbial activity, from corrosion or as a result of water treatment (e.g., chlorination) (WHO, 2004). Color, cloudiness, particulate matter and visible organisms can also contribute to unacceptability of water sources. These factors can vary for each community and are dependent on local conditions and characteristics.

### **2.8. The use of Groundwater for irrigation purpose**

Irrigation water whether derived from springs, diverted from streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. In addition to the dissolved salts, which has been the major problem for centuries, irrigation water always carry substances derived from its natural environment or from the waste products of man's activities (domestic and industrial effluents). These substances may vary in a wide range, but mainly consist of dirt and suspended solids resulting into the emitters' blockages in micro-irrigation systems and bacteria populations and coli forms harmful to the plants, humans and animals (Ayers, 1976). The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil. Highly soluble salts in the soil make soil moisture more difficult for plants to extract, and crops become water stressed even when the soil is moist. When excessive sodium accumulates in the soil, it causes clay and humus particles to float into and plug up large soil pores. This plugging action reduces water movement into and through the soil, thus crop roots do not get enough water even though water may be standing on the soil surface (Zhang, 1990). Groundwater quality comprises the physical, chemical and biological qualities of groundwater. Temperature, turbidity, color, taste and odor make up the list of physical water quality parameters. Since



most groundwater is colorless, odorless and without specific taste, we are typically more concerned with its chemical qualities (Harter, 2003).

The lists of dissolved solids in natural ground water may be classified as major constituent, secondary constituent and trace constituents and are given in the Table 2.5.

Table 2.5: Major, secondary and trace constituents of Groundwater (Harter, 2003)

	Major(1-1000 mg/l)	Secondary (0.01-10 mg/l)	Trace(0.0001-0.1 mg/l)	Trace( less than 0.0001 mg/l)
Cations	Na, Ca, Mg	K, Fe Strontium	Antimony, Al, As, Barium, Br, Cd, Cr, Co, Cu, Germanium, Iodide, Pb, Li, Mn Molybdenum, Ni, Phosphate, Rubidium Selenium Titanium	Beryllium, Bismuth, Cerium, Cesium Gallium, Gold, Indium, Lanthanum, Niobium, Platinum, Radium, Ruthenium, Scandium Silver, Thallium, Thorium, Thim Tungsten, Ytterbium Yttrium, Zirconium
Anions	HCO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> ,Cl Silica	CO <sub>3</sub> <sup>2-</sup> , NO <sub>3</sub> <sup>-</sup> , F B		

Mostly the groundwater quality is measured by analyzing the chemicals that are in it. To measure it, indices or chemical concentrations like total dissolved solids, electric conductivity, sodium concentration, calcium concentration, bicarbonates, sulphate,

chloride and other trace chemicals need to be found out by making analysis of the water in the laboratory. Generally, use of poor quality irrigation water can create four types of problems. These problems are grouped in to: water infiltration rate, alkalinity, specific ion toxicity and miscellaneous (Ayers and Westcot, 1994).

**Sodium Adsorption Ratio (SAR)**

SAR is a measure of the suitability of water for irrigation use, because sodium concentration can reduce the soil permeability and soil structure (Todd, 1980). SAR is a measure of alkali/sodium hazard to crops and it was estimated by the formula given in equation (2.1).

$$SAR = \frac{(Na^+)}{\sqrt{(Ca^{2+} + Mg^{2+}) \times .5}} \dots\dots\dots (2.1)$$

Where [Na<sup>+</sup>], [Ca<sup>2+</sup>] and [Mg<sup>2+</sup>] are concentration of sodium, calcium and magnesium in meq/l. The SAR value of water for irrigation purposes has a significant relationship with the extent to which sodium is absorbed by the soils. Irrigation using water with high SAR values may require soil amendments to prevent long-term damage to the soil, because the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production.

Table 2.6: Irrigation water classification based on SAR (Richards, 1954).

SAR	Water class
Less than 10	Excellent
10 to 18	Good
18 to 26	Permissible
More than 26	Unsuitable

**Soluble sodium percentage (SSP)**

Wilcox (1948) used percentage sodium and electrical conductance in evaluating the suitability of groundwater for irrigation. The percentage of sodium is computed with

respect to the relative proportions of cat ions present in water, where the concentrations of ions are expressed in meq/l using the formula as shown in equation (2.2).

$$SSP = \frac{[Na^+ + K^+] \times 100}{[Ca^{2+} + Mg^{2+} + Na^+ + K^+]} \dots\dots\dots (2.2)$$

Excess Na<sup>+</sup>, combining with carbonate, leads to formation of alkali soils, whereas with chloride, saline soils are formed. Neither soil will support plant growth (Rao, 2006). Generally, percent of Na<sup>+</sup> should not exceed 60 % in waters intended for irrigation purpose.

Table 2.7: Classification of irrigation water based on SSP (Wilcox, 1955)

SSP	Water class
< 20	Excellent
20 - 40	Good
40 - 60	Permissible
60 - 80	Doubtful
>80	Unsuitable

**Residual Sodium Carbonate (RSC)**

RSC has been calculated to determine the hazardous effect of CO<sub>3</sub><sup>2-</sup> and HCO<sub>3</sub><sup>-</sup> on the quality of water for irrigation purpose (Eaton, 1950). The RSC value was calculated using the formula given in equation (2.3).

$$RSC = [CO_3^{2-} + HCO_3^-] - [Ca^{2+} + Mg^{2+}] \dots\dots\dots (2.3)$$

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

RSC <1.25 are safe for irrigation; it is considered unsuitable if it is greater than 2.5. The high RSC value in water leads to precipitation of Ca<sup>2+</sup> and Mg<sup>2+</sup> (Raghunath, 1987). As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah *et al.*, 2008). The higher concentration of RSC causes the soil structure to deteriorate, the movement of air and water through the soil is restricted; soil alkalinity increases and plant growth is shunted (Reddy and Reddy, 2011).

Table 2.8: Suitability of groundwater for irrigation according to RSC value

Class	Quality	Hazard
<0	Very good quality	None
0-1.25	Water of good quality, used for irrigation of all soils.	Low, with some removal of calcium and magnesium from irrigation water.
1.25-2.5	Water of medium quality used in case of good drainage especially with calcium.	Medium, with appreciable removal of calcium and magnesium from irrigation water.
>2.5	Unsuitable water, especially in poor drainage or when soluble calcium.	High, with most calcium and magnesium removed leaving sodium to accumulate.

### Kelley's Ratio (KR)

Kelley *et al.*, (1940) have suggested that the sodium problem in irrigational water could very conveniently be worked out on the basis of the values of Kelley's ratio (equation 2.4). Groundwater having Kelley's ratio more than one is generally considered as unfit for irrigation.

$$KR = \frac{[Na^+]}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (2.4)$$

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

### Magnesium Hazard (MH)

Magnesium is essential for plant growth; however at high content it may associate with soil aggregation and friability (Khodapanah *et al.*, 2009). More  $Mg^{2+}$  present in waters affects the soil quality converting it to alkaline and decreases crop yield (Joshi *et al.*, 2009). Szabolcs and Darab (1964) proposed MH value for irrigation water as given by the formula expressed in equation (2.5).

$$MH = \frac{[Mg^{2+}] \times 100}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (2.5)$$

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

MH values  $>50$  are considered harmful and unsuitable for irrigation purposes.

### **2.9. Aquachem water quality database**

Aquachem is a Water Quality Database software package with functionality for graphical and numerical analysis (Abreha, 2014). Its feature has a fully customizable database Physical and Chemical parameters and provides a comprehensive selection of analytical tools such as calculations and graphs for interpreting water quality data ( Hounslow, 1995; Nies et al., 2011).

### 3. MATERIALS AND METHODS

#### 3.1. Study area

This study was conducted at Gimbi District, Oromia Regional state, Ethiopia. It is located 441 km west of Addis Ababa. The district has a latitude and longitude of 9° 10' N 35° 50' E/ 9.169° N 35.833°E with an elevation lying between 1845 and 930 meters above sea level. The mean annual rainfall is 1400-1800 ml. The mean minimum and maximum annual temperature ranges between 10 and 30°C. The district has 87,056 population residing in 32 rural kebeles and Gimbi Town, administrative city of the zone. The district is a mountainous area with full of ups and downs topography and it covers 113,818 ha of land area. There are three agro-ecological zones in the district in a range of 1100 - 2100 m altitude; Majority classified as midland (72%), as high land (18.75%) and the rest as low land.

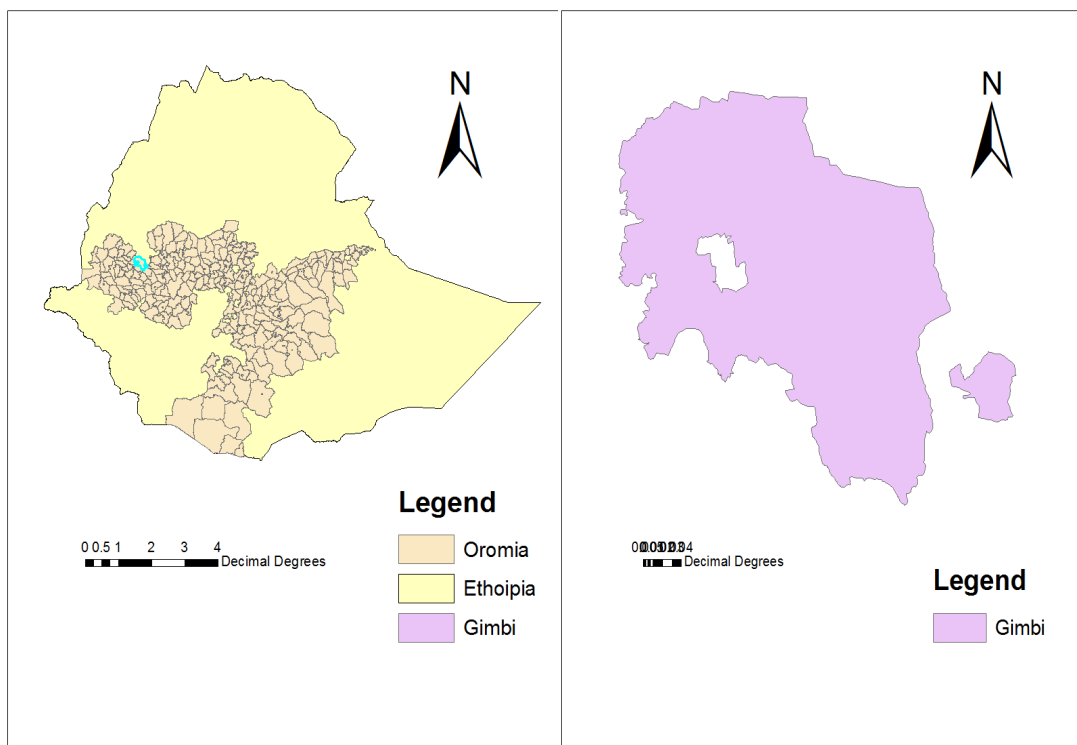


Figure 3.1: map of the study area

### **3.2. Study period and design**

The study was carried out from the beginning of June to end of September 2016 in twelve sub-areas of Gimbi District, namely: Chuta Kaki, Choli Michael, Melka Gasi, Chuta Gochi, Chuta Giorgis, Tole, Bikilti Tokuma, Loya Gefere, Wera Seyo, Lelisa Bikilal, Lelisa Seriti and Lalo choli. Experimental research was used. An experimental design is a study design that gives the most reliable proof for causation. Experimental research takes place in the laboratory because it aims at finding out the relationship existing between two factors under controlled conditions. Thus, the experimental research strictly adopts the Scientific Method in its investigation.

### **3.3. Sample size and sampling procedures**

Groundwater samples were collected by purposive sampling technique from 12 groundwater sources (5 hand dug borehole, 4 hand dug well and 3 protected springs). For selection of groundwater sampling location, based on the different criteria: Wells closer to polluting sources like Improper waste disposal sites, Natural deposits minerals, municipal effluents, leakage of gasoil from fuel oil storage tank, road construction, Garages, municipal Abattoir etc.; Locations and altitudes of selected sample sites were determined on the field using a Garmin GPS. Water samples were collected from pumping wells after minimum of several minutes of purging prior to sampling. This was done to remove groundwater stored in the well. Samples were drawn with a pre cleaned plastic polyethylene bottle. For determination of biological parameters, samples were collected in sterile bottles of 100 ml capacity. Prior to sampling, all the sampling containers were rinsed thoroughly with the groundwater. Water quality parameters such as temperature, pH and electrical conductivity, DO and TDS were analyzed immediately by using portable multi parameter probe (HQ40d Model ). Each sample of groundwater were collected and filtered with 0.45  $\mu\text{m}$  filter membrane into an individual clean 1L plastic water bottle. Sample for metal determination such as  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  were preserved by adding 10% nitric acid solution to the sample to reduce the pH of the sample, which were transported immediately to the laboratory. The samples were filled up to the brim and were immediately sealed to avoid exposure to air and were labeled according to

the location name systematically. The samples were transported in a cool box with ice at 4<sup>0</sup>c to laboratory until analysis. The necessary precautions were adopted during sampling.

Table 3.1: GPS reading of the selected sites in the study area

Sample code	Name of the location	Water sources	GPS Reading		
			Easting	Northing	Elevation
S <sub>1</sub>	Melka Gasi	Protected Spring	166494	1004079	1971
S <sub>2</sub>	Chuta Kaki	Hand Dug Bore hole	148259	1020755	2013
S <sub>3</sub>	Chuta Giorgis	Hand Dug Bore hole	153301	1019665	2072
S <sub>4</sub>	Choli Michael	Protected Spring	157253	1018980	1714
S <sub>5</sub>	Wera Seyo	Hand Dug Well	160387	1013533	1766
S <sub>6</sub>	Lelisa Seriti	Hand Dug Well	153303	1009309	1719
S <sub>7</sub>	Chuta Gochi	Hand Dug Well	148396	1013260	1855
S <sub>8</sub>	Lelisa Bikilal	Hand Dug Bore hole	151666	1008491	1920
S <sub>9</sub>	Bikiltu Tokuma	Hand Dug Bore hole	162431	1016667	1786
S <sub>10</sub>	Tole	Hand Dug Well	161478	1009581	1748
S <sub>11</sub>	Loya Gefere	Protected Spring	160932	1016530	1866
S <sub>12</sub>	Lalo choli	Hand Dug Bore hole	144580	1011898	1768



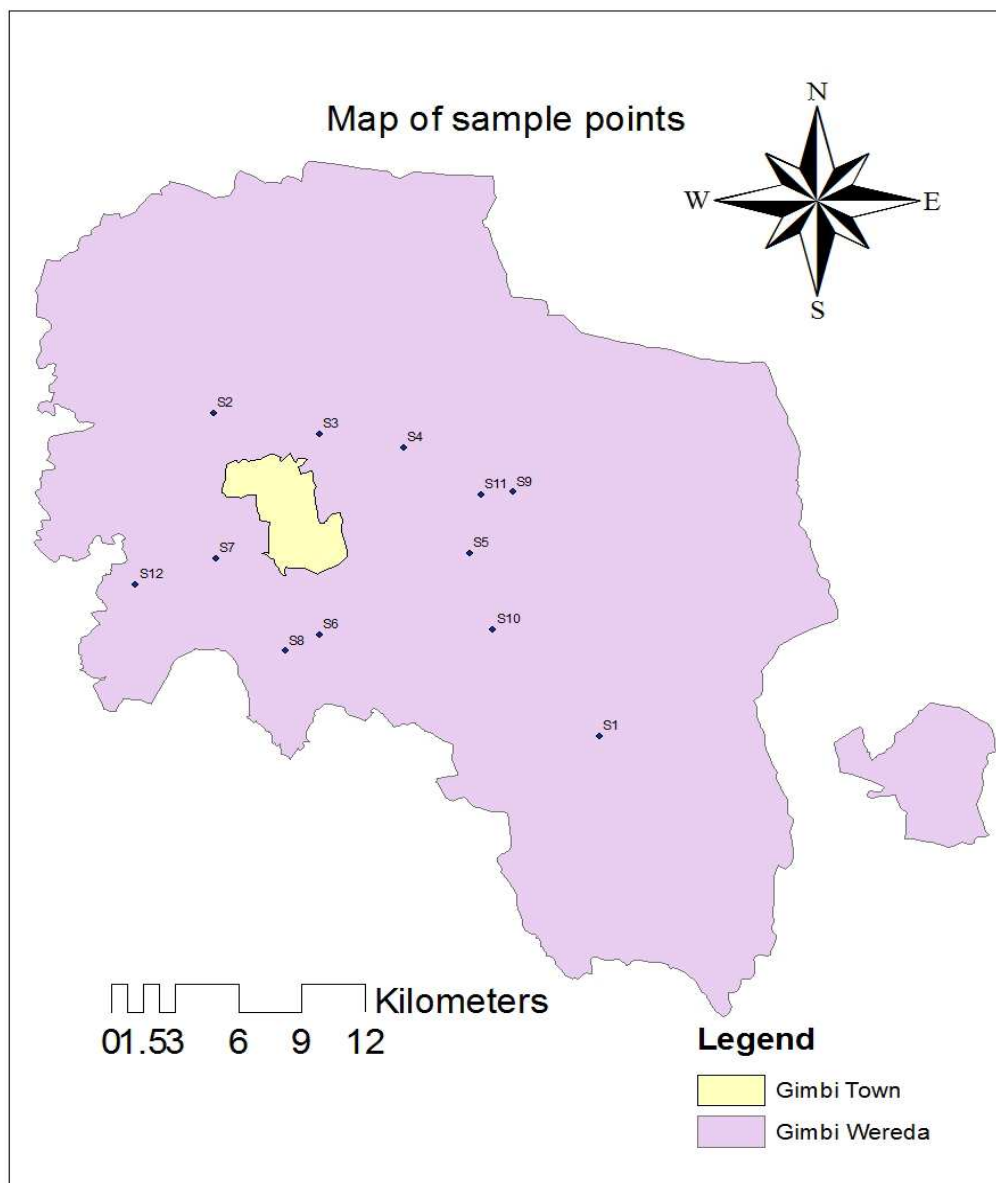


Figure 3.2: map of sample site

### 3.4. Instruments and apparatus

The apparatus used for the experiments are: evaporating dishes, analytical balance, beaker, graduated cylinder, standard flasks, funnel, wash bottle, forceps, burette, pipette, pipette bulb, dish tongs, gooch crucibles, filter, vacuum pumps, crucible tongs, measuring cylinders, conical flasks, spectro photometric cuvette, drying oven, desiccator, pH meter with a combination of pH electrode and temperature compensation probe, UV-

Spectrophotometer, conductivity meter, burettes and stand, autoclave, fume hook, petri dish, filter unit, incubator and photo cameras.

### **3.5. Study variables**

The study variables were physical parameters (temperature, pH, electrical conductivity, total dissolved solid, turbidity and dissolved oxygen) and chemical parameters (total alkalinity, total hardness, calcium, magnesium, carbonate, bicarbonate, sodium, potassium, iron, manganese, chloride, sulfate, nitrate).

### **3.6. Sample analysis**

All the water samples were analyzed in Oromia Water Works Design and Supervision Enterprise (OWWDSE) Laboratory. Temperature, pH, TDS, DO and EC were determined at the site with the help of portable multi-parameter probe (HQ40d Model ). For rest of the analysis, water samples were preserved and brought to the laboratory within holding time and were determined as per standard methods (APHA-1995). The chemical analysis was carried out for Calcium, Magnesium, Iron and Manganese was estimated by Atomic Absorption Spectrophotometer. Chloride, Carbonate and bicarbonate were estimated by volumetric titration methods. Nitrate was estimated by spectrophotometer methods and sodium and potassium by flame photometry methods. All the results were compared with standard limits recommended by WHO (2004).

Interpretation of all water chemistry data were carried out using Aqua Chem (version 4.0) software, Origin Pro 8 and Microsoft excel (2007). Aqua Chem is a fully-integrated software package developed specifically for graphical and numerical analyses and interpretation of aqueous geochemical data sets. The analyzed data was presented by using table, figure and piper diagram. Piper Diagrams are one of the most useful ways of representing and comparing water quality.

### **3.7. Ethical consideration**

The study was conducted after getting permission from ethical committee of Jimma Institute of Technology, school of civil and environmental engineering. In order to ensure the confidentiality of data collection and to keep the right of the respondents the following ethical protocols was carefully applied: The respondents were asked for their willingness,

based up on their permission they were oriented or informed with the objectives and aim of the study, letter of confirmation for conducting the study was presented for respondents and the investigator was use a pseudo name instead of their real name for respondents whom do not permit their name to be mentioned.

### **3.8. Data quality assurance and quality control**

According to (APHA, 1995) proper quality assurance procedures and precautions were taken to ensure the reliability of the results. Data quality assurances were assessed carefully and triple measurements were performed to assure quality of data. For the sake of data quality assurance Ion Balance Error (IBE) was calculated and samples whose IBE > 5% were discarded.

$$IBE = \frac{\sum Cation - \sum Anions}{\sum Cation + \sum Anions} \times 100$$

### **3.9. Plan for dissemination**

The final result of this study will be presented to Jimma Institute of Technology School of civil and environmental engineering, Environmental engineering chair and will be disseminated to west wollega zone and other governmental and non-governmental organizations which are concerned with the study findings. Publication in national and international journals will also be considered.

## 4. RESULTS AND DISCUSSION

### 4.1. Physical Parameters

#### 4.1.1. Temperature

The temperature of groundwater samples ranges from 23.60 to 26.18°C with a mean value of 24.93°C (Table 4.4). The highest temperature (26.18°C) was observed at location S<sub>8</sub> and the lowest temperature (23.60°C) was observed at S<sub>5</sub> (Figure 4.1). The standard value recommended for groundwater temperature by WHO (2004) should not exceeds 15°C. But the temperature of all groundwater samples of study area was above the standard value recommended by WHO and national standard. This may be due to variations in solar energy received at the earth's surface create periodicities, both diurnal and annual, in temperature below ground surface. Season and topography influences the temperature. Moreover, calcium carbonate (CaCO<sub>3</sub>) precipitation also increases temperature of groundwater (Jensen *et al.*, 2003). Therefore the temperature of groundwater samples in study area is not suitable for drinking purpose.

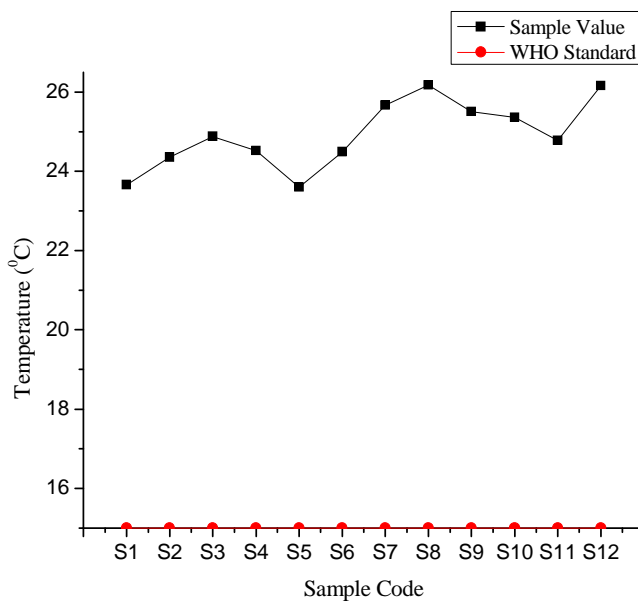


Figure 4.1: Variation of groundwater temperature in study area

### 4.1.2. pH

The pH of groundwater samples ranges from 4.71 to 6.20 with a mean value of 5.66 (Table 4.4). The highest pH (6.20) was observed at location S<sub>9</sub> and the lowest (4.71) was observed at S<sub>1</sub> (Figure 4.2). The limit of pH value for drinking water is specified as 6.5 to 8.5 (WHO, 2004). The result clearly shows that the groundwater in the study area is slightly acidic in nature. This may be due to the presence of dissolved carbon dioxide and organic acids which are derived from the anthropogenic activities, decay and subsequent leaching of plant materials. However, when water has a pH that is too low, it will lead to corrosion and pitting of pipes in plumbing in distribution systems. It was concluded that the pH value of groundwater samples of study area is not suitable for drinking purpose.

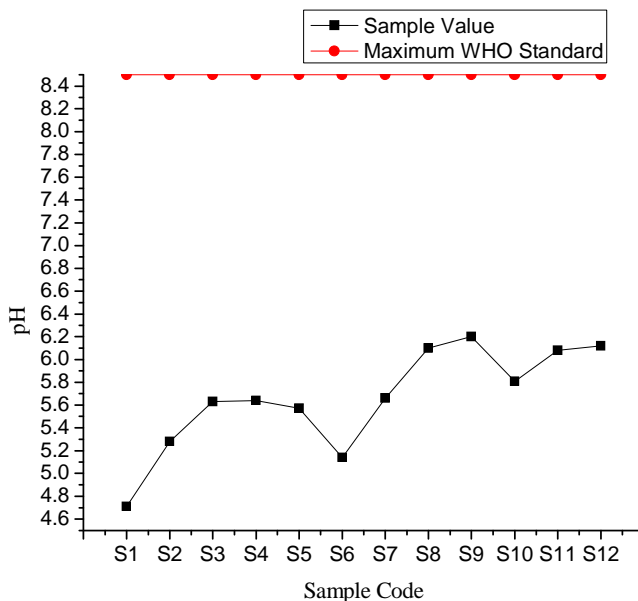


Figure 4.2: Variation of groundwater pH in study area

### 4.1.3. Electrical Conductivity

The electrical conductivity of groundwater samples ranges from 36.73 to 233.0  $\mu\text{S}/\text{cm}$  with a mean value 153.42  $\mu\text{S}/\text{cm}$  (Table 4.4). The highest EC (233.0  $\mu\text{S}/\text{cm}$ ) was observed at location S<sub>2</sub> and the lowest EC (36.73  $\mu\text{S}/\text{cm}$ ) was observed at S<sub>7</sub> (Figure 4.3). The most desirable limit of EC in drinking water is prescribed as 250 $\mu\text{S}/\text{cm}$  (WHO, 2004). The conductivity of clean water is lower but as it moves down the earth it leaches and dissolves ions from the soil and also picks up organic from biota and detritus. Lower EC in the study

area indicates the low enrichment of salts in the groundwater. As observed from (Figure 4.3) the water samples are suitable for drinking purpose because its conductivity does not exceed 250 $\mu$ S/cm. This means the EC value fallen below the WHO standard. Generally the conductivity values recorded in the study area does not pose any potential health risk for consumers.

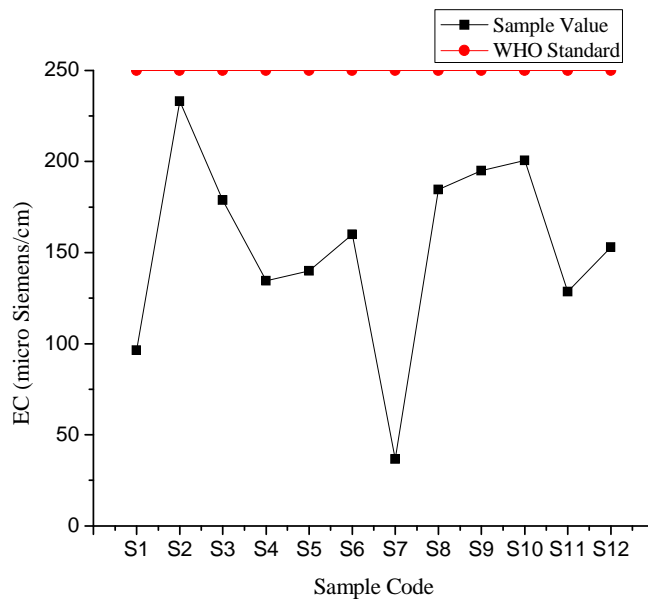


Figure 4.3: Variation of groundwater EC in study area

#### 4.1.4. Total Dissolved Solids

The total dissolved solid value varies between a minimum of 53.60 mg/l and a maximum of 174.50 mg/l with a mean value of 95.84 mg/l (Table 4.4). The highest TDS (174.50 mg/l) was recorded at location S<sub>2</sub> and the lowest (22.90 mg/l) was observed at S<sub>5</sub> (Figure 4.4). This may be derived from natural sources which includes inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonate, chlorides, sulfates, and small amounts of organic matter that are dissolved in water. TDS also originate from sewage and urban run-off. Groundwater samples in study area contain less than 500 mg/l of dissolved solids. It can be concluded that the TDS of groundwater samples of study area is below the WHO and national standard. Therefore it was suitable for drinking and irrigation purposes.

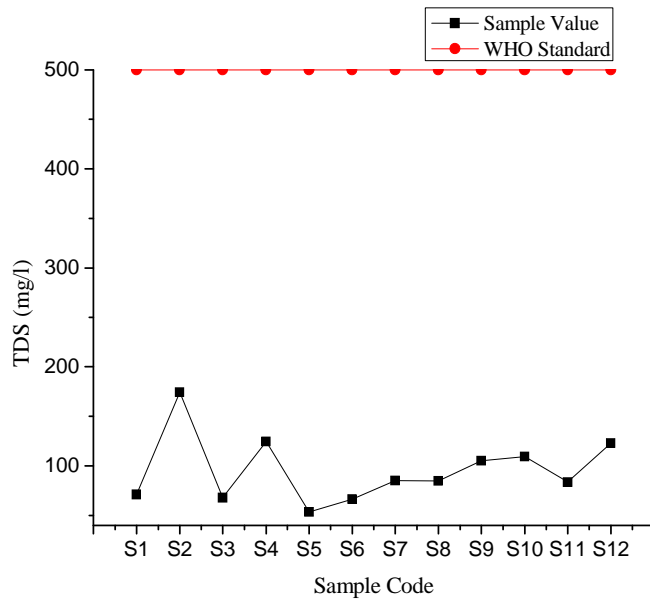


Figure 4.4: Variation of groundwater TDS in study area

#### 4.1.5. Dissolved Oxygen

In present study the DO values of groundwater samples ranged from 2.85 at S<sub>1</sub> to 3.96 mg/l at S<sub>7</sub> with a mean value of 3.29 mg/l (Table 4.4). The mean DO value of water samples obtained from the all water sample was below the maximum acceptable limits of 7.5 mg/l recommended by WHO (2004) Standards. Lower levels of DO indicate microbial contamination or corrosion. All the samples showed low DO levels situation may result through the decomposing organic matter, dissolved gases, mineral waste, municipal effluents and improper waste disposal sites of the area. It can be concluded that the DO of groundwater samples of study area is suitable for drinking purpose.

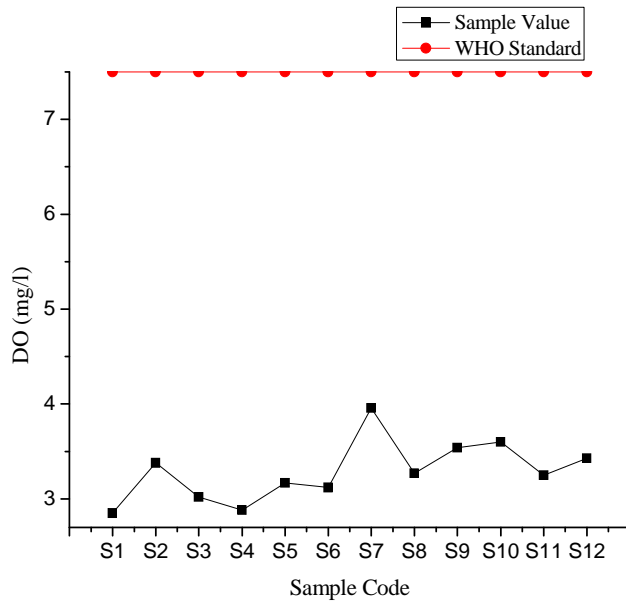


Figure 4.5: Variation of groundwater DO in study area

#### 4.1.6. Turbidity

In present study the turbidity values of groundwater samples ranged from 1.06 at S<sub>4</sub> to 10.33 NTU at S<sub>6</sub> with a mean value of 4.89 NTU (Table 4.4). However, the prescribed limit of turbidity for drinking water is 5 NTU (WHO, 2004). The high turbidity of groundwater in the study area may be due to urban runoff, decaying plants and animals. Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. Turbidity of water affects other water quality parameters such as color, when it is imparted by colloidal particles. It also promotes the microbial proliferation, thus affecting negatively the microbiological quality of water. It can be concluded that 41.67% of groundwater samples in study area were above the WHO standard which is not suitable for drinking purpose and 58.33% of the samples was below the WHO standard and it was suitable for drinking purpose.



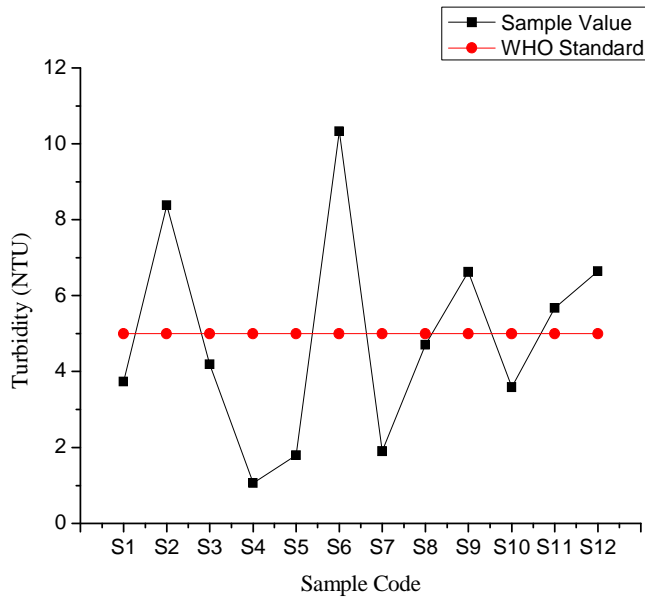


Figure 4.6: Variation of groundwater turbidity in study area

## 4.2. Chemical Parameters

### 4.2.1. Total Hardness

A total hardness value of groundwater samples varies from 0.0 to 16.50 mg/l with a mean value of 3.25 mg/l (Table 4.4). According to the portability of drinking Water set by WHO standard, the maximum permissible allowable limit should not be exceeded 200mg/l. The TH value of study area may be due to presence of calcium and magnesium. Hardness does not have health effects but it can make the water unsuitable for different use. High range of TH in water may cause corrosion in pipes in the presence of certain heavy metals. The degree of hardness of the study area groundwater supply can be categorized as soft water, which is not harmful for consumers according to the WHO and Ethiopian standards. It can be concluded that the concentration of total hardness of groundwater samples in study area was suitable for drinking purpose.

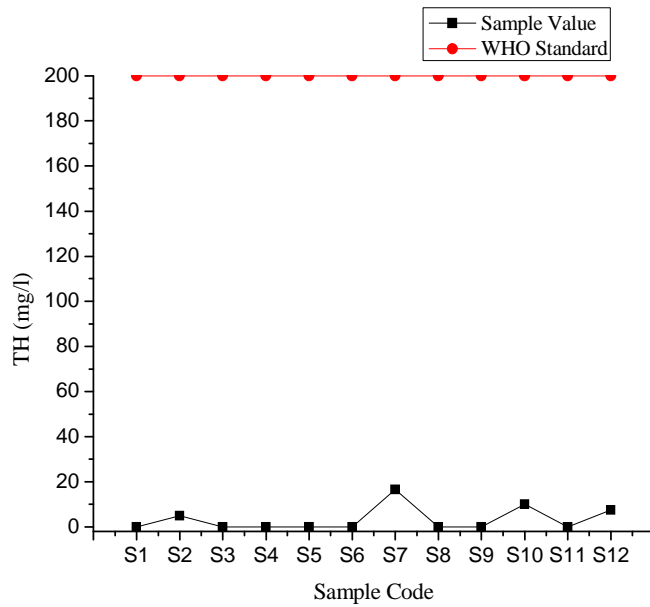


Figure 4.7: Variation of groundwater TH in study area

#### 4.2.2. Total Alkalinity

The alkalinity measurements ranged from 12.0 mg/l at S<sub>9</sub> to 50.0 mg/l at S<sub>4</sub> with a value of 27.75 mg/l (Table 4.4). According to the portability of drinking Water set by WHO standard, the maximum permissible allowable limit should not be exceeded 200mg/l of CaCO<sub>3</sub>. These results show that at all points of sample taken the values of total alkalinity lay below the WHO maximum permissible limit. Thus, there is no significance harm effect on human health. However, excessive quantities may cause a number of problems. Thus, these values were under the permissible limit of WHO standards and may not caused health related problems. It can be concluded that alkalinity of the groundwater in the study area was suitable for drinking purpose.

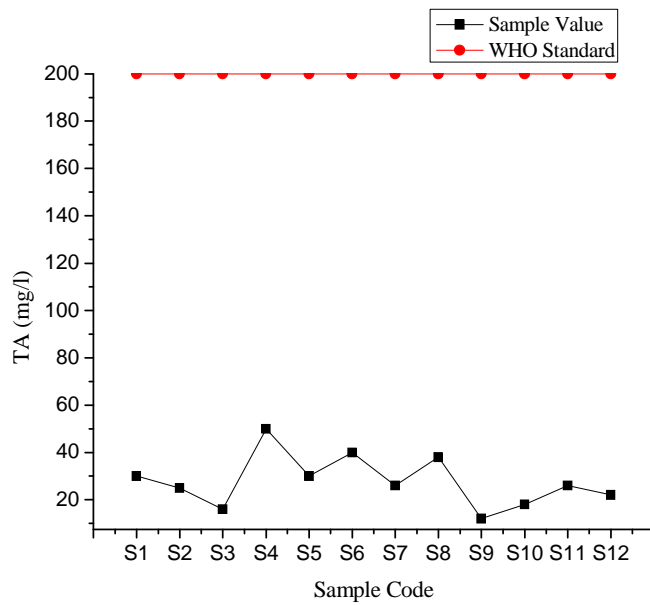


Figure 4.8: Variation of groundwater TA in study area

#### 4.2.3. Bicarbonate

The bicarbonate measurements of groundwater samples ranged from 12.0 mg/l at S<sub>9</sub> to 50.0 mg/l at S<sub>4</sub> with a value of 27.75 mg/l (Table 4.4). The value of bicarbonates is not recommended by WHO or Ethiopian standard. However it is considered to be not more than 500 mg/l. The weathering of rocks adds bicarbonate content in water. Mostly bicarbonates are soluble in water i.e. bicarbonate of magnesium and calcium etc. is the main causes of hardness of water. The concentration of bicarbonate in study area was below the standard. It can be concluded that the concentration of bicarbonate of groundwater samples of study area was suitable for drinking purpose.

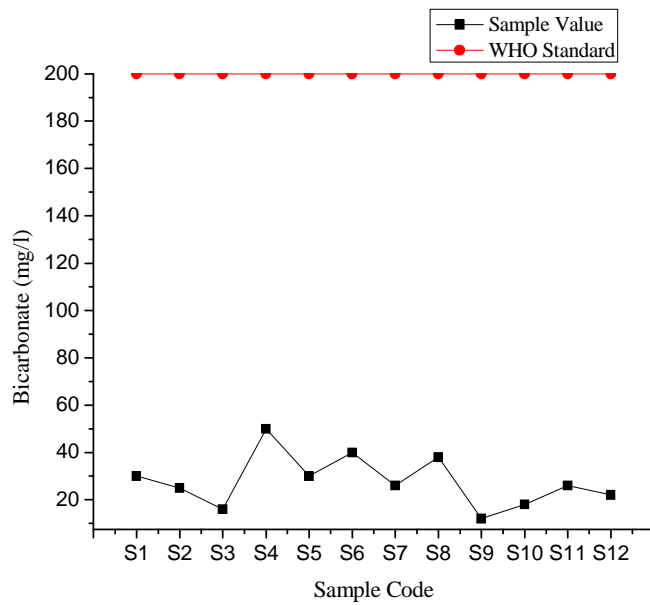


Figure 4.9: Variation of groundwater bicarbonate in study area

#### 4.2.4. Chloride

In study area the chloride value ranges from 4.0 at S<sub>4</sub> and S<sub>12</sub> to 18.30 mg/l at S<sub>11</sub> with a mean value of 9.46 mg/l (Table 4.4). According to WHO (2004) standards concentration of chloride should not exceed 250 mg/l. All the groundwater samples have lower concentration of chloride maximum permissible limit value set by WHO standard. Thus the water for all study area considered as fresh water because they were containing low levels of chloride. Therefore it can be concluded that the concentration of chloride in groundwater samples was suitable for drinking purposes.

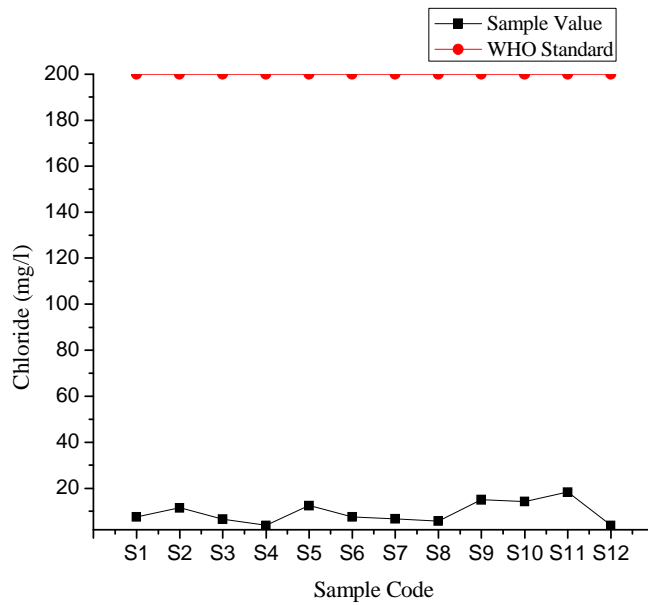


Figure 4.10: Variation of groundwater chloride in study area

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

Nitrate in study area ranged from 0.40 at S<sub>12</sub> to 2.23 mg/l at S<sub>7</sub> with a mean value of 1.29 mg/l (Table 4.4). The WHO allows maximum permissible limit of nitrate in drinking water is 10 mg/l. But the concentration of nitrate in groundwater samples of study area was fallen below the WHO and national standard. The source of nitrate might be the agricultural fields which uses fertilizers. Nitrate one of the most important diseases causing parameters of water quality particularly blue baby syndrome in infants. It was concluded that the water in the study area did not have nitrate concentration that could lead to health problems. Therefore the results indicate that the concentration of nitrate in study area was suitable for drinking and irrigation purpose.

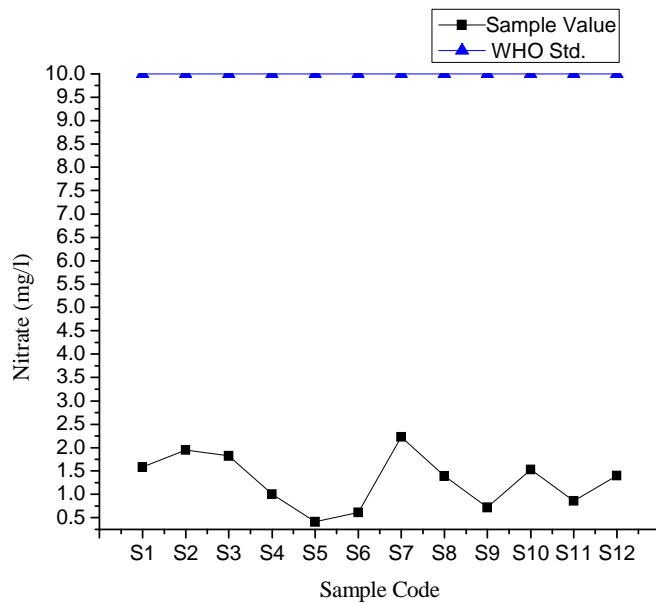


Figure 4.11: Variation of groundwater nitrate in study area

#### 4.2.6. Sulfate ( $\text{SO}_4^{2-}$ )

Sulphate in study area ranged from 0.0 to 0.47 mg/l with a mean value of 0.15 mg/l (Table 4.4). The WHO has established 250 mg/l as the highest desirable limit of sulfate in drinking water. Sulfate mainly derived from the dissolution of salts of sulfuric acid and abundantly found in almost all water bodies. Accordingly, the laboratory results of study area at all points of sample location were shown in Figure 4.12, and the values were below the maximum permissible limit set by WHO standard. There is no significance effect on the health of the users. Therefore, the results clearly indicate that the concentration of sulfate in study area was suitable for drinking purpose.

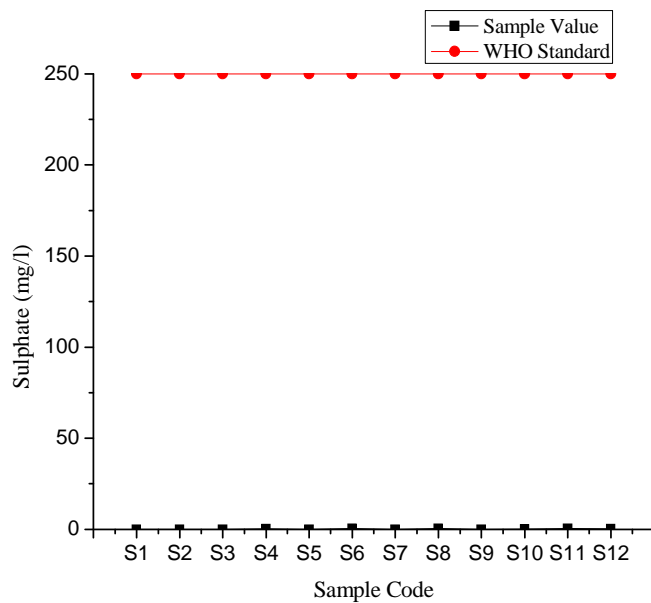


Figure 4.12: Variation of groundwater sulphate in study area

#### 4.2.7. Calcium

Calcium concentration of study area ranged from 2.73 mg/l at S<sub>10</sub> to 32.26 mg/l at S<sub>9</sub> with a mean of 13.87 mg/l. The desirable limit of calcium concentration for drinking water is specified as 75 mg/l (WHO, 2004). The high deficiency of calcium in humans may caused rickets, poor blood clotting, bones fracture etc. and the exceeding limit of calcium produced cardiovascular diseases (Magesh, et al., 2012). The result shows the values were below the maximum permissible limit set by WHO standard. This implies that the source of water is almost soft water and there is no any health effect and economic implication on the users.

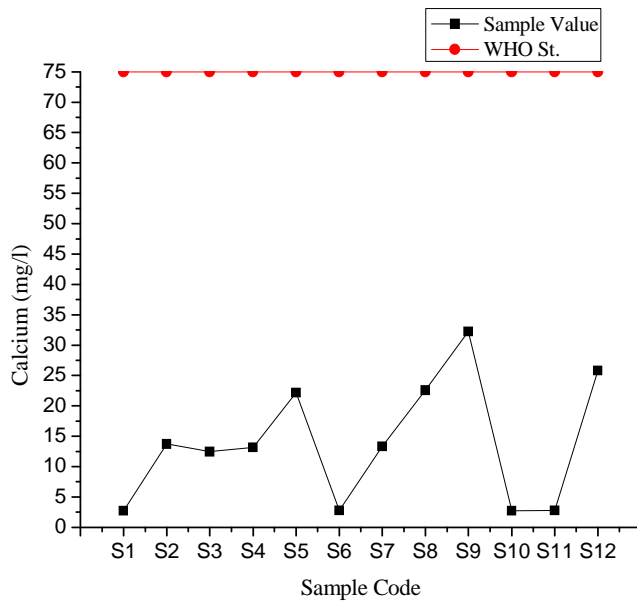


Figure 4.13: Variation of calcium in groundwater in study area

#### 4.2.8. Magnesium

Magnesium concentration of study area ranged from 1.14 mg/l at S<sub>6</sub> to 5.47 mg/l at S<sub>9</sub> with a mean of 2.63 mg/l. According to WHO standards the permissible range of magnesium in water should be 50 mg/l. The quantity of magnesium is significantly low in study area. Such a low concentration somewhat affects health of residents as it is essential for human body. Magnesium was found in less quantity such that the hardness of the water in some water points was related to calcium than magnesium. It can be concluded that the concentration of magnesium in groundwater samples of study area was suitable for drinking purposes.



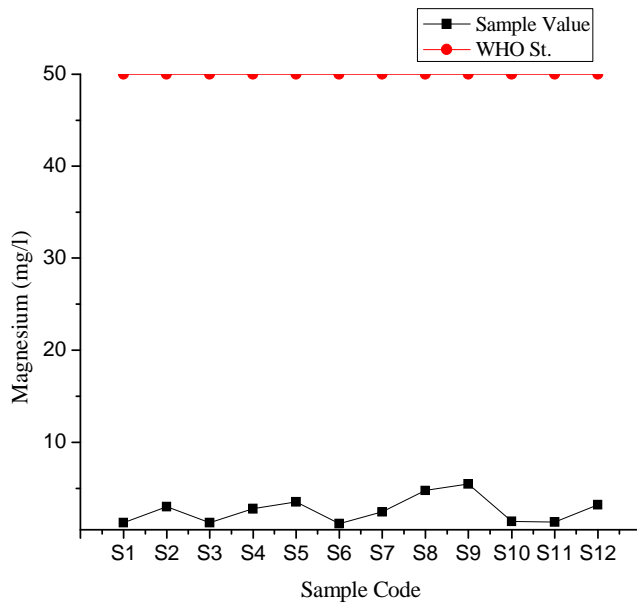


Figure 4.14: Variation of magnesium in groundwater in study area

#### 4.2.9. Sodium

The concentration of  $\text{Na}^+$  is varied from 2.46 at  $\text{S}_5$  to 5.48 mg/l at  $\text{S}_{10}$  with a mean value of 4.14 mg/l (Table 4.1). The WHO (2004) and Ethiopian Standards value for sodium is 200 and 358 mg/l respectively (Table 4.1). Sodium quantity in study area is quietly low which could be harmful for the health of local inhabitants. Proper quantity of sodium in human body prevents many fatal diseases like kidney damages, hypertension, headache etc. The low sodium concentration recorded in all the locations in the study area less than 200mg/l. It can be concluded that all the groundwater samples in study area have low sodium concentration which is below the limit for drinking water. Therefore, the concentration of sodium in study area was suitable for drinking and irrigation purpose.

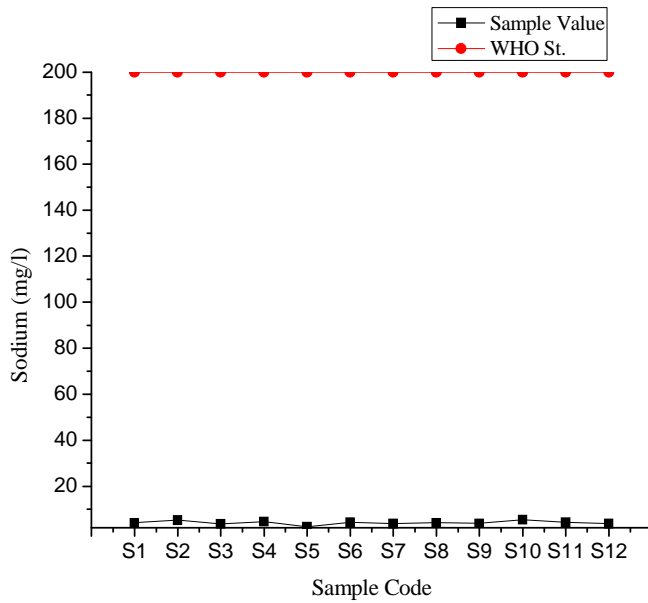


Figure 4.15: Variation of sodium in groundwater in study area

#### 4.2.10. Potassium

The concentration of  $K^+$  in study area is varied from 0.12 at  $S_4$  to 2.53 mg/l at  $S_8$  with a mean value of 1.31 mg/l (Table 4.1). According to WHO standards the permissible limit of potassium is 10 mg/l. These results were meet the WHO standards and may become preventive from diseases associated from potassium extreme deficiency. The laboratory result of potassium concentration at all groundwater sample points of the location of the study area were found below the maximum permissible limit value set by WHO as shown in Figure 4.16.

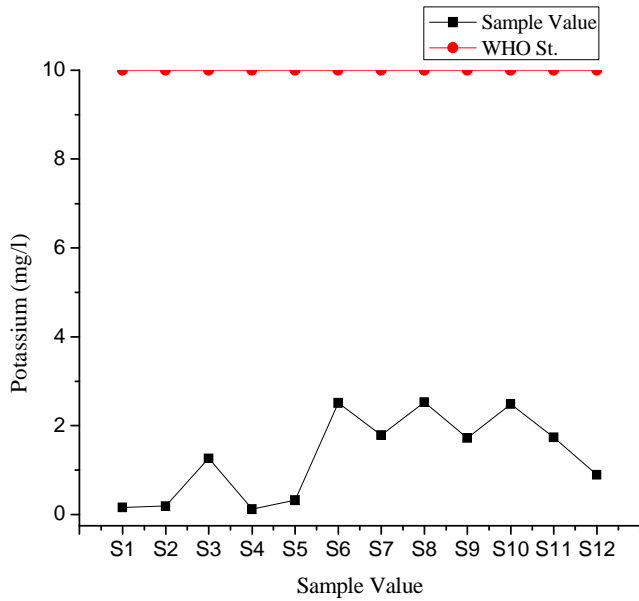


Figure 4.16: Variation of potassium in groundwater in study area

#### 4.2.11. Iron

The concentration of  $Fe^{2+}$  is varied from 0.0 to 0.48 mg/l with a mean value of 0.20 mg/l (Table 4.1). In drinking water the desirable concentration set by WHO (2004) is 0.3 mg/l for iron. Rock and mineral dissolution are causes of high iron levels in groundwater. The higher concentration of Iron ( $> 0.3$  mg/l) in the area may be due to the result of the weathering of rocks and minerals and cast iron pipes during water distribution (Hem,1972). Long term consumption of drinking water with high concentration of iron may leads to liver diseases (Gyamfi et al. 2012). Nearly all the studied sites have acceptable levels of  $Fe^{2+}$  except samples S<sub>2</sub>, S<sub>3</sub>, S<sub>5</sub>, S<sub>8</sub>, and S<sub>12</sub>. It can be concluded that most of the concentration of iron in study area were not suitable for drinking purpose.

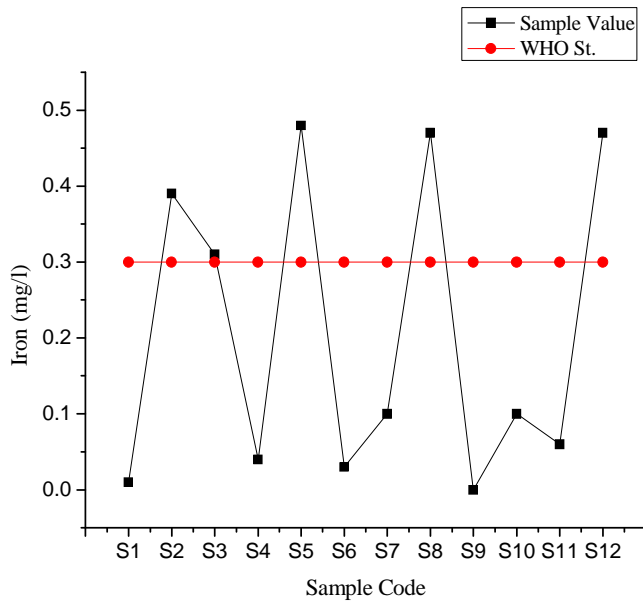


Figure 4.17: Variation of iron in groundwater in study area

#### 4.2.12. Manganese

The concentration of  $Mn^{2+}$  in study area is varied from 0.0 to 0.31 mg/l with a mean value of 0.07 mg/l (Table 4.1). The desirable limit of manganese concentration for drinking water is specified as 0.1 mg/l (WHO, 2004). The result shows that all groundwater samples below the permissible limit except  $S_{10}$  and  $S_{12}$ . The highest value of 0.31 mg/l was recorded at  $S_{10}$  and the lowest value of 0.0 mg/l was recorded at  $S_1$  and  $S_7$ . A high dose of manganese causes apathy, headaches, insomnia and weakness of legs (Amankona, 2010). It can be concluded that most of the concentration of manganese in study area were suitable for drinking purpose. Therefore, there is no health effect regards to this parameters on the customers.

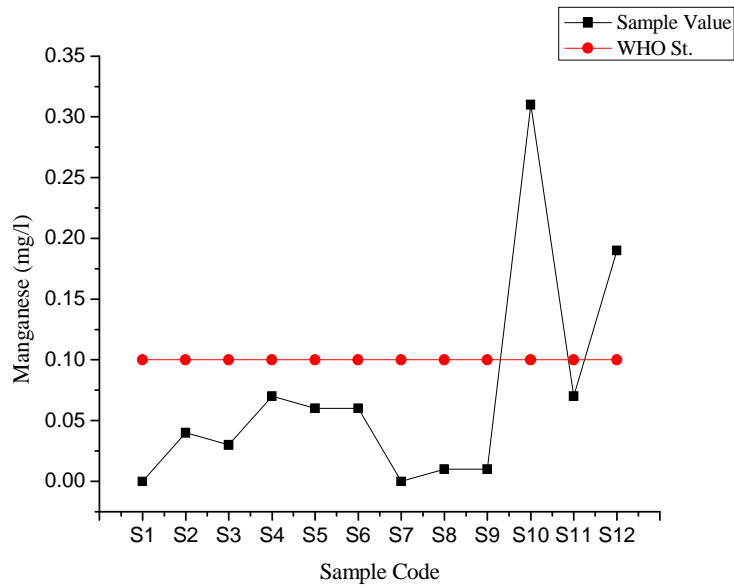


Figure 4.18: Variation of manganese in groundwater in study area

### 4.3. Biological Parameters

#### 4.3.1. Fecal Coli form (FC)

The results of analysis indicated that the values of fecal coliform (FC) ranged from 17 cfu/100ml at S<sub>1</sub> to 396 cfu/100ml at S<sub>10</sub> with a mean value of 144.0 cfu/100 ml (Table 4.4). In drinking water, TC and FC should be absent (WHO, 2004). The danger of coliform presence can rest on the health or sensitivity of the user. The concentration of FC obtained from the groundwater samples exceeds the acceptable limits (0 cfu/100ml) in all the investigated wells, bore holes and protected spring. From the result, it may be concluded that drinking water samples collected from all the water sources are not safe for human consumption.

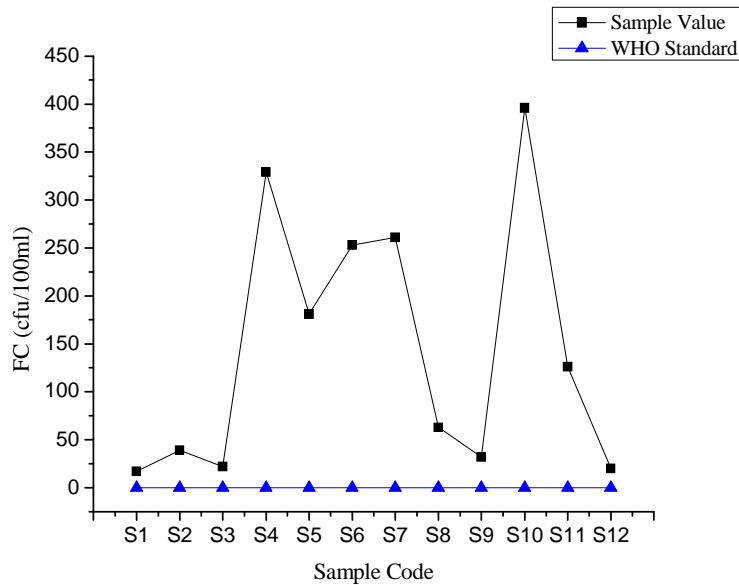


Figure 4.19: Variation of FC in groundwater in study area

#### 4.3.2. Total Coli form (TC)

The results of analysis indicated that the values of TC ranged from 284 cfu/100ml to 4586 cfu/100ml with a mean value of 2262.5 cfu/100 ml (Table 4.4). In drinking water, TC and FC should be absent (WHO, 2004). The presence of bacteria in water not only can cause objectionable odors but also may indicate a breakdown in the disinfection system (Corzatt, 1990). Total coliforms do not positively indicate contamination of fecal origin (Amundson et al., 1988). Only fecal bacteria can positively indicate contamination by feces of humans or other warm-blooded animals (Weigman & Kroehler, 1990). The highest TC may be as a result of the refuse dump, human faeces scattered nearby the spring in the forest, dog excrement, decomposition of plant material by the action of microbial washed down into the soil and domestic animals that normally visit the site to drink and defecate around the water source. Bacterial growth commonly occurs on walls of pipes, valves, pipe fittings, aerators and surface of media in point-of-use products (Regunathan et al., 1983).

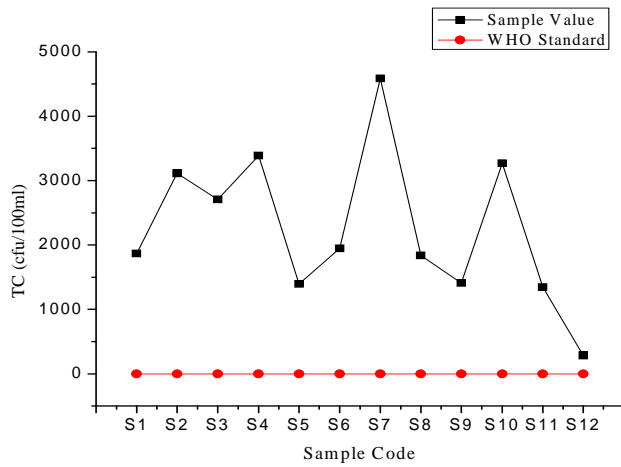


Figure 4.20: Variation of TC in groundwater in study area

Table 4.1: Minimum, maximum and mean physic-chemical and biological parameters of groundwater in study area.

Parameters	Range	Mean
Temp( <sup>0</sup> C)	23.60 - 26.18	24.93
EC( $\mu$ S/cm)	36.73 - 233.0	153.42
pH	4.71 - 6.20	5.66
Turbidity(NTU)	1.06 - 10.33	4.89
DO(mg/l)	2.85 - 3.96	3.29
TDS(mg/l)	53.60 - 174.5	95.84
TH(mg/l as CaCO <sub>3</sub> )	0.0 - 16.50	3.25
TA(mg/l as CaCO <sub>3</sub> )	12.0 - 50.0	27.75
HCO <sub>3</sub> <sup>-</sup> (mg/l as CaCO <sub>3</sub> )	12.0 - 50.0	27.75
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.41 - 2.23	1.29
Cl <sup>-</sup> (mg/l)	4.0 - 18.30	9.46
SO <sub>4</sub> <sup>2-</sup> (mg/l)	0.0 - 0.47	0.15
FC (cfu/100 ml)	17.0 - 396	144.0
TC (cfu/100 ml)	284.0 - 4586	2262.5

#### 4.4. Hydro-geochemical facies

Most natural water can be represented as solution of three cationic constituents,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and alkaline metals and of three anionic constituents,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  and those contributing to alkalinity, i.e.,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ . Therefore, linear plots are most suitable for the representation of groundwater composition. The modified trilinear diagram was presented by Piper (1944). The diagram consists of three distinct fields-two triangular fields and one diamond-shaped field. Different groundwater can be identified by their position in the diamond field. Cations expressed as percentages of total cations in meq/l plot as a single point on the left triangle while anions plot in the right triangle.

Similarities and differences among groundwater samples can be revealed from the trilinear because water of similar qualities will tend to plot together as groups. Distinct groundwater qualities can be quickly distinguished by their plotting in certain areas of the diamond field. The analytical values obtained from the groundwater samples are plotted on Piper trilinear diagram to understand the hydro chemical regime of the study area. The Piper trilinear diagram for the groundwater samples is presented in the Figure 4.9, which clearly explains the variations of cation and anion concentration in the study area.

Table 4.2: Groundwater type of study area

Sample No.	Water Type
S <sub>1</sub>	Na-Ca-HCO <sub>3</sub> -Cl
S <sub>2</sub>	Ca-Mg-Na-Cl-HCO <sub>3</sub>
S <sub>3</sub>	Ca-Na-Cl-HCO <sub>3</sub>
S <sub>4</sub>	Ca-Mg-HCO <sub>3</sub>
S <sub>5</sub>	Ca-Mg-HCO <sub>3</sub> -Cl
S <sub>6</sub>	Na-HCO <sub>3</sub> -Cl
S <sub>7</sub>	Ca-Mg-HCO <sub>3</sub> -Cl
S <sub>8</sub>	Ca-Mg-HCO <sub>3</sub>
S <sub>9</sub>	Ca-Mg-Cl
S <sub>10</sub>	Na-Cl-HCO <sub>3</sub>
S <sub>11</sub>	Na-Cl-HCO <sub>3</sub>
S <sub>12</sub>	Ca-Mg-HCO <sub>3</sub>



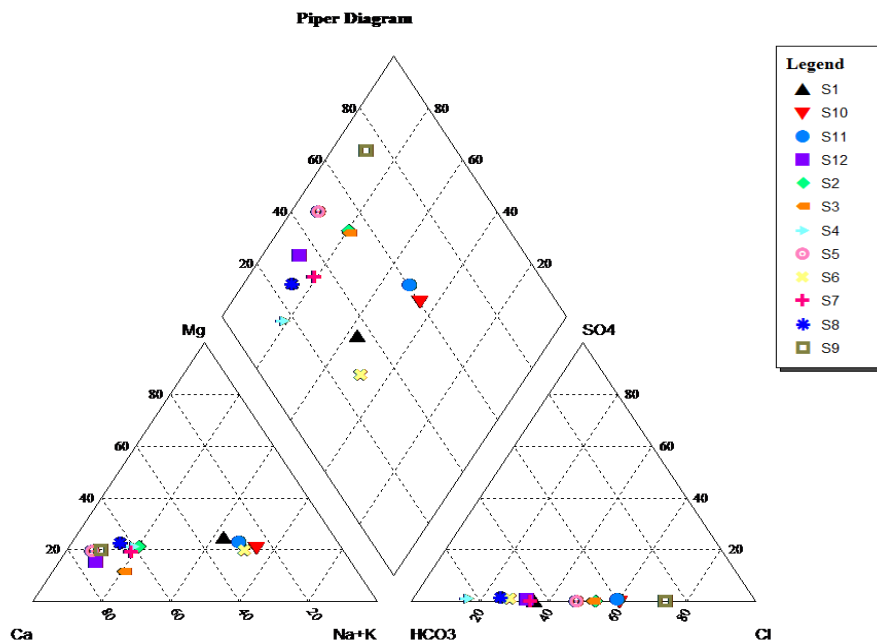


Figure 4.21: Piper plot describing hydro geochemical facies of the study area

#### 4.5. Evaluation of water quality for irrigation

The concentration and composition of dissolved constituents in a water determine its quality for irrigation use, several chemical constituents affect water suitability for irrigation from which the total concentration of the soluble salts and the relative proportion of sodium to calcium and magnesium. Moreover suitability of water for irrigation is depending on the effect of some mineral constituents in the water on both the soil and the plant (Wilcox, 1948 & 1955). The following are the important characteristic properties of groundwater of determine its suitability of irrigation purposes.

##### 4.5.1. Electrical Conductivity

The electrical conductivity of groundwater samples ranges from 36.73 to 233.0 $\mu$ S /cm with a mean value of 153.42 $\mu$ S /cm (Table 4.4). The highest EC (233.0 $\mu$ S /cm) was observed at location S<sub>2</sub> and the lowest EC (36.73 $\mu$ S /cm) was observed at S<sub>7</sub>. The most desirable limit of EC in drinking water is prescribed as 250 $\mu$ S/cm (WHO, 2004). The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. The most influential water quality guideline on crop productivity is

the salinity hazard as measured by electrical conductivity. As observed from the result the classification of the groundwater samples was fallen below the WHO standard. Groundwaters in the study area have low salinity, making them generally suitable for irrigation.

#### 4.5.2. Sodium Adsorption Ratio (SAR)

The SAR value of groundwater samples ranges from 0.17 to 0.67 with a mean value of 0.4 (Table 4.10). The highest SAR (0.67) was observed at location S<sub>10</sub> and the lowest SAR (0.17) was observed at S<sub>9</sub>. SAR was estimated based on the given formula expressed in equation (4.1) for the each sample location of the study area. The suitability of the well and bore hole samples were evaluated by determining the SAR value and these were categorized into different irrigation classes based on salinity and alkalinity hazards.

$$SAR = \frac{[Na^+]}{\sqrt{[Ca^{2+} + Mg^{2+}] \times 0.5}} \dots\dots\dots (4.1)$$

Where [Na<sup>+</sup>], [Ca<sup>2+</sup>], and [Mg<sup>2+</sup>] are in meq/l. Irrigation using water with high SAR values may require soil amendments to prevent long-term damage to the soil, because the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production. SAR for groundwater samples of the study area are less than 10 indicating excellent quality for irrigation and samples fall in excellent (S1) category (Table 2.6) and can be used safely for all types of soil. SAR for groundwater samples of the study area are class C1S1 (Figure 4.22), which indicate all samples fall in excellent category. It was concluded that the SAR value of groundwater samples in study area was suitable for irrigation purpose.



of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (Khodapanah *et al.*, 2009). This causes soil aggregates to disperse, reducing its permeability (Tijani, 1994). Classifying groundwater based on SSP following Wilcox (1955) it was found that all of the groundwater samples have SSP values  $<60$  indicating permissible irrigation water type (Table 2.7).

#### 4.5.4. Residual Sodium Carbonate

RSC has been calculated to determine the hazardous effect of  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  on the quality of water for agricultural purpose (Eaton, 1950). The RSC value was calculated using the formula expressed in equation (4.3).

$$RSC = [\text{CO}_3^{2-} + \text{HCO}_3^-] - [\text{Ca}^{2+} + \text{Mg}^{2+}] \dots\dots\dots (4.3)$$

Where the concentration of all ion are in meq/l.

While RSC  $<1.25$  are safe for irrigation (Table 4.6), it is considered unsuitable if it is greater than 2.5. The high RSC value in water leads to precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (Raghunath, 1987). As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah *et al.*, 2008). The higher concentration of RSC causes the soil structure to deteriorate, the movement of air and water through the soil is restricted; soil alkalinity increases and plant growth is shunted (Reddy and Reddy, 2011). The computed RSC varied from -1.17 to 0.46meq/l (Table 4.6). Most the groundwater samples fall in the suitable class (RSC $< 1.25$ ). Negative RSC indicates that  $\text{Na}^+$  buildup is unlikely since sufficient  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are in excess of what can be precipitated as  $\text{CO}_3^{2-}$ . Based on Residual sodium carbonate (RSC) values, all the samples of study area having values less than 1.25 and were safe for irrigation (Table 4.6).

#### 4.5.5. Magnesium Hazard (MH)

Magnesium is essential for plant growth; however at high content it may associate with soil aggregation and friability (Khodapanah *et al.*, 2009). More  $\text{Mg}^{2+}$  present in waters affects the soil quality converting it to alkaline and decreases crop yield (Joshi *et al.*, 2009). Szabolcs and Darab (1964) proposed MH value for irrigation water as given by the formula expressed in equation (4.4).

$$MH = \frac{[Mg^{2+}] \times 100}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (4.4)$$

Where the concentration of all ions are in meq/l.

In the study area the magnesium hazard values falls in the range of 17.5 to 59.5 % (Table 4.6). In the study area S<sub>1</sub>, S<sub>3</sub>, S<sub>6</sub>, S<sub>8</sub>, S<sub>9</sub>, S<sub>10</sub>, S<sub>11</sub> and S<sub>12</sub> have MH ratio < 50 % (suitable for irrigation) while S<sub>2</sub>, S<sub>4</sub>, S<sub>5</sub> and S<sub>7</sub> falls in the unsuitable category with magnesium hazard > 50 %. MH values > 50 are considered harmful and unsuitable for irrigation purposes.

#### 4.5.6. Kelley's Ratio

Sodium measured against Ca<sup>2+</sup> and Mg<sup>2+</sup> is used to calculate Kelley's ratio. The formula used in the estimation of Kelley's ratio is expressed in equation (4.5).

$$KR = \frac{[Na^+]}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (4.5)$$

A Kelley's Ratio (KR) of more than 1.0 indicates an excess level of sodium in waters. Hence, waters with a Kelley's Ratio less than one are suitable for irrigation, while those with a ratio more than one are unsuitable for irrigation. Kelley's ratio (KR) values for the groundwater of study area are less than 1 and indicate good quality water for irrigation purpose (Table 4.6).

Table 4.3: Minimum, maximum and mean of metal analysis of groundwater in study area.

Parameters	Range	Average	WHO Standards	Ethiopian Standards
Ca <sup>2+</sup>	2.73- 32.26	13.87	75	200
Mg <sup>2+</sup>	1.14 - 5.47	2.63	50	150
Na <sup>+</sup>	2.46 – 5.48	4.14	200	358
K <sup>+</sup>	0.12- 2.53	1.31	10	50
Mn <sup>2+</sup>	0.0 – 0.31	0.07	0.1	0.5
Fe <sup>2+</sup>	0.0 - 0.48	0.20	0.3	0.4

Table 4.4: Study area physical and biological parameters comparisons with standards of WHO (2004) and Ethiopian Standards.

S.N.	Sample Location	Temp( <sup>0</sup> C )	EC (μS/cm )	PH	Turbidity (NTU)	DO (mg/l )	TDS (mg/l)	FC(cfu /100ml )	TC(cfu /100ml )
S <sub>1</sub>	Melka Gasi	23.66	96.46	4.71	3.74	2.85	71.2	17	1867.0
S <sub>2</sub>	Chuta Kaki	24.36	233.0	5.28	8.38	3.38	174.5	39.0	3114.0
S <sub>3</sub>	Chuta Giorgis	24.88	178.8	5.63	4.19	3.02	67.90	22.0	2707.0
S <sub>4</sub>	Choli Michael	24.52	134.5	5.64	1.06	2.88	124.8	329.0	3388.0
S <sub>5</sub>	Wera Seyo	23.60	140.0	5.57	1.80	3.17	53.60	181.0	1396.0
S <sub>6</sub>	Lelisa Seriti	24.49	160.0	5.14	10.33	3.12	66.30	253.0	1945.0
S <sub>7</sub>	Chuta Goci	25.67	36.73	5.66	1.90	3.96	85.20	261.0	4586.0
S <sub>8</sub>	Lelisa Bikilal	26.18	184.50	6.10	4.70	3.27	85.0	63.0	1838.0
S <sub>9</sub>	Bikiltu Tokuma	25.51	195.0	6.20	6.62	3.54	105.4	32.0	1410.0
S <sub>10</sub>	Tole	25.36	200.5	5.81	3.59	3.60	109.40	396.0	3296.0
S <sub>11</sub>	Loya Gefere	24.78	128.50	6.08	5.67	3.25	83.76	118.0	1346.0
S <sub>12</sub>	Lalo Choli	26.16	153.0	6.12	6.64	3.43	123.0	18.0	284.0
	Minimum	23.60	36.73	4.71	1.06	2.85	53.60	17.0	284.0
	Maximum	26.18	233.0	6.20	10.33	3.96	174.50	396.0	4586.0
	Mean	24.93	153.42	5.66	4.89	3.29	95.84	144.0	2262.5
	WHO (2004)	≤ 15	250	6.5-8.5	5	≤ 14	500	0	0
	Ethiopian Standards	NA	NA	6.5-8.5	5	NA	1,500	0	0

NA: Not Available

Table 4.5: Study area chemical parameters comparisons with standards of WHO (2004) and Ethiopian Standards.

S.N.	TH	TA	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
S <sub>1</sub>	0.0	30.0	30.0	0.0	7.50	0.0	1.58
S <sub>2</sub>	5.0	25.0	25.0	0.0	11.5	0.0	1.95
S <sub>3</sub>	0.0	16.0	16.0	0.0	6.50	0.0	1.82
S <sub>4</sub>	0.0	50.0	50.0	0.0	4.0	0.28	1.0
S <sub>5</sub>	0.0	30.0	30.0	0.0	12.5	0.0	0.41
S <sub>6</sub>	0.0	40.0	40.0	0.0	7.50	0.32	0.61
S <sub>7</sub>	16.5	26.0	26.0	0.0	6.75	0.0	2.23
S <sub>8</sub>	0.0	38.0	38.0	0.0	5.75	0.47	1.39
S <sub>9</sub>	0.0	12.0	12.0	0.0	15.0	0.0	0.72
S <sub>10</sub>	10.0	18.0	18.0	0.0	14.2	0.11	1.53
S <sub>11</sub>	0.0	26.0	26.0	0.0	18.3	0.37	0.86
S <sub>12</sub>	7.5	22.0	22.0	0.0	4.0	0.2	1.40
Min	0.0	12.0	12.0	0.0	4.0	0.0	0.40
Max	16.50	50.0	50.0	0.0	18.30	0.47	2.23
Mean	3.25	27.75	27.75	0.0	9.46	0.15	1.29
WHO, 2004	200	100	200	NA	250	250	10
Eth. Std.	500	600	NA	NA	533	483	10

Table 4.6: Irrigation water quality parameters

Sample No.	SAR	SSP	RSC	KR	MH
S <sub>1</sub>	0.51	43.40	0.26	0.75	41.67
S <sub>2</sub>	0.50	35.86	0.0	0.55	59.50
S <sub>3</sub>	0.44	33.0	0.01	0.62	38.46
S <sub>4</sub>	0.45	34.20	0.46	0.51	59.0
S <sub>5</sub>	0.19	15.70	-0.08	0.17	51.72
S <sub>6</sub>	0.53	50.90	0.45	0.76	40.42
S <sub>7</sub>	0.37	35.84	0.16	0.44	54.50
S <sub>8</sub>	0.20	14.24	-0.82	0.12	23.13
S <sub>9</sub>	0.17	9.40	-1.85	0.08	21.80
S <sub>10</sub>	0.67	54.60	0.12	0.95	45.85
S <sub>11</sub>	0.54	48.35	0.20	0.76	44.0
S <sub>12</sub>	0.18	10.47	-1.17	0.10	17.15



## **5. CONCLUSIONS AND RECOMMENDATIONS**

### **5.1. Conclusions**

The groundwater is the main water source in the study area. The main physic-chemical parameters considered for investigation include temperature, turbidity, pH, electrical conductivity, total dissolved solids, total hardness, total alkalinity, carbonate, bicarbonate, calcium, potassium, sodium, magnesium, iron, manganese, chloride, nitrate and sulphate. Bacteriological tests such as faecal coliforms and total coliforms were analyzed. The laboratory results have shown that except for turbidity, total coliform, faecal coliform, iron concentration and pH the remaining all parameters were found within the permissible limit of WHO standard and Ethiopian recommended values concerning the safety and acceptability level. The study of the physic-chemical parameters in the present investigation indicates that the groundwater quality is almost within the standard limits at all locations. Based on the TH and TDS of almost all samples, the groundwater from study area is found to be safe and suitable for drinking purposes.

Generally, concerning the physic-chemical parameters, the water seems to be not safe and there is significant effect on the health of the users. The results of bacteriological analyses have shown that all of the sample points are at very high risk. Also, SAR, RSC and SSP values indicate that almost all the groundwater samples are suitable for irrigation. The dominant hydro chemical facies of groundwater in the study area is Ca–Mg–HCO<sub>3</sub>. Distribution of the groundwater samples in piper diagram reveals that all of the groundwater samples fall under the calcium-magnesium-bicarbonate category. Classification of the water sample for irrigation based on sodium adsorption ratio indicates the entire water sample is good for irrigation. Classification of the water sample for irrigation based on sodium percentage indicates all samples are good for irrigation.

## **5.2. Recommendations**

By recognizing the reality of ground water quality distribution from the study, the following recommendations should be considered.

- ❖ Continuous monitoring of groundwater table along with quality study will minimize the chances of further deterioration.
- ❖ Awareness and training programs should be conducted for the NGO's and the local people for the sustainable use and management of groundwater of the study area.
- ❖ The result shows that the existing groundwater supply of study area is slightly acidic. Therefore, Gimbi District Water Supply Authority should adjust pH ranges by inject Soda Ash (Sodium Carbonate) solution.
- ❖ The result shows that the concentration of iron in most of the groundwater supply of study area is above WHO standard. Therefore, Gimbi District Water Supply Authority should consider the problem and report to Authorized Organization.
- ❖ The result shows that a high degree of faecal and total coliform contamination which are poor and unsuitable for human consumption. Thus, it would be wise that all water sources should be treated with chlorination or boiling before being used
- ❖ The hand dug wells are open, it has to be sealed or closed in order to protect from any water born diseases.

## REFERENCES

- Anonymous, 2008. Assessment of surface water for drinking quality. Directorate of Land Reclamation Punjab, Irrigation and Power Department, Canal Bank, Mughalpora, Lahore, Pakistan.
- American Public Health Association, 1995. Standard Methods for the Examination of Water and Waste, 14<sup>th</sup> Edition Washington D. C. Pp. 76-265
- Appelo, C.A.J. and D. Postma (2005). Geochemistry: Groundwater and pollution. 2nd Ed. Balkema, Rotterdam.
- AYERES R. S and WESTCOT D.W, 1994. Water quality for agriculture. FAO Irrigation and Drainage Paper.
- AYERES R.S (1976). Water Quality for Agriculture. Food and Agricultural Organization of the United Nations, Rome. Irrigation and Drainage paper, No. 29.
- Balakrishnan, P., Saleem, A., and N. D. Mallikarjun , 2011. Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City, Karnataka, India. African Journal of Environmental Science and Technology, Vol. 5, No. 12, Pp: 1069-1084.
- Babu, K.N., Padmalal, D., Maya, K., Sreeja, R. and Arun, P.R, 2007. Quality of Surface and Ground Water Around Tile and Brick Clay Mines in the Chalakudy River Basin, Southwestern India. Jour. Geol. Soc. India, Vol.69, Pp: 279-284.
- Barcelona, M. J., Gibb, J. P., Helfrich, J.A., et al, 1985. Practical guide for groundwater sampling (E. a. N. Resources, Trans.) (Pp. 103): Illinois State Water Survey.
- Bartran, J. and R. Balance, 1996. Water Quality Monitoring: A Practical Guide to the Design and Implementation of Fresh Water Quality Studies and Monitoring Programmes. E and F.N. Spoon: London, UK.
- Bear J., 1979. Hydraulics of Groundwater. McGraw-Hill International Book, New York
- CAWST, 2013. Introduction to Drinking water Quality Testing.
- Central ground water board ministry of water resources government of India, 2010. Ground water quality in shallow aquifer of India.

- Chilton, J, 1996. Water Quality Assessments : A Guide to Use of Biota, Sediments and Water in Environmental Monitoring . UNESCO/WHO/UNEP, Second Edition.
- Crossgrove, J. and W. Zheng, 2004. Manganese toxicity upon overexposure. *NMR Biomedicine*, Vol. 17, Pp: 544–553.
- Doneen, L.D., 1964. Water quality for agriculture. Department of Irrigation, University of California, Davis, 48.
- Doria M. D. F, 2010. Factors influencing public perception of drinking water quality. *water policy* Vol.12, Pp: 1-19.
- Eaton, F.M., 1950. Significance of carbonate in irrigation waters. *Soil Science*, Vol. 69, Pp: 123-133.
- Elton, N.W., W.J. Elton and J.P. Narzareno, 1963. Pathology of acute salt poisoning in infants. *American Journal of clinical pathology*, Vol. 39, Pp: 252-264.
- Emsley, J., 2003. Manganese. *Nature's building blocks: an A–Z guide to the elements*, USA: Oxford University, Pp: 249-253.
- Fetter, CW., 1994. *Applied Hydrogeology*, Third Edition. Prentice Hall, New Jersey.
- Freeze, R. A., Cherry, J. A., 1979. *Groundwater*: Prentice Hall Inc, New Jersey
- Gadgil A., 1998. *Drinking water in developing countries*. Lawrence Berkeley National laboratory, environmental energy technologies division, 1 Cyclotron Road, California, s.l.
- Gupta, D. P., Sunita and J. P. Saharan, 2009. *Physiochemical Analysis of Ground Water of Selected Area of Kaithal City (Haryana) India*, *Researcher*, 1(2), Pp: 1-5.
- HARTER T., 2003. *Groundwater Quality and Pollution*. FWQP Reference Sheet 11.2, University of California.
- Hem, J.D., 1985, *Study and interpretation of the chemical characteristics of natural water*: U.S. Geological Survey Water-Supply Paper 2254, 263 p.
- Hounslow, A. W., 1995. *Water quality data; analysis and interpretation*. United States of America: LEWIS.

- Iliopoulos, V., Stamatis, G., and Stournaras, G., 2011. Marine and human activity effects on the groundwater quality of Thriassio Plain, Attica, Greece. [Advances in the Research of Aquatic Environment]. Environmental Earth Sciences, Pp: 409-419.
- Jensen, P.K., J.H.J. Ensink, G. Jayasinghe, W. Van der Hoek, S. Cairncross and A. Dalsgaard, 2003. Effect of Chlorination of Drinking-water on Water Quality and Childhood Diarrhoea in a Village in Pakistan. 21, Pp:26-31.
- Joshi, D.M., A. Kumar and N. Agrawal, 2009. Assessment of the irrigation water quality of River Ganga in Haridwar District. Rasayan journal of chemistry, 2(2), Pp: 285-292.
- Karthikeyan.N, Saranya.A, and Sashikkumar M.C., 2013. Spatial analysis of Ground water quality for virudhunagar district, Tamil Nadu Using GIS.
- Kebede T. and Tadesse H.M., (1990). Engineering Geological Map of Addis Ababa, EIGS (unpublished report)
- Khodapanah, L., W.N.A. Sulaiman and N. Khodapanah, 2009. Groundwater Quality Assessment for different Purposes in Eshtehard District, Tehran, Iran. European Journal of Scientific Research, 36(4), Pp: 543-553.
- Madrid, Y., and Zayas, Z. P., 2007. Water sampling: Traditional methods and new approaches in water sampling strategy.
- Mazor, E., 1991. Applied Chemical and Isotopic Groundwater Hydrology. USA, Canada and Latin America: HALSTED PRESS.
- Michael H., 2006. Drinking water quality assessment and treatment in east Timor a case study: Tangkae, the University of East Timor.
- Mirabbasi, R., S.M. Mazlounzadeh and M.B. Rahnama, 2008. Evaluation of irrigation water quality using fuzzy logic. Research Journal of Environmental Sciences, Vol. 2, No.5, Pp: 340-352.
- Muhammad, M., Samira, S., Fayal, A., & Farrukh, J., 2013. Assessment of Drinking Water Quality and its impact on Residents Health in Bahawalpur City. *International Journal of Humanities and Social Science*, Vol.3, No.15.

- Nickson, R. T., McArthur, J. M., Shrestha, B., Kyaw- Nyint, T.O., Lowry, D., Arsenic and other drinking water quality issues, Muzaffargarh District. Pakistan Applied Geochemistry, Pp: 55–68, 2005.
- Patil, P. R., Badgajar, S. R., and Warke A. M. 2001. Oriental J Chem. 17 (2), Pp: 283.
- Patil, V.T., and Patil, P.R., 2010. Physicochemical Analysis of Selected Groundwater Samples of Amalner Town in Jalgaon District, Maharashtra, India. E-Journal of Chemistry. 7(1), Pp: 111-116.
- Raghunath, M., 1987. Groundwater, 2nd Ed., Wiley Eastern Ltd., New Delhi, India.
- Ramesh.K and Elango,L., 2011. Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India, Environ Monit Assess DOI 10.1007/s10661-011-2231-3.
- Reddy, K.S.S.N. and T.A. Reddy, 2011. Qualitative characterization of groundwater resources for irrigation: a case study from Srikakulam area, Andhra pradesh, India. International Journal of Engineering Science and Technology, 3(6), Pp: 4879-4887.
- Sadashivaiah, C., C.R. Ramakrishnaiah and G. Ranganna, 2008. Hydrochemical Analysis and Evaluation of Groundwater Quality in Tumkur Taluk, Karnataka State, India. Int. J. Environ. Res. Public Health, 5(3): 158-164
- Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsas, D., Anthemidis, A., Sofoniou, M. and Kouimtzis, T.H., 2003. Assessment of the surface water quality in Northern Greece. Water Research, Vol.37, Pp: 4119–4124.
- Shahnawaz, M., and Singh K. M. 2009. Ground Water Quality of Piro and Jagdishpur Blocks of Bhojpur District: A Middle Gangatic Plain. International Journal of Pharmaceutical Quality Assurance. 1(1):9-12.
- Sheat A., 1992. Public perception of drinking water quality. Should we care? Paper presented at the New Zealand Water Supply and Disposal Association Annual Conference. Cited in Syme & Williams (1993). Slovic, P. (2000). The Perception of Risk. Earthscan, London.

- Sreedevi, P.D. Groundwater quality of Pageru river basin, Cuddepah district Andhra Pradesh. *J. Geol. Soc. India*, Vol.64 (5), 2004: pp.619– 636.
- Stevens M., Ashbolt N. and Cunliffe D. (2003). Recommendation to change the use of coli form as microbial indicators of drinking water quality. Australia Government National Health and Medical Research Council.
- Subba Rao, N., 2006. Seasonal variation of groundwater quality in a part of Guntur District, Andhra Pradesh, India. *Journal Environ Geol* 49: 413–429.
- Thorne, D.W. and H.B. Peterson, 1954. *Irrigated soils*, London: Constable and Company.
- Todd DK. 1980. *Groundwater hydrology* [M], 2nd edn. Wiley, New York, p 535.
- Trivedy, R.K. and P.K. Geol, 1984. *Chemical and biological methods for water pollution studies*. Karad: Environ Publications.
- TWDB (Texas Water Development Board), 2002, *People and groundwater*. Water for Texas. Texas Water Development Board, Document no.GP-7-1, Austin, Texas, 156 pp. <<http://www.esi.utexas.edu>> (accessed on 29 November 2008).
- UNEP , 2003. *Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management*.
- UNICEF, 2008. *UNICEF hand book on water quality*. United Nations Children's Fund (UNICEF), New York.
- Van Koppen, B., Moriarty, P., Boelee, 2006. *Multiple-Use water Services to Advance the Millennium Development Goals*. Research Report 98, IWMI, Colombo Sri Lanka.
- WHO, 2011. *Guidelines for Drinking-Water Quality, Fourth Edition*. WHO, Geneva, Switzerland.
- Wilcox L.V., *The quality of water for irrigation use* vol. 40. US Department of Agriculture Technology Bulletin 962, Washington DC, 1948.
- ZHANG H., 1990. *Classification of Irrigation Water Quality*. Oklahoma State University Soil, Water and Forage Analytical Laboratory. Oklahoma Cooperative Extension, Factsheet PSS-2401-4.

## ANNEXES

### Annex 1

#### 1A. Temperature, Electrical Conductivity, P<sup>H</sup>, TDS and Dissolved oxygen determination

Temperature, conductivity, pH, TDS and DO of the water samples were determined with a multi parameter probe. The meter was calibrated prior to use with 0.001 N and 0.10 N standard potassium chloride solutions (according to the manufacturer's specifications) and buffer standards of pH 4, 7 and 9.2 at room temperature. The analysis involved dipping the probe of the meter directly into 100 ml water sample measured in a beaker, then taking the reading as displayed on the screen of the equipment. After each measurement, the probe was rinsed in distilled water and the display mode adjusted to the standardization value for measurement of the next parameter.

#### 1B. Turbidity Determination

Turbidity was determined using the Nephelometric method (APHA, 1998) with turbidity meter in which the sample was shaken vigorously and transferred into a sample cell to at least two-thirds full. The sample cell was placed in the turbid meter and the appropriate range on the turbid meter was selected. The stable turbidity reading was then recorded.

#### 1C. Chloride Determination

For the determination of Chloride, Mohr's argentometric titration method was used.

One ml potassium chromate was added in 20 ml sample in a 250 ml conical flask and the solution turns yellow in color. The solution was titrated with 0.0141N AgNO<sub>3</sub> till the first brick red appears. This was the end point and noted down the volume of AgNO<sub>3</sub> added (V<sub>s</sub>).

#### Blank titration

- ❖ 1ml potassium chromate was added in 20 ml distilled water in a 250 ml conical flask and the solution turns yellow in color. The solution was titrated with 0.0141N AgNO<sub>3</sub> till the first brick red appears. This was the end point and noted down the volume of AgNO<sub>3</sub> added for distilled water (V<sub>b</sub>).
- ❖ Calculation :



$$\text{Chloride (mg/l)} = \frac{(V_s - V_b) \times N \times 1000 \times 35.45}{S} \dots\dots\dots (3.1)$$

Where;  $V_s$  = volume of  $\text{AgNO}_3$  for sample

$V_b$  = volume of  $\text{AgNO}_3$  for blank

$S$  = volume of sample (ml)

1D. Total Hardness Determination

A 20 ml sample was measured into a 250 ml conical flask. To this was added 5 drops of buffer solution and was then followed by the addition of 4-5 drops of erichome black-T was mixed. The mixture was titrated with 0.02 N EDTA solutions until the wine red color of the solution changed to blue (end point) and noted down the burette reading.

Calculation: Total hardness (mg/L) =  $\frac{T \times N \times 50 \times 1000}{V} \dots\dots\dots (3.2)$

Where;  $T$  = volume of EDTA

$N$  = Normality

$V$  = volume of sample

1E. Total Alkalinity Determination

A 50 ml of sample was pipette into a conical flask and 4-6 drops of phenolphthalein indicator was added in the solution and finally 3 drops of bromocresol was mixed with it respectively. In the samples, carbonates were absent as there was no color change appeared after addition of phenolphthalein indicator. To the same flask, 4 drops of methyl orange was added and titrated with 0.02N  $\text{H}_2\text{SO}_4$  continued until the color changed from yellow to brick red which was the end point of bicarbonate and jot down the value ( $V_2$ ).

Calculation:

Total alkalinity (mg / L) =  $\frac{\text{Volume of sulphuric acid (V2)} \times N \times 50 \times 1000}{\text{Volume of sample taken}} \dots\dots\dots (3.3)$

$$\text{HCO}_3^- \text{ as mg CaCO}_3 / \text{L} = \frac{T - (5 * 10^{(PH-10)})}{1 + 0.94 * 10^{(PH-10)}} \dots\dots\dots (3.4)$$

$$\text{CO}_3^{2-} \text{ as mg CaCO}_3 / \text{L} = 0.94 * \text{HCO}_3^- * 10^{(PH-10)} \dots\dots\dots (3.5)$$

Where:  $T$  = total alkalinity as  $\text{mg CaCO}_3/\text{l}$

Determination of Bicarbonate and Carbonate (Standard Analytical Procedures for Water Analysis, May 1999).

Alkalinity result	Bicarbonate, mg CaCO <sub>3</sub> /L	Carbonate, mg CaCO <sub>3</sub> /L
P = 0	T	0
P < ½T	T-2P	2P
P = ½T	0	2P
P > ½T	0	2(T-P)
P = T	0	0

Where; P = Phenolphthalein alkalinity

T = Total alkalinity

#### 1F. Sulfate Determination

The water sample was checked with qualitative test whether the concentration of the sulfate exists or not before going to measure by UV-Spectrophotometer.

Qualitative test:

Two ml of the 37% HCl and 5ml of 10% BaCl<sub>2</sub> was added to 7ml water sample respectively. The sample was heated on flame to identify the existence of sulfate concentration in the water sample until white precipitation appeared. Finally the end result was white precipitation appeared, and then analysis indicate that sulfate concentration in the sample.

#### 1G. Determination of Calcium (Ca<sup>2+</sup>) and Magnesium (Mg<sup>2+</sup>)

50 ml of water sample was diluted to 50 ml such that the calcium content was 5 - 10 mg. Samples which contain alkalinity greater than 300 mg/L was neutralized with acid and boiled for 1 minute and cooled before titration. 2 ml NaOH solution was produced a pH of 12 to 13 and the titration was immediately started after addition of the alkali and then 0.1 - 0.2 indicators was added. Finally, titrated with EDTA solution, with continuous mixing, till the color was changed from pink to purple. The end point was checked by adding 1 to 2 drops excess titrant to make certain that no further color change occurs.

Calculation:

$$\text{Ca (mg / L)} = \frac{A \times B \times 400.8}{V} \dots\dots\dots (3.6)$$

$$\text{Calcium hardness as CaCO}_3 \text{ (mg / L)} = \frac{A \times B \times 1000}{V} \dots\dots\dots (3.7)$$

Where; A = ml titrant for sample

$$B = \frac{\text{mL of standard calcium solution taken for titration}}{\text{mL EDTA titrant}} \dots\dots\dots (3.8)$$

$$\text{Mg (mg/L)} = (\text{Total Hardness as mg CaCO}_3\text{/L} - \text{Calcium Hardness as mg CaCO}_3\text{/L}) \times 0.243$$

#### 1H. Determination of Sodium (Na<sup>+</sup>) and Potassium (K<sup>+</sup>)

##### Sodium

A blank and Sodium calibration standards was prepared in the ranges of 0-100, 0-10, or 0-1 mg Na/L. The instrument was set zero with standard containing no sodium and measured emission at 589nm and calibration curve was also prepared. The sodium concentration of the sample was determined from the curve.

Calculation:

$$\text{Mg Na/L} = \text{mg Na/L from the calibration curve} \times \text{Dilution} \dots\dots\dots (3.9)$$

$$\text{Where: Dilution} = \frac{\text{ml sample} + \text{ml distilled water}}{\text{ml sample}} \dots\dots\dots (3.10)$$

##### Potassium

A blank and Potassium calibration standards was prepared in the ranges of 0-100, 0-10, or 0-1 mg K/L. The instrument was set zero with standard containing no potassium and measured emission at 766 nm and calibration curve was also prepared. The Potassium concentration of the sample was determined from the curve.

Calculation:

$$\text{Mg K/l} = \text{mg K/l from the calibration curve} \times \text{Dilution} \dots\dots\dots (3.11)$$

$$\text{Where; Dilution} = \frac{\text{ml sample} + \text{ml distilled water}}{\text{ml sample}} \dots\dots\dots (3.12)$$

#### 1I. Analysis of Iron and Manganese

The concentrations in mg/L of two metals were determined in the samples namely, Fe and Mn with the Atomic Absorption Spectrophotometer(Perkin Elmer Analyst 400). The flame

used for the analysis was air-acetylene mixture. A 100ml stock solution of two elements solution was obtained from the laboratory. Standard solutions ranging from 0.2 to 5.0mg/l were prepared for calibration curves of those metals. A blank analysis was performed with distilled water treated to the sample treatment. The following concentrations of metal solutions were prepared to determine the baseline absorbance value at Fe: 5.5 mg/l and Mn: 10 mg/l. The metal concentrations were determined one after the other using their respective hollow cathode lamps (HCL) and calibration curves. Air-acetylene wave flame was used for the analysis. The respective wavelengths employed for the metal determinations were Fe at 248.7 nm and Mn at 525 nm.

#### 1J. Microbiological analysis of water samples

Fecal coliform and total coliform bacteria were determined using the membrane-filter technique (APHA, 1992). One hundred milliliters of each sample were aseptically filtered through sterile 0.45µm-pore size membrane filters (Whatman) and the filters transferred onto agar nutrient (MacFaddin, 1985) with rosolic acid in glass Petri dishes for Coliform. Petri dish was closed and labeled at the top of the lid with code number of the water sample and incubated at 37<sup>0</sup>C for 24 hr. Upon completion of the incubation period typical blue colored for Fecal Coliform and both red and blue colony for Total coliform bacteria.

### **Annex 2**

#### 2A. Determination of Irrigation water quality

##### Determination of SAR

SAR is a measure of alkali/sodium hazard to crops and it was estimated by the formula expressed in equation (3.13).

$$SAR = \frac{[Na^+]}{\sqrt{[Ca^{2+} + Mg^{2+}] \times .5}} \dots\dots\dots (3.13)$$

Where [Na<sup>+</sup>], [Ca<sup>2+</sup>] and [Mg<sup>2+</sup>] are concentration of Na<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> in meq/l, respectively.

#### 2B. Determination of SSP

SSP is computed with respect to the relative proportions of cat ions present in water, where the concentrations of ions are expressed in meq/l using the formula expressed in equation (3.14).

$$SSP = \frac{[Na^+ + K^+] \times 100}{[Ca^{2+} + Mg^{2+} + Na^+ + K^+]} \dots\dots\dots (3.14)$$

Where  $[Na^+]$ ,  $[Ca^{2+}]$  and  $[Mg^{2+}]$  are concentration of  $Na^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$  in meq/l, respectively.

### 2C. Determination of RSC, KR and MH

The RSC value was calculated using the formula expressed in equation (3.15)

$$RSC = [CO_3^{2-} + HCO_3^-] - [Ca^{2+} + Mg^{2+}] \dots\dots\dots (3.15)$$

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

$$KR = \frac{[Na^+]}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (3.16)$$

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

$$MH = \frac{[Mg^{2+}] \times 100}{[Ca^{2+} + Mg^{2+}]} \dots\dots\dots (3.17)$$

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

### Annex 3

#### A) Results of the physical analysis of groundwater sample for the study area

Parameters	Triplicate											
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>
Temp (°c)	23.60	24.20	24.80	24.40	23.70	24.30	25.60	26.00	25.50	25.20	24.80	26.10
	23.68	24.50	24.98	24.52	23.65	24.55	25.70	26.16	25.62	25.60	24.65	26.10
	23.70	24.40	24.86	24.64	23.46	24.62	25.70	26.40	25.42	25.30	24.90	26.30
<b>Average</b>	23.66	24.36	24.88	24.52	23.60	24.49	25.67	26.18	25.51	25.36	24.78	26.16
p <sup>H</sup>	4.80	5.40	5.80	5.60	5.50	5.00	5.90	5.60	6.20	5.74	6.10	6.00
	4.74	5.24	5.60	5.76	5.62	5.18	5.58	6.62	6.30	5.74	5.95	6.12
	4.60	5.20	5.50	5.58	5.60	5.24	5.50	6.10	6.12	5.96	6.20	6.24
<b>Average</b>	4.71	5.28	5.63	5.64	5.57	5.14	5.66	6.10	6.20	5.81	6.08	6.12
EC(µs/cm)	96.6	234.0	178.5	134.5	140.0	160.4	36.4	185.0	194.8	201.0	128.0	153.0
	95.8	232.6	178.0	134.0	140.4	159.6	36.8	184.0	194.8	200.6	128.6	152.8
	97.0	232.4	180.0	135.0	139.8	160.0	37.0	184.7	195.4	200.0	129.0	153.4
<b>Average</b>	96.46	233.0	178.8	134.5	140	160.0	36.73	184.5	195	200.5	128.5	153.0
TDS (mg/l)	70.2	174.5	68.30	122.0	52.20	65.80	84.60	86.60	106.20	110.30	84.00	125.0
	72.0	176.0	69.20	128.0	54.60	67.60	82.90	84.40	104.90	108.00	82.70	121.0
	71.4	173.0	66.20	124.6	54.00	65.50	88.10	84.00	105.10	110.00	84.60	123.0
<b>Average</b>	71.2	174.5	67.90	124.8	53.60	66.30	85.20	85.0	105.4	109.4	83.76	123.0
Turbidity(NT U)	3.80	8.49	4.26	1.00	1.70	10.00	2.00	4.50	6.60	3.62	5.60	6.54
	3.72	8.32	4.14	1.10	1.84	10.80	1.92	4.76	6.54	3.53	5.74	6.76
	3.70	8.34	4.18	1.10	1.86	10.20	1.80	4.84	6.72	3.64	5.66	6.64
<b>Average</b>	3.74	8.38	4.19	1.06	1.80	10.33	1.90	4.70	6.62	3.59	5.67	6.64
DO (mg/l)	2.84	3.41	3.00	2.90	3.10	3.16	4.00	3.32	3.54	3.60	3.26	3.40
	2.88	3.37	2.96	2.87	3.18	3.10	3.96	3.30	3.56	3.62	3.27	3.46
	2.85	3.38	3.10	2.87	3.23	3.12	3.94	3.20	3.54	3.62	3.24	3.45
<b>Average</b>	2.85	3.38	3.02	2.88	3.17	3.12	3.96	3.27	3.54	3.60	3.25	3.43

## Annex 4

### A) Results of the chemical analysis of groundwater sample for the study area

Parameter	Triplicate													
	Trial	Unit	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>
Cl <sup>-</sup>	1	ml	0.8	0.7	0.7	0.6	0.8	0.8	0.7	0.5	1.0	1.1	1.3	0.6
	2	ml	0.5	0.8	0.5	0.4	0.8	0.5	0.5	0.6	0.9	0.9	1.1	0.4
	3	ml	0.5	0.8	0.5	0.4	0.8	0.5	0.5	0.5	0.8	0.9	0.7	0.4
	Av	ml	0.6	0.76	0.56	0.46	0.8	0.6	0.57	0.53	0.9	0.97	1.03	0.46
	B	ml	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	S	ml	20	20	20	20	20	20	20	20	20	20	20	20
	V <sub>D</sub>	ml	20	20	20	20	20	20	20	20	20	20	20	20
	N	N	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141	0.0141
	Cl <sup>-</sup>	mg/l	7.5	11.5	6.5	4.0	12.5	7.5	6.75	5.75	15	14.2	18.3	4.0
SO <sub>4</sub> <sup>2-</sup>		mg/l	0.0	0.0	0.0	0.28	0.0	0.33	0.0	0.48	0.0	0.12	0.38	0.2
			0.0	0.0	0.0	0.28	0.0	0.32	0.0	0.48	0.0	0.12	0.36	0.2
			0.0	0.0	0.0	0.28	0.0	0.32	0.0	0.46	0.0	0.11	0.37	0.2
Mean			0.0	0.0	0.0	0.28	0.0	0.32	0.0	0.47	0.0	0.11	0.37	0.2
TH	1	ml	0.0	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2	0.0	0.2
	2	ml	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.1
	3	ml	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.15
	Av	ml	0.0	0.1	0.0	0.0	0.0	0.0	0.33	0.0	0.0	0.2	0.0	0.15
	V	ml	20	20	20	20	20	20	20	20	20	20	20	20
	N	N	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	TH	mg/l	0.0	5.0	0.0	0.0	0.0	0.0	16.5	0.0	0.0	10.0	0.0	7.5
TA	1	ml	1.45	1.25	0.8	2.50	1.48	2.0	1.1	1.90	0.6	1.0	1.2	1.1
	2	ml	1.50	1.25	0.75	2.52	1.50	1.9	1.2	1.90	0.8	0.90	1.2	1.1
	3	ml	1.50	1.24	0.8	2.48	1.50	2.1	1.2	1.88	0.7	0.80	1.3	1.2

	Av	ml	1.50	1.25	0.8	2.50	1.50	2.0	1.2	1.90	0.6	0.90	1.2	1.1
	V	ml	50	50	50	50	50	50	50	50	50	50	50	50
	N	N	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	TA	mg/l	30.0	25.0	16.0	50.0	30.0	40.0	26.0	38.0	12.0	18.0	26.0	22.0
<b>HCO<sub>3</sub><sup>-</sup></b>		mg/l	30.0	25.0	16.0	50.0	30.0	40.0	26.0	38.0	12.0	18.0	26.0	22.0
<b>CO<sub>3</sub><sup>2-</sup></b>		mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0
<b>NO<sub>3</sub><sup>-</sup></b>		mg/l	1.60	2.0	1.80	1.0	0.42	0.60	2.20	1.40	0.74	1.6	0.86	1.4
			1.56	1.90	1.86	1.10	0.40	0.62	2.21	1.37	0.71	1.5	0.88	1.4
			1.58	1.96	1.82	1.0	0.42	0.62	2.30	1.41	0.73	1.5	0.86	1.4
<b>Mean</b>			1.58	1.95	1.82	1.0	0.41	0.61	2.23	1.39	0.72	1.53	0.86	1.4

B: volume of Blank

S = V: Volume of Sample

V<sub>D</sub>: Volume of distilled water

N: Normality for (Chloride, 0.0141 AgNO<sub>3</sub> and Total Alkalinity, 0.02H<sub>2</sub>SO<sub>4</sub><sup>2-</sup>)



## Annex 5

### A) Results of the metal analysis of groundwater sample for the study area

Sample Code	Triplicate						
		Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Mn <sup>2+</sup>	Fe <sup>2+</sup>
S <sub>1</sub>		2.60	1.00	4.10	0.10	0.00	0.01
		3.00	1.40	4.20	0.20	0.00	0.02
		2.66	1.38	4.16	0.18	0.00	0.01
	Mean	2.75	1.26	4.15	0.16	0.00	0.01
S <sub>2</sub>		13.80	2.90	5.30	0.16	0.06	0.38
		13.40	3.20	5.26	0.22	0.04	0.42
		14.0	2.85	5.28	0.20	0.04	0.39
	Mean	13.73	2.98	5.28	0.19	0.04	0.39
S <sub>3</sub>		13.80	1.15	3.70	1.26	0.04	0.28
		12.00	1.40	3.66	1.24	0.03	0.34
		11.60	1.26	3.50	1.32	0.03	0.32
	Mean	12.46	1.27	3.62	1.27	0.03	0.31
S <sub>4</sub>		12.00	2.60	4.30	0.10	0.06	0.05
		11.10	3.0	4.90	0.12	0.08	0.04
		13.15	2.68	4.50	0.16	0.09	0.04
	Mean	12.0	2.76	4.56	0.12	0.07	0.04
S <sub>5</sub>		21.0	3.30	2.40	0.36	0.05	0.48
		23.0	3.46	2.65	0.28	0.08	0.46
		22.50	3.88	2.34	0.34	0.07	0.50
	Mean	22.16	3.54	2.46	0.32	0.06	0.48
S <sub>6</sub>		2.80	1.00	4.10	2.50	0.08	0.03
		2.00	1.24	4.20	2.58	0.06	0.04
		3.60	1.20	4.40	2.46	0.05	0.03
	Mean	2.80	1.14	4.23	2.51	0.06	0.03

S <sub>7</sub>		13.00	2.40	3.50	1.80	0.00	0.09
		14.90	2.16	3.85	1.72	0.00	0.12
		12.0	2.80	3.70	1.85	0.00	0.10
	Mean	13.30	2.45	3.68	1.79	0.00	0.10
S <sub>8</sub>		22.0	4.60	3.90	2.60	0.01	0.48
		23.40	5.0	4.40	2.48	0.02	0.46
		22.50	4.72	4.20	2.52	0.02	0.49
	Mean	22.60	4.77	4.16	2.53	0.01	0.47
S <sub>9</sub>		32.80	5.80	3.80	1.72	0.02	0.00
		30.40	5.42	4.20	1.80	0.01	0.00
		33.60	5.20	4.10	1.64	0.02	0.00
	Mean	32.26	5.47	4.0	1.72	0.01	0.00
S <sub>10</sub>		2.00	1.44	5.40	2.40	0.33	0.10
		3.20	1.66	5.58	2.60	0.30	0.13
		3.0	1.12	5.46	2.48	0.32	0.09
	Mean	2.73	1.40	5.48	2.49	0.31	0.10
S <sub>11</sub>		2.90	1.30	4.30	1.70	0.06	0.06
		3.50	1.46	4.22	1.78	0.08	0.07
		2.0	1.25	4.48	1.76	0.08	0.05
	Mean	2.80	1.33	4.33	1.74	0.07	0.06
S <sub>12</sub>		26.00	3.0	3.80	0.86	0.26	0.48
		24.50	3.36	3.62	0.90	0.24	0.45
		27.0	3.24	3.92	0.92	0.25	0.48
	Mean	25.80	3.20	3.78	0.89	0.19	0.47

## Annex 6

### A) Results of Bacteriological quality of the groundwater samples for the study area

Parameters	Triplicate											
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>
FC (cfu/100 ml)	14	42	26	340	180	270	262	65	42	408	120	15
	18	35	22	312	200	230	280	56	30	384	108	18
	20	39	18	336	164	258	240	68	24	396	126	20
<b>Average</b>	17	39	22	329	181	253	261	63	32	396	118	18
TC (cfu/100 ml)	1800	3640	2260	3480	1282	1620	4800	1900	1330	3400	1380	228
	1920	2442	3662	3276	1674	1881	4700	1415	1200	3160	1258	364
	1880	3260	2200	3410	1234	2335	4260	2200	1700	3248	1400	260
<b>Average</b>	1867	3114	2707	3388	1396	1945	4586	1838	1410	3269	1346	284

## Annex 7

A) Simplified results of the physical, chemical and biological analysis of groundwater sample for the Second sampling trip.

Parameters	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>
Temp	23.66	24.36	24.88	24.52	23.60	24.49	25.67	26.18	25.51	25.36	24.78	26.16
EC	96.46	233.0	178.8	134.5	140.0	160.0	36.73	184.5	195.0	200.5	128.5	153.0
PH	4.71	5.28	5.63	5.64	5.57	5.14	5.66	6.10	6.20	5.81	6.08	6.12
Turbidity	3.74	8.38	4.19	1.06	1.80	10.33	1.90	4.70	6.62	3.59	5.67	6.64
DO	2.85	3.38	3.02	2.88	3.17	3.12	3.96	3.27	3.54	3.60	3.25	3.43
TDS	71.2	174.5	67.90	124.80	53.60	66.30	85.20	85.0	105.4	109.4	83.76	123.0
TH	0.0	5.0	0.0	0.0	0.0	0.0	16.5	0.0	0.0	10.0	0.0	7.5
TA	30.0	25.0	16.0	50.0	30.0	40.0	26.0	38.0	12.0	18.0	26.0	22.0
HCO <sub>3</sub> <sup>-</sup>	30.0	25.0	16.0	50.0	30.0	40.0	26.0	38.0	12.0	18.0	26.0	22.0
CO <sub>3</sub> <sup>2-</sup>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl <sup>-</sup>	7.5	11.5	6.5	4.0	12.5	7.5	6.75	5.75	15.0	14.2	18.3	4.0
SO <sub>4</sub> <sup>2-</sup>	0.0	0.0	0.0	0.28	0.0	0.32	0.0	0.47	0.0	0.11	0.37	0.20
NO <sub>3</sub> <sup>-</sup>	1.58	1.95	1.82	1.0	0.41	0.61	2.23	1.39	0.72	1.53	0.86	1.40
FC	17	39	22	329	181	253	261	63	32	396	118	18
TC	1867	3114	2707	3388	1396	1945	4586	1838	1410	3269	1346	284

## Annex 8

A) Simplified results of the chemical analysis of groundwater sample and irrigation water parameters.

Sam ple No.	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	SAR	SSP	RSC	KR	MH
S <sub>1</sub>	0.18	0.00 4	0.14	0.10	0.0	0.50	0.51	43.40	0.26	0.75	41.67
S <sub>2</sub>	0.23	0.00 5	0.17	0.25	0.0	0.42	0.50	35.86	0.0	0.55	59.50
S <sub>3</sub>	0.16	0.03 3	0.16	0.10	0.0	0.27	0.44	33.0	0.01	0.62	38.46
S <sub>4</sub>	0.20	0.00 3	0.16	0.23	0.0	0.85	0.45	34.20	0.46	0.51	59.0
S <sub>5</sub>	0.10	0.00 8	0.28	0.30	0.0	0.50	0.19	15.70	-0.08	0.17	51.72
S <sub>6</sub>	0.18	0.06 4	0.14	0.09 5	0.0	0.68	0.53	50.90	0.45	0.76	40.42
S <sub>7</sub>	0.16	0.04 5	0.17	0.20	0.0	0.53	0.37	35.84	0.16	0.44	54.50
S <sub>8</sub>	0.18	0.06 4	1.13	0.34	0.0	0.65	0.20	14.24	-0.82	0.12	23.13
S <sub>9</sub>	0.17	0.04 4	1.61	0.45	0.0	0.22	0.17	9.40	-1.85	0.08	21.80
S <sub>10</sub>	0.24	0.06 4	0.14	0.12	0.0	0.37	0.67	54.60	0.12	0.95	45.85
S <sub>11</sub>	0.19	0.04 4	0.14	0.11	0.0	0.45	0.54	48.35	0.20	0.76	44.0
S <sub>12</sub>	0.16	0.02 2	1.29	0.27	0.0	0.39	0.18	10.47	-1.17	0.10	17.15

**Annex 9**

A) Field activity photo



Onsite measurement of non-conservative parameters



Taking sample at different site

B) Laboratory activity photo

